



FUEL CELLS AND HYDROGEN
JOINT UNDERTAKING

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PROGRAMME REVIEW REPORT 2020-21

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The FCH-JU Programme Office has asked the Joint Research Centre of the European Commission to develop an improved programme review methodology and perform the full review for the year 2020-2021. This report is an edited version of the full 2020-2021 Programme Review Report produced by the JRC. The Joint Research Centre (JRC) performed the 2020-2021 Programme Annual Review Assessment under the Framework Contract approved by the FCH-JU Governing Board on 23/12/2015.

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FCH JOINT UNDERTAKING



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EXECUTIVE SUMMARY

Recognizing the important role of hydrogen and fuel cells technology (FCH) to reach carbon neutrality in 2050, the European Commission launched the European Hydrogen Strategy in July 2020. Hydrogen, as a versatile, flexible and clean energy carrier, and fuel cells, as an efficient conversion technology, have significant potential to reduce carbon dioxide emissions, reduce dependence on hydrocarbons and contribute to economic growth.

The Fuel Cells and Hydrogen Joint Undertaking (FCH 2 JU) aims to facilitate the market introduction of FCH technologies in Europe and realise their potential in a carbon-clean energy system. Since the start of FCH JU, 287 projects have been funded, with a total budget of EUR 1.08 billion complemented by almost the same amount from other sources (e.g. regional, national, private). In 2020 FCH JU launched its last call for proposals. Despite the pandemic, most projects are on track to achieve their objectives.

The 2020-21 Programme Review Report (PR) presents the findings of a review into activities supported by the FCH 2 JU under the EU's Seventh Framework Programme and Horizon 2020. The review was performed by the European Commission's Joint Research Centre (JRC). It paid particular attention to the added value, effectiveness and techno-economic efficiency of FCH 2 JU projects. For the purpose of the review, the projects were assigned to six review panels, under the two main research and innovation pillars – Transport and Energy – and the cluster of support for market uptake activities (cross-cutting), such as Regulation, Codes and Standards, Safety, Education and Training.

Two of the panels fall under **Transport** (trials and deployment of fuel cell applications and the next generation of products); three under **Energy** (trials and deployment of fuel cell applications, next generation of products, and hydrogen for sectorial integration); and one under the **Support for Market Uptake** (cross-cutting pillar). The 2020-21 PR includes 98 ongoing projects and assesses the strengths and accomplishments of each panel.

Activities under the Transport pillar are designed to accelerate the commercialisation of FCH technologies in transport applications through a programme that includes demonstration and research projects. These 35 projects aim to reduce system costs, increase their lifetime and reduce the use of critical raw materials. The demonstration activities covered in this report explore FCH in relation to cars, buses and refuelling infrastructure. Research projects focus on membrane electrode assemblies, catalysts, bipolar plates, advanced refuelling, auxiliary power units, FC system integration, and design, manufacturing and process development.

The energy pillar aims to accelerate the commercialisation of FCH technologies for stationary FC and to advance the production of green or low-carbon hydrogen as an energy vector in Europe. The goal of the 52 projects assessed under the Energy pillar is to accelerate the commercialisation of FCH technologies for stationary fuel cells and for the production of low-carbon hydrogen as an energy source, by increasing efficiency while cutting costs. In particular, stationary FC (power and heat) demonstrations and PoC activities aim to prove both technology capability and readiness, as well as improve performance, durability and cost. In parallel, a number of projects aim at reducing costs and improving the efficiency of hydrogen production, with a clear focus on demonstrating large-scale electrolyzers.

Within the Support for Market Uptake (cross-cutting) activities, the report highlights progress made by 11 projects in defining potential cost reductions, producing educational tools and developing analytical methods and test procedures, as well as overall impact and dissemination of results.

At programme level, some general trends can be observed. The contribution to demonstration activities has increased and projects focusing on manufacturing have received a relatively higher level of financing than in previous years. The contribution to research activities on transport applications increased significantly under H2020. The main conclusions are summarized in section 5 of this report.

With the transition from H2020 to Horizon Europe Framework Program, the work of the FCH 2 JU will be continued by the new public-private partnership Clean Hydrogen JU, which is expected to start its R&I activities in 2022.

LIST OF ACRONYMS

AEM	Anion exchange membrane
AFC	Alkaline fuel cell
AE	Alkaline electrolyser
AFID	Alternative Fuels Infrastructure Directive
APU	Auxiliary power unit
AST	Accelerated stress tests
AWP	Annual work programme
BoL	Beginning of life
BoP	Balance of plant
CAPEX	Capital expenditure
CEF	Connecting Europe Facility
CHP	Combined heat and power
CO₂	Carbon dioxide
CRM	Critical raw material
DBT	Dibenzyltoluene
EHSP	European Hydrogen Safety Panel
FC	Fuel cell
FCEV	Fuel cell electric vehicle
FCH 2 JU	Fuel Cells and Hydrogen Joint Undertaking: FCH 2 JU (2014-2020/Horizon 2020) succeeds FCH JU (2008-2014/FP 7) ¹
FCH	Fuel cell and hydrogen
GHG	Greenhouse gas
H₂	Hydrogen
HDV	Heavy-duty vehicle
HRS	Hydrogen refuelling station
HT	High temperature
ICT	Information Communication Technology
IEC	International Electrotechnical Commission
IPHE	International Partnership for Hydrogen and Fuel cells in the Economy
ISO	International Organization for Standardization
JRC	Joint Research Centre of the European Commission
KPI	Key performance indicator
kW	Kilowatt
kg	Kilogramme
km	Kilometre
LCA	Life-cycle assessment
LHV	Lower heating value
LOHC	Liquid organic hydrogen carrier
LT	Low temperature
MAWP	FCH 2 JU's Multi-Annual Work Plan (2014-2020)
MEA	Membrane electrode assembly

1. FCH JU has been replaced by FCH 2 JU which has taken over all the rights and obligations of its predecessor.

MHV	Material Handling Vehicle
MPa	Megapascal
MW	Megawatt
Mt	Metric tonne
NECP	National Energy and Climate Plan
Ni	Nickel
OEM	Original equipment manufacturer
PCEL	Proton ceramic electrolyser
PEM	Proton exchange membrane
PEMFC	Proton exchange membrane fuel cell
PGM	Platinum group metals
PNR	Pre-normative research
PoC	Proof of concept
PR	Programme Review
Pt	Platinum
R&I	Research and innovation
R&D	Research and development
RCS	Regulations, codes and standards
RES	Renewable energy sources
rSOC	Reversible solid oxide cell
SME	Small and medium-sized enterprise
SoA	State of the art
SOE	Solid oxide electrolyser
SOEC	Solid oxide electrolyser cell
SOFC	Solid oxide fuel cell
StH	Solar to hydrogen
TWh	Terawatt hour
TIM	Tool 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)
US, USA	United States of America

01

INTRODUCTION

1.1. EU AND INTERNATIONAL POLICY CONTEXT

In December 2019, the President of the Commission, Ursula von der Leyen, presented the European Green Deal² as part of Commission political agenda. This new growth strategy for Europe aims to transform the Union into a modern, resource-efficient and competitive economy. At the core of the European Green Deal lies the need to fight climate change.

In March 2020, the EC proposed a European Climate Law³, capturing the climate-neutrality objective in EU law. At the same time, it underlined the need to review the EU's targets for 2030 and define a trajectory compatible with the climate-neutrality objective by 2050. To this end, in September 2020, the EC adopted the 2030 Climate Target Plan⁴, with the ambition to reduce the increase in GHG emissions for 2030 from 40 % to at least 55 %, setting Europe on a cost-effective path for climate neutrality by 2050. The Communication builds on an extensive impact assessment and a public consultation carried out in spring 2020. The analysis concludes that the current policy framework is insufficient and without changes to this framework and legislation, the European Commission communication projects that the emissions reduction will only be 60 % by 2050.

To instigate this greater ambition, on 14 July 2021, the Commission presented the first series of adopted files under the 'Fit for 55' package⁵. It contains a number of proposals, including updated ambitious targets for renewable energy, energy efficiency and the reduction in greenhouse gases (GHGs) in 2030:

- A minimum of 55 % reduction in GHG emissions compared to 1990 levels by 2030 and 100 % by 2050;
- A minimum of 40 % of total energy consumption arising from renewable energy sources;
- A minimum of 36 to 39 % new 2030 energy-efficiency targets for final and primary energy consumption.

In this body of work, hydrogen was recognised as an integral part of the solution, which led to an exponential growth in European, national and regional hydrogen initiatives.

The Clean Hydrogen Alliance was announced in March 2020 in the Communication 'The New industrial strategy for Europe'.

In July 2020, the European Commission issued a proposal for a European Hydrogen Strategy⁶ with the clear targets of deploying 6 GW of electrolysis and the production of up to 1 million tonnes of renewable hydrogen by 2024 and 40 GW of electrolysis and up to 10 million tonnes of renewable hydrogen by 2030.

In July 2020, the FCH 2 JU published a study analysing the role of hydrogen in National Energy and Climate Plans (NECPs)⁷. The study analyses the extent to which policy measures and industrial initiatives are already being taken to facilitate the large-scale implementation of hydrogen in the current and the next decade (2030 time horizon). On 8 March 2021, the European Commission published a report to the European Parliament and the Council⁸ on the application of Directive

2. European Green Deal Communication, COM(2019) 640 final.

3. https://ec.europa.eu/clima/policies/eu-climate-action/law_en

4. 2030 Climate Target Plan, COM(2020) 562 final.

5. https://ec.europa.eu/commission/presscorner/detail/en/ip_21_3541

6. https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf

7. <https://www.fch.europa.eu/publications/opportunities-hydrogen-energy-technologies-considering-national-energy-climate-plans>

8. Report from the Commission to the European Parliament and the Council on the application of Directive 2014/94/EU on the deployment of alternative fuels infrastructure, <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0103>

2014/94/EU on the deployment of alternative fuels infrastructure (AFID). This report presents the results of the assessment of actions taken by Member States in implementing the AFID and the development of markets for alternative fuels and alternative fuels infrastructure in the Union.

Hydrogen is also mentioned in the NextGenerationEU which expects EUR 750 billion to be invested to boost recovery and help rebuild a post-COVID-19 Europe. The objectives of this recovery package revolve around the priorities set out in the European Green Deal and define among its strategical objectives kick-starting a clean European hydrogen economy in Europe.

1.2. FUEL CELL AND HYDROGEN TECHNOLOGIES CONTRIBUTING TO EU GOALS

Fuel cell and hydrogen (FCH) technologies can play a major role in achieving goals for climate change, energy efficiency, pollution mitigation and internal energy sourcing.

A roadmap published by FCH 2 JU⁹ sees the potential for generating approximately 2 250 terawatt hours (TWh) of hydrogen in Europe in 2050, representing roughly a quarter of the EU's total energy demand (Figure 1). According to estimates, this amount would fuel about 42 million large cars, 1.7 million trucks, approximately a quarter of a million buses, and more than 5 500 trains. It would heat more than 52 million households (about 465 TWh) and provide 10 % of building power demand. In industry, approximately 160 TWh of hydrogen would produce high-grade heat and another 140 TWh would replace coal in steelmaking processes through direct reduced iron. Furthermore, 120 TWh of hydrogen with captured carbon or carbon from biomass would also produce synthetic feedstock for 40 metric tonnes (Mt) of chemicals in 2050. Achieving this vision would put the EU on a path to reducing about 560 Mt of carbon dioxide (CO₂) emissions by 2050 – i.e. half of the required abatements needed to achieve the 2 °C scenario (Figure 1).

Figure 1: Benefits of hydrogen for the EU according to the 2019 FCH 2 JU study.

Ambitious scenario

2050 hydrogen vision



¹ Incl. feedstock

² Compared to the Reference Technology Scenario

³ Excl. indirect effects

9. https://www.fch.europa.eu/sites/default/files/Hydrogen%20Roadmap%20Europe_Report.pdf

1.3. THE ROLE OF THE FCH 2 JU

The overall objective of the FCH 2 JU is to implement an optimal research and innovation (R&I) programme at the EU level in order to develop a portfolio of clean and efficient solutions exploiting the properties of hydrogen as an energy carrier and fuel cells (FCs) as energy converters to the point of market readiness. This has enabled support for EU policies on sustainable energy and transport, climate change, the environment and industrial competitiveness, as embodied in the Europe 2020 strategy, and job creation. It will also help to achieve the EU’s overarching objective of smart, sustainable and inclusive growth. The core objectives are described in Figure 2. With the transition from H2020 to Horizon Europe, the FCH 2 JU will be followed by a new public-private partnership, while the process of setting up a new multi-annual work plan (MAWP) for 2021-2027 is ongoing.

Figure 2: The core objectives of the FCH 2 JU programme.

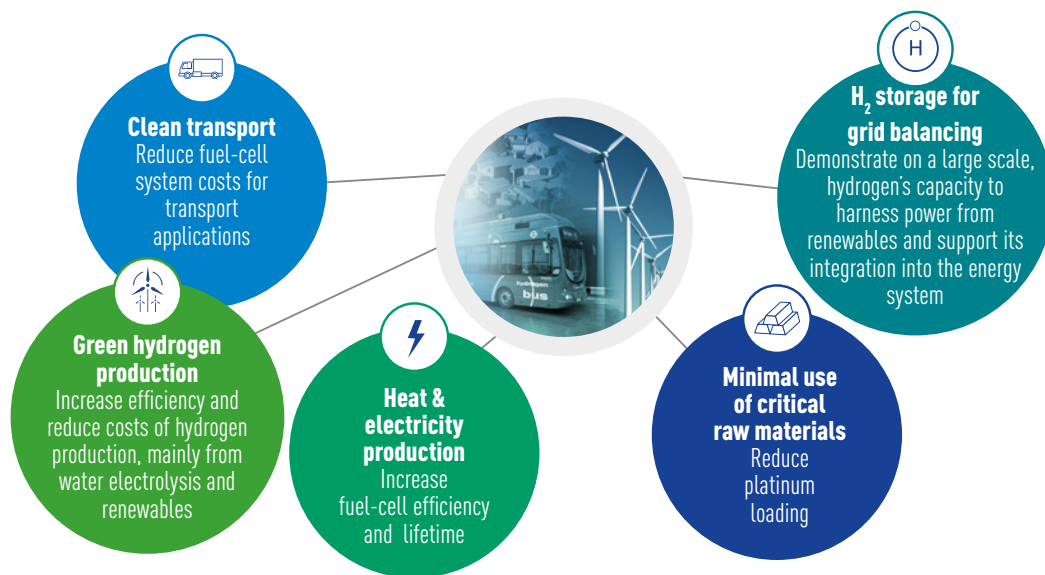


Figure 3 shows the number of projects supported by FCH 2 JU since its foundation: 287 projects have been funded with a total budget of EUR 1.08 billion boosted by almost the same amount from other sources (e.g. regional, national, private).

Figure 3: Number of FCH 2 JU-supported projects and annual budget for calls during 2008-2020.

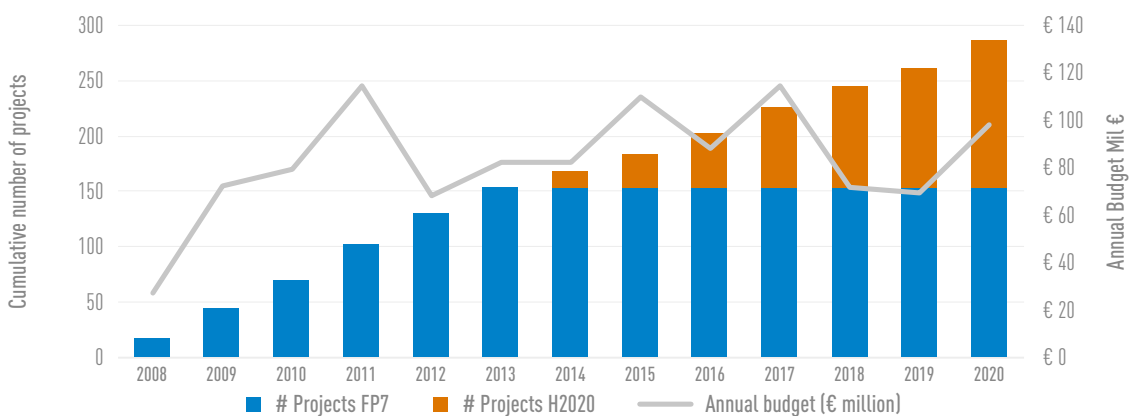
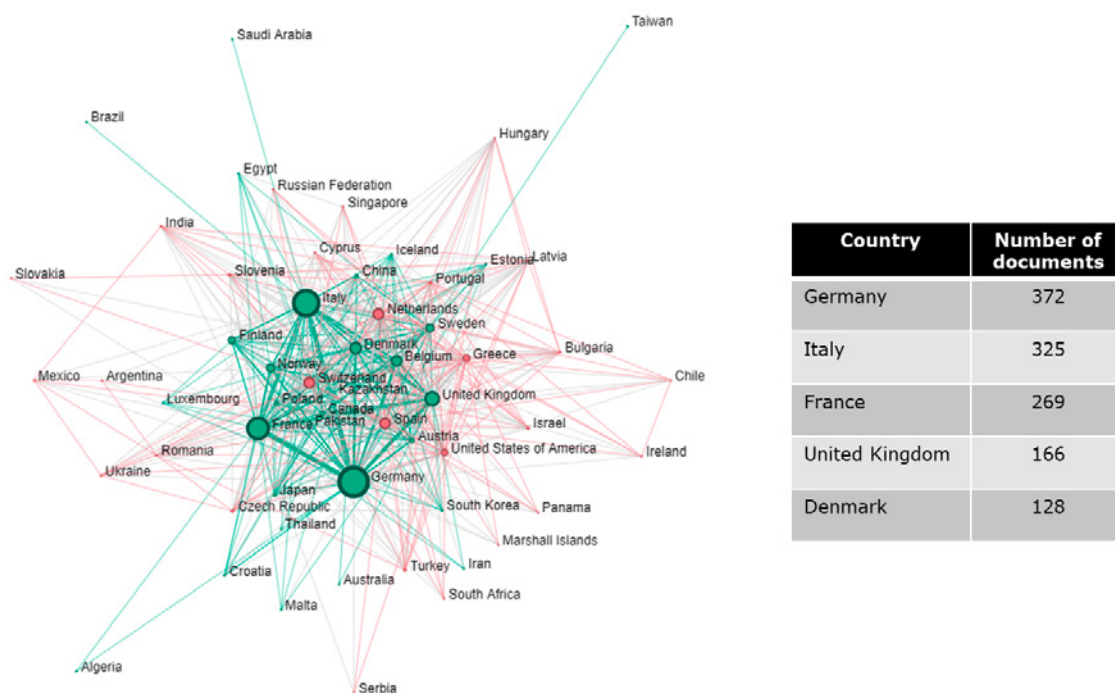


Figure 4 presents a visualisation of collaborations between beneficiaries from EU countries¹⁰ obtained with TIM software (Tool for Innovation Monitoring), developed by the JRC to make better sense of the intricate web of connections and collaborations among different actors. TIM includes three types of documents: scientific publications, patents and granted EU projects. The size of each node (circle) represents the number of items (scientific publications, patents and FCH 2 JU projects) that have at least one participating member from that country. The thickness of the lines connecting the nodes corresponds to the number of these items countries have in common. This representation help identify Germany, Italy and France as the countries with the highest contribution of documents originating from FCH 2 JU funding. The large number of countries present in addition to EU Member States and associated countries usually originates from common publications between FCH 2 JU recipient organisations and other organisations across the globe.

Figure 4: TIM visualisation of the location of organisations involved in output related to FCH 2 JU.



1.4. PURPOSE AND SCOPE OF PROGRAMME REVIEW 2020-2021

The purpose of the periodic Programme Review (PR) is to ensure that the FCH 2 JU programme is aligned with the strategy and objectives set out in the founding Council Regulation (EU) No. 559/2014¹¹ and in the MAWP and annual work programmes (AWPs).

The JRC was entrusted with the 2017 PR as part of its activities under the multiannual Framework Contract between the FCH 2 JU and JRC. The present PR follows the same procedure as defined for previous years. The collection of relevant information from projects was carried out using multiple sources, including the TRUST (Technology Reporting Using Structured Templates) database and a dedicated EU survey.

10. Counting common articles, publications, conference participations, books, patents, EU projects. Extracted from the version of TIM adapted by the JRC for the FCH 2 JU. For more information please see: <http://tech.timanalytics.eu/TimTechnology/main.jsp?analyzer=nmworldgram&dataset=15788>

11. OJ L 169, 7.6.2014, p. 108-129

The FCH 2 JU programme structure comprises two main pillars (transport and energy) plus cross-cutting activities. The reviewed projects have been assigned to six 'review panels' listed in Table 1 below.

Table 1: Review panels for the 2020-21 PR

PILLAR/ACTIVITY	PANEL NAMES	TOPICS
Transport	1 - Trials and Deployment of Fuel Cell Applications	Projects targeting the demonstration and proof of concept (PoC) of FCH applications in the transportation pillar
	2 - Next Generation of Products	Basic and applied research projects tackling subjects related to the transportation pillar
Energy	3 - Trials and Deployment of Fuel Cell Applications	Projects targeting the demonstration and PoC of FCH stationary heat and power applications in the energy pillar
	4 - Next Generation of Products	Basic and applied research projects tackling subjects related to FCH stationary heat and power applications
	5 - Hydrogen for Sectorial Integration	All projects addressing hydrogen production, distribution and storage issues
Cross-cutting	6 - Support for Market Uptake	Projects addressing cross-cutting issues

The 2020-21 PR includes all ongoing projects (between project start and end date): 98 projects, 6 of which began under FP7 and 92 under H2020. Of the 98 projects under consideration, 56 were initially reviewed for the 2019 PR report, and 20 have been reviewed for the first time this year.

1.5. PRESENTATION OF THE REVIEW FINDINGS

This PR report summarises the findings from the assessment of the projects in the six panels listed in Table 1. Due to their wide-ranging scope, the activities and applications of the projects included which cover similar or related topics were grouped into a set of focus areas for each panel. The assessment was performed for each focus area. In this document, qualitative observations are provided regarding the projects' major accomplishments and any difficulties they encountered. The six indicators used by reviewers for evaluation, and their relative weight in the total score, are:

1. Target achievement
2. Project impact
3. Benchmarking against international state of the art (SoA)
4. Exploitation plans and intellectual property
5. Interactions with other projects, sectorial organisations, and initiatives
6. Dissemination efforts.

A weighted sum for the six indicators was used to obtain an overall project score and a quantitative evaluation. Each panel review also identifies the strengths of the panel, areas that would benefit from additional focus, and proposes a set of actions for follow-up.

02

TRANSPORT PILLAR



2.1. OBJECTIVES

FCH technologies play an important role in reducing emissions, (GHG, SO_x, NO_x, particulate matter), as well as vibration and noise from Europe's transportation activities, especially road transport. On a well-to-wheel basis, the use of 'green' hydrogen significantly reduces the carbon emissions from transport. The aim of the activities is to accelerate the commercialisation of FCH technologies in transport through a programme including both demonstration and research projects. The main goals are to reduce FC system costs for transport applications, increase their lifetime and decrease the use of critical raw materials such as platinum group metals.

2.2. BUDGET

To date (project calls from 2008 until 2020), 80 projects in the transport pillar have received financial contributions from the FCH 2 JU totalling about EUR 485.7 million. The distribution of projects in the two main activity areas (panels) is shown in Table 2.

Table 2: FCH 2 JU financial contribution for the two main activity areas in the transport pillar

Trials and deployment of FC applications – transport	EUR 321.7 m
Next Generation of Products – transport	EUR 164.0 m
Total	EUR 485.7 m

2.3. PANEL 1 - TRIALS AND DEPLOYMENT OF FC APPLICATIONS – TRANSPORT

The demonstration actions in this panel aim to validate technologies and to prove technology readiness, reliability, robustness, fuel efficiency and sustainability. Historically, demonstration activities have focused on road transport, based on cars and buses, but are now shifting towards heavy-duty transport, rail and maritime applications. In 2020, an in-depth analysis of the market potential of heavy-duty FCs on trucks was published¹² as well as a 'Study on use of fuel cells & hydrogen in the railway environment'¹³. In addition, activities on scaling up maritime applications have been ongoing with new proposed call topics¹⁴

Demonstration projects considered in this year's PR focus on the following main areas:

- A. Cars and related refuelling infrastructure
- B. Buses and related refuelling infrastructure
- C. Trucks and related fuelling infrastructure
- D. Ships and maritime ports.

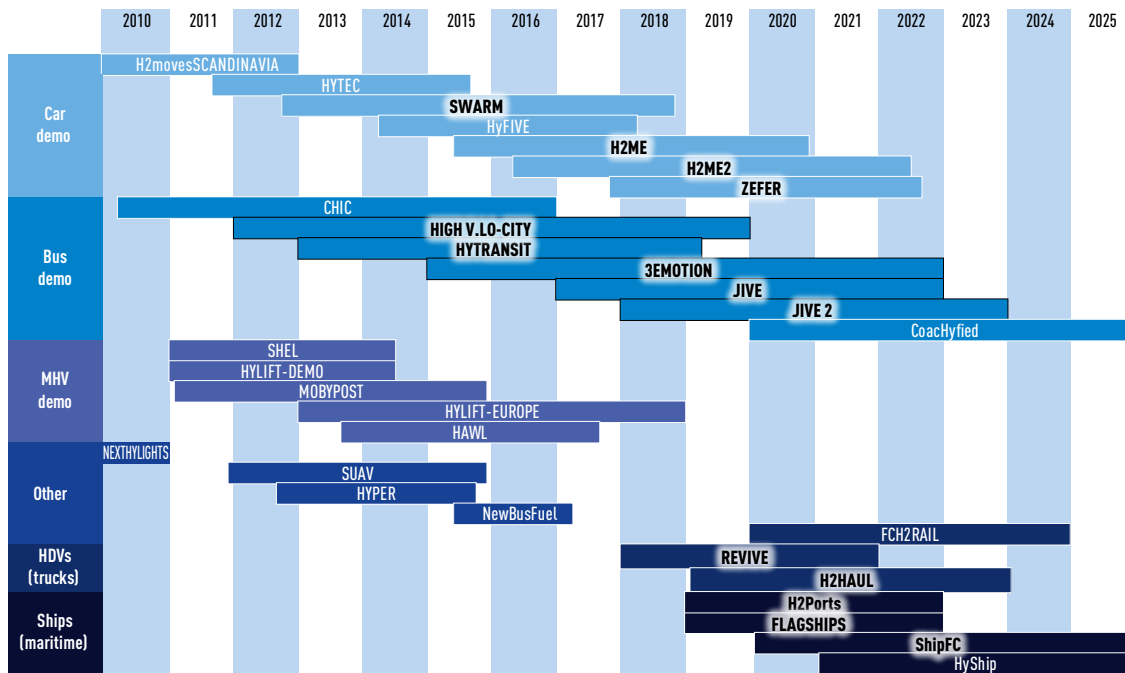
The timeline for the FCH 2 JU programme portfolio of transport demo projects and their distribution across the above-mentioned four focus areas is shown in Figure 5 below.

12. <https://www.fch.europa.eu/publications/study-fuel-cells-hydrogen-trucks>

13. <https://www.fch.europa.eu/news/fuel-cell-railway-fch-ju-shift2rail-ju-launch-new-study>

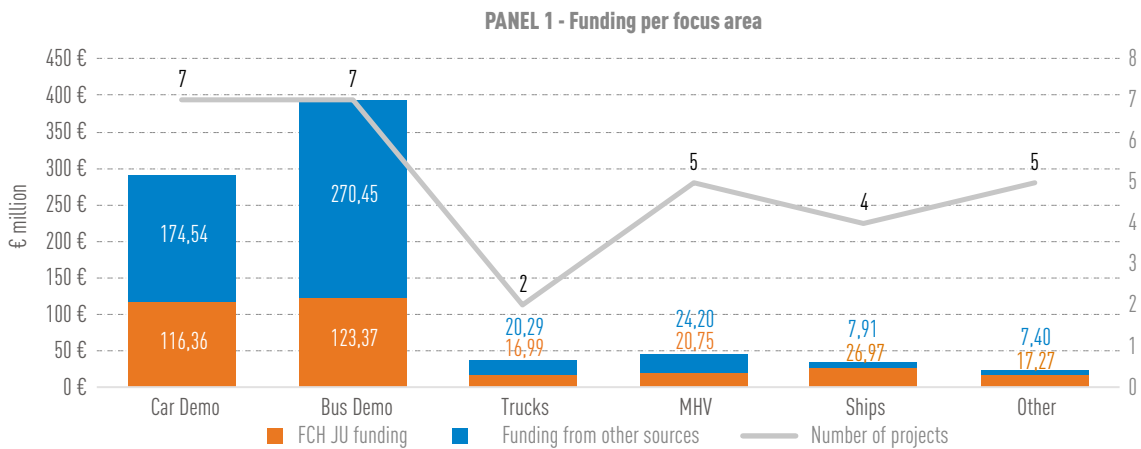
14. <https://www.fch.europa.eu/sites/default/files/FCH%202%20JE%20Annual%20Work%20Plan%20and%20Budget%202019%20%28ID%205167414%29.pdf>

Figure 5: Trials and deployment of FC application projects within the transport pillar. Only projects whose names have been highlighted in a larger black font size have been considered in PR 2020-21.



The present review covers the 14 projects highlighted in black in the figure. Following the calls between 2008 and 2020, the FCH 2 JU supported 30 projects¹⁵ relevant to this panel. The total FCH 2 JU contribution amounted to EUR 321.7 million and the contribution from partners to EUR 504.8 million¹⁶. The distribution of the total budget over the six focus areas from 2008 until 2020 (topic call year) is shown in Figure 6 and indicates that approximately 85 % of FCH 2 JU panel 1 funding went to support on-road vehicles (mainly cars and buses – the FCH 2 JU budget is split roughly between the two).

Figure 6: Funding for panel 1 (Trials and deployment of FC applications – transport) from 2008, including call 2020.



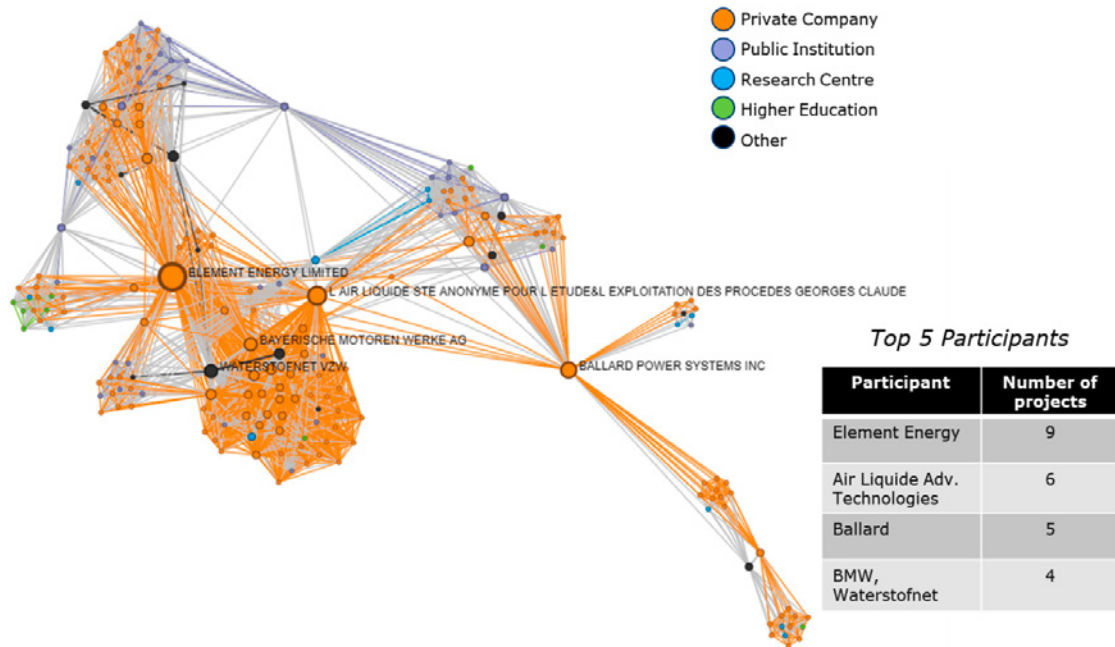
15. Projects associated with auxiliary power unit (APU) development have been moved to panel 2 since PR 2018.

16. These figures include the overarching project H2ME2 which draws EUR 8 million (from a total of EUR 35 million) from the energy pillar.

Figure 7 shows the connections between partners present in the projects in panel 1 covered in this PR. Only the partners involved in the largest numbers of projects are named in the figure. The size of the node (circle) represents the number of projects a partner is involved in, whilst the thickness of the lines ('edges') linking the nodes represents the number of projects two partners have in common. For clarity, only the partners involved in the largest numbers of projects are named in the figure. The colours indicate the type of organisation.

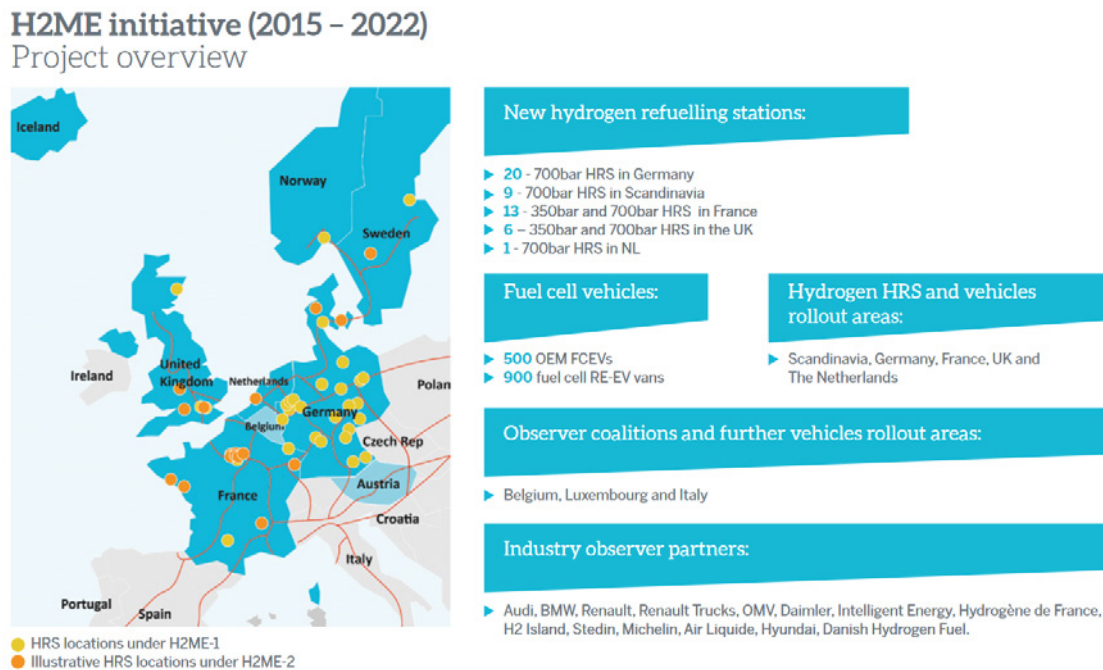
In this case, it can be seen that there are groups of consortia with certain players providing links between the groups. The cluster in the top left of the figure is based around the JIVE and JIVE 2 consortia, whilst the large cluster in the centre of the figure includes the car-fleet-related projects H2ME and H2ME2. The key players providing the links between clusters are participants such as Element Energy, who generally act as project coordinators, hydrogen refuelling station (HRS) supplier Air Liquide, and FC system supplier Ballard. Due to the high technology readiness level (TRL) demonstration nature of the projects, a large number of private companies are involved (orange nodes) plus a number of public organisations (e.g. city councils: purple nodes).

Figure 7: TIM plot showing the participants in the 14 projects in panel 1.



Focus area 1.A: FC car demonstration projects

The projects included in the car demo focus area are H2ME, H2ME2, SWARM and ZEFER. H2ME and H2ME2 are the largest European deployment initiatives to date for hydrogen mobility, with plans to deploy more than 1 200 vehicles in 8 countries and 49 HRS in 5 countries. H2ME finished in 2020 and H2ME2 will go on until 2022, having already deployed 687 vehicles and 38 HRS in total.

Figure 8: Overview of H2ME initiative, January 2021.


Source <https://h2me.eu/>

Project H2ME has deployed 311 vehicles and 29 new HRSs in Germany, Scandinavia, France and the United Kingdom. H2ME2 has already deployed 376 (out of 874) FC electric vehicles (FCEVs) from 5 original equipment manufacturers (OEMs) and 9 HRSs (out of 20). The findings from the H2ME transport demo activities are publicly available in the report 'Strategic recommendations for supporting the commercialisation of fuel cell electric vehicles in Europe'¹⁷.

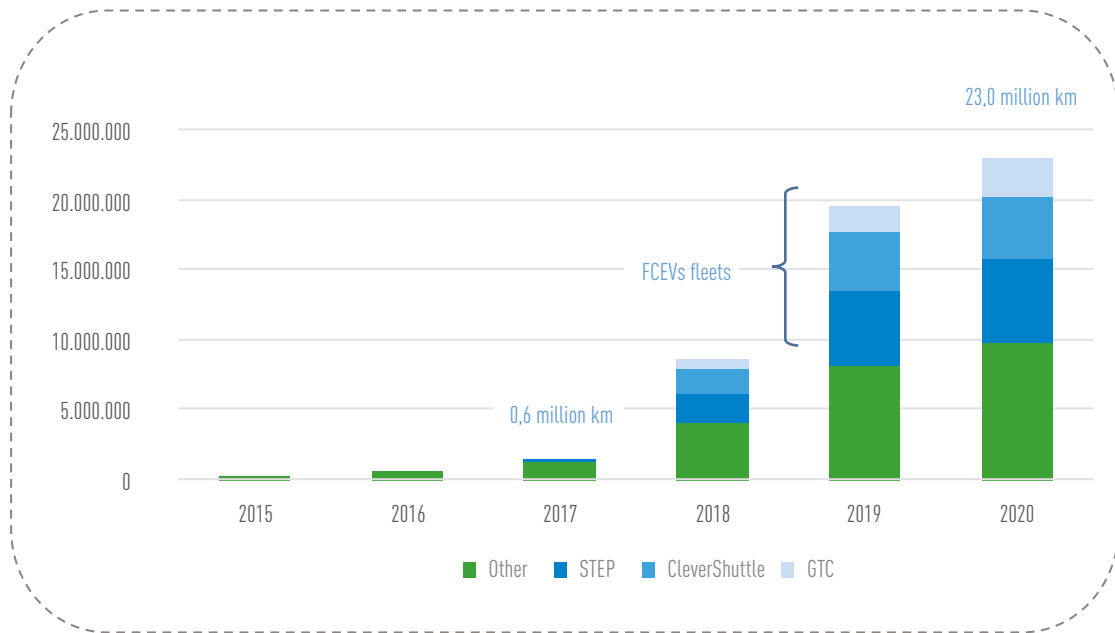
Project ZEFER started in 2017 with the aim of demonstrating viable business cases for captive fleets of FCEVs (taxi, private hire and police services) and will continue until 2022. Of the 180 FCEVs planned, 117 are already in operation (57 in Paris and 60 in London).

The project SWARM, which finished in 2017, successfully deployed 13 small, low-weight hybrid electric-hydrogen vehicles in three European regions. Final SWARM data compiled in TRUST have been taken into account for the 2020-21 PR.

In 2020, in total 607 cars were reported in TRUST, close to the 597 cars reported in 2019. In 2020, they drove slightly more than 4.9 million kilometres (km) and consumed 52.7 tonnes of hydrogen, which is around half of that reported in 2019, with 8.9 million km driven and 91.5 tonnes of hydrogen consumed. These differences can be explained partly by the COVID-19 pandemic, which had a direct impact on the operation of the taxi fleets (in practice, operating only from January to March 2020). A second reason concerned structural changes in the fleets, whereby a number of cars were sold in the first half of 2020 and thus stopped reporting in TRUST. The cumulative distance driven is shown in Figure 9.

17. <https://h2me.eu/publications/d5-15-strategic-recommendations-for-supporting-the-commercialisation-of-fuel-cell-electric-vehicles-in-europe/>

Figure 9: Cumulative distance driven by FCH 2 JU-demonstrated light-duty-vehicle taxi fleets: STEP in Paris, Green Tomato Cars in London (GTC), CleverShuttle in Berlin.

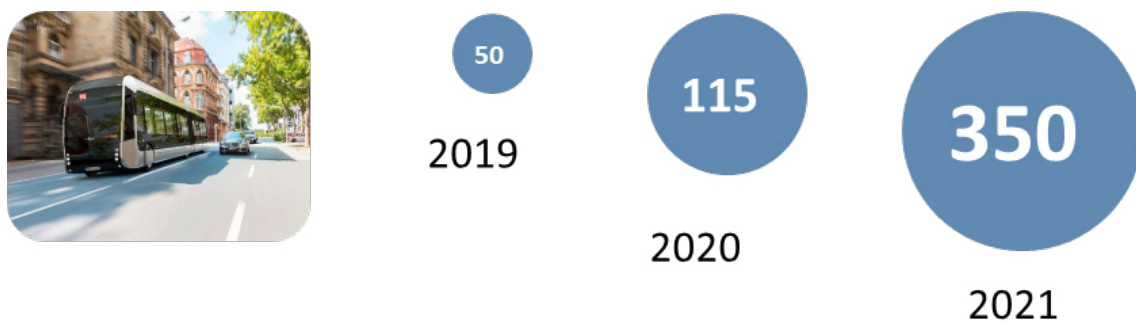


In 2020, the average fuel consumption of 1.19 kilogramme (kg) per 100 km is close to the MAWP 2020 target (1.15 kg per 100 km). The expected MAWP 2020 targets for availability (98 %) and fuel cell system durability (5 000 hours) have been reached. FCEVs have been demonstrated as reliable, with driving ranges equal to those of conventional light-duty vehicles. Current car incident records highlight a positive safety performance for hydrogen technologies used in transport applications. The H2ME initiative reported that, even for FCHVs accruing a significant mileage (e.g. taxis), the number of incidents involving hydrogen release was zero, with a total number of incidents similar to those of comparable vehicles powered by conventional combustion engines. Improvements are still required regarding the FCEV purchase price, the number of models available and, in some cases, restrictions on underground parking.

Focus area 1.B: FC bus demonstration projects

European deployment activities have grown considerably from earlier projects to the most recent, as shown in Figure 10. In 2019 and 2020, FCH 2 JU bus demonstration activities concerned the projects High V.LO-City, HyTransit, 3EMOTION, JIVE and JIVE 2.

Figure 10: Evolution of FCB in operation in the EU.



Bus demonstrations financed with FCH 2 JU grants involve 350 vehicles in 11 countries. High V.LO-City, which started in 2012 and ended in December 2019, put 14 FCBs into operation in Aberdeen (UK), Antwerp (BE), Groningen (NL) and San Remo (IT). HyTransit finished in March 2019 and deployed five hybrid FCBs into daily fleet service in Aberdeen (UK). 3EMOTION, JIVE and JIVE 2 are ongoing and progressing, although with delays with respect to the original planning. Combined, JIVE and JIVE 2 will deploy nearly 300 FCBs in 22 cities across Europe (Figure 11). The local fleets range from 5 to 50 FCBs, typically 10 to 20. As of 2020, JIVE had ordered all 142 planned buses and 59 are in operation, while JIVE 2 ordered 110 buses out of the 152 planned, has 5 buses in operation and expects to have half of the committed fleet in operation by the end of 2021.

Figure 11: FCB demonstration in Europe (source <https://www.fuelcellbuses.eu/>) including national initiatives and Interreg-funded demos.



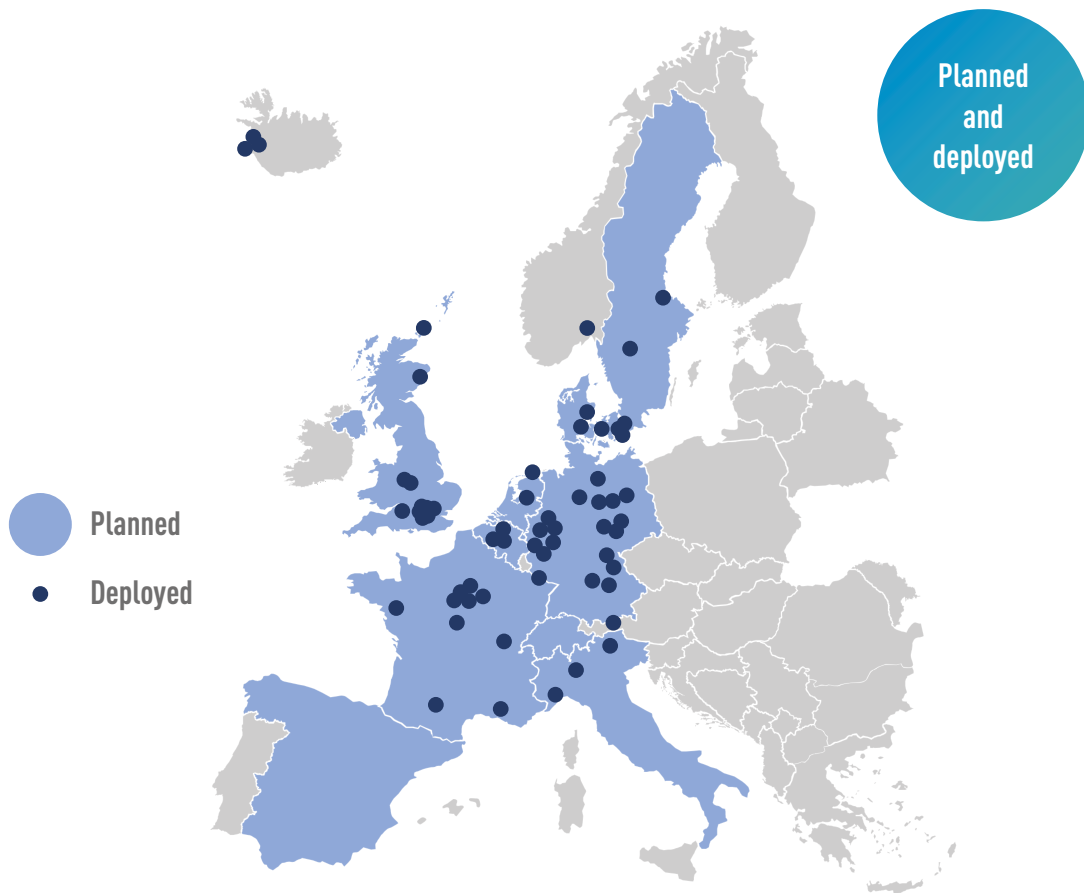
In 2019-2020, 119 buses were in operation in 7 cities. From the bus demonstration projects that were reporting in TRUST between 2016 and 2020, a total distance of over 8.9 million km was accumulated, with almost 1 million km accumulated in 2020 alone. Over the last 4 years, over 602 tonnes of hydrogen have been consumed. In 2020, the average fuel consumption was 10.42 kg H₂/100 km, while the minimum reported was 8 kg H₂/100 km, meeting the 2020 MAWP target (8 to 10.2 kg H₂/100 km). The 2020 MAWP targets for FC system cost and vehicle cost (based on procurement prices) which had already been achieved in 2018, were also met in 2020. However, the 2020 MAWP targets for FC system durability (20 000 h) as well as those for yearly operating costs (16 000 €/kW) have yet to be fully achieved.

In 2020, the average FCB availability was 82 %, although there is a significant spread in the reported values with the maximum availability being 96.1 %. This highlights the impact of ageing fleets and the long period required to receive replacement parts from international suppliers due to the pandemic. In addition, a teething period of a few months is usually observed at the start of FCB operation on sites previously unfamiliar with FCB, which adversely affects their availability. Other non-FCH 2 JU initiatives, such as the H2Bus consortium supported by the Connecting Europe Facility (CEF) with EUR 40 million for the first phase, are aiming to deploy 1 000 FC hydrogen buses in Europe. FCBs are getting ready for commercialisation: 12 European bus OEMs are offering them for sale or lease¹⁸.

Focus area 1.A and 1.B: Hydrogen refuelling infrastructure for cars and buses

The geographical coverage of hydrogen refuelling infrastructure continues to expand, supporting the increasing number of FCEVs being deployed (see Figure 12). The total number of HRSs funded under the transport demo panel is 113¹⁹, of which 64 (53 for cars and 11 for buses) have already been deployed (56 were reported in 2019). Twenty H2ME refuelling stations for cars are publicly available, dispensing hydrogen at 700 bars, and have been integrated into petrol forecourts; 13 also have a 350 bars dispenser. The European HRS availability system (<https://h2-map.eu/>), an initiative sponsored by the FCH 2 JU, provides a portal giving information on the live status of each HRS in Europe, and available on any mobile application or tool for the convenience of FCEV users. Currently, 153 fuelling stations (some not funded by the FCH 2 JU) are both connecting and sending live data.

Figure 12: Distribution of hydrogen refuelling stations co-funded by FCH 2 JU.



18. <https://assured-project.eu/storage/files/jive-presentation-user-group-11062019-element-energy-jive-assured-ug-meeting.pdf>

19. Including two discontinued stations

To date, the FCH 2 JU-funded HRS network for cars covers 8 countries and, in 2020, delivered 58.8 tonnes of hydrogen in 25 060 refuelling operations. This figure represents 40 % of the total amount of hydrogen refuelled since 2016. The average HRS availability for cars in 2020 was 90 %. The major causes of station downtime are the compressor and the scheduled maintenance/upgrades. H2ME reported that with the increasing number of HRS, chiller cooling hydrogen to the level required by SAE J2601 is also becoming a reason for downtime.

Car demonstration projects have reported that 66 % of dispensed hydrogen was certified as low carbon. Of this, renewable hydrogen accounted for 57 %. The average cost of renewable hydrogen is 11.31 €/kg H₂, which means the related MAWP 2020 target of 11.31 €/kg H₂ has not been achieved by a few tenths of a euro. The average capital expenditure (CAPEX) for hydrogen stations is 6.95 €/kg H₂/day, which is still higher than the expected MAWP 2020 targets for station capital expenditure of 4-2.1 €/kg H₂/day.

FCH 2 JU has also funded the installation of 23 refuelling stations for buses in 10 European cities, 16 of which have been deployed. The amount of hydrogen dispensed between 2016 and 2020 was almost 529.8 tonnes, 16 % of which was consumed in 2020 in 5 917 refuelling operations. Of this dispensed amount, 63 % is certified as renewable hydrogen.

Demonstration projects are recurrently suffering from a lack of experience among local authorities and the absence of standardised processes for reviewing and approving HRS permit authorisation. However, difficulties encountered when requesting permits for HRS are declining, with the lead time for commissioning an HRS in Germany falling from 24 to 12 months.

Focus area 1.C: Truck demonstration projects

FCH 2 JU demonstration activities on heavy-duty trucks started in 2018 with the REVIVE project which aims to demonstrate 15 heavy-duty refuse trucks in 8 sites across Europe. It was enlarged in 2019 with the addition of the H2Haul project.

REVIVE will set the basis and SoA reference for future HDV refuse truck demonstration projects. Its activities include the LCA of the project performance in terms of CO₂ emissions, air pollution and noise reductions.

H2Haul, 'Hydrogen fuel cell trucks for heavy-duty, zero emission logistics', will lead to the deployment of 16 trucks, in 4 European countries. In addition, three new HRSs for truck refuelling will be deployed in Belgium, France and Switzerland. The project is currently in the planning and pre-deployment phase. The design of three new types of FC trucks (including rigid and articulated vehicles up to 44 tonnes) is ongoing and specifications are being prepared as per specific customer requirements and mission profiles. These two projects will establish policy recommendations to foster the deployment of FCH trucks. The HRSs that will support the truck fleet are also being deployed or upgraded.

The Study on Fuel Cells Hydrogen Trucks²⁰ commissioned by FCH 2 JU concluded that, when the market is scaled up, FCH heavy-duty trucks might become cost competitive by 2030.

Focus area 1.D: Waterborne demonstration projects

Three demo projects deploying zero-emission FC ships and hydrogen in maritime ports started in 2019-2020, thereby increasing the FCH 2 JU portfolio of transport demo activities. The three projects have common issues, in particular, hydrogen safety, the permitting of ships and infrastructure, and standards.

20. <https://www.fch.europa.eu/publications/study-fuel-cells-hydrogen-trucks>

FLAGSHIPS will demonstrate two FCH vessels in commercial operation: one cargo vessel in France and one passenger and car ferry in Norway. In addition, FLAGSHIPS will perform a techno-economic analysis of European marine FC power systems.

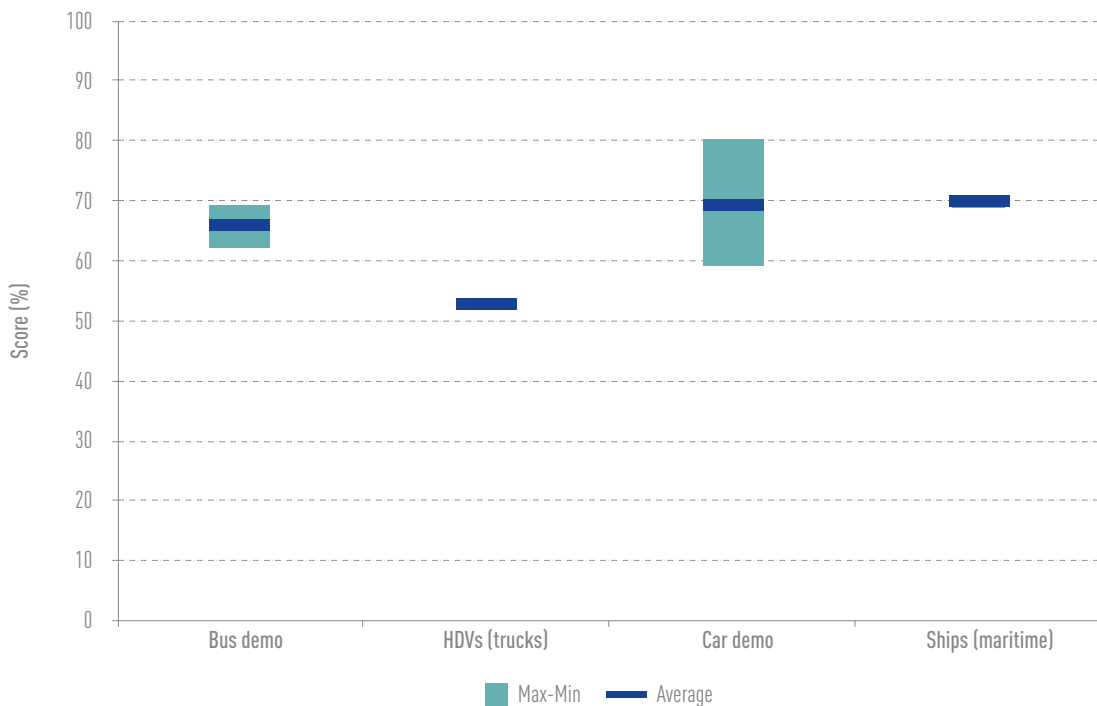
The ShipFC project will develop a 2-megawatt (MW) ammonia-powered FC and will operate a retrofitted offshore vessel. ShipFC aims to prove that long-range zero-emission voyages with high power are possible on larger ships. In addition, the project is providing input on alternative shipping fuels LCAs and is studying how to set up a certification scheme for green ammonia.

The purpose of H2Ports is to demonstrate hydrogen as an alternative fuel in maritime ports. It will carry out pilot tests in the Port of Valencia (ES), under real operation conditions, on a hydrogen-powered reach stacker in a port container terminal, an FC yard tractor for container transport and ro-ro loading/unloading operations, and a mobile hydrogen supply station.

Panel 1 - Summary

Figure 13 shows the overall assessment of panel 1 projects. The evaluation is positive in both cases, although it appears that HRS permitting processes (strongly dependent on local administrations), procurement, and the supply chain have been critical issues hampering even more satisfactory achievements.

Figure 13: Maximum, minimum and average scores for relevant focus areas in panel 1. No score is given for focus areas with a single project whilst, in the case of two or three projects, only the average is provided.



The main observations on project strengths and areas where additional focus is needed for panel 1 projects are summarised below:

Strengths:

- Transport demo projects are deploying on the road a large number of cars and buses; they are successful and support the business case for vehicles and fuelling stations. This project model should also be used for future demonstrations of fleets of coaches (as in the call 2020 project CoachHyfied) and trucks.
- Heavy-duty/truck projects will, as has been the case for the buses demo, help to establish an EU supply chain for FC and FC systems suited for heavy-duty applications.
- New projects are aiming to demonstrate HDVs; results from JIVE and JIVE 2 refuelling operations could be extrapolated to support truck demos handling large quantities of hydrogen and using large-capacity HRS (800-1 000 kg/day).
- The potential for H2Haul and REVIVE data from refuelling operations will generate valuable insights for both the PRHYDE project and ISO standardisation efforts.
- Consistent training of bus drivers and repair and maintenance technicians.
- Thanks to demonstration projects, local authorities are gaining experience in hydrogen technologies and time to grant permits is declining.
- Current efforts to increase volumes will kick-start the development of a European FC supply chain for buses and trucks.

Additional focus needed:

Based on the findings and observations described above, the following specific follow-up actions for panel 1 are proposed:

- Define actions aimed at facilitating permitting for establishing new HRSs and setting the basis for an EU harmonised HRS permitting procedure.
- Reliable ICT tools for data monitoring from vehicles and HRSs.
- In view of the increasing hydrogen demand, an assessment of distribution and storage for large hydrogen volumes should be tackled as soon as possible.
- Supply of spare parts for vehicles along with plans to provide onsite maintenance services should be ensured throughout the entire project duration. Although this is improving, it is still a bottleneck.
- Following the REVIVE example, the FCH 2 JU should consider funding more projects addressing 'waste-to-wheel' concepts trying to find integrated solutions for hydrogen production from waste.
- There are not enough manufacturers of FC and FC systems suitable for maritime applications. This risks ending up with a single producer and the consequent inadequate supply of spare parts.

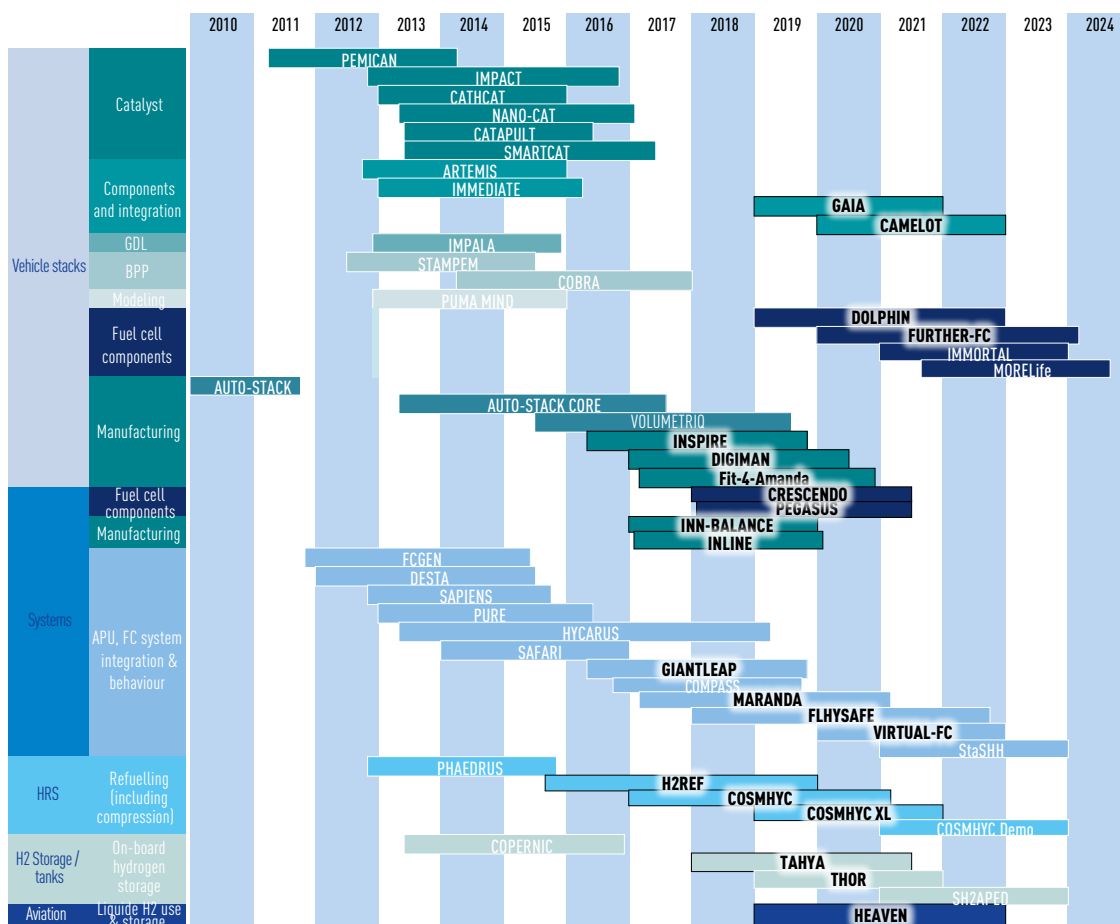
2.4. PANEL 2 - NEXT GENERATION OF PRODUCTS – TRANSPORT

These projects focus on the development of platinum-group metal-free catalysts, manufacturing better-performing and more durable FC for transport, including APU, improved HRS systems and on-board hydrogen storage. The project portfolio for transportation R&I activities covers the following focus areas:

- A. Vehicle stacks – components and integration, FC components, and manufacturing.
- B. Systems – manufacturing, FC components, APU, FC system integration (and behaviour)
- C. HRS - refuelling (including compression)
- D. Hydrogen storage/tanks – on-board hydrogen storage and tanks
- E. Aviation – liquid hydrogen use and storage.

The 2020-21 PR covers 21 projects. Figure 14 shows the timeline for the entire FCH 2 JU programme portfolio of transport research projects and their distribution across focus areas.

Figure 14: Next Generation of Products projects within the transport pillar. Only projects whose names have been highlighted in larger black font size have been considered within the PR 2020-21.



Between 2008 and 2020, the FCH 2 JU supported 50 projects relevant to this panel, with a total contribution of around EUR 164.0 million plus a contribution from partners of EUR 75.6 million. Figure 15 shows the distribution of the total budget over the five focus areas across the 2008-2020 call topics.

Figure 15: Funding for panel 2 (Next Generation of Products - transport) from 2008, including call 2020.

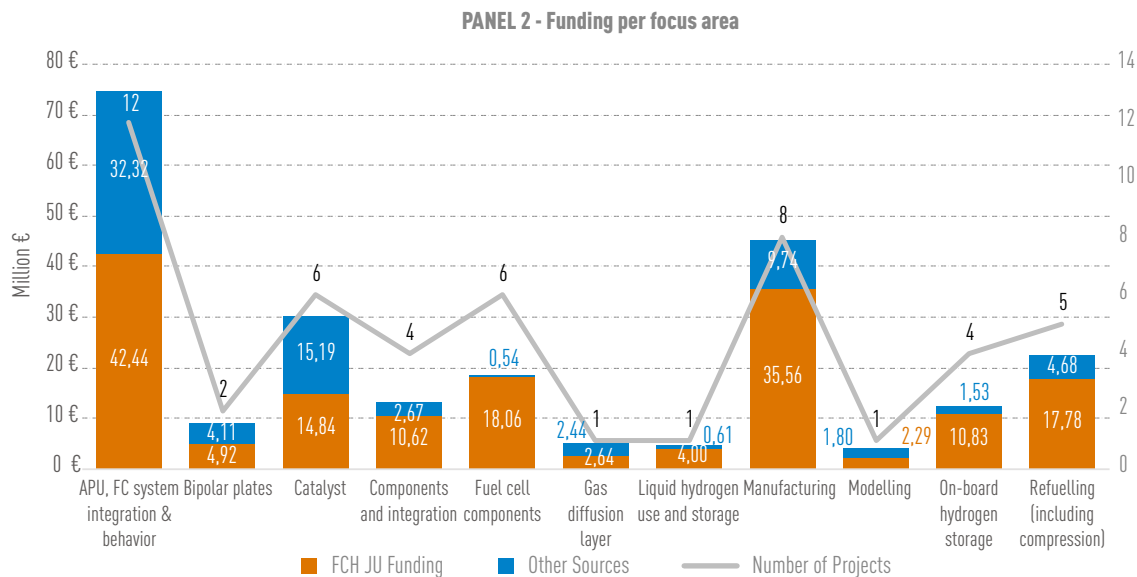
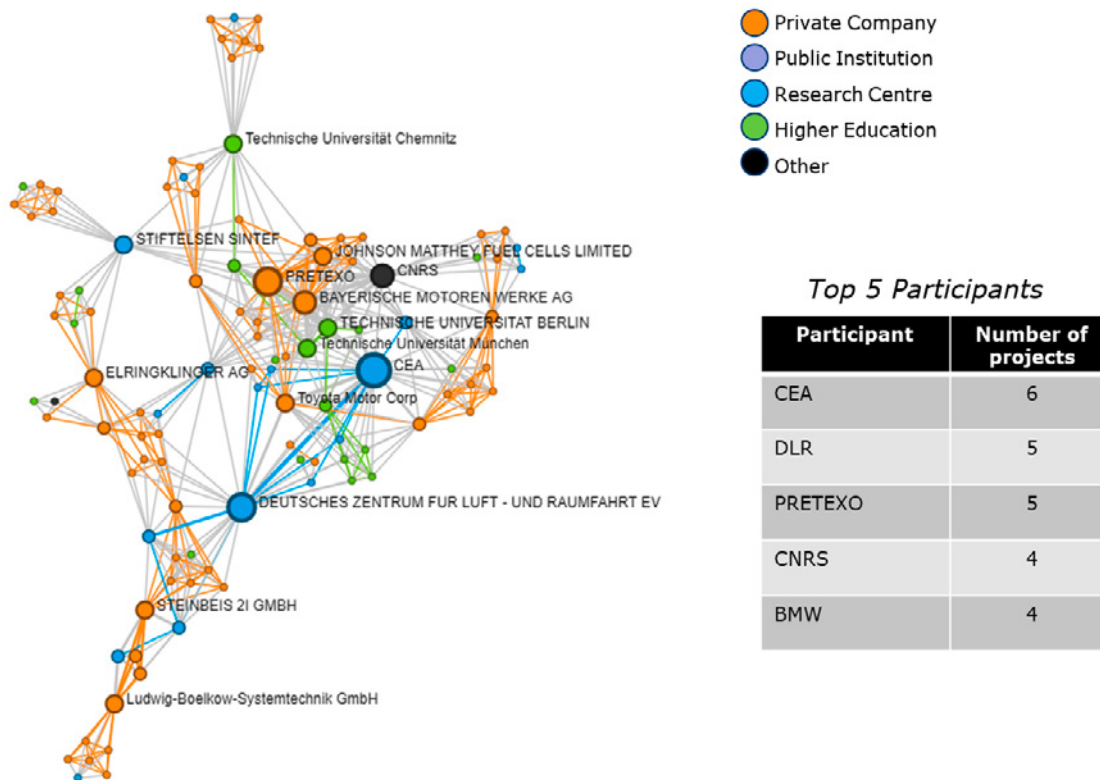


Figure 16 shows how consortia in panel 2 are often quite independent from each other, with individual partners frequently providing links between different projects.

Figure 16: TIM plot showing the participants in the 21 projects in panel 2.



Focus area 2.A: Vehicle stacks

Components and integration

GAIA is developing components (electro-catalysts, membranes, Gas Diffusion Layer, and MPL) and is aiming to improve their interfaces to minimise polarisation resistance in next-generation membrane electrode assembly (MEA). This will lead to reduced costs, increased power density, and greater durability, while accommodating higher operating temperatures. It has delivered a beginning of life (BoL) power density of 1.8 W/cm² at 0.6 V, thereby achieving its performance target.

CAMELOT is investigating the performance of ultra-thin and ultra-low-loading layers required by future MEAs by combining numerical modelling with innovative in-situ characterisation and is developing a scientific understanding of the limitations of advanced MEAs, achieving an open-source model accessible to the global FC community.

FC components

DOLPHIN is exploring an unconventional, highly innovative route towards a newly designed cell architecture featuring a dual-core single repeat unit (DC-SRU) delivering a lightweight and compact FC stack architecture. By using mechanically strong and corrosion-resistant structures redesigned for more coherent cell-internal interfaces to delay ageing and increase system reliability compatible with automotive durability targets, it is aiming for stack production costs of less than 20 EUR/kW.

FURTHER-FC builds upon the PEMICAN project. It is aiming to improve gas and proton transfer near catalytic structures and to investigate and validate performance limitations resulting from the coupling of electrochemical and transport issues in the cathode catalyst layer. It has progressed with the characterisation of reference catalyst layers by AFM, Raman and 3D FIB-SEM and direct numerical simulations.

Manufacturing

Three projects are included in this category, with the following goals:

- To advance the critical steps of the proton exchange membrane (PEM) FC assembly processes and associated in-line quality control and end-of-line test (DIGIMAN).
- To industrialise stack production, delivering affordable FC systems in larger quantities able to meet the demands of the emerging market, and building new manufacturing machines allowing for serial stack production (Fit-4-AMandA).
- To develop and integrate the most-advanced critical proton exchange membrane FC (PEMFC) stack components into an automotive stack showing a BoL performance of 1.5 W/cm² at 0.6V, less than 10% power degradation after 6 000 hours, and costing less than €50/kW at a 50 000 units annual production scale (INSPIRE).

DIGIMAN's main outputs are a proof-of-process and a blueprint design for beyond-current state automotive PEM FC European manufacturing. The demonstrator equipment for the uplifted cell assembly automation process has been manufactured and validated.

Fit-4-AMandA completed the assembly and validated the machine for serially producing PEMFC stacks using automatic assembly methods. For a 90 % automated production process, it demonstrated stack production in less than 30 minutes throughput time for one stack on a small scale. Nevertheless, it has also highlighted that the machine will need to undergo further engineering before it can reach its goal of 50 000 units per year.

INSPIRE designed and tested three generations of stack prototypes. The project met its performance and durability targets and the estimated stack costs are within 10 % of its target.

Focus area 2.B: Systems

Manufacturing

INLINE and INN-BALANCE started in 2017. Their goals include the scale-up of PEM manufacturing, balance of plant (BoP) definition (identifying and developing efficient and reliable components to reduce overall system costs), and the development of quality control practices for manufacturing and assembly procedures. At the same time, they should reduce the life cycle environmental impacts of stacks and components.

INLINE aimed to reduce the cycle time for production of an entire FC system from 15 hours to under 2.5 hours, thanks to continuous improvements in the production process. INN-BALANCE will develop highly efficient and reliable FC BoP components and therefore reduce the cost of current market products using FCs.

FC components

PEGASUS is exploring a promising route towards the removal of platinum (Pt) and other critical raw materials (CRM) from PEMFC. Their replacement with non-critical elements and structures should still provide stable electro-catalysis conditions, and the development of appropriate uses of Pt-alternative and competitive cathode catalysts.

CRESCENDO is developing diagnostic methods for determining active site density and turnover frequency and realising successful approaches to the stabilisation of non-platinum group metals (PGM) cathode catalysts during operation, as well as advancing research on non-PGM and ultra-low-PGM hydrogen oxidation catalysts.

APU, FC system integration and behaviour

FLHYSAFE has drawn on the experience of HYCARUS and completed the design for FC integration into airborne applications. FC short-stack testing (using oxygen instead of air) as well as start/stop cycle stack-degradation analysis is in progress. The emergency power system architecture is also being finalised, and a virtual reality tool enabling design optimisation and maintenance instructions has also been developed.

Giantleap has successfully demonstrated in a real traffic environment an FC range-extender prototype for FCBs in operation in the Netherlands. The project aimed to increase the reliability and availability of FCBs, which was achieved by the use of diagnostic and prognostic algorithms, for both the stack and several BoP components, and a range-extender design with a system mounted on a trailer. The project has been completed and an evolution of the prototype is currently in regular operation in the Netherlands.

The MARANDA project is developing an emission-free hydrogen-fuelled 165 kW (2 x 82.5 kW AC) PEMFC-based hybrid powertrain system for marine applications. Of the three assembled FCS, one was tested in December 2020 and connected to the electricity grid. A significant improvement in stack and FC durability was achieved (15 000 hours) along with a system electrical efficiency of 48 % (lower heating value – LHV).

VIRTUAL-FCS is developing an open source (under MIT licence) a software-hardware toolkit for rapidly designing and optimising PEM FCs/battery hybrid powertrains and systems (rail, maritime, bus, HDV). The project has defined a hybrid system design and parameters for an initial platform and model development and has produced a working model of an FC system.

Focus area 2.C: HRS – refuelling (including compression)

COSMHYC and COSMHYC XL are developing a hybrid compression solution (1-1 000 bar) by combining a metal hydride compressor and a mechanical diaphragm compressor. This new design allows for a reduction in CAPEX and the operating expense (OPEX), less noise, greater availability and therefore better hydrogen delivery efficiency in HRS (COSMHYC) and extra-large HRSs able to serve HDVs (COSMHYC XL).

H2REF developed and tested a novel hydraulic-based compression and buffering system. Both have high potential for improving techno-economic parameters for hydrogen compression at refuelling stations. The compressor is a critical component of HRSs and is still the main source of downtime. The compressor concept was finalised by including improved diaphragm materials and heating/cooling at reduced noise levels. H2REF

is demonstrating the use of a bladder accumulator technology applied to existing 70 MPa refuelling solutions. A full-scale prototype system was built and operated at Haskel's test area in France.

Focus area 2.D: Hydrogen storage/tanks – on-board storage

TAHYA is developing a completely innovative European hydrogen storage system for the automotive industry (a thermoplastic composite cylinder with a mounted on-tank valve) with the ambition to 'up-perform' the current Asian and US solutions.

THOR is developing a demonstrator for a high-pressure thermoplastic composite hydrogen storage vessel to validate innovative compressed hydrogen recyclable tanks for further integration into transportation applications.

Focus area 2.E: Aviation – liquid hydrogen use and storage

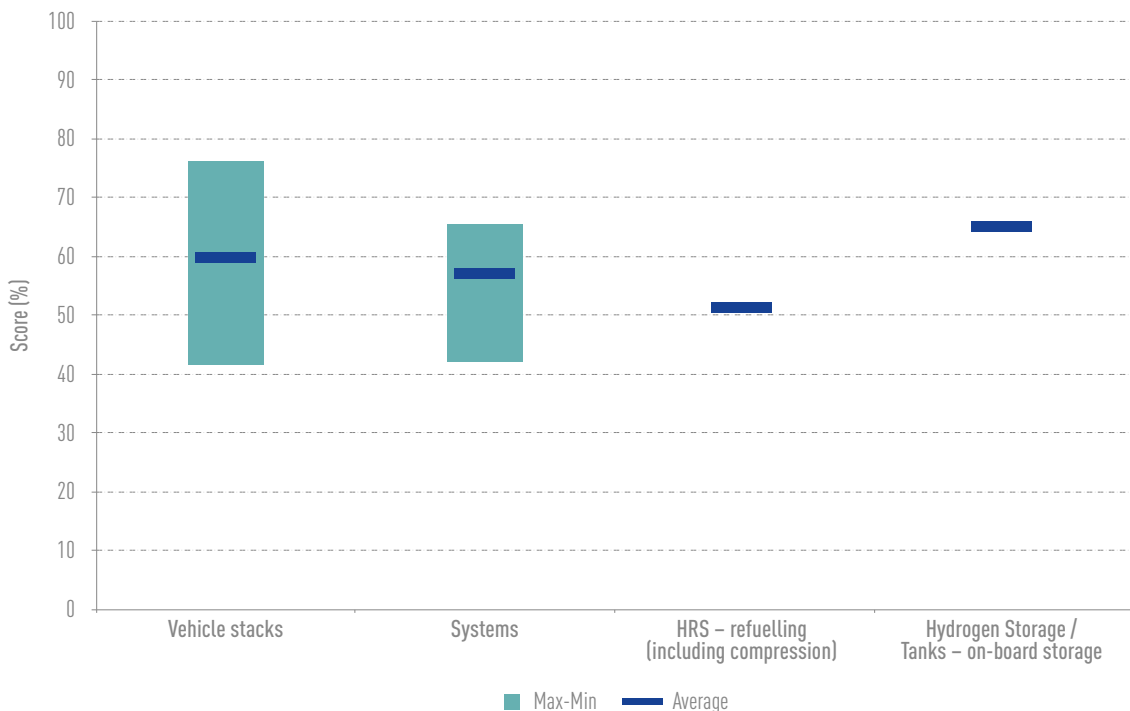
HEAVEN is aiming to build the powertrain for propelling an existing small four-passenger aircraft by adapting two 45 kW PEM FC systems. It also intends to integrate them with optimised BoP components using cryogenic hydrogen-storage technology and without employing a battery.

Panel 2 – Summary

Figure 17 presents the overall results for the assessment of projects in the panel and aggregates them into focus areas. Projects focusing on manufacturing, APUs and FC components have been grouped together irrespective of the fact that they address systems or vehicle stacks.

Overall, projects focusing on manufacturing, APUs and on-board storage have positive average scores, while those focusing on refuelling have lower average scores overall (due the lower performance of one of the projects in the portfolio). Dispersion in total evaluations is especially evident for manufacturing, refuelling and FC components and should be taken as an indication that projects are quite heterogeneous in their achievements.

Figure 17: Maximum, minimum and average scores for relevant focus areas in panel 2. No score is given for focus areas with a single project whilst, in the case of two or three projects, only the average is provided.



Strengths:

- Joint workshops are occurring more and more and enabling fruitful discussions and technical exchanges.
- Project interactions are facilitated by project consortia composition, with projects sharing their members.
- New projects that explore the use of non-PGM for electro-catalysis have the potential to reduce the use of EU-defined CRMs.
- Recyclability of compressed hydrogen storage tanks is being addressed.
- European development of innovative hydrogen-compressor technology is continuing and has advanced from low to higher TRL thanks to the COSMHYC family of projects.

Additional focus needed:

- The shift towards open source software libraries for FC and system modelling would be very welcome; attention should be paid to the details of the licence so as to encourage future improvements to be made public and freely available.
- Following the example of SHIPFC, future transport actions could consider the development of solid oxide FC (SOFC) and HT-PEMFC, including the use of other hydrogen-based fuels, for example, ammonia and methanol.
- Focus on cost-effective and affordable PEMFC, feasible low-PGM alternatives and their mass adoption. This should include appropriate screening tools based on computational materials science prior to lab-scale candidate testing.
- Future activities should aim to establish a common product design for compact, modular, and flexible FC and BoP components and provide integrated systems suitable for all modes of transport (except aviation).

- The development of smart and cost-effective quality control techniques should remain a central aspect of all manufacturing-oriented projects.
- APU solutions must be developed following the expected fuel choices for the different sectors (heavy-duty road transport, aviation, maritime).
- Field test activities largely depend on approval from different authorities, which is not always straightforward due to the absence of a well-established regulations, codes and standards (RCS) framework.

03

ENERGY PILLAR



3.1. OBJECTIVES

The energy pillar aims to accelerate the commercialisation of FCH technologies for stationary FC and to advance the production of green or low-carbon hydrogen as an energy vector in Europe. The widespread deployment of competitive FCH technologies can deliver substantial benefits in terms of energy efficiency, emissions and security, while simultaneously enabling the integration of renewables into the energy systems. As such, the FCH 2 JU programme supports activities in three main areas:

- Stationary FC (power and heat) demonstrations and PoC activities to prove technology capability and readiness;
- Stationary FC (power and heat) for improving performance, durability and cost;
- Hydrogen production pathways from renewable energy sources (RES); handling, distribution and storage technologies enabling hydrogen to become a major energy vector for Europe.

3.2. BUDGET

Between 2008 and 2020, 159 projects under the energy pillar received financial contributions from the FCH 2 JU, totalling more than EUR 523.5 million across several types of technologies. The distribution of projects is shown Table 3:

Table 3: FCH 2 JU financial contribution (EUR) for the three main activity areas in the energy pillar

Trials and deployment of FC applications	EUR 159.3 m
Next Generation of Products	EUR 124.9 m
Hydrogen for sectorial integration	EUR 239.3 m
Total	EUR 523.5 m

3.3. PANEL 3 – TRIALS AND DEPLOYMENT OF FC APPLICATIONS – ENERGY

Stationary combined heat and power (CHP) generation FC systems of all sizes still need additional development and larger production volumes to reduce CAPEX and operational costs, whilst improving system durability. The focus areas for the 2021/21 review are:

- I. Demonstration projects aiming to prove technology readiness bringing the technology to end-users and developing and experience in installing, operating and maintaining units in real applications. These projects are clustered into four focus areas:
 - A. micro-CHP (or μ -CHP) for domestic and small commercial buildings (<5 kWe);
 - B. mid-size installations for larger commercial buildings and service sectors (5-400 kWe);
 - C. large-scale size installations, mainly for industrial applications (>400 kWe);
 - D. off-grid, back-up and gen-set demonstration projects.
- II. PoC projects seeking to test and validate whole-system concepts, around TRL 4-6, and also aiming to improve performance, reliability, durability and cost of BoP and control subsystems for FC installations. These projects are clustered around two main drivers:
 - E. off-grid, back-up and gen-set PoC projects;
 - F. mid-size FC for diverse applications.

Half of the projects in this year's review involve SOFC; 6 out of 10 involve PEMFC; and one project considers AFC, with some projects working on multiple technologies. The FCH 2 JU programme portfolio of trials and deployment of stationary FC application projects is shown in Figure 18.

Figure 18: Trials and deployment of FC application projects in the energy pillar. Only projects whose names have been highlighted in larger black font size have been considered within PR 2020-21.

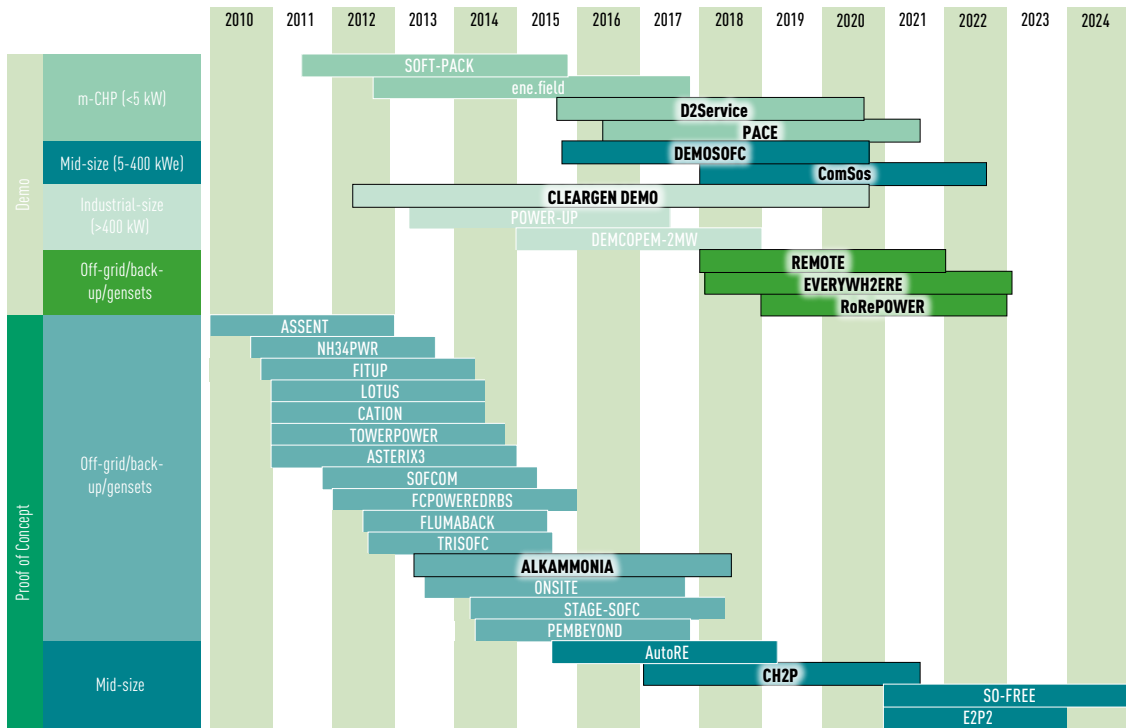


Figure 19: Funding for panel 3 (Trials and deployment of FC applications - energy) from 2008, including call 2020

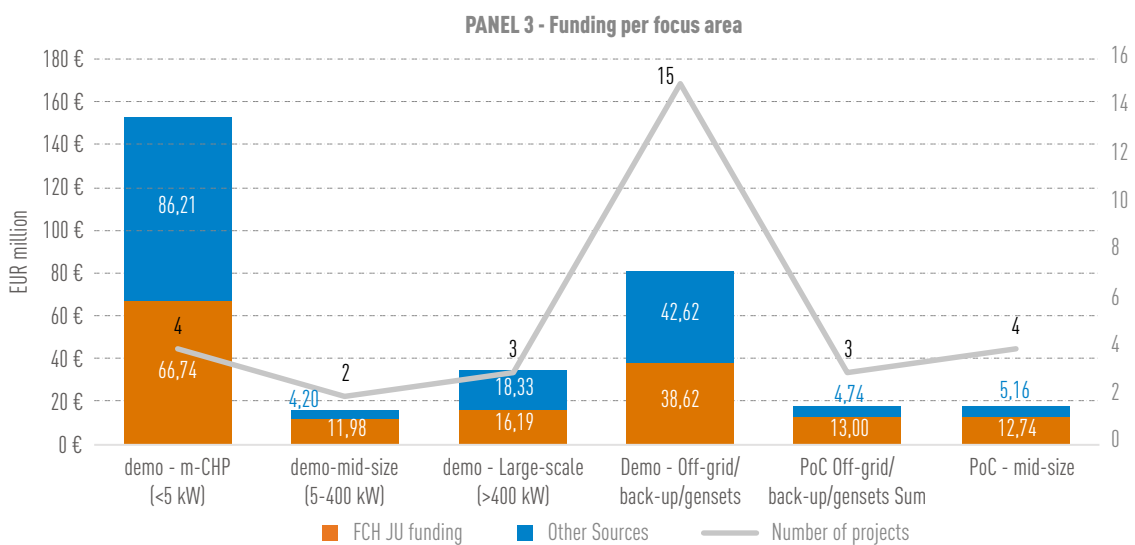


Figure 20 shows the cumulative project contributions to various FC technologies from 2010 onwards. It can be seen that on average, funding has been split more or less equally between SOFC

and PEMFC, with a slightly higher sum allocated to the latter. In 2013, two projects using AFC were funded under this panel.

Figure 20: Cumulative level of the EU funding for panel 3 projects: per FC technology.

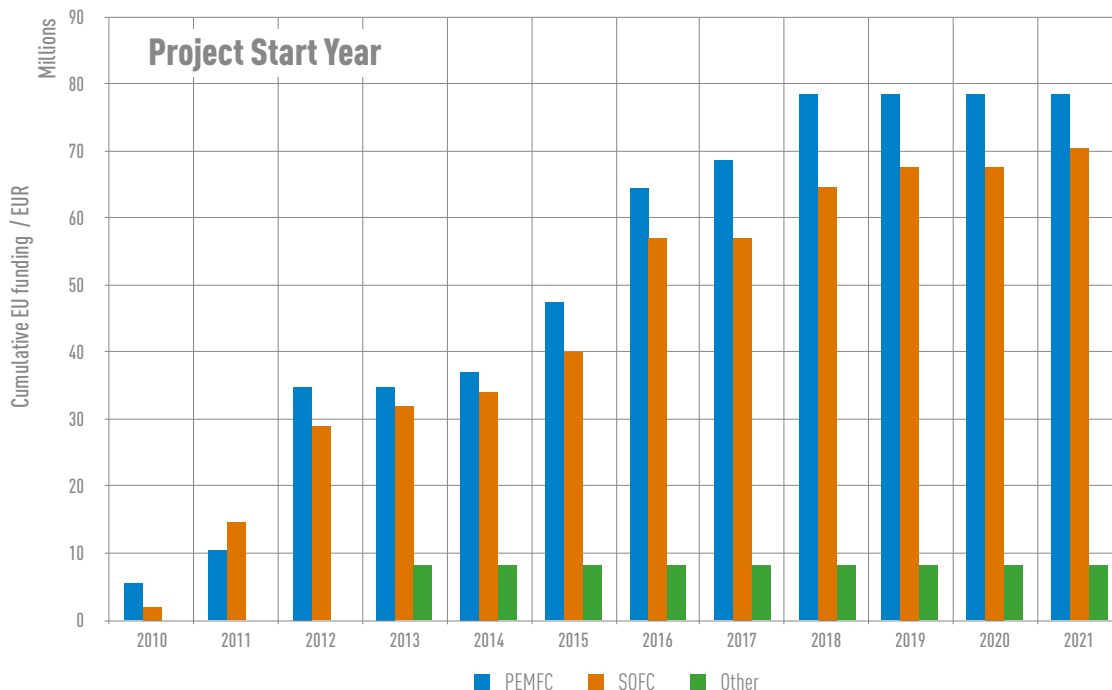
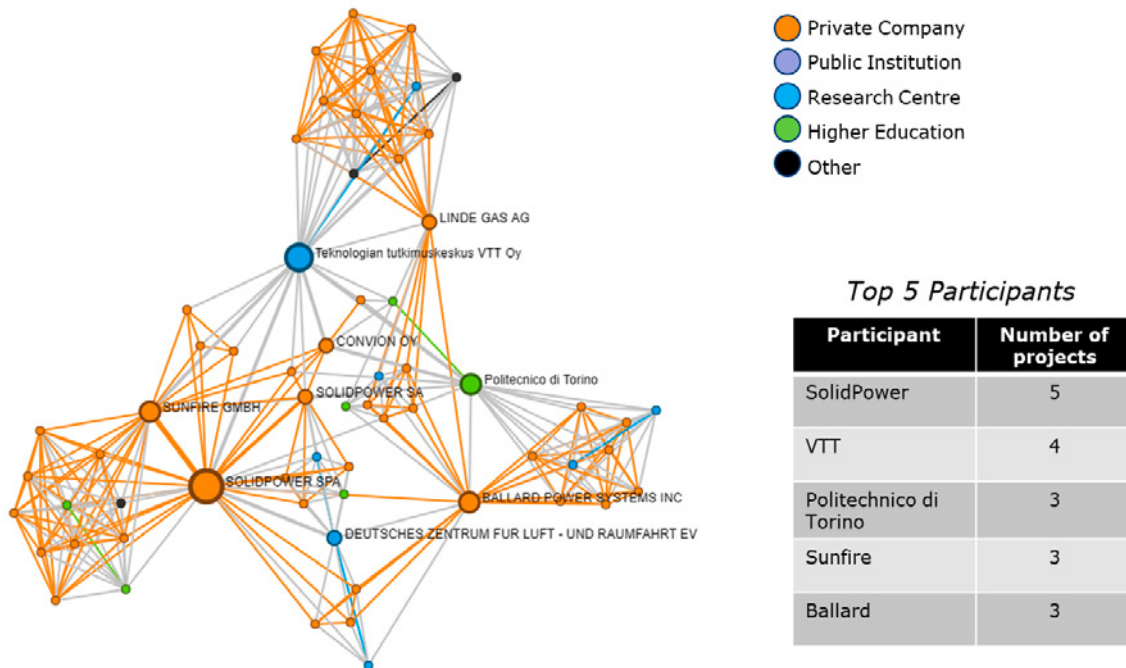


Figure 21 shows the connections between partners present in the projects in panel 3. For clarity, only the partners involved in the largest numbers of projects are named. TIM indicates clusters of partners by colour²¹ using its own algorithm. This figure shows that many projects are strongly linked to each other. However, there is one stand-alone project with no common interactions (shown in orange) – ALKAMMONIA is the only project dealing with alkaline fuel cells (AFCs). The key partners present in multiple projects in panel 3 are the FC stacks/system providers (SOLIDpower, Sunfire, Ballard), the Politecnico di Torino, and the research institute VTT. As these projects are higher TRL demonstration projects, it is evident that private companies dominate the participants.

21. The colour is based on the type of organisation, private registered company (PRC), public organisation (PUB), research centre (REC), higher education or secondary education (HES), other (OTH).

Figure 21: TIM plot showing the participants in the 10 projects in panel 3.



Focus area 3.A: Demonstration projects – μ -CHP (<5 kWe)

This focus area covers the projects PACE and D2Service. FCs have proven potential to provide CHP in domestic and small commercial building sectors due to their good efficiency and their ability to run on natural gas, a fuel popular with the domestic sector. European OEMs are approaching the commercialisation stage.

PACE, a successor to the ene.field project, plans to move the market towards mass commercialisation with up to 2 800 FC μ -CHP units expected to be installed by the end of the project. By 2020, it also aims to reduce the average unit costs to below EUR 10 000 per small FC system (<1 kWe) and below EUR 10 000 kWe for systems above 1 kWe, through more automated production and introduction of the next-generation systems.

At the time of this review (May 2021), the manufacturers involved in the project had concluded contracts for 2 183 units and installed 1 688 units, making PACE Europe's largest micro-CHP project to date. As it is clear that restrictions due to COVID-19 have slowed the rate of sales and installations to a certain degree, achieving the final target by project end date will be challenging (more than 1 000 units still need to be commissioned by the end of 2021).

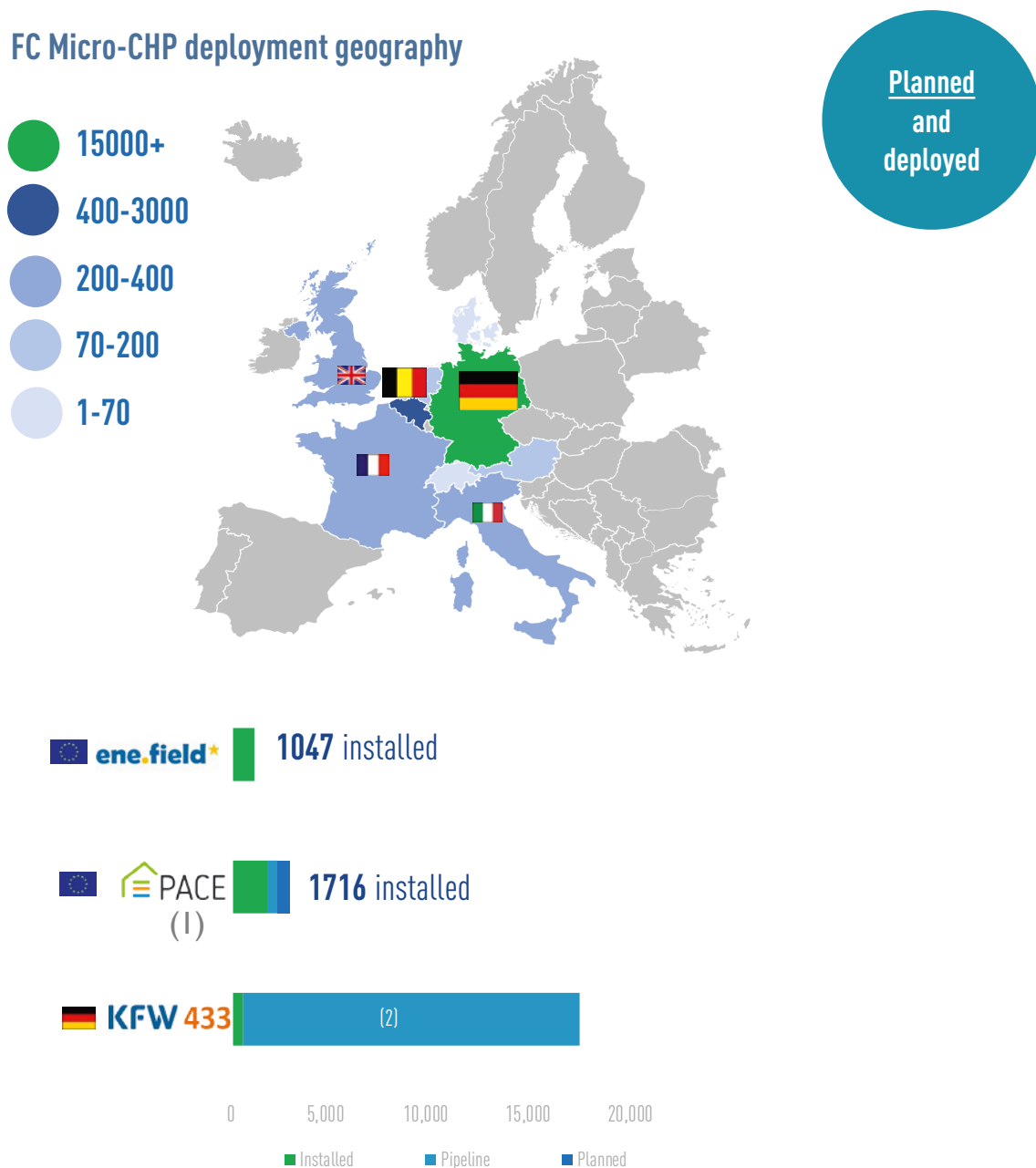
The project also plans to model (without a field demonstration) the potential benefits to the electricity grid when a large number of μ -CHP units are combined in a virtual power plant.

The D2Service project aimed to significantly reduce costs and labour for maintenance work and to promote the distribution of FC-based micro-CHP, supplemental power and back-up technology. Outcomes from the project, which was completed in March 2020, included simplification of components and system layout for component exchange. Furthermore, standardisation of components and improvements in their durability were achieved. Steps were also made towards improving remote monitoring systems to avoid service visits and provide early indication of failures. Another important aspect of the project was to improve service manuals to allow non-specialised technicians to perform routine service actions. The changes introduced led to an increase in the periodic service intervals for micro-CHP systems by a factor of 2 to 4, whilst service costs have

been reduced by more than 40 %. Remote monitoring can reduce the service frequency by 20 % and contribute to service cost reduction by up to 30 %.

Deployment of the FC μ -CHP units in Europe resulting from FCH 2 JU and the German national support programmes is shown in Figure 22.

Figure 22: Deployed and planned FC micro-CHP installations across the EU (up to March 2021).



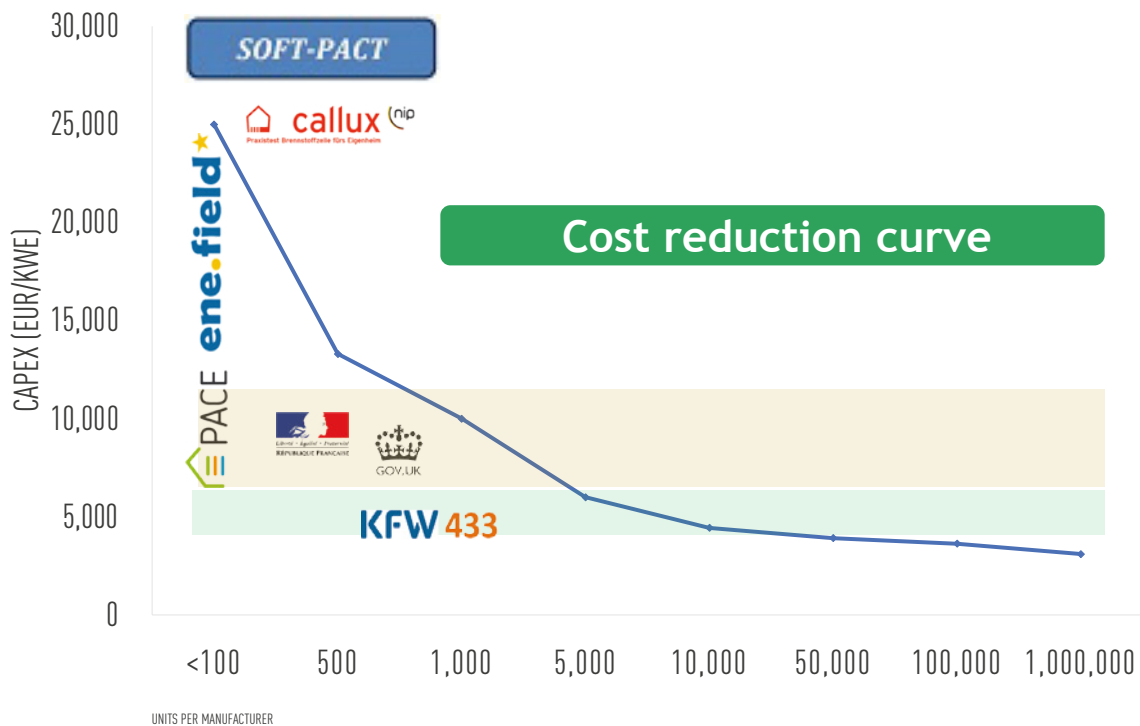
(1) Figures updated to the end of March 2021

(2) Applications filed under German KfW since 2016 until March 2021

Based on these figures, it can be said that the technological development of μ -CHP installations is mature. However, CAPEX is still high and additional incentives will be needed to ensure a widespread take-up and will require additional support.

Figure 23 shows how the cost-reduction curve can be expected to progress with increasing manufacturing volumes. There are still some areas where FCH 2 JU could provide targeted support for stationary μ -CHP units (e.g. improvement in materials, better mass manufacturing techniques). Greater emphasis could be placed on adapting SOFC technologies to run on pure hydrogen, considering the longer-term targets of full decarbonisation.

Figure 23: Cost reduction with market scale-up in the focus area μ -CHP demo (<5 kWe).



Focus area 3.B: Demonstration projects – mid-size installations (5-400 kWe)

In the mid-size installations focus area, the DEMOSOFC project, completed in October 2020, aimed to demonstrate the technical and economic feasibility of installing a 174 kWe SOFC system at a wastewater treatment plant in the Turin area (IT). This would have supplied ~30 % of the site's electricity needs and almost 100 % of its thermal energy consumption. Ultimately, the project was only able to install two SOFC modules (1 x 58 kWe and 1 x 44 kWe) due to delays to the final module. Despite this reduction in size, the overall goal of demonstrating an industrial-size biogas-fed SOFC plant has been achieved. The lessons learned have informed the design of the next generation of units developed under the R&I project INNOSOFC. These next-generation units are expected to be deployed in real installations in the COMSOS project. Further reductions in CAPEX and OPEX have been identified as essential for market take-up.

The main objective of the COMSOS project is to validate and demonstrate the advantages of mid-sized SOFC-based CHP systems in industrial or utility services environments. Three different sizes of 'mini/commercial-size FC-CHP' are being deployed in the power ranges of 10-12 kW, 20-25 kW and 50-60 kW. The consortium plans to install 23 demo systems.

Focus area 3.C: Demonstration projects large-scale installation (>400 kWe)

In this focus area, the project ClearGenDemo aims to demonstrate a 1 MWe PEMFC system utilising a refinery by-product hydrogen and using the 1 MW PEM FC to produce electricity for the Martinique public electricity grid (French overseas territory). Installation of the FC system and component was completed, along with integration in the refinery systems. However, complications

arising from regulations regarding earthquakes and other factors led to additional delays. Due to the COVID-19 travel ban, it was not possible to complete commissioning within the project's lifetime (which ended in September 2020). The system achieved 50 % electrical efficiency in the factory acceptance test, which exceeded its target (48 %). The lessons learned from ClearGenDemo will be taken up by a power-to-power project in French Guiana which is being developed by one of the partners, Hydrogene de France. ClearGenDemo intends to report on system performance once it has been commissioned, even if the project has ended.

Focus area 3.D Demonstrations – off-grid, back-up and genset

This focus area gathers together three demo projects – REMOTE, RoRePower and EVERYWH2ERE – focused on off-grid applications, both in remote places as well as in temporarily powered event areas.

The REMOTE project is demonstrating the technical and economic feasibility of FC technologies combined with RES and hydrogen storage solutions on island grids or in remote areas. In 2020, two demonstrations were installed in Norway and Greece and are now operational. The third new demonstration site will be in the Canary Islands, Spain). Detailed engineering and the permitting procedures are currently being developed.

A number of MAWP targets have been successfully achieved: rated PEM electrolyser efficiency of 50.5 kWh/kg, rated alkaline electrolyser efficiency of 50.6 kWh/kg, rated PEM FC efficiency of 45 % LHV, 15 years lifetime for the FC and 20 years lifetime for the BoP equipment. REMOTE was awarded the title of best renewable energy project in the European Sustainable Energy Week (EUSEW) 2020 Awards in the Innovation section.

In general, project results could be applied in new fields where there is need for storage of local RES, not only for power production but also for hydrogen use in different sectors. Grid balancing and the production of hydrogen for mobility could be potential fields of application.

The aim of the RoRePower project is to further develop and demonstrate SOFC systems for off-grid power generation in markets, such as gas and oil infrastructure, in remote regions with harsh climate conditions (from -40 °C to +50 °C), and the power supply for telecommunication towers, especially in emerging countries.

Twelve RoRePower units have been installed at customer sites. The Sunfire-remote 400 and 900 units have passed design freeze and have been introduced on to the market. The first RoRePower unit has been installed for a telecom application in Alaska, with the aim of gathering reliable field data and demonstrating the technology.

The EVERYWH2ERE project aims to demonstrate at TRL 8 FC gensets to replace diesel-fuelled generators for temporary power at construction sites, music festivals, exhibition centres, etc.). Two prototypes (1x25 kW and 1x100 kW), together with their hydrogen storage bundles, have currently been commissioned and were expected to start demonstration in June 2021.

Focus area 3.E: Proof of concept – off-grid, back-up and genset

This focus area covers projects focused on developing new solutions for off-grid applications, targeting both back-up power and CHP. For the period covered, this concerns only one project – ALKAMMONIA. This project, launched in 2013, aims to integrate an AFC with ammonia (NH₃) thermal decomposition technologies to provide zero-emission power from hydrogen derived from cracked ammonia. The targeted market is the replacement of stationary diesel generators. Ammonia, which has a higher energy content than hydrogen, brings the benefit of reduced transport and logistics costs, and is seen as an ideal fuel for offgrid power in both stationary and some mobile applications, such as maritime.

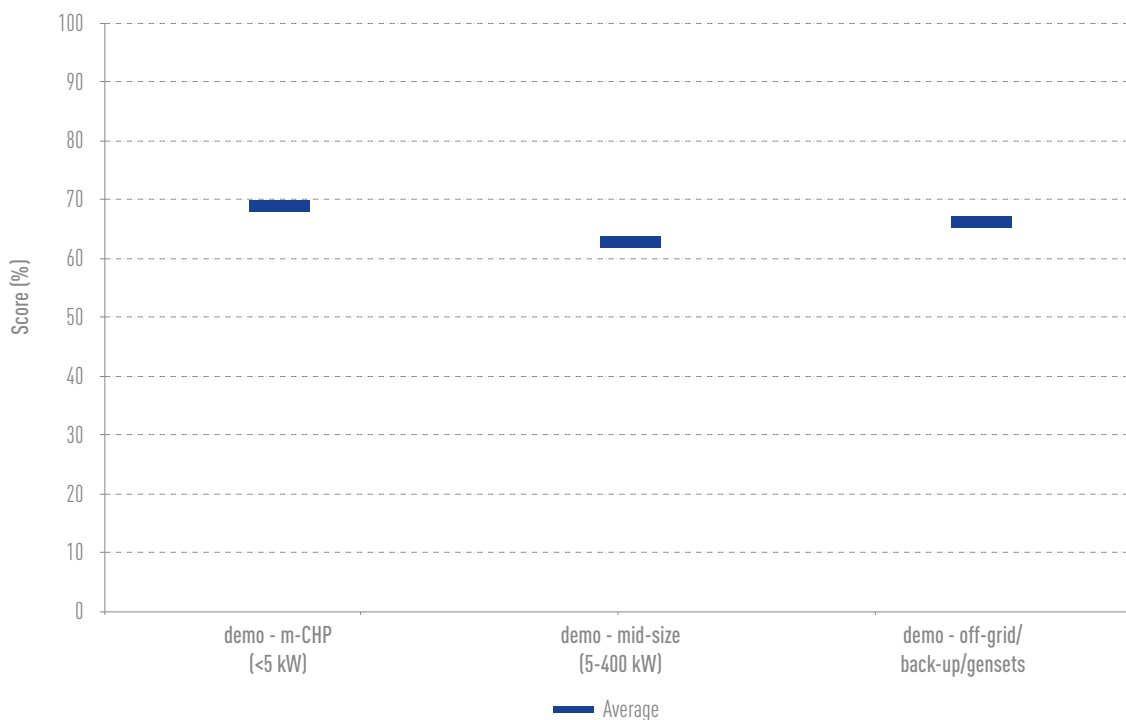
Focus area 3.F: Proof of concept – mid-size CHP

In this focus area, TRLs fall in the range 4-5 and are significantly lower than those for other focus areas in this panel. For the period covered, only one project – CH2P – falls into this focus area. The CH2P project focuses on flexible SOFC-based cogeneration of heat, power, and hydrogen for distributed hydrogen production in HRSs. The new system co-generates hydrogen, heat and electricity using solid oxide cell technology fuelled by carbon-lean natural gas or – possibly in the future – bio-methane. The project’s main achievement to date is the successful testing of the 25 kW large stack module. The estimated cost of hydrogen production equals ~4.5 €/kg.

Panel 3 – Summary

This section presents an assessment of panel 3 projects grouped into focus areas, based on the aggregated scores from all the reviewed categories, as shown in Figure 24. Data is only shown for focus areas with more than a single project. Average values are shown for focus areas with two or three projects. For the three focus areas shown, good average evaluation scores (60-70%) were achieved.

Figure 24: Maximum, minimum and average scores for relevant focus areas of panel 3. No score is given for focus areas with a single project whilst, in the case of two or three projects, only the average is provided.



Strengths:

For μ -CHP applications:

- For μ CHP applications, the majority of targets for 2020 have been achieved for both PEMFC and SOFC.
- Manufacturer-rated values for system lifetime and stack durability are higher than 2020 targets for both technologies. (It should be noted that they exceed the duration of the project and thus cannot be verified experimentally within the project time frame).

- Technology development enabled some improved products to match the MAWP system cost target for both PEMFC and SOFC.
- Installations within the PACE project have been operating more than 99 % of the time, achieving 'availability' key performance indicator (KPI) targets.
- FC μ -CHP systems are being included in the product portfolios of EU heating solution providers.
- European integrators of SOFC offering products on the market include small and medium-sized enterprises (SMEs).

For mid-size applications:

- Both technologies have achieved lifetime and electrical efficiency targets. Significant steps are still needed to achieve all targets for both technologies, e.g. CAPEX for SOFCs.
- An industrial-size biogas-fed SOFC plant has been demonstrated (DEMOSOFC).
- CH2P is opening up additional market opportunities in transport thanks to tri-generation.
- First-of-their-kind projects are demonstrating the technical and economic feasibility of FCs based in isolated micro-grid or off-grid remote areas, in particular in remote regions with harsh climate conditions.

For large-scale applications:

- The electrical and thermal efficiency targets have been achieved, along with the lower limit for stack durability.
- Products developed in the EU might be interesting for non-EU markets, as demonstrated by examples in the chloralkali industry in China.
- The development of FC solutions for large-scale stationary applications may induce a positive spill-over of know-how and greater manufacturing capabilities for emerging application fields, e.g. in the maritime or aviation sectors.

Additional focus needed and follow-up actions:

- To achieve the targets for full decarbonisation, the role played by natural gas will need to be reduced significantly. Adapting SOFC technologies to run on pure hydrogen should be considered, especially with the greater focus on the injection of hydrogen into the gas grid.
- Whilst the demonstration projects have taken deployment of FC μ -CHP to an advanced level, further research activities to reduce material costs are necessary as well as additional projects focused on manufacturing and scale-up to provide a range of competitive products on the market.
- There are still a few KPIs where progress against the SoA has not been achieved to date: in particular, reliability (which requires significant data from deployed systems to determine improvement), maintenance costs and installation volume.
- Mid-size and large-scale systems deployed in an industrial environment are often exposed to higher levels of contaminants. Attention should be given to methods of eliminating contaminants or increasing stack resistance. In particular, the durability of the PEMFC stack on upscaling is an issue.
- Whilst projects are optimistic about achieving CAPEX targets for mid-size SOFC in mass production, they are not achieving 2020 CAPEX targets. Further research may be required to reduce the cost of components and materials and to focus on volume engineering.

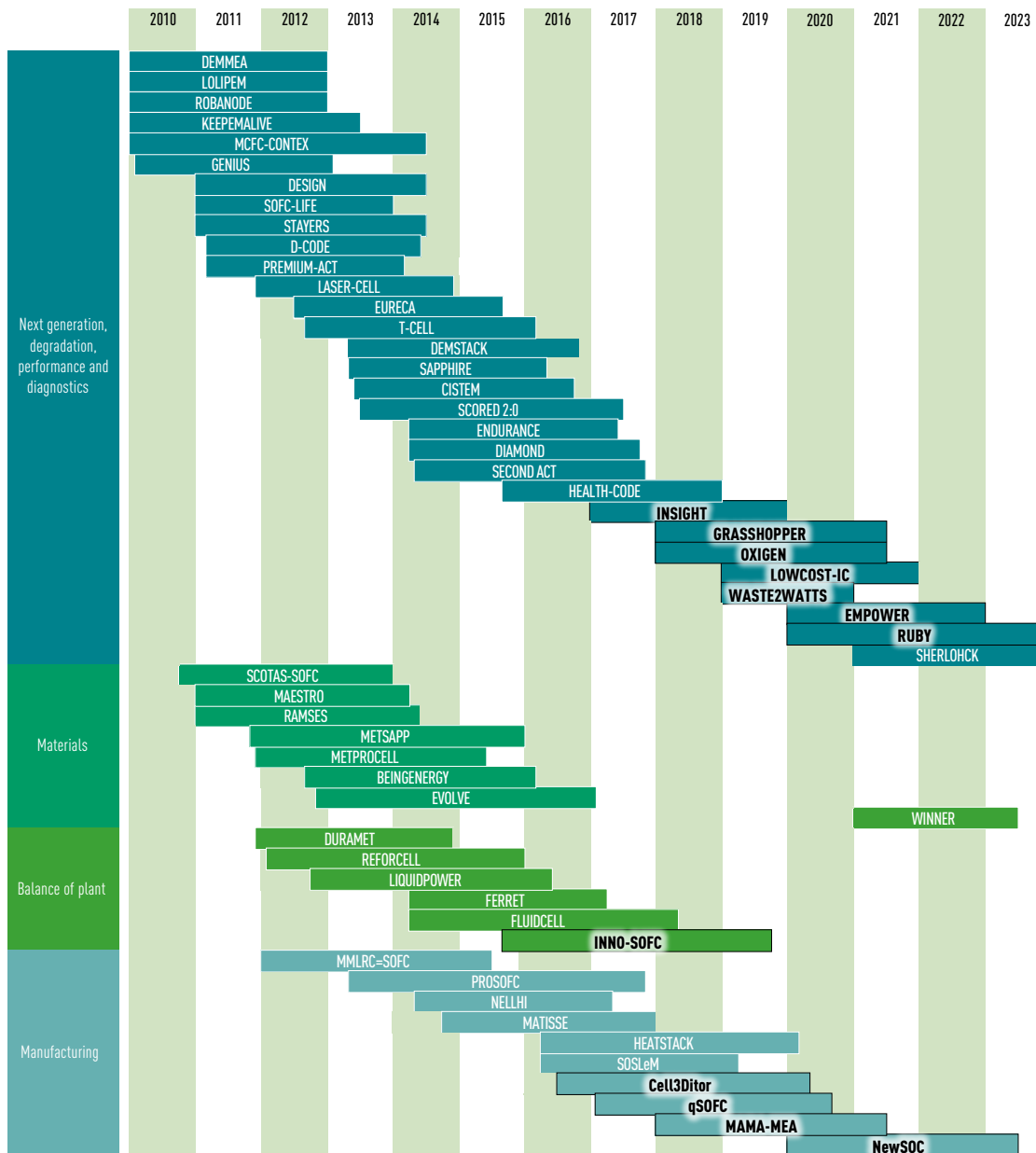
3.4. PANEL 4 - NEXT GENERATION OF PRODUCTS – ENERGY

For the scope of this PR, the projects in this panel were grouped into three focus areas:

- A. Next generation, degradation, performance and diagnostics
- B. Manufacturing
- C. BoP.

An overall picture of the FCH 2 JU programme portfolio of research projects on stationary fuel cells is given in Figure 25.

Figure 25: Next Generation of Products projects in the energy pillar. Only projects whose names have been highlighted in larger black font size have been considered within PR 2020-21.



Following the calls between 2008 and 2020, the FCH 2 JU supported 54 projects relevant to this panel with a total FCH 2 JU contribution of about EUR 124.9 million plus a contribution from partners of EUR 76.7 million. The historical distribution of total budgets over the four focus areas is shown in Figure 26.

Figure 26: Funding for panel 4 (Next Generation of Products - energy) from 2008, including call 2020.

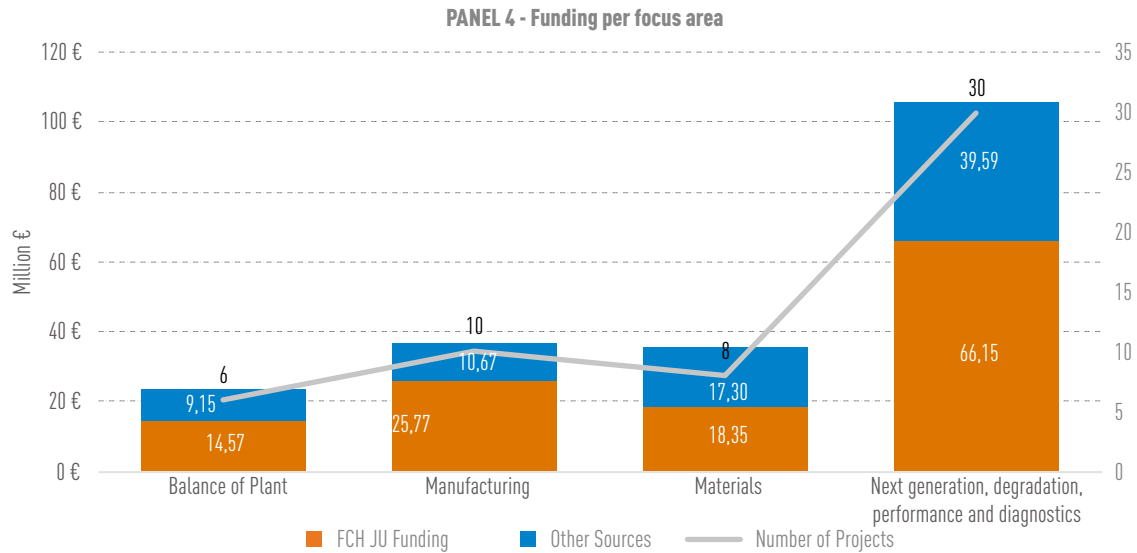


Figure 27 shows the cumulative funding contribution for different technologies from 2010 onwards. It can be seen that, prior to 2014, funding for SOFC was slightly higher than for PEMFC. Then, since 2016, it has markedly surpassed PEMFC funding and continued to grow at a much higher rate than it.

Figure 27: Cumulative level of EU funding contribution for panel 4 projects; funding per FC technology used.

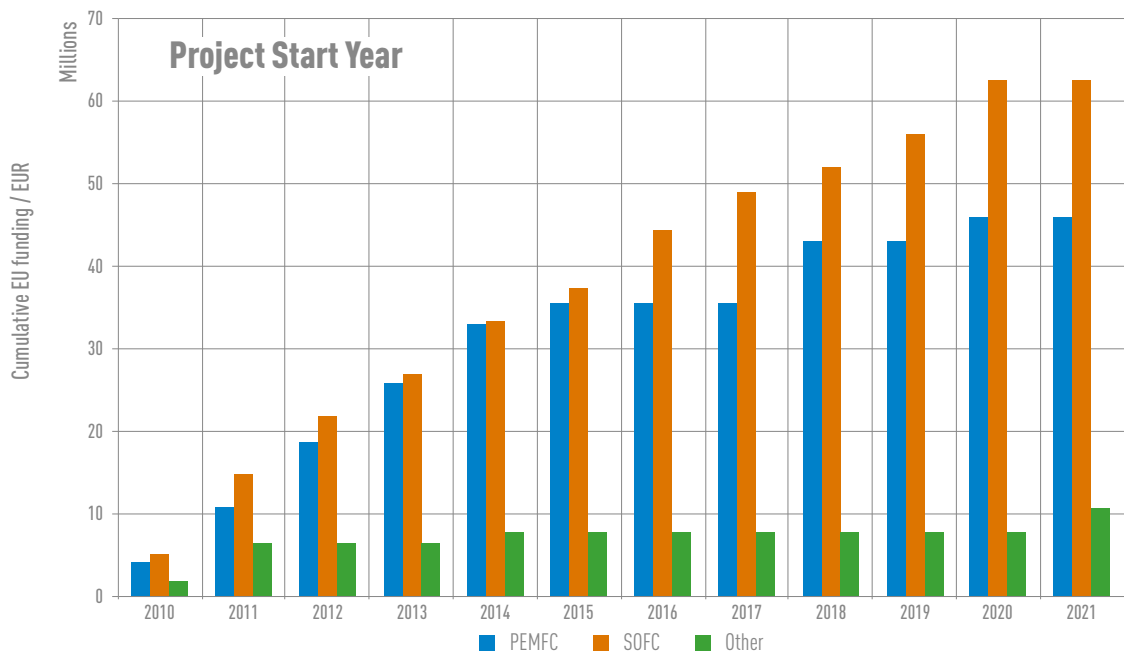
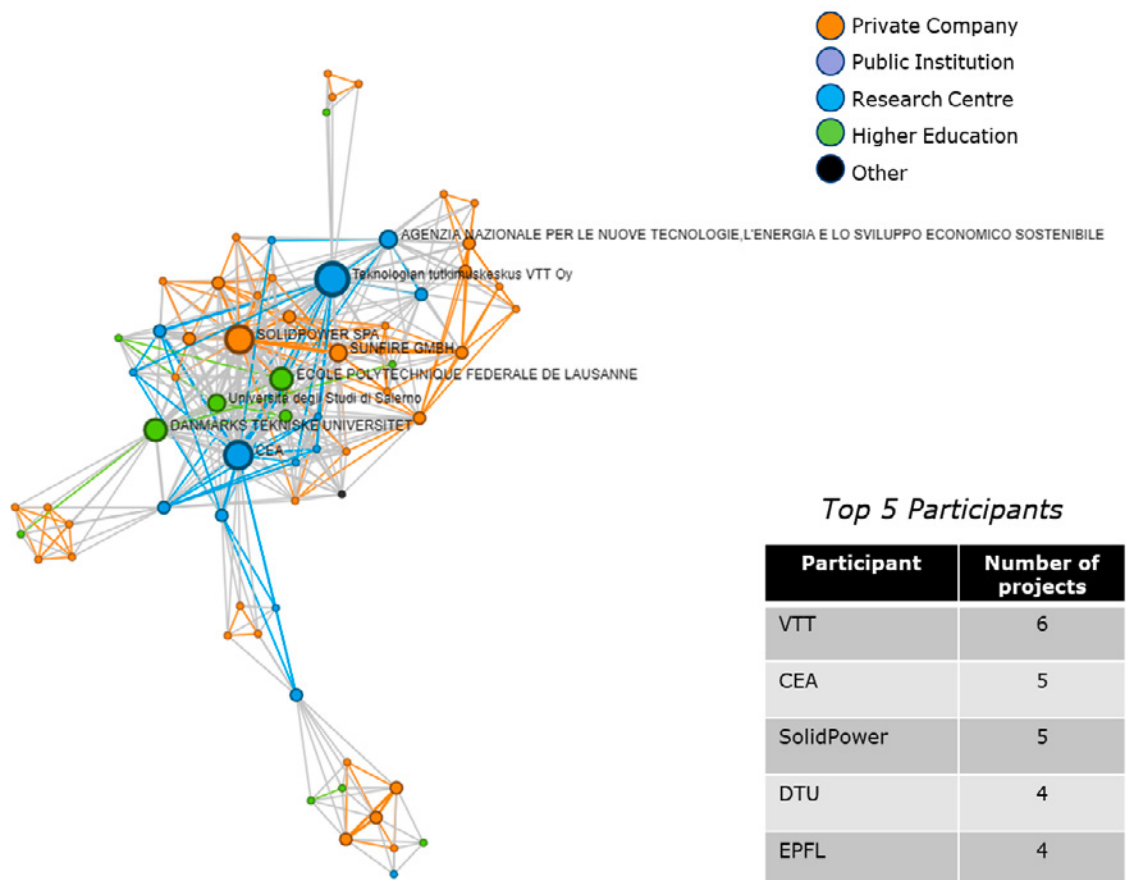


Figure 28 is a plot produced using TIM which shows the connections between partners present in the projects in panel 4. The size of the node (circle) represents the number of projects a partner is involved in, whilst the thickness of the lines linking the nodes represents the number of projects two partners have in common. For clarity, only the partners involved in the largest numbers of projects are given. TIM indicates clusters of partners by colour using its own algorithm. Figure 28 includes one large cluster around the projects dealing with SOFC technologies (INSIGHT, Waste2Watts, NewSOC, etc.) whilst the smaller cluster at the bottom of the figure contains two PEMFC projects (MAMA-MEA and GRASSHOPPER). Due to the lower TRL nature of projects in panel 4, a good mix of private companies, universities and research centres are present. VTT is the most active participant in this panel, followed by CEA and SOLIDpower.

Figure 28: TIM plot showing the participants in the 12 projects in panel 4.



Focus area 4.A: Next generation, degradation, performance and diagnostics

In this focus area, projects are aiming to bring the TRL for the investigated technological solutions up to 5-7 from an initial level of 3.

The INSIGHT project built on knowledge developed by past consortia with a well-defined constant core of participants developing different diagnostic tools for SOFCs and PEMFCs across several already finished projects (GENIUS, D-CODE, DESIGN, DIAMOND and HEALTH-CODE).

The project is finished and positive technical results have been achieved. The combined project targets of a 5 % lifetime increase at the expense of a maximum increase of 3 % for system cost have been reached. A significant experimental result from INSIGHT is the build-up of a library of data linked to typical faults and associated mitigation measurements.

Demonstrating the advantages of the large-scale introduction of these diagnostic instruments for both PEM and SOFCs now lies with the RUBY project, which should bring the TRL above level 7. Involving two FC system manufacturers, RUBY is continuing the long sequence of concluded projects already described for INSIGHT. At the end of the project, the tools developed are expected to be integrated into a commercial FC system.

The OxiGEN project is developing an all-ceramic stack design and specifications for a modular hotbox for an innovative SOFC platform. It is aiming to build a prototype μ -CHP system with an electrical power capacity of 1kW. Detailed market specifications for residential and small commercial applications have already been defined.

LOWCOST-IC is aiming to apply SoA large-scale roll-to-roll manufacturing to increase the reliability and reduce 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 selection of more resistant and cheaper steels which can be incorporated in available Sunfire and SOLIDpower FC stacks is the project's main goal.

GRASSHOPPER aims to test a new concept for an MW-size PEM FC plant unit. The objective is to provide more cost-effective and flexible grid support in its power output. Modelling and validations have been completed and have been instrumental in achieving an innovative stack design. The targeted CAPEX is below EUR 1 500 kWe for the FC at a yearly production rate of 25 MWe. The newly developed MEA has higher durability with lower Pt loadings. The pilot plant 100-kW prototype system is expected to be fully tested soon.

Waste2Watts will design and engineer an integrated biogas-SOFC CHP system with minimal gas preprocessing, focusing on low-cost biogas pollutant removal and optimal thermal system integration. The project is addressing unutilised biogas produced by millions of farms and bio-wastes from municipalities. The aim is to perform a test campaign using representative test gases with viable reforming catalysts and SOFC stacks (supplied by SOLIDpower and Sunfire).

EMPOWER is aiming to develop a micro-CHP system fed by methanol and based on HT-PEMFC. The project is still designing and testing sub-components.

Focus area 4.B: Manufacturing

All but one project in this focus area (MAMA-MEA) focuses on PEMFC manufacturing, with the rest investigating SOFC manufacturing options (qSOFC, CELL3DITOR and NewSOC).

The projects' overall goal is to enable the efficient manufacturing of large volumes of FC technologies with improvements regarding current costs, FC performances and environmental impact. Noticeable improvements have been achieved by FC products developed using innovative manufacturing methods. Even if improvements can be detected for many KPIs linked to performance, it seems that CAPEX is a crucial parameter which remains a long way from the expected values.

With the exception of MAMA-MEA, all projects explicitly mention CHP as target applications. Cost projections (especially for smaller-sized FC applications like micro-CHP) highlight the potential savings offered by scaling up manufacturing volumes. The reported rated electrical efficiency for SOFC has reached an impressive maximum of 74 % at stack level.

MAMA-MEA (finishing in 2021) is working on an innovative additive layer-deposition process using a single, continuous roll-to-roll MEA manufacturing process for the PEM FCs. The first two MEA prototypes have been assembled into rainbow stacks and their testing has been performed successfully.

Cell3Ditor developed a 3D-printing technique for the fabrication of SOFCs. A hybrid industrial printing machine, now commercially available, is able to print complete cells and stacks. The

environmental impact of the new 3D-printing method has been assessed through LCA and deemed more favourable than conventional SOFC manufacturing techniques.

NewSOC is aiming to significantly improve the performance, durability, and cost competitiveness of solid oxide cells and stacks compared to the current SoA. The project has five industrial partners offering finite SOFC products. It will develop several actions targeted at developing innovative architectures based on conventional materials. It will also test new materials with enhanced performance and new manufacturing processes providing products with excellent durability and better environmental performances, using less raw materials.

By increasing the automation level of the production process, the qSOFC project has significantly driven down the production cost of SOFCs for an Elcogen SOFC design. A purposely developed new automated machine vision inspection system was used to improve the quality assurance processes. Time-saving stack conditioning procedures were developed and reductions of the order of 75 % achieved.

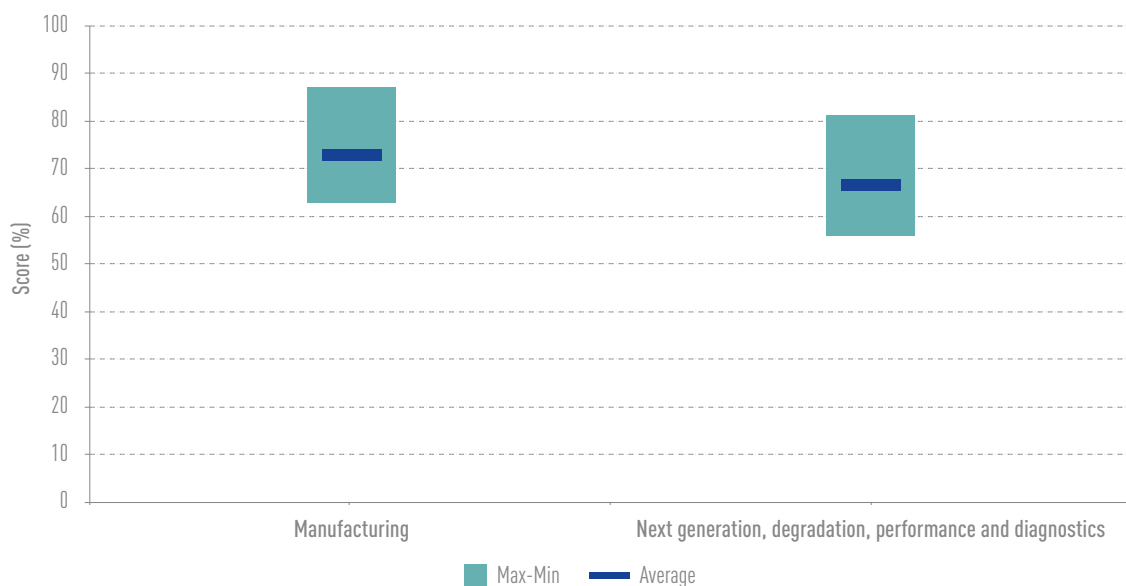
Focus area 4.C: Balance of plant

The finished INNOSOFC project has developed an innovative 50-kW SOFC system based on an all-European value chain (an Elcogen stack and Convion system). The project identified three niche applications with EU market potential under current energy prices: small server rooms, smart grid CHP, and bio-CHP. System calculations and preliminary field tests confirm that the targeted performance of the 50-kW SOFC system developed has been achieved with 61.4 % electrical and 81 % CHP system efficiencies. In addition, (and based on successful results in the FCH JU projects) Elcogen has received a EUR 12 million European Investment Bank quasi-equity loan facility for expanding research capacity and manufacturing. A new factory with a capacity target of 50 MW/year will be located in Tallinn (EE).

Panel 4 – Summary

Figure 29 shows the overall assessment of the projects reviewed in panel 4. Overall, the projects obtained positive evaluations (with some achieving a very good evaluation). The relatively low spread in scores also shows consistency in project performance.

Figure 29: Maximum, minimum and average scores for relevant focus areas in panel 4. No score is given for focus areas with a single project whilst, in the case of two or three projects, only the average is provided.



Strengths:

- Manufacturing projects have helped European FC producers (SOFC in particular) to modernise production lines and increase quality while reducing costs and environmental impacts.
- Opening a new production plant in Estonia thanks to intellectual property from qSOFC and INNOSOFC.
- The SOFC system developed by the INNOSOFC project has been deployed in a smart grid, providing an opportunity to gather relevant field-test information.
- Understanding degradation processes has been pursued extensively and the diagnostic and control tools developed, aiming to improve efficiency, reliability, and durability of stationary fuel cells, are progressing to higher TRLs and are being prepared for integration in commercial products.

Additional focus needed:

- Projects aiming at niche markets should present suitable business cases from the beginning and not at the end of the project.
- Project strategies rely on volumes (and therefore market demand) if costs are to be driven down. Thus, the development of sufficient volumes is a prerequisite to achieve the expected reduction in manufacturing costs.
- More structural feedback opportunities should be developed between demo projects in panel 3 and panel 4. Often, the transfer of knowledge is based on the presence of the same partners across consortia.
- Manufacturing consortia are organised around a single manufacturer. Priority should be given to future projects which can involve a larger set of European players.

3.5. PANEL 5 - HYDROGEN FOR SECTORAL INTEGRATION

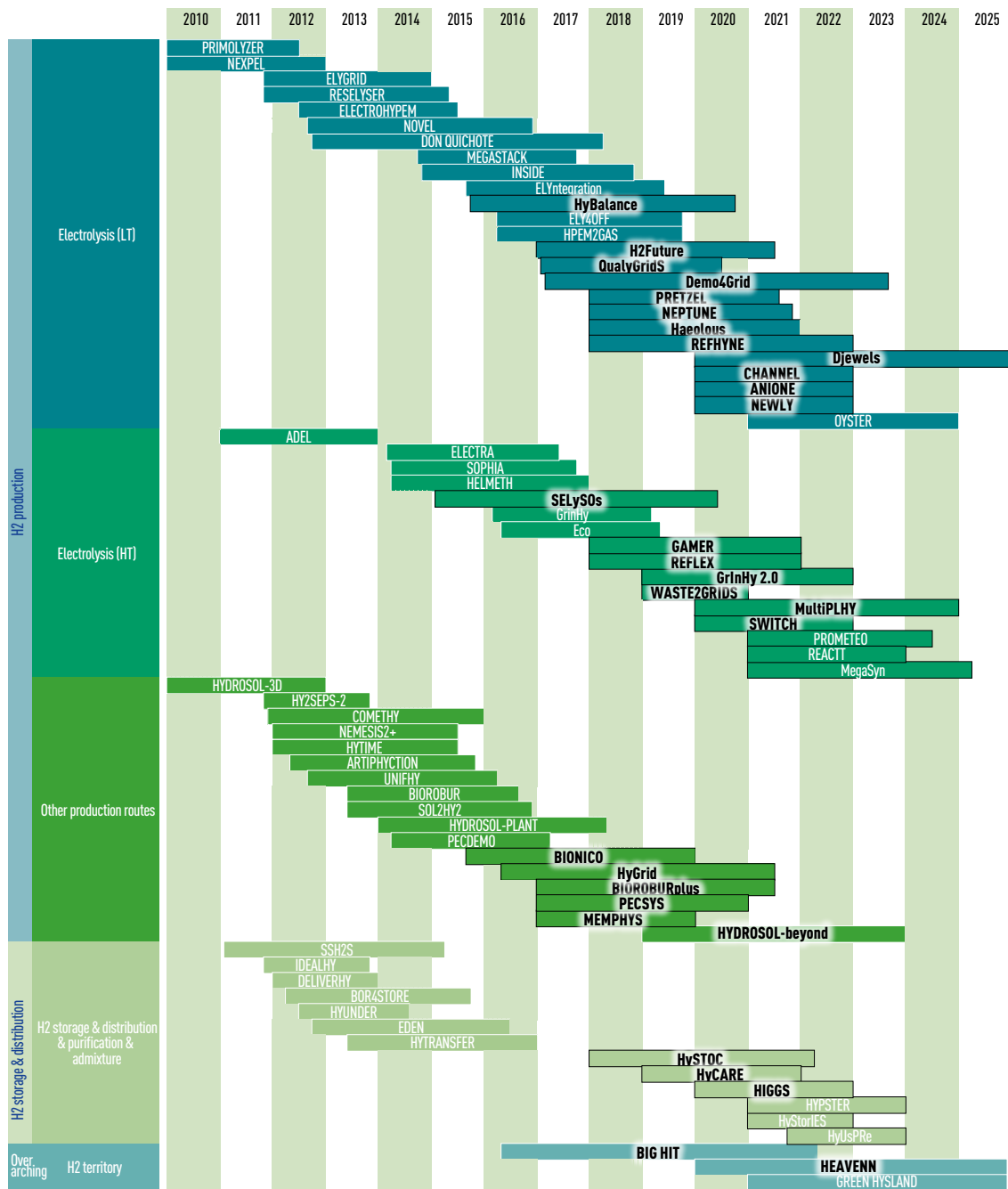
The projects in panel 5 contribute towards achieving the techno-economic objectives of making hydrogen production from renewables competitive, demonstrating hydrogen as a medium for energy storage, and sector coupling.

This part of the energy pillar is aimed mainly at reducing costs and improving the efficiency of hydrogen production, with a clear focus on demonstrating large-scale electrolysers. Green hydrogen production systems are being designed for integration into both the energy system and industrial processes. Five main focus areas, covering hydrogen production through to electrolysis, were defined for this year's review:

- A. Low-temperature electrolysis
- B. High-temperature electrolysis (incl. co-electrolysis)
- C. Other production routes
- D. Hydrogen storage and distribution, purification and admixture
- E. Hydrogen territories.

The current review covers the 30 projects highlighted in Figure 30.

Figure 30: Hydrogen for sectoral integration projects within the energy pillar. Only projects whose names have been highlighted in larger black font size have been considered within PR 2020-21.



Following the calls between 2008 and 2020, the FCH 2 JU supported 74 projects relevant to this panel with a total contribution of EUR 239.3 million plus a contribution of EUR 227.1 million²² from partners. In total, 59 % of panel 5 FCH 2 JU funding went to electrolysis (38 % of panel 5 FCH 2 JU funds supported LT electrolysis and 21 % supported HT electrolysis). The distribution of funding over the five focus areas considered in this panel is shown in Figure 31.

22. These figures include the overarching project BIGHIT which draws EUR 5 million of FCH 2 JU funding split between the energy (EUR 2.5 million) and transport (EUR 2.5 million) pillars, as well as MEMPHYS, which is funded by energy (EUR 1 million) and transport (EUR 1 million).

Figure 31: Funding for panel 5 (Hydrogen for sectoral integration – energy) from 2008, including call 2020.

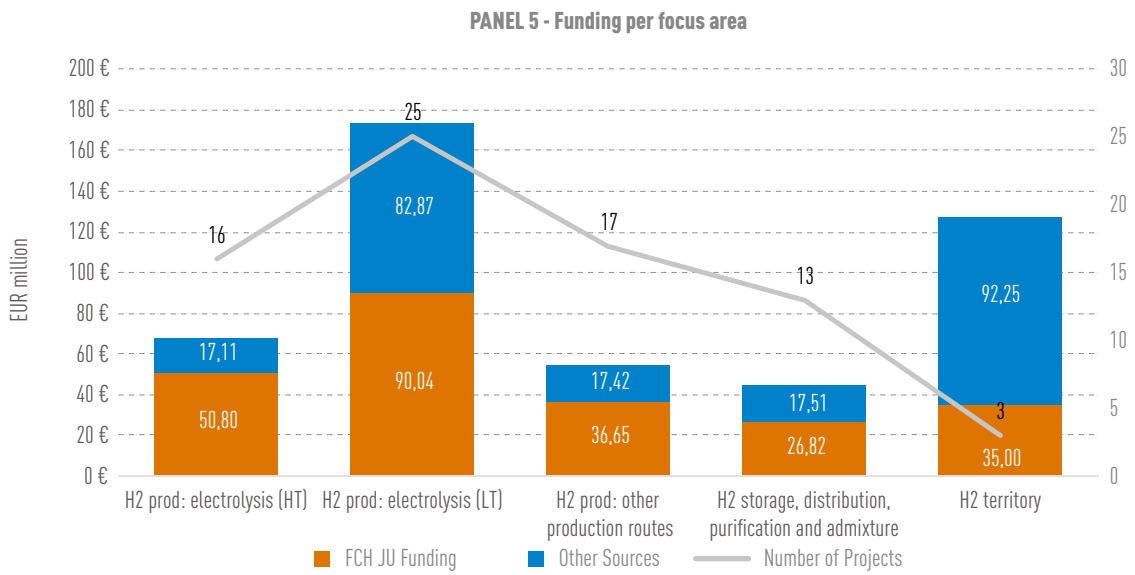


Figure 32 shows the cumulative contribution to projects working on various electrolyser technologies since 2008. Although PEM electrolysers have received the largest share of funds, from 2018 onwards, there has been a shift towards mainly SO as well as other types of electrolysers.

Figure 32: Cumulative EU funding for projects related to different electrolyser technologies.

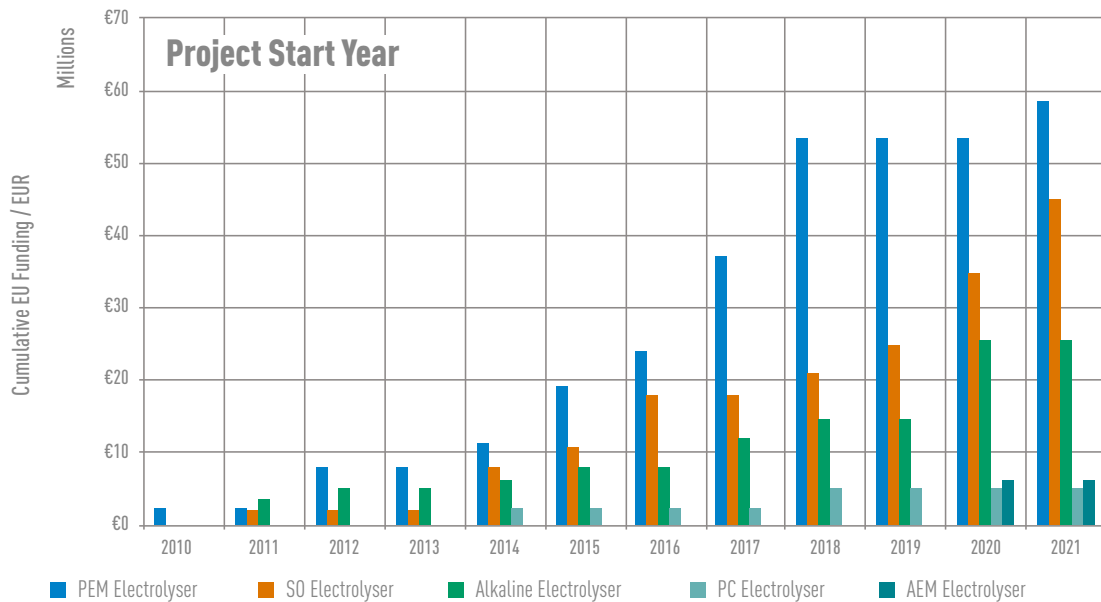
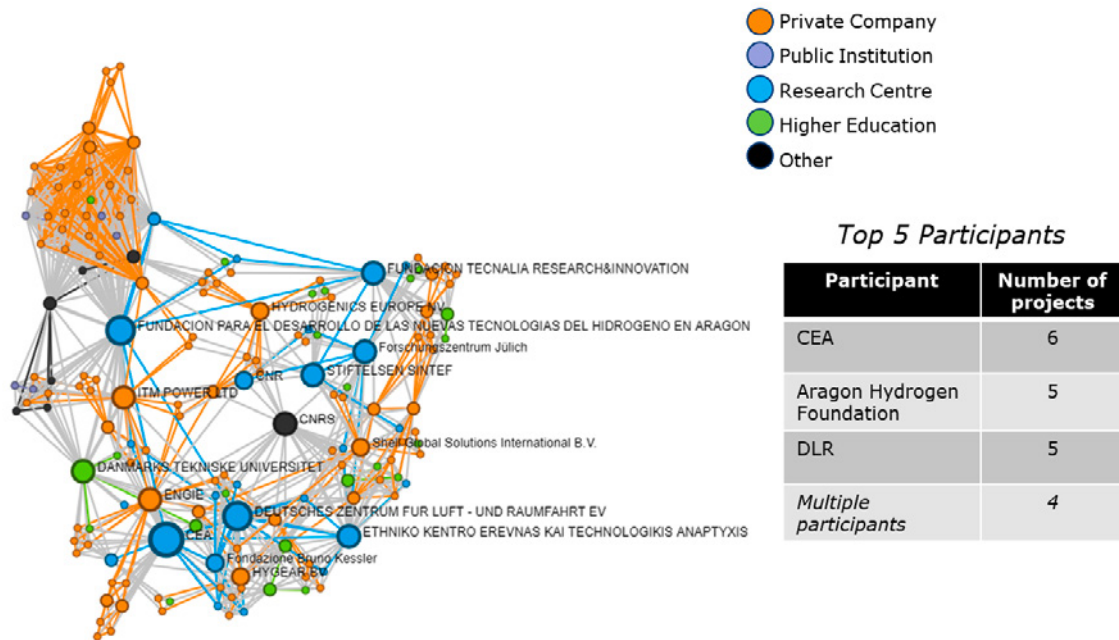


Figure 33 is a plot produced using TIM showing the connections between the partners in the projects in Panel 5. According to the plot, this panel has a very strong presence of research centres and strong collaboration between participants, resulting in a dense network which is somewhat surprising given the diversity of the technologies supported. Only one project on PEM electrolysis (H2FUTURE) has no connection with participants in other projects (the isolated cluster at the top of the figure), whilst all other projects are linked through at least one participant. Once again, the most active partner in this panel is CEA which is involved in six projects, followed by DLR and Aragon Hydrogen Foundation which are both involved in five projects.

Figure 33: TIM plot showing the participants in the 30 projects in panel 5.



Focus area 5.A: Low-temperature electrolysis

This focus area currently consists of 12 projects including 3 on anion exchange membrane electrolysis, 2 on alkaline electrolysis, and 6 on PEM electrolysis. One project is focused on the development of testing protocols for grid services. Hydrogen production through electrolysis has also been supported in the transport pillar (panel 1), where low-temperature electrolysers have been deployed to provide hydrogen for HRSs.

The previously noted trend in lower support from the FCH 2 JU per MW capacity deployed has continued, with capacity having increased 100-fold in the past 8 years and support decreasing 50-fold.

Alkaline electrolysis

The DEMO4GRID and Djewels projects aim to demonstrate AEL technology at the multi-MW scale in an industrial environment with dynamic operation. Two major goals in the programme are improvements in coupling alkaline electrolysers to renewable sources, i.e. improving their flexibility under variable and partial loads and increasing their response times, and the scale-up of alkaline electrolyser systems. Once operational, Djewels, the newer project, may reach the 2024 electricity consumption target of 49 kWh/kg H₂ as well as that for stack current density, at least according to the design specifications.

The Demo4Grid project, building on the outcomes of ELYGRID and ELYNTEGRATION, is preparing to install a 3.1-MW pressurised alkaline electrolyser which will supply hydrogen for FC trucks and provide heat for an industrial bakery. The project has carried out an assessment of potential business cases, with a focus on power-to-heat and mobility markets. The former will become interesting when natural gas prices are high and electricity costs low. This application would be best combined with either the provision of grid services or supplying hydrogen for mobility.

The Djewels project is deploying a 20-MW electrolyser for the production of renewable methanol. The design foresees a system efficiency of 75 % which would make a significant contribution towards reaching the MAWP 2024 targets. The stacks should have an operating range of 20-110 %, and the

system a hot ramp idle time of 30 seconds. A current density of 0.9 A/cm² can be implemented through the development of novel electrodes. The project is currently at the engineering phase and the construction of the 1-MW stack testing facility has been completed.

PEM electrolysis

As intended, the electrolyzers deployed should have a rapid response time (of a few seconds) in order to participate in the primary and secondary grid-balancing markets. A key challenge has been to upscale the PEM electrolyzers (PEMEL) to a multi-MW level, and much progress has been made in this respect.

The HyBalance project, which ended in 2020, has installed and commissioned a 1.25-MW PEMEL in Hobro in northern Denmark, providing hydrogen for industrial and mobility customers. The stack operates at 30 bar with an efficiency of 72 %. As certified by the Danish Transmission System Operator Energinet.dk, the plant can provide grid services on the energy market. The overall energy demand of the plant per kg of hydrogen produced has reached 56.5 kWh/kg H₂ in line with the project target of 57.5 kWh/kg H₂.

Through the H2FUTURE project, a 6-MW PEMEL from Siemens has been operating at the Voestalpine Linz steel plant in Austria since October 2020. The hydrogen produced will support fossil-fuel-based steelmaking technology as part of a stepwise decarbonisation approach to steel production proposed by the steel manufacturer. In future, the direct reduction of iron ore by hydrogen will lower the footprint of steelmaking significantly.

Refineries need hydrogen for upgrading fuels and removing sulphur components. The REFHYNE project will provide bulk quantities of hydrogen to the Shell Rhineland refinery in Germany (currently supplied by two steam methane reformers). With a capacity of 10 MW, it is Europe's largest electrolyser (ITM). It began operations in July 2021 and will produce 4 000 kg H₂/day at a pressure of 20 bar. Plans are under way to expand the capacity of the electrolyser from 10 megawatts to 100 megawatts. The project is also seeking to mobilise additional income through the provision of grid services.

HAEOLUS is combining a 2.5-MW PEMEL and a 100-kW FC in the remote harbour of Berlevåg, Norway. The aim of the project is to test control strategies for each mode of operation in wind-hydrogen systems: energy storage, mini-grid and fuel production. The results will be relevant to many wind farms across Europe and worldwide. The two components were installed in the remote harbour in May 2021, the objective being to optimise the use of wind power for this challenging location close to the Arctic Circle.

Game-changer PEM electrolyzers

Hydrogen costs must be reduced for the large-scale provision of hydrogen to industry. Whilst OPEX is inextricably linked to the local cost of electricity, CAPEX reductions could be instigated by increasing current density or improving efficiency by operating at higher pressures. Thus, the FCH 2 JU started to fund the development of 'game-changer' electrolyzers. The two projects funded – NEPTUNE and PRETZEL – focused on increasing the current density and output pressure of PEM electrolyzers.

The NEPTUNE project aims to reduce CAPEX for PEMEL, by increasing both hydrogen production rates and the output pressure in order to enhance efficiency. The goals are to achieve a current density of 4 A/cm² at low PGM loading and an increase in output pressure to 100 bar, while retaining the nominal energy consumption of <50 kWh/kg H₂. The project includes developments at cell, stack and system level resulting in a final demonstration at 48- kW capacity.

The PRETZEL project is aiming to develop an innovative game-changer PEMEL. A maximum 25-kW system generating 4.5 m³ h⁻¹ of hydrogen at rated power, with a feed water temperature up to 90

°C and 100-bar output pressure are the project's ultimate goals. The stack is based on a hydraulic system of pressurisation where it is contained within a pressure vessel, which should ensure homogeneous pressure, even current density distribution and should minimise degradation. This means that the targeted oxygen output pressure is also 100 bar. The targeted current density (4 A cm⁻²) required by the call goes well beyond the MAWP 2020 target (2.2 A cm⁻²).

During the assessment period, catalyst synthesis has been successfully upscaled to the levels required, and both catalysts and coated components have passed compliance tests, providing the necessary activity, stability and corrosion-resistance properties. The first 100 bar H₂ tests have been carried out successfully for the 5 Nm³ h⁻¹ system.

Testing protocols

The testing and qualification of electrolysers is essential to assess their ability to operate dynamically and perform electricity-balancing grid services. The QualyGridS project has developed testing protocols for AEL and PEMEL electrolysers taking into consideration a variety of different grid services as well as multiple hydrogen end-users. The scope was to identify the systems' capability to provide grid services as well as to indicate possible gaps. Testing protocols have been defined and applied for three alkaline and two PEMEL systems. The project ended successfully on 30 June 2020. The results showed that protocols are clear and implementable, and that all proton exchange membrane water electrolysis and alkaline water electrolysis can meet most of the grid services' requirements. A report compiling testing protocols for five different low-temperature electrolysers in various locations in Europe was submitted to the ISO/TC197 standardisation technical committee and formally approved by its members, which constitutes a great success for the project.

AEM electrolysers

In addition to the two main low-temperature electrolyser technologies (alkaline and PEM electrolysis), recent years have seen the development of anion exchange membrane electrolysers (AEMEL) which operate in alkaline media but use a solid electrolyte. In principle, this means they can combine the use of non-Pt group metal catalysts with the production of high-purity hydrogen due to the presence of the solid electrolyte. However, this technology is currently at a low TRL level and has yet to achieve the performance and durability of other water electrolysis technologies. To date, there is only one AEMEL manufacturer (Enapter) on the market. Three projects are funded by FCH 2 JU: CHANNEL, ANIONE and NEWELY, all of which have been included in the PR for the first time this year.

The objective of the CHANNEL project is to develop a low-cost electrolyser stack and associated BoP. The project aims to use low-cost materials, non-PGM catalysts, SoA anion-exchange membranes and ionomers, along with low-cost transport layers, current collectors and bipolar plates to construct a 2-kW prototype stack. The project partners intend to demonstrate a preliminary short stack before the end of 2021 to mitigate risk regarding the full stack demonstration. The consortium has performed a market and cost analysis of the 2-kW prototype to develop a cost-reduction strategy towards a capital cost of < EUR 600 per kW for a 500-kW system.

The objectives of the ANIONE project are similar: to develop high-performance, cost-effective and durable AEMEL technology. In the project's initial stages, non-CRM catalysts and novel membranes are being developed with the ultimate aim of achieving TRL 4 for a validated 2-kW electrolyser. To date, the project has successfully developed non-CRM anode catalysts which achieve the project's performance and durability targets. Work is ongoing to improve the performance, in particular the durability, of novel cathode catalysts under investigation.

The third project in this grouping is NEWELY with goals which are very similar regarding the three challenges of AEMEL: membrane, catalyst and stack performance and durability. By the end of the project, a prototype five-cell stack of 2 kW should have undergone 2 000 hours of testing. MEAs using their novel catalysts (but a commercial membrane) have achieved 2 V at 2 A cm⁻² in

0.1 M KOH (potassium hydroxide) and a degradation rate of 500 $\mu\text{V/h}$ at 1 A cm^{-2} . The project has completed its first publication and submitted its first patent applications.

Focus area 5.B: High-temperature electrolysis

This focus area covers the research and development (R&D) projects SElySOs, GAMER, and SWITCH, as well as the demonstration projects GrinHy2.0, MultiPLHY, REFLEX and Waste2GridS.

R&D projects

The SElySOs project is testing modified nickel (Ni)-based and Ni-free cathodes and new air electrodes, seeking to enable the development of new solid oxide electrolyser cells (SOECs) less prone to degradation and with improved performance and stability. Experimental work is combined with theoretical modelling to understand reaction mechanisms and processes that cause degradation.

As the project acronym implies, the SWITCH projects seeks to develop a reversible system able to operate in both SOEC and SOFC mode, with a capacity of 25 kW (SOFC)/75 kW (SOEC) and a minimum operating time of 5 000 hours. In FC mode, other feedstocks (natural gas, biomethane, etc.) can be used to produce hydrogen when renewable electricity prices are high. A number of possible use cases are being considered, such as integration into a HRS to supply hydrogen, heat and electricity.

The GAMER project seeks to develop and operate a 10-kW tubular proton ceramic electrolyser (PCEL), producing hydrogen at 30 bar at a high electrical efficiency of up to 77 % for the system, provided there is an external steam source. In addition, the project should aim to decrease the cost of the hydrogen produced to below EUR 6.9 per kg, and has demonstrated a single engineering unit in pressurised electrolysis mode at 600 °C at up to 10 bar (the initial target was 30 bar). The advantage of an operating temperature lower than that of the SOEC is reduced corrosion of the components, thereby enabling the use of cheaper materials and helping to lengthen the lifetime. If maintained at the final stage, the performance and degradation results achieved to date at the small scale would make tubular stack configuration a game changer for PCEL.

Demonstration projects

The GrinHy2.0 project is the successor to the GrinHy project's electrolyser installed at the Salzgitter steel production plant. This will be the world's biggest high-temperature electrolyser with a capacity of 720 kW AC and an electrical efficiency of 84 % LHV. The aim is to achieve production of at least 100 tonnes of hydrogen over 13 000 operational hours with a system availability of 95 % by the end of 2022.

To date, the manufacturing of the system units 'electrolyser' and 'hydrogen processing' have been completed and they have been installed onsite. The first-time injection of about 100 Nm^3/h of hydrogen took place during commissioning. The CAPEX target of 4 500 EUR/(kg/d) was met by the project mainly due to the integration of multiple stacks in one system

Building on GrinHy and GrinHy2 results, the MultiPLHY project aims to install and operate the world's first high-temperature electrolyser system at the multi-megawatt-scale (~2.4 MW), at a chemical refinery in Salzbergen (DE) to produce hydrogen (≥ 60 kg/h) for the refinery's processes.

In May 2021, the MultiPLHY project successfully tested a 225-kW HT electrolysis module, consisting of 60 stacks with 1 800 cells. This module will be part of a 2.7-MW system for a total of 12 modules for the 2.2-MW electrolyser, with a power consumption of less than 40 kWh/kg H_2 . The electrolyser will be deployed in a biorefinery in Rotterdam (NL). The project is seeking to demonstrate that SOE technology is reducing the TRL gap (by bringing it to TRL 8) to PEMEL and AEL by installing and

operating a multi-MW system. It is aiming for a design enabling a CAPEX of $\leq 2\,400$ EUR/(kgH₂/d), in line with the 2024 MAWP target.

The REFLEX project is developing reversible solid oxide cell technology (rSOC) to be implemented as an integrated energy-storage solution (Smart Energy Hub) at community/district level. The project has developed improved rSOC component cells, stacks, power electronics and heat exchangers. The performance and durability target were achieved in rSOC operation at cell scale as well as with enlarged cells (200 cm²). A current density of 1.25 A/cm² was achieved in SOEC mode (target 1.2 A/cm²). Several other objectives were partially achieved, such as durability in the SOEC step during rSOC operation at 0.58 A/cm² and SC=68 % power range in SOEC and SOFC.

The aim of the Waste2GridS project is to identify the most promising industrial pathways for waste gasification and solid-oxide-technology integrated plants. Biomass sources being considered are agricultural wastes, forest residues and municipal solid waste. Waste2GridS is proposing a novel concept of a triple-mode grid-balancing plant enabled by biomass gasification and rSOC technology. These plants can provide a grid-balancing service by switching between: (i) power-generation mode, converting waste to electricity for the grid; (ii) power-storage mode, using the grid electricity to convert waste into methane; and (iii) power-neutral mode, converting waste into methane with no grid interaction.

Feasible business cases were identified for power generation and power storage operations of over 3 500 hours. The project concluded that Waste2GridS plants could be feasible economically with 5 years payback time with a significant cost reduction $< 1\,600$ EUR/kWe-SOFC in stack costs.

Focus area 5.C: Other production routes

This focus area covers the projects BioROBURplus, BIONICO, HYDROSOL- beyond and PECSYS.

Reforming

The BIONICO and BioROBURplus projects are aiming to develop the decentralised production of renewable hydrogen by reforming biogas at capacities of around 100 kg H₂/day.

The goal of the BioROBURplus project, set to end mid-2021, is to demonstrate a biogas fuel processor for decentralised hydrogen production based on oxidative steam reforming. Focus is on increasing the efficiency of the reactor to 72 % (higher heating value). An extensive testing programme was carried out to identify a suitable catalyst. If the testing campaign proves successful, this technology should reach TRL 6. The demonstration unit has been installed in a biogas facility and is being commissioned.

The BIONICO project (ended in 2019) developed and tested a catalytic membrane reactor system to produce pure hydrogen from raw biogas (CO₂ containing) in a single step (reforming and purification). With 125 ceramic-supported tubular membranes, it was the largest of its kind in the world. The project's achievements include the development of a novel reforming catalyst and support. The lab experiments demonstrated the stability of both catalyst and membrane in fluidised bed conditions. The performance of palladium-silver-gold membranes were measured in the presence of hydrogen sulphide, showing improved performance for the membrane with higher gold content.

Thermochemical hydrogen production

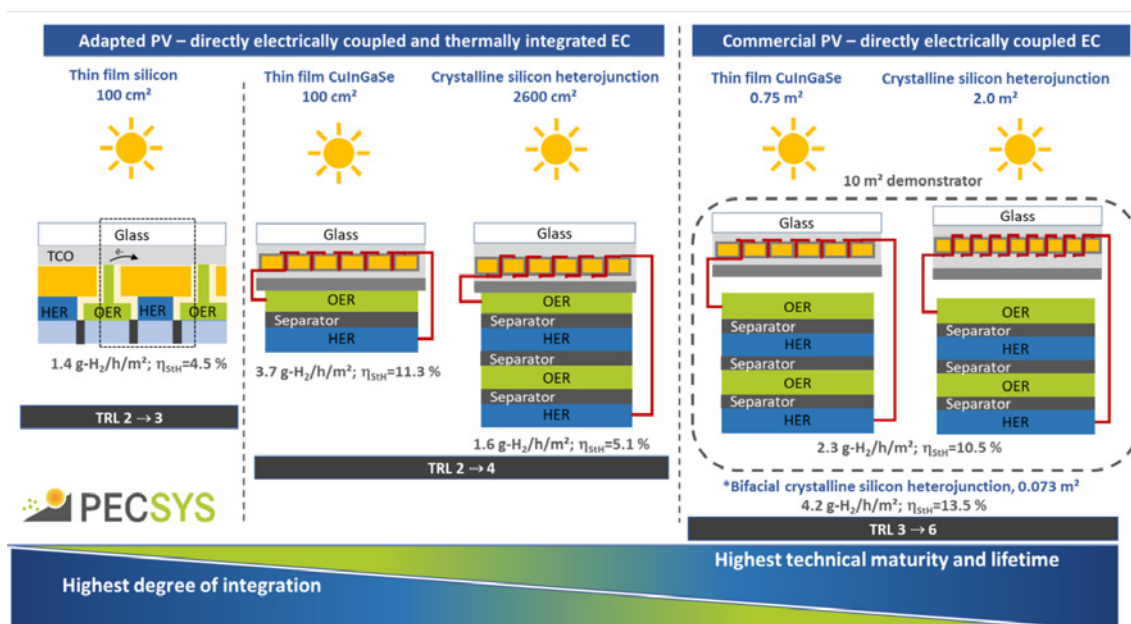
The HYDROSOL-beyond project, a 750-kW solar plant in Almeria, Spain, is currently the only large-scale solar thermochemical hydrogen production unit in the world. The concept is based on redox-structured monolithic solar reactors for the production of hydrogen from water. HYDROSOL-beyond is aiming to address material and component issues encountered in its predecessor HYDROSOL-

PLANT. The project should double the current SoA of 5 % solar-to-hydrogen efficiency through novel design solutions, in particular a more efficient heat exchanger to improve heat recovery.

Photoelectrochemical hydrogen production

The PECSYS project, which ended in 2020, developed and tested an integrated photo-electrochemical cell hydrogen generator at various prototype scales. Several concepts were explored for the direct coupling of an electrolyser to photovoltaic panels (see Figure 34). For a smaller device, a solar to hydrogen (StH) conversion efficiency of up to 13 % (ambient conditions 1 000 W/m², 25 °C) for a 100 cm² CIGS/NiO|NiMoV unit has been reached. Overall, the project achieved TRL 6; the demonstrator achieved an average StH efficiency of 10 % and produced 22 kg of hydrogen during its 9 months of operation. The final 10 m² demonstrator consisted of an array of CIGS and SHJ photovoltaic modules directly coupled to an electrolyser stack. A hydrogen production rate which is almost double that of the current SoA of 2.3 g/h m² has been achieved.

Figure 34: PECSYS concepts.



Source: <https://www.helmholtz-berlin.de/projects/pecsys/>

The cost and lifetime issues may limit the potential of this technology for its intended application, namely, to be deployed on residential rooftops in remote areas. More operational data would be needed for the FCH 2 JU programme to assess the prospects of this technology.

Focus area 5.D: Hydrogen storage and distribution, purification and admixture

This focus area covers the projects HySTOC, HyCARE, HyGrid, MEMPHYS and HIGGS.

The HySTOC project is aiming to develop and demonstrate a transport and storage system for HRS using liquid organic hydrogen carriers (LOHC). These compounds, which are able to release or accept hydrogen, have similar properties to crude oil and can be stored and transported over long distances at ambient conditions in large oil tankers without significant losses. According to a recent study by the JRC²³, hydrogen carrier systems can be among the lowest cost options for the long-distance transportation of hydrogen.

23. https://ec.europa.eu/jrc/sites/default/files/jrc124206_assessment_of_hydrogen_delivery_options.pdf

In the HySTOC project, the LOHC under consideration is dibenzyltoluene (DBT) which has advantageous properties in terms of storage and transport efficiency: a high storage density and little or no need for cooling and compression or purification. As heat demand for DBT is playing a major role in LOHC, the project is investigating mixtures of DBT with other LOHC in order to improve the energy efficiency of the dehydrogenation process. Currently, the project is close to finalising the commissioning of a hydrogen release plant which will be able to release up to 20 kg of hydrogen per day, with the hydrogenation plant already operational.

The HyCARE project is developing and testing a large-scale hydrogen storage tank (50 kg of hydrogen) based on solid-state storage. The metal hydride material is based on ferro-titanium, which has been further optimised by elemental substitution to improve the activation processes and hydrogen storage properties. The prototype system has been tested and the project aims to further optimise the operational parameters.

The HyGrid project is targeting the separation of hydrogen from a mixture with natural gas, thereby supporting the possible transport of hydrogen through the natural gas grid and then separating it at the location where it is needed. The project is developing a membrane-based hybrid technology combining membranes, electrochemical separation, and temperature swing adsorption. The objective is to reduce the cost of hydrogen separation to < 1.5 EUR/kg H₂ for recovery rates > 95 % and with an energy consumption of < 5kWh/kg H₂. These targets are for hydrogen concentrations of < 10 vol % in natural gas. All relevant components of the prototype are ready and the project can start to test the concept. The development of membranes has led to the creation of a new company involving TECNALIA and TUE, namely H2SITE²⁴, for the manufacturing and commercialisation of the technology developed in the project.

The MEMPHYS project is working to overcome technical challenges of a low-energy electrochemical hydrogen-purification system, which combines purification and compression to 200 bar in a one-step process. The concept is based on electrochemical hydrogen pumping. The project, which ended in 2019, aimed to achieve a recovery rate of 95 % from a 50 % concentration of hydrogen in a matrix gas. The project objectives included identifying a catalyst with sufficient activity and durability, in particular when exposed to compounds such as carbon monoxide. The best performance of the third-generation stack fell significantly short of the project targets (recovery rate of 95 % and energy demand of 3 kWh/kg H₂) with an energy demand of 6.4 kWh/kg H₂ at an 83 % recovery rate.

The HIGGS project will contribute to a common understanding of the possible acceptance of high concentrations of hydrogen in the natural gas infrastructure. This could create a favourable environment for a greater roll-out of the hydrogen economy as the use of existing natural gas infrastructure for hydrogen transport lowers costs. The project is performing pre-normative research (PNR) to increase the knowledge base concerning the impact of high levels of hydrogen on high-pressure natural gas infrastructure, its components and its management, from low concentrations up to 100 vol % hydrogen. HIGGS is also developing an admixture system able to feed up to 5 kg/h of electrolytic hydrogen into a natural gas piping system. Civil works have started for the admixture system and testing platform.

Focus area 5.E: Hydrogen territories

In the hydrogen territories focus area, the FCH 2 JU is working together with regions to realise their potential to deploy such technologies. Building on the FCH Regions' Initiative, the FCH 2 JU is supporting the European Hydrogen Valleys Partnership, which has been joined by 42 European regions.

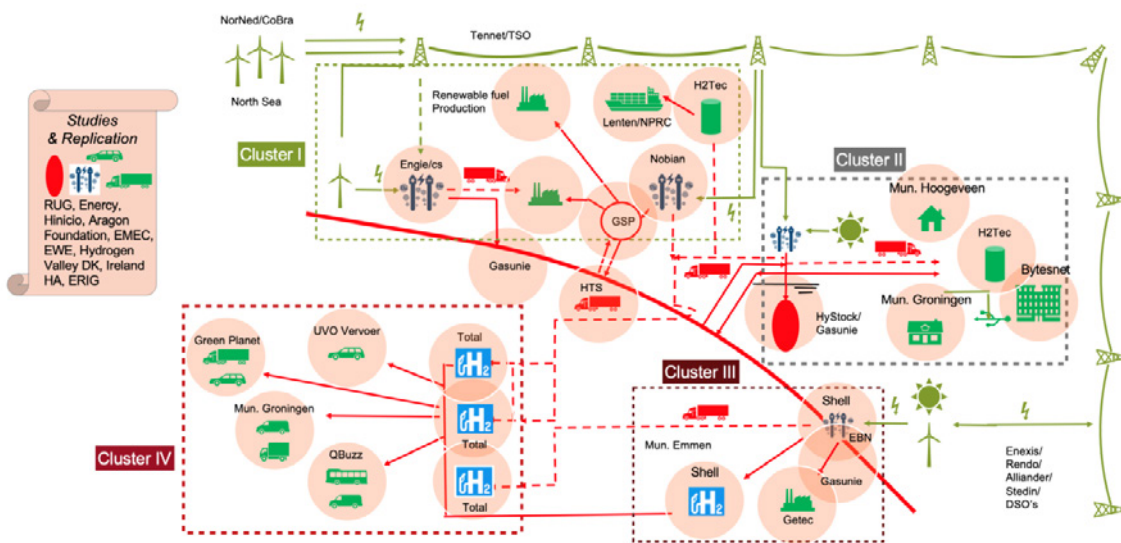
Part of a larger regional initiative in the Netherlands, the HEAVENN hydrogen valley is seeking to promote and enable the use of green hydrogen across the whole value production chain, distribution, storage and end-use. The project comprises four clusters (see Figure 35) which are

24. <https://www.h2site.eu/en/>

at various stages of implementation. For cluster 4, the first vehicles have been procured, including garbage trucks, and the HRS will open soon. A 4-MW electrolyser, for which the concept design has been completed, will be deployed as part of cluster 3. The hydrogen pipeline will be designed to enable a future connection to the hydrogen backbone. In cluster 2, activities for the salt-cavern hydrogen storage have commenced with first test set-ups.

The project is set to receive complementary regional funding. The plan is to establish a link with the Djewels project regarding the infrastructure for hydrogen delivery and with JIVE 2 for the provision of hydrogen for buses. The outcomes of this novel type of project will be highly relevant to prove the business model and replicability of the hydrogen valley concept.

Figure 35: Schematic of the HEAVENN project.



The Building Innovative Green Hydrogen Systems in Isolated Territories (BIG HIT) project is in the process of creating a hydrogen ecosystem in the Orkney Islands (Scotland), which will help to minimise the curtailment of renewable electricity. The hydrogen produced is used locally in cogeneration and transport applications. The project has achieved several milestones by deploying 5 hydrogen trailers (250 kg hydrogen storage), a hydrogen catalytic boiler (30 kW), 1-MW electrolyser (ITM Power), 5 hydrogen FC vans, and a 75-kW FC system for cogeneration. The electrolyser is operating and capable of providing hydrogen for the FC vans, and 833 refuelling actions were performed in 2020.

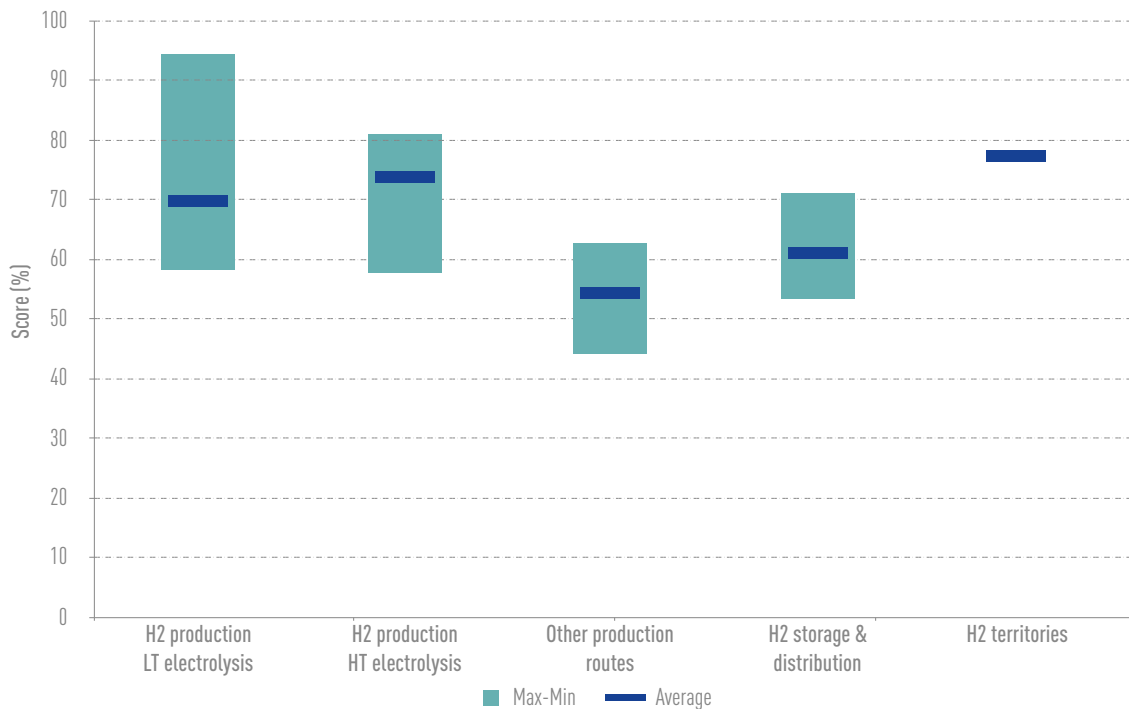
Panel 5 – Summary

The overall assessment of the projects in Panel 5 is shown in Figure 36. In addition to the average, the range between minimum and maximum ratings for the focus areas with more than three projects is also shown.

Most electrolysis projects largely achieved their objectives and have had a high impact at programme level. Since 2018, the average score for low-temperature (LT) electrolysis projects has risen from 60 %, with the largest increase in the categories’ target achievement, impact and SoA. For high-temperature (HT) electrolysis, there is also an improvement from an average score of 67 % in 2018.

The projects covering other hydrogen production routes fared less well with an average score of only 55 %. The hydrogen separation storage and distribution projects were somewhat more successful with an average score of 61 %.

Figure 36: Maximum, minimum and average scores for relevant focus areas in panel 5. No score is given for focus areas with a single project while, in the case of two or three projects, only the average is provided.



Strengths:

- Flagship projects are contributing to the overall EU goals of electrolyser deployment at the GW scale. There are now many 100 MW demonstration projects, building on the achievements of FCH JU projects.
- Electrolyser projects are receiving markedly less support per MW as the programme transitions to larger deployed capacities.
- The EU is maintaining a leading role in the development and commercialisation of PEMEL and SOEL.
- Demonstration projects have sparked interest from hydrogen end-users and facilitated the formation of strategic partnerships by raising the interest of industrial partners.
- Good progress has been made towards the next generation PEMEL.
- Technical progress has been made for HTE in terms of increasing efficiency and durability but also for upscaling reversible systems.
- An increase in the hydrogen-territory type of project seeking to integrate numerous technologies and applications is both new and very positive.

Additional focus needed and follow-up actions:

- Novel concepts should be pursued for flagship projects – for example, seawater electrolysis.
- There should be a focus on the development of cost-effective manufacturing processes for low temperature electrolysis.
- More aggressive action on reducing PGMs and obtaining innovative catalysts should be considered to improve the sustainability of the hydrogen production process. In general, recyclability should be a requirement for funded projects at a higher TRL.

- Recyclability should be part of the design process, in particular for PEM electrolyzers.
- Reduction in rare-earth metals used for high-temperature electrolysis should be the focus of future actions.
- To date, thermochemical hydrogen production technology has demonstrated a rather poor performance, which suggests there might be a case for funding fundamental research before trying to go to higher TRL.

04

**SUPPORT FOR
MARKET UPTAKE
(CROSS-CUTTING)**

4.1. OBJECTIVES

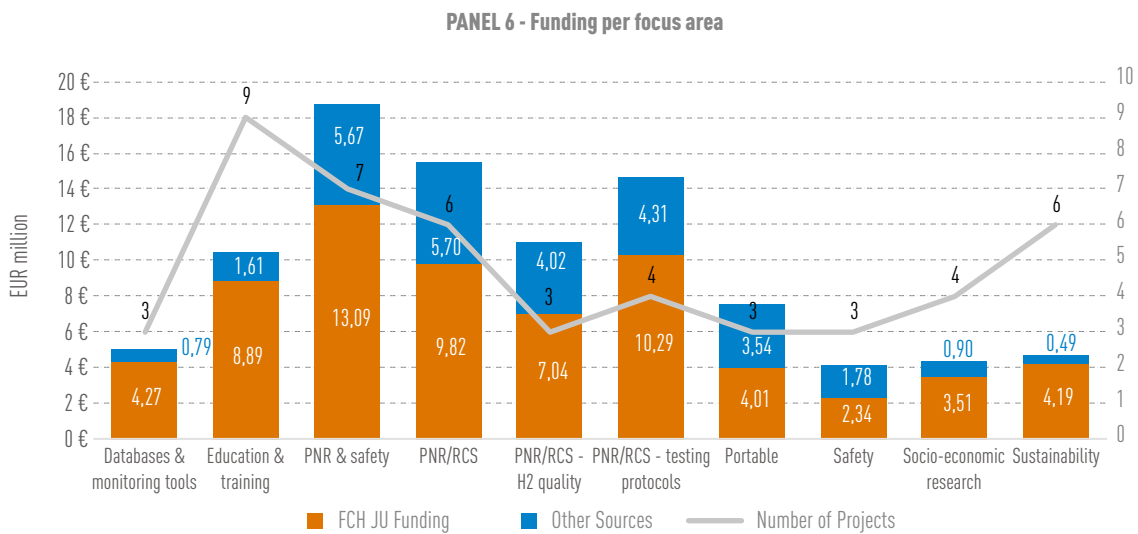
Support for market uptake (cross-cutting) activities is contributing to progress across the entire programme. These cross-cutting projects support market preparation and readiness by:

- Providing new knowledge for improved RCS;
- Generating experimental data and validating modelling approaches to address the safety of FCH technologies and applications;
- Preparing the European workforce;
- Increasing public awareness and social acceptance;
- Characterising and improving the environmental footprint of FCH technologies;
- Databases.

4.2. BUDGET

To date (2008 to 2020 calls), the FCH 2 JU has supported 48 projects relevant to this panel with a total contribution of EUR 67.5 million complemented by EUR 28.8 million of other contributions. The distribution of total historical budgets over the six focus areas is shown in Figure 37.

Figure 37: Funding for panel 6 Support for market uptake (cross-cutting) from 2008 and including the 2020 calls.



4.3. PANEL 6 – SUPPORT FOR MARKET UPTAKE (CROSS-CUTTING)

In line with the MAWP, the multiannual panel 6 projects portfolio supports a number of focus areas, with the current PR focusing on the following:

- PNR and input into RCS
- Education and training
- Safety aspects.

The present PR covers the 11 projects highlighted in black in Figure 38.

Figure 38: Support for market uptake projects within the cross-cutting activities. Only projects whose names have been highlighted in larger black font size have been considered within PR 2020-21. Some projects can be attributed to more than one focus area (not indicated in the figure).

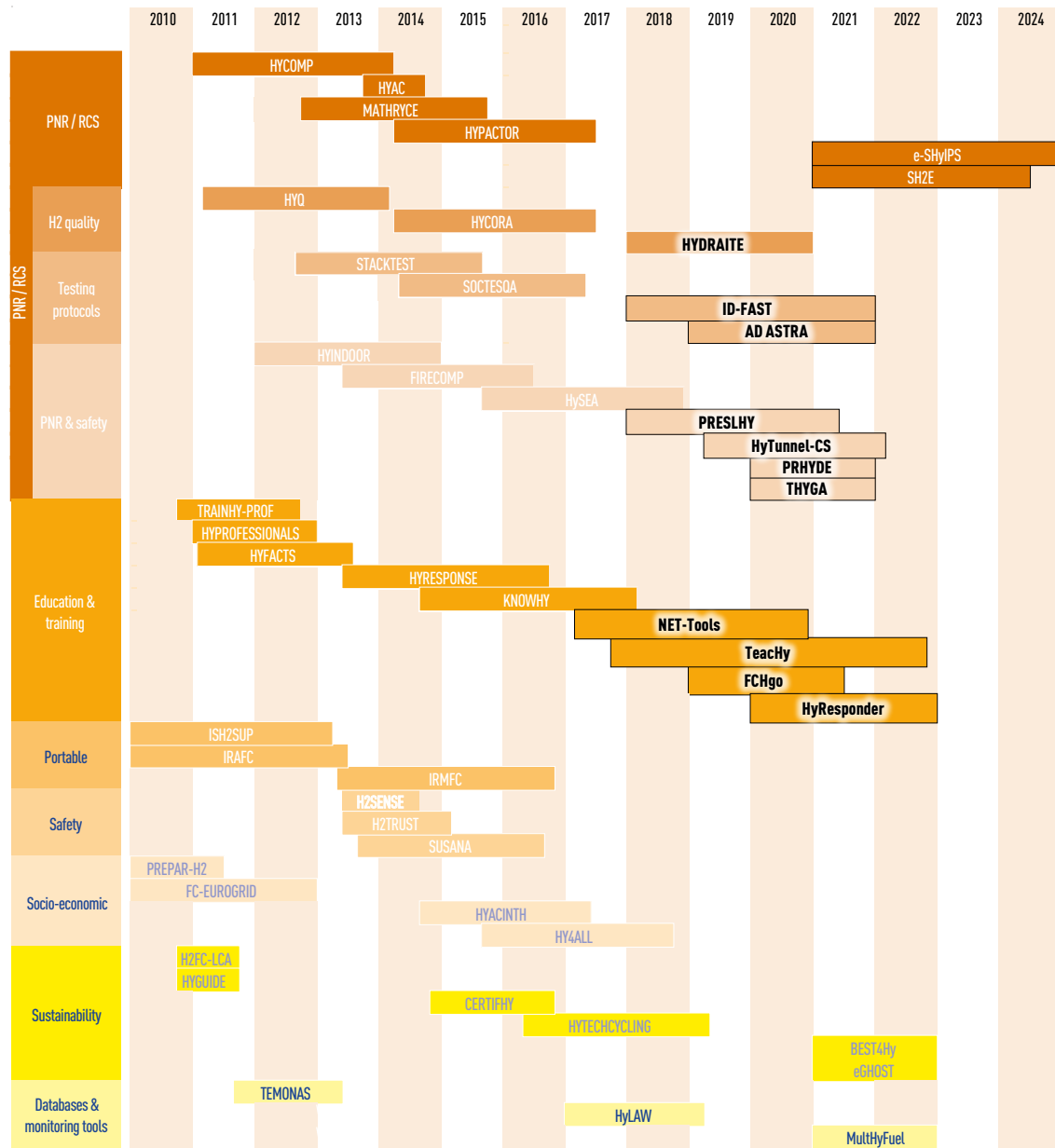
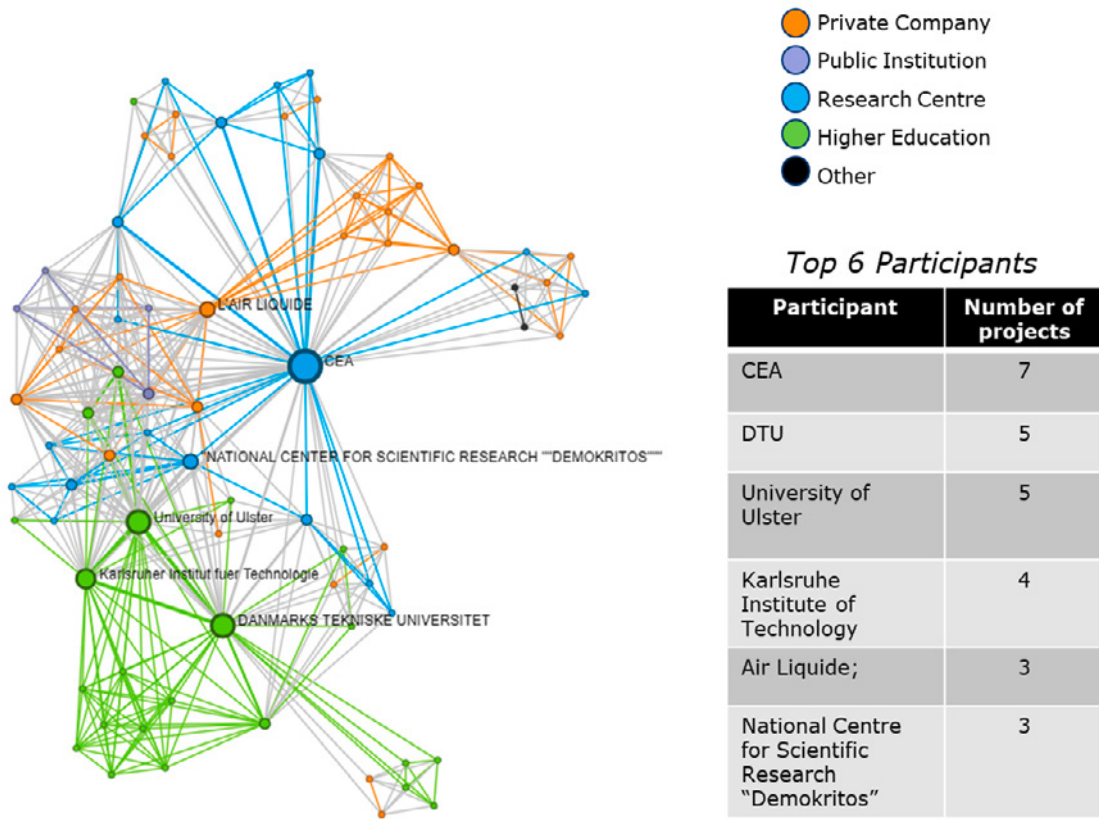


Figure 39 is a TIM plot showing the participants in panel 6 with some of them active in two or three consortia. One cluster represents the PNR serving performance-testing activities, another cluster is typical of partners with a broad competence on safety themes, and a third is about education and training.

Figure 39: TIM plot showing the participants in the 11 projects in panel 6.



Focus area 6.A: PNR/RCS

The focus area PNR/RCS comprises five pre-normative research projects: HYDRAITE, ID-FAST, AD ASTRA, THyGA and PRHYDE.

HYDRAITE (2018-2021) is studying the effects of hydrogen contaminants on FC systems in automotive applications, building on the results of the previous project HyCORA. A major achievement of the HYDRAITE project is the development of three laboratories in Europe capable of measuring hydrogen quality according to the European harmonised standard EN 17124:2018 and the international standard ISO 14687: 2019.

Project ID-FAST (2018-2021) is developing accelerated stress tests (AST) for PEMFC for automotive applications and a methodology able to predict ageing. The AST tests will allow for a shorter testing time, which means that all FCH 2 JU projects and industries will profit from a shorter testing time when assessing PEMFC durability. The test carried out in the ID-FAST project will contribute to the development of a new standard by IEC/TC 105 on FC technologies.

With a similar approach to ID-FAST (2019-2022), the AD ASTRA project is developing AST protocols for SOC stacks, operating in both FC and electrolysis modes. The final product will test protocols able to predict the degradation of SOC and their integration into a future standard.

Project THyGA is testing how domestic and commercial gas appliances perform in the presence of hydrogen up to 60 % in volume of the natural gas. It will then establish the hydrogen concentration limit below which hydrogen can be added to natural gas without changing the current certification of boilers, burners and cookers. THyGA will propose revisions of the existing standards section within the European RCS framework covered by the Gas Appliances Regulation 2016/426.

PRHYDE is studying the parameters and components required for the hydrogen refuelling of heavy-duty vehicles, such as trucks and buses, to identify the optimal solutions for minimising filling time, maximising travel autonomy and, at the same time, guaranteeing safety. The final output will be the recommendation of a non-proprietary filling protocol ready for integration in the ISO 19885-3 which is already being prepared by the ISO/TC 197 WG24.

Focus area 6.B: Education and training

This focus area is made up of four projects: NET-Tools, TeachHy, FCHgo! and HyResponder.

The NET-Tools project focuses on the development of new e-education methods based on ICT tools, enhancing knowledge, productivity and competitiveness of those interested in FCH technology deployment. It addresses a broad range of groups and educational levels, from high schools and universities (undergraduate and graduate students) to professionals and engineers from industry. The project's tangible output is an e-learning platform based on open source software.

The TeachHy project is developing learning tools and materials mainly for university students (undergraduates and postgraduates) although it also includes vocational training. Its overarching goal is to give students across Europe access to high-quality and harmonised training material. Its major aim is a European MSc course on FCH technologies.

The project FCHgo! is focusing on school pupils by developing educational tools directed at future generations. FCHgo! outputs range from a toolkit with narrative explanations of the technology to workshops in classrooms, a website and an annual award for the best ideas.

The HyResponder project builds on the previous project HyResponse (2013-2016) which targeted first responders and developed a physical platform for this purpose. This new project will provide a 'train the trainer' programme in hydrogen safety for responders across Europe. The European Emergency Response Guide developed by HyResponse will be revised and expanded to include strategies and tactics for liquefied hydrogen applications.

The FCH Observatory has been online since 2020 providing a one-stop shop for data and indicators related to hydrogen technologies. Of specific interest for panel 6 are sections on the European RCS and on education and training. The latter includes an inventory of courses and training.

Focus area 6.C: Safety

The two projects in this focus area (PRESLHY and HyTunnel-CS) also have a genuine PNR/RCS dimension. PRESLHY, the first European project in over 10 years completely dedicated to the study of liquid hydrogen, looked into the safety of liquid hydrogen release under accidental conditions. It provided information and data on release, ignition and combustion under realistic conditions which have been used to improve and validate the physical models and simulations used for describing releases. The results will be used by the newly formed ISO/TC 197 WG 29 to review and update obsolete ISO standard(s) on liquid and cryogenic hydrogen.

HYTUNNEL-CS is focusing on the public and environmental safety of hydrogen vehicles in semi-confined spaces, such as tunnels and public garages. The project identifies hazards and risks and reviews the safety measures already in place, including emergency response strategies. The final goal is to propose a new safety approach to this public infrastructure, which could become the basis for a standard within the framework of the CEN-CENELEC Joint Technical Committee 6 on Hydrogen in the energy systems.

Other projects in panel 6 are contributing to a certain degree to progress in the safety focus area, even though they do not belong to it. Table 4 summarises the contribution made by these projects to standards.

Table 4: Safety dimensions of panel 6 projects

Support for market uptake (cross-cutting) projects with a safety dimension	Focus area	Project contribution to safety assessment and safety progress
HyTunnel-CS	PNR/RCS	Safety is the main driver: the project provides conditions for the safe use of confined public spaces.
PRESLHY	PNR/RCS	Safety is the main driver: the project is closing the knowledge gaps related to the behaviour of liquid hydrogen in accidental conditions related to new public-use cases.
PRHYDE	PNR/RCS	One of the most important dimensions: the optimisation of fuelling protocols for HDV must guarantee the safety of the process by avoiding the operative limits of the components being exceeded.
NET-Tools	Education	Safety and PNR are integral parts of the e-laboratory.
TeachHy	Education	One of the training modules is dedicated to all aspects of hydrogen safety.

In addition to projects, the European Hydrogen Safety Panel (EHSP) has the goal of coordinating safety strategy at the programme level. During the 2020-2021 period, the EHSP has delivered a safety planning guidance document, has reached out to projects by means of a workshop, and worked on safety dissemination and communication. It has also continued to review and analyse the data in the HIAD2.0 database, reporting on general returns of experience from the accidents by analysing and quantifying the individual lessons learned.

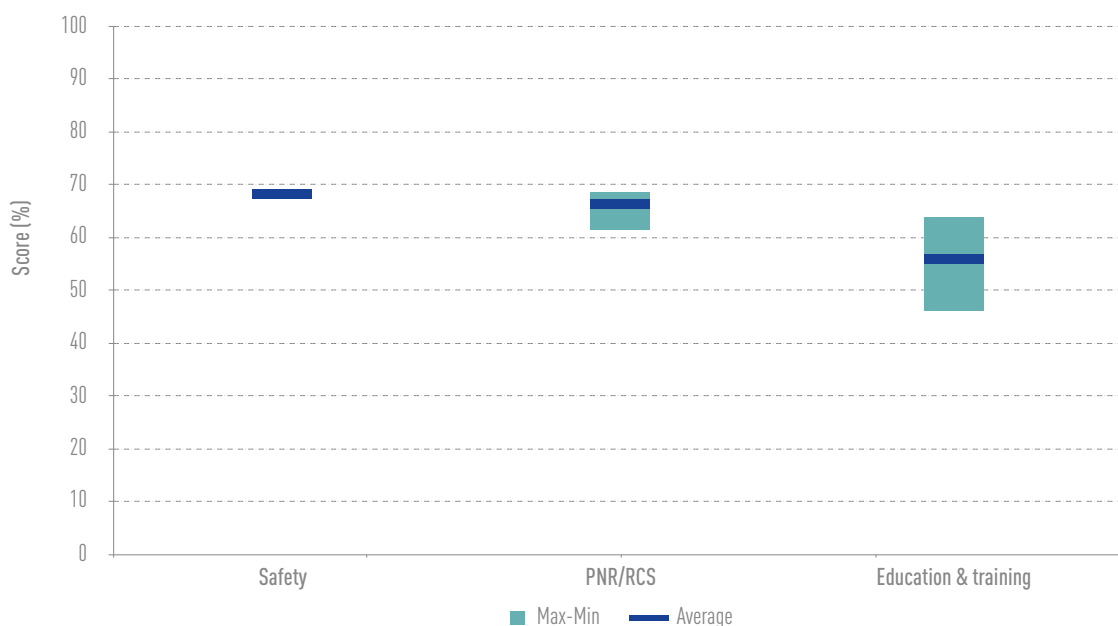
At programme level, the HIAD2.0²⁵ and HELLEN databases contain the description and analysis of safety-related events along the entire FCH technology chains.

Panel 6 – Summary

The average assessment of focus areas is shown in Figure 40 where three or more projects are available; in addition to the average, the minimum-to-maximum range is also shown. The figure confirms the good performance of PNR projects in this panel. The lower score for the education and training projects is not only related to the well-known difficulty for education projects to establish a long-term business plan beyond the end of their funding period, but also to the challenges encountered by schools and universities during COVID-19.

25. HIAD2.0 is a new generation of the first HIAD database developed by the Network of Excellence HySafe (2004-2009) and later maintained by the JRC in the framework of the international SAFE Association. Upon request of the FCH 2 JU, the JRC has developed the upgraded version HIAD2.0, which has been operative since 2017.

Figure 40: Maximum, minimum and average scores for the relevant focus areas of panel 6. No score is given for focus areas with a single project while, in the case of two or three projects, only the average is provided.



Strengths:

- Several PNR projects are contributing to European or international standards in the CEN, ISO and IEC bodies.
- The activities around liquid-hydrogen accident behaviour will boost the European capacity to handle this technology. PRESLHY results are of global interest and are attracting international attention; the USA, Japan and Norway are represented on the project's advisory board.
- In recent years, FCH 2 JU has succeeded in filling in the gap which originally existed between PNR projects and their utilisation for standardisation goals.
- In the area of education and training, FCH 2 JU learning tools will be available to a broad range of users, from technicians and professional operators to university students, regulators and public safety officials, including emergency responders.
- Attention to sustainability aspects has increased stepwise in the last two years, and has generated three new projects which will shape this dimension in the next programme.
- The FCH Observatory is an important provider of structured data and indicators. It will facilitate knowledge-management goals and overcome the dissemination of results and tools produced by individual projects.

Additional focus needed and their follow-up actions:

- As part of preparations for the Clean Hydrogen Partnership in Horizon Europe, a reflection initiated on the RCS Strategy Coordination Group made the following recommendations:
 - To evaluate the possibility to fund an RCS SCG secretary enabling continuity of coordination.
 - To investigate the possibility of a formal collaboration with standardisation bodies (CEN/ CENELEC JRC6, TC268, ISO TC197 and IEC TC105) in the form of a Liaison A, which allows for participation as an observer at the strategic level.

- Projects in the training and education focus areas still find it difficult to maintain available and up-to-date training tools once the related projects have been completed. To address this concern, projects are explicitly required to commit to service continuity. For securing funds, the FCH Observatory should facilitate the update of and access to all educational tools in a one-stop shop.

05

CONCLUSIONS

The Programme of FCH 2 JU has advanced over the years based on the strategy and objectives set out in the founding regulation and planned in its MAWP and AWP. The FCH 2 JU has supported a significant number of projects enabling a step change in the use of hydrogen to phase out fossil fuels and reduce emissions in different sectors, while at the same time setting the new standards for the State of the Art.

Building on the experience gained from the portfolio of clean and efficient solutions developed by the FCH 2 JU Programme in the period 2008-2017, the last phase of the Programme (2018-2020) mainly focused on:

- Applications with significant market potential and high policy importance;
- Industry-led applied research, development and demonstration activities, with particular emphasis on enabling/emerging technologies for next generation of products that could reach the market by 2020-2025;
- Cost reduction and strengthening of the European value chains as a top priority;
- Strategically important lower TRL research objectives were also addressed.

The purpose of JRC's periodic Programme Review (PR) is to view the implementation from a result-oriented perspective, identify its strengths and provide recommendations for its further improvement. As the assessment is performed bottom-up, qualitative observations focus on the projects' major accomplishments and any difficulties they may have encountered. Finally, some interesting policy related conclusions also arise out of the transport demo projects.

The JRC followed the same procedure as defined for previous years, collecting information from different sources, including the project deliverables, the TRUST database and a dedicated EU survey. The reviewed projects were assigned to six review panels. Due to their wide-ranging scope, the projects covering similar or related topics were grouped into a set of focus areas for each panel. The assessment was performed for each focus area.

A short summary per panel is provided below:

PANEL 1 - Trials and deployment of FC applications – Transport

- Transport demo projects are deploying on the road a large number of cars and buses, supporting the business case for hydrogen vehicles and refuelling stations. A similar project model should be used to demonstrate HDVs and to help establish an EU supply chain for FC systems for these applications.
- It is recommended that more support is targeted to manufacturers of FC and FC systems suitable for maritime applications, aiming to increase their number.
- Policy actions may be required to facilitate HRS permitting and ensure that adequate hydrogen infrastructure (distribution, storage) will be in place to support supply & demand for large hydrogen volumes.

PANEL 2 - Next Generation of Products – Transport

- European development of innovative hydrogen-compressor technology is continuing and has advanced from low to higher TRL. The Programme addresses important sustainability topics, like recyclability of compressed hydrogen storage tanks and the use of non-PGM for electro-catalysts.
- Building on the knowledge acquired by the Programme so far, a number of transport actions can be considered for the future, like establishing a common product design for FC and BoP components.

PANEL 3 – Trials and deployment of FC applications – Energy

- The majority of KPIs have been achieved, especially for the μ -CHP. Products developed in the EU might be interesting for non-EU markets, while μ -CHP systems are being included in the product portfolios of EU heating solution providers. The developed FC solutions may induce a positive spill-over of know-how and greater manufacturing capabilities for emerging application fields.
- The technical and economical feasibility of FC applications to provide power in isolated micro-grid and remote areas have been demonstrated. Combined with RES production, this represents a promising alternative to diesel generators and an opportunity for these regions to become energy self-sufficient.
- Significant progress has been achieved in a number of research areas, although certain KPIs have not been achieved yet. Adapting SOFC technologies to run on pure hydrogen should be considered. Further research may also be required to reduce the cost of components and materials and to focus on volume engineering.

PANEL 4 - Next Generation of Products – Energy

- Manufacturing projects have helped European FC producers to modernise production lines and increase quality while reducing costs and environmental impacts. Following extensive research, diagnostic and control tools aiming to improve efficiency, reliability, and durability of stationary fuel cells are progressing to higher TRLs and are being prepared for integration in commercial products.
- There exist a number of opportunities for the transfer of knowledge between demo projects in Panels 3 and 4. In many cases this is happening as project partners are common. Still, a more structured approach could help to also foster knowledge transfer among projects which do not share common partners. The development of a larger set of European players should be encouraged.

PANEL 5 - Hydrogen for sectoral integration

- Significant progress has been achieved in this panel, with EU is maintaining a leading role in the development and commercialisation of PEMEL and SOEL. Electrolyser projects are receiving markedly less support per MW as the programme transitions to larger deployed capacities.
- Electrolyser demonstration projects up to 20 MW are paving the way to reach the EU goals at the GW scale. They are stepping stones to develop 100 MW projects which will be soon funded and developed in the EU.
- Building on the knowledge acquired by the Programme so far, a number of actions can be considered for the future, like the development of cost-effective manufacturing processes for low temperature electrolysis and the improvement of circularity of the hydrogen production technologies.

PANEL 6 – Support for market uptake - Cross-Cutting

- The cross-cutting activities of the Programme have contributed to multiple areas. PNR projects are contributing to European or international standards, filling in a gap which the previously originally existed. FCH 2 JU learning tools will be available to a broad range of users. Sustainability aspects have increased stepwise in the last two years, highlighting the importance of this dimension.
- Projects in the training and education focus areas should commit more strongly to service continuity. Similarly, the continuity if the RCS SCG should be ensured, investigating also the possibility of a formal collaboration with standardisation bodies.

Overall, the Programme has been advancing in line with the priorities and objectives set out for the FCH 2 JU. Many of the Programme KPIs have already been achieved, while demo projects have enabled several technologies to come close to maturity and to achieve EU global leadership for future technologies, notably on electrolysers, 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.

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**PANEL 1
TRIALS AND
DEPLOYMENT
OF FUEL CELL
APPLICATIONS –
TRANSPORT**



Project ID:	633174
Call topic:	SP1-JTI-FCH.2013.1.1 - Large-scale demonstration of road vehicles and refuelling infrastructure VI
Project total costs:	€39 232 162.6
FCH JU max. Contribution:	€14 999 983
Project start - end:	01/01/2015 - 31/12/2022
Coordinator:	VAN HOOL NV, BE
Website:	www.3emotion.eu

BENEFICIARIES: AALBORG KOMMUNEACETILENE & 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 MOBILITA DEL COMUNE DI ROMA SPA, CENTRO INTERUNIVERSITARIO DI RICERCA PER LO SVILUPPO SOSTENIBILE, COMMISSARIAT A L'ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES, COMMUNAUTE URBAINE DE CHERBOURG, COMMUNE DE CHERBOURG-EN-COTENTIN, COMPAGNIA TRASPORTI LAZIALI, CONNEXION OPENBAAR VERVOER NV, CONNEXION 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 VALLEE DE CHEVREUSE SAS, SYNDICAT MIXTE DES TRANSPORTS URBAINS DE PAU PORTE DES PYRENEES, UNIVERSITA DEGLI STUDI DI ROMA LA SAPIENZA, VLAAMSE VERVOERSMAATSCHAPPIJ DE LIJN, WATERSTOFNET VZW

PROJECT AND OBJECTIVES

The 3Emotion project aims to operate 29 FCBs in 5 leading European cities: London, Pau, Versailles (2x), Rotterdam and in the Province of South Holland, and in Aalborg (DK) and to develop 3 new HRS.

Objectives:

- Lower H2 consumption <9 kg/100 km
- Integrate latest drivetrain, FC and battery technology < TCO and > lifetime
- Ensure availability >90 %
- Increase warranties (>15 000 hours and improve delivery times of the key components)
- Reduce bus investment costs to €850 000 for a 13 m bus.

Status:

- 24 operational buses; due to COVID-19, 5 buses are still in production (Safra)
- All HRS are operational.

NON-QUANTITATIVE OBJECTIVES

- Contribution to safety improvements for fuel cell buses
- Solution for the hydrogen sensor problem, which arose earlier in the project, enabled the same issue to be avoided in the new buses.

PROGRESS AND MAIN ACHIEVEMENTS

- 24 fuel cell buses in operation, the remaining 5 buses will follow soon after the coronavirus measures have been eased
- 3 different OEMs, with 2 different fuel cell suppliers, have sold their buses to different EU sites for the 'set' bus price stated in the FCH JU call
- Buses are meeting their targets on hydrogen consumption, and averaging 8 kg/100 km, with increasing availability of >90 %.

FUTURE STEPS AND PLANS

- Catch up on the delays and start operation of all buses at all sites, including the last 5 that are stuck in production due to COVID-19
- Use and full operation, meeting the 3 HRS requirement
- Data monitoring and gathering of operational and performance indicators (KPIs) for the FCBs and HRS.



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 FOR SOA TARGET
Project's own objectives and AIP 2013	Lower H ₂ consumption for FCBS to less than 9 kg/100 km	kg/100 km	9	Average of 8 kg/100 km	✓	N/A	2020
	Ensure availability >90 %	%	90	<= 80	✗		
	Increase warranties (>15 000 hours)	Hours	15 000	15 000	✓		
	Investment cost of <€850 000 for a 13 m bus	Euro	850 000	850 000	✓		



Project ID:	826215
Call topic:	FCH-01-2-2018: Demonstration of Fuel Cell applications for midsize passenger ships or inland freight
Project total costs:	€6 790 561.43
FCH JU max. Contribution:	€4 999 978.75
Project start - end:	01/01/2019 - 31/12/2022
Coordinator:	TEKNOLOGIAN TUTKIMUSKESKUS VTT OY, FI
Website:	flagships.eu/



BENEFICIARIES: LMG MARIN FRANCE, LMG MARIN AS, NORLED AS, WESTCON POWER AND AUTOMATION AS, MARITIME CLEANTECH, PERSEE, COMPAGNIE FLUVIALE DE TRANSPORT, BALLARD POWER SYSTEMS EUROPE AS, ABB OY, KONGSBERG MARITIME AS

PROJECT AND OBJECTIVES

The project aims to deploy two hydrogen fuel cell vessels. The Paris (FR) demo vessel is a self-propelled barge operating as a utility vessel on the River Seine, while the Stavanger (NO) demo vessel is a passenger and car ferry. The design of both vessels is almost ready, pending a few details. In addition, a design case study for a push-boat in Lyon has been conducted. The Stavanger demo vessel is currently suspended and will resume once the issues with the hydrogen supply and bunkering have been solved.

NON-QUANTITATIVE OBJECTIVES

- Strengthen the European supply chain and competence network for hydrogen fuel and PEMFC system technologies for maritime applications
- Contribute to highlight gaps in the rules and regulations for the use of hydrogen in maritime applications
- Contribute to make politicians and lawmakers aware of the practical challenges related to the lack of hydrogen production plants in Norway.

PROGRESS AND MAIN ACHIEVEMENTS

- Design of H2 & FC systems and powertrains for all three vessels is almost ready. Some minor details are still pending
- Design of the marine-based 200 kW FCwave fuel cell module is ready. DNV GL type approval is ongoing
- Tools for logging, tracking and analysing voyage energy consumption and performance have been developed.

FUTURE STEPS AND PLANS

- Solve the issues with the Stavanger case. A solution for feasible hydrogen supply/bunkering will be sought. If no solution is found, we will look for an alternative demo case for the project
- The Zulu ship is to start operation. Main tasks to be completed are: finalise the design, get the derogation, integrate the H2 system, commission the H2 system
- Finalise FCwave testing following the test plan
- Manufacture 5x FCwave for the 2 demonstrations.



QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	PARAMETER	UNIT	TARGET	TARGET ACHIEVED?
Project's own objectives and MAWP Addendum (2018-2020)	PEMFC system availability	%	95	✘
	A complete FC & H2 system cost	€/kW	4 000	✘
	PEMFC system lifetime	Hours	25 000	



H2HAUL

HYDROGEN FUEL CELL TRUCKS FOR HEAVY-DUTY, ZERO EMISSION LOGISTICS

Project ID: 826236
Call topic: FCH-01-1-2018: Large Scale Demonstration of H2 fuelled HD Trucks with High Capacity Hydrogen Refuelling Stations (HRS)
Project total costs: €28 033 073.41
FCH JU max. Contribution: €12 000 000
Project start - end: 01/02/2019 - 31/01/2024
Coordinator: ELEMENT ENERGY LIMITED, UK
Website: www.h2haul.eu



BENEFICIARIES: ELRINGKLINGER FUELCELL SYSTEMS AUSTRIA GMBH, ELEMENT ENERGY, H2 ENERGY AG, AIR LIQUIDE FRANCE INDUSTRIE, VDL ENABLING TRANSPORT SOLUTIONS BV, VDL BUS CHASSIS 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, ETABLISSEMENTEN FRANZ COLRUYT NV, WATERSTOFNET VZW

PROJECT AND OBJECTIVES

H2Haul brings together two major European truck OEMs (IVECO/FPT and VDL) and three fuel cell stack/system suppliers (ElringKlinger, Bosch and PowerCell) to develop and demonstrate fleets of heavy-duty trucks (26-44 t) in day-to-day commercial operations at four sites across four countries. The overall objective of H2Haul is to prove that hydrogen trucks can be a practical zero-emission and zero-carbon solution for much of Europe's trucking needs and so pave the way for the commercialisation of fuel cell trucks in Europe. The project is currently in the planning and pre-deployment phase.

NON-QUANTITATIVE OBJECTIVES

- Develop long-haul heavy-duty (26 and 44 t) fuel cell trucks that meet customers' requirements in a range of operating environments. Truck design is ongoing and specifications are being designed as per specific customer requirements and mission profiles. Objectives are expected to be met
- 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 to secure all necessary safety approvals for using the trucks on public roads in Europe

- Develop the business case for the further roll-out of heavy-duty fuel cell trucks. H2Haul will provide a valuable database of real-world performance information and insights into the next steps required for the commercialisation of this sector. Business case to be developed as a result of FC truck design to meet customers' needs. Operation of FC trucks and subsequent data collection will highlight the costs involved in the technology. 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 further roll-out of fuel cell trucks through: (i) the development of innovative commercial models; and (ii) disseminating information from the project to a wide audience of relevant stakeholders. H2Haul's dissemination activities will share key findings with relevant audiences to prepare the market for wider roll-out of fuel cell trucks on a commercial basis. The project's dissemination strategy and communication activities, created in the first year, have stimulated significant interest from relevant audiences.

PROGRESS AND MAIN ACHIEVEMENTS

- Data on the technical specifications of the fuel cell trucks and hydrogen refuelling stations

- Commissioning of the first hydrogen refuelling station in Rothenburg, Switzerland, in January 2021
- The first Observer Group meeting took place on 2 July 2020.

FUTURE STEPS AND PLANS

- Finalise design phase for FPT/IVECO and VDL trucks and continue preparation for full construction. Design phase is near completion
- Development of first prototype of fuel cell systems and fuel cell trucks, and commencement of internal testing. Construction of H2Haul trucks for end-users. Testing of prototypes to commence in 2021, in preparation for full deployment from 2022
- Preparatory activities for HRS deployment; all sites selected, permits requested, and the commencement of civil works. Currently one HRS is in operation. Remaining HRS are in pre-deployment phase, with civil works to commence
- Continued high-profile dissemination and lobbying work through attendance and presentation at key conferences and events. Continue work on Observer Group and other stakeholder engagement. Communication and dissemination activities have been strong in the first phase of the project. As equipment and trucks are deployed, key milestones, achievements and results will be disseminated extensively.

QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	PARAMETER	UNIT	TARGET	SOA RESULT ACHIEVED TO DATE (BY OTHERS)	YEAR FOR SOA TARGET
Project's own objectives and MAWP Addendum (2018-2020)	Truck operational period	Months	Start of operation incl. 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 max. 6 months	N/A	N/A
	Truck specific fuel consumption	kg/100 km	<7.5 kg/100 km (rigid, 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	98	2017
	Mean distance between failures	km	Fuel cell MDBF >2 500 km		
	WtW CO ₂ emissions <50 % compared to diesel truck	kg CO ₂ /km	kg CO ₂ /vehicle km (per vehicle type, average across fleet) <50 % compared to diesel truck	N/A	N/A
	Speed of hydrogen dispensing	kg/min	>2.5 kg/min		
	Cost of hydrogen dispensed to HRS	€/kg	≤7.5 €/kg dispensed (excl. taxes) at end of project – in practice, lower values are expected	12	2017
	Amount of hydrogen dispensed to project trucks	kg/year	>2 500 kg per truck per year	N/A	N/A



Project ID: 671438
FCH-01.7-2014
Call topic: - Large scale demonstration of refuelling infrastructure for road vehicles
Project total costs: €69 044 206.16
FCH JU max. Contribution: €32 000 000
Project start - end: 01/06/2015 - 30/11/2020
Coordinator: ELEMENT ENERGY LIMITED, UK
Website: www.h2me.eu



BENEFICIARIES: LINDE GMBH, MERCEDES-BENZ AG, LINDE HYDROGEN FUELTECH GMBH, MCPHY ENERGY ITALIA SOCIETA A RESPONSABILITA LIMITATA, ELEMENT ENERGY, LINDE GAS GMBH, H2 MOBILITY DEUTSCHLAND GMBH & CO KG, COMMUNAUTE D'AGGLOMERATION SARREGUEMINES CONFLUENCES, FALKENBERG ENERGI AB, HYOP AS, DANISH HYDROGEN FUEL AS, OMV DOWNSTREAM GMBH, BOC LIMITED, HONDA R&D EUROPE (DEUTSCHLAND) GMBH, AGA AB, HYUNDAI MOTOR EUROPE GMBH, SYMBIO, AIR LIQUIDE ADVANCED TECHNOLOGIES SA, AREVA H2GEN, INTELLIGENT ENERGY LIMITED, ITM POWER (TRADING) LIMITED, CENEX - CENTRE OF EXCELLENCE FOR LOW CARBON AND FUEL CELL TECHNOLOGIES, MCPHY ENERGY, MERCEDES-BENZ FUEL CELL GMBH, WATERSTOFNET VZW, NISSAN MOTOR MANUFACTURING (UK) LIMITED, AIR LIQUIDE ADVANCED BUSINESS, NEL HYDROGEN AS, TOYOTA MOTOR EUROPE NV, ICELANDIC NEW ENERGY LTD, EIFER EUROPAISCHES INSTITUT FUR ENERGIEFORSCHUNG EDF KIT EWIV, LINDE AG, RENAULT SAS, BAYERISCHE MOTOREN WERKE AKTIENGESELLSCHAFT, DAIMLER AG

PROJECT AND OBJECTIVES

Hydrogen Mobility Europe (H2ME) brought together Europe's four most ambitious national initiatives on hydrogen mobility (in Germany, Scandinavia, France and the UK). The project expanded their developing networks of HRS – 29 new stations will be deployed in total – and the fleets of FCEV operating on Europe's roads – 339 vehicles – creating both a physical and strategic link between these four regions and three 'observer countries', namely Austria, Belgium and the Netherlands, which are using what has been learnt by this project to develop their own strategies.

NON-QUANTITATIVE OBJECTIVES

- Minimum of 100 FCEV and 23 HRS
- 339 vehicles and 29 HRS have been delivered to customers
- Further activities for deployment of HRS
- Further FCH JU and CEF projects have been developed and new projects are in the making
- HRS to be accessible to private users
- All of the 700 bar HRS are accessible to private drivers
- Ensure cross-fertilisation of knowledge acquired in the project

- The project summarised all findings in a final report that is publicly available. The lessons learnt and best practices will continue to be exploited through H2ME 2.

PROGRESS AND MAIN ACHIEVEMENTS

- Successful deployment of all foreseen activities, with 29 HRS and 339 vehicles delivered to customers

- Building a rich dataset valuable for Europe: jointly with H2ME 2. Since 2016, 14 340 000 km have been driven and 134 t of H2 distributed at 61 850 events
- The H2ME project has shown that FCEV and HRS are ready for commercial roll-out and can meet customers' expectations.

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)	YEAR FOR SOA TARGET
Project's own objectives, MAWP Addendum (2018-2020) and AWP 2014	Min. vehicle operation during the project	Months	12	50	✓	12	2017
	Vehicle availability	%	>95	>99	✓	98	
Project's own objectives, MAWP Addendum (2018-2020) and AWP 2014	HRS availability	%	97	>95	✗	98	2017
	Min. HRS operation	Months	24	50	✓	32	2017
	Hydrogen purity	%	99.99	99.99	✓	99.99	2015

Project ID:	700350
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:	€101 449 352.03
FCH JU max. Contribution:	€34 999 548.50
Project start - end:	01/05/2016 - 30/06/2022
Coordinator:	ELEMENT ENERGY LIMITED, UK
Website:	www.h2me.eu



BENEFICIARIES: TOYOTA NORGE AS, TOYOTA DANMARK AS, ELEMENT ENERGY, B. KERKHOF & ZN BV, TECH TRANSPORTS COMPAGNIE, ALPHABET FUHRPARKMANAGEMENT GMBH, LINDE GAS GMBH, ISLENSKA VETNISFELAGID EHF, COMMUNAUTE URBAINE DU GRAND NANCY, STEDIN DIENSTEN BV, SOCIETE DU TAXI ELECTRIQUE PARISIEN, H2 MOBILITY DEUTSCHLAND GMBH & CO KG, HYOP AS, BRINTBRANCHEN, NEW NEL HYDROGEN AS, COMPAGNIE NATIONALE DU RHONE SA, HYDROGENE DE FRANCE, HONDA R&D EUROPE (DEUTSCHLAND) GMBH, GNVERT SAS, AGA AB, SYMBIO, AIR LIQUIDE ADVANCED TECHNOLOGIES SA, AREVA H2GEN, SOCIETE D'ECONOMIE MIXTE DES TRANSPORTS EN COMMUN DE L'AGGLOMERATION NANTAISE (SEMITAN), MINISTERIE VAN INFRASTRUCTUUR EN WATERSTAAT, INTELLIGENT ENERGY LIMITED, MANUFACTURE FRANCAISE DES PNEUMATIQUES MICHELIN, ITM POWER (TRADING) LIMITED, CENEX - CENTRE OF EXCELLENCE FOR LOW CARBON AND FUEL CELL TECHNOLOGIES, KOBENHAVNS KOMMUNE, HYSOLUTIONS GMBH, MCPHY ENERGY, MERCEDES-BENZ FUEL CELL GMBH, NISSAN MOTOR MANUFACTURING (UK) LIMITED, AIR LIQUIDE ADVANCED BUSINESS, RENAULT TRUCKS SAS, NEL HYDROGEN AS, ICELANDIC NEW ENERGY LTD, EIFER EUROPAISCHES INSTITUT FUR ENERGIEFORSCHUNG EDF KIT EWIV, STEDIN NETBEHEER BV, RENAULT SAS, BAYERISCHE MOTOREN WERKE AKTIENGESELLSCHAFT, AUDI AKTIENGESELLSCHAFT, OPEN ENERGI LIMITED, DAIMLER AG, THE UNIVERSITY OF MANCHESTER

PROJECT AND OBJECTIVES

H2ME 2 brings together actions in 8 countries in a 6-year collaboration to deploy 20 HRS and over 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.

NON-QUANTITATIVE OBJECTIVES

- Min. of 1 200 fuel cell vehicles and 20 HRS
- >1 200 fuel cell vehicles and 20 HRS foreseen by the end of the project
- Demonstration of electrolyser integrated HRS operating in grid balancing
- H2ME 2 has a dedicated WP to assess how electrolytic hydrogen production in the mobility sector can link to the wider energy system
- Vehicles supplied by multiple OEMs, including cars and utility vehicles

- H2ME 2 will deploy cars, light-duty vans and trucks from OEMs, including Daimler, Honda, Symbio, Hyundai and Toyota
- Ensure cross-fertilisation of knowledge acquired in the project
- Dedicated WP and dissemination and exploitation plan to achieve this. Three observer countries are included in the coalition.

PROGRESS AND MAIN ACHIEVEMENTS

- Demonstration under way for 296 vehicles from 5 OEMs (Daimler, Honda, Hyundai, Symbio and Toyota) and 9 HRS from 5 suppliers across 5 countries
- Demonstration of positive business cases under H2ME 2 has led to further commitments from partners to expand fleets in France, Denmark and Germany
- Building a rich dataset for Europe – jointly with H2ME. Since 2016, 14.5 million kilometres have been driven and 147 t of H₂ distributed at 68 000 events.

FUTURE STEPS AND PLANS

- Most of the 20 HRS planned for the project are expected to have been commissioned and to be in operation in the next 16 months. Commissioning of new HRS has been impacted by the COVID-19 pandemic
- Most of the vehicles planned for the project are expected to be deployed in the next 16 months. Deployment of vehicles has been impacted by the COVID-19 pandemic
- Solid and growing basis of operational data from vehicles and stations and further fact-based analysis of vehicles and HRS performances. The H2ME initiative is the largest European deployment to date for hydrogen mobility, with 632 vehicles and 37 HRS deployed
- Further exploitation of results. Across H2ME and H2ME 2, c. 50 reports have been prepared to date. The projects have prepared a summary report for the end of phase 1 of the initiative.

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 FOR SOA TARGET
Project's own objective aligned with AWP 2015/MAWP Addendum (2018-2020)	HRS availability	%	98	>95	✘	98	2017
	Min. HRS operation	Months	36	48	✔	32	
	Hydrogen purity	%	99.99	99.999	✔	99.99	
Project's own objectives, MAWP Addendum (2018-2020) and AWP 2015	Min. vehicle operation during project	Months	36	50	✔	12	2017
	Vehicle availability	%	98	>99	✔	98	

Project ID:	826339
Call topic:	FCH-03-1-2018: Developing Fuel Cell applications for port/harbour ecosystems
Project total costs:	€4 117 197.50
FCH JU max. Contribution:	€3 999 947.50
Project start - end:	01/01/2019 - 31/12/2022
Coordinator:	FUNDACION DE LA COMUNIDAD VALENCIANA PARA LA INVESTIGACION, PROMOCION Y ESTUDIOS COMERCIALES DE VALENCIAPORT, ES
Website:	h2ports.eu/



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 EXPERIMENTACIONE TECNOLOGIAS DE HIDROGENO Y PILASDE COMBUSTIBLE CONSORCIO, GRIMALDI EUROMED SPA, BALLARD POWER SYSTEMS EUROPE AS, AUTORIDAD PORTUARIA DE VALENCIA, ENAGAS SA, UNIVERSITA DEGLI STUDI DI NAPOLI PARTHENOPE, UNIVERSITA DEGLI STUDI DI SALERNO, AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE, L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE

PROJECT AND OBJECTIVES

The H2Ports project will demonstrate and validate, through real port operations at the port of Valencia, two innovative solutions based on FC technologies and a mobile HRS specifically designed for the project. A Reach Stacker to be tested at a container terminal (MSCTV) and a Terminal Tractor to be tested at Valencia Terminal Europa (part of the Grimaldi Group) have been selected as being especially suited to fuel cell use in port facilities. The project will run the equipment on a daily basis for two years. All three pilots are currently being built and the pilot period is expected to start in November 2021.



PROGRESS AND MAIN ACHIEVEMENTS

- Design and start of construction of a mobile HRS
- Design and component selection for an FC Reach Stacker
- Design and component selection for a Terminal Tractor.

FUTURE STEPS AND PLANS

- Finalisation of the HRS, expected in August 2021
- Construction of the Reach Stacker, expected in November 2021
- Retrofit of the Terminal Tractor, expected in November 2021.



QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	PARAMETER	UNIT	TARGET	TARGET ACHIEVED?
Project's own objectives, MAWP Addendum (2018-2020) and AWP 2018	Lifetime	Hours	20 000	✘
	Tank-to-wheel efficiency	%	50	
	HRS availability	%	>98	



HIGHVLOCITY

HIGH V.LO-CITY CITIES SPEEDING UP THE INTEGRATION OF HYDROGEN BUSES IN PUBLIC FLEETS

Project ID:	278192
Call topic:	SP1-JTI-FCH.2010.1.1 -Large-scale demonstration of road vehicles and refuelling infrastructure III
PRD 2020 Panel:	1 - Trial and Deployment of Fuel Cell Applications - Transport
Project total costs:	€30 494 110.49
FCH JU max. contribution:	€13 491 724.00
Project start - end:	01/01/2012 - 31/12/2019
Coordinator:	VAN HOOL NV, BE
Website:	highvlocity.eu/



BENEFICIARIES: PITPOINT.PRO BV, PITPOINT.BE, QBUZZ BV, CNG NET BV, BALLAST NEDAM INTERNATIONAL PRODUCT MANAGEMENT B.V., RIVIERA TRASPORTI SPA, ABERDEEN CITY COUNCIL *, WATERSTOFNET VZW, HYDROGEN, FUEL CELLS AND ELECTRO-MOBILITY IN EUROPEAN REGIONS, DANThERM POWER AS, REGIONE LIGURIA, SOLVAY SA, VLAAMSE VERVOERSMAATSCHAPPIJ DE LIJN, UNIVERSITA DEGLI STUDI DI GENOVA, FIT CONSULTING SRL

PROJECT AND OBJECTIVES

The overall objective of High V.LO-City was to facilitate deployment of the last-generation fuel cell hybrid buses (FCB) in public transport operations by addressing key environmental and operational concerns that transport authorities are facing today. Through the strategic location of the project's four demo sites it envisions demonstration and the dissemination of actual FCBs in these different European geographic locations and their performance in normal bus operations. The project was completed and ended on 31 December 2019.

NON-QUANTITATIVE OBJECTIVES

- FCBs centre of excellence website
- The fuel cell busses.eu knowledge portal and centre of excellence was created and is now part of the JIVE project
- Improvements in the FCBs supply chain
- Next concepts for service and onsite storing of components were introduced during the project, which now is the way to go for all projects.

PROGRESS AND MAIN ACHIEVEMENTS

- The development, construction and operation of all (14) the hydrogen buses planned for in the project at four sites
- The installation and operation of three hydrogen generation and refuelling stations in three of the four sites
- The development, usage and dissemination of the results to interested operators and stakeholders via the detailed 'FC-bus centre of excellence' website.

FUTURE STEPS AND PLANS

- The project has finished.



QUANTITATIVE TARGETS AND STATUS

PARAMETER	UNIT	TARGET	ACHIEVED TO DATE BY THE PROJECT	TARGET ACHIEVED?	SOA RESULT ACHIEVED TO DATE (BY OTHERS)	YEAR FOR SOA TARGET
Fuel consumption	kg/100 km	11-13	9-13		7-9	2020
Demonstration size	Buses/site	5	5,5,3 & 2		>20	
Refuelling time	Min./fuelling	10-12	10-12	✓	10	
Bus cost	€/bus	1 300 000	1 100 000 -1 300 000		650 000	
Fuelling station capacity	kg/day	200	285		>300	
Fuelling station availability	%	98	96.8	✗	99	

Project ID:	303467
Call topic:	SP1-JTI-FCH.2011.1.1 - Large-scale demonstration of road vehicles and refuelling infrastructure IV
PRD 2020 Panel:	1 - Trial and Deployment of Fuel Cell Applications - Transport
Project total costs:	€17 850 708.85
FCH JU max. contribution:	€6 999 999
Project start - end:	01/01/2013 - 31/03/2019
Coordinator:	BOC LIMITED, UK
Website:	https://www.fuelcellbuses.eu/projects/hytransit



BENEFICIARIES: STAGECOACH BUS HOLDINGS LIMITED, VAN HOOL NV, ABERDEEN CITY COUNCIL*, HYDROGEN, FUEL CELLS AND ELECTRO-MOBILITY IN EUROPEAN REGIONS, DANThERM POWER AS, ELEMENT ENERGY LIMITED, PLANET PLANUNGSGRUPPE ENERGIE UND TECHNIK GBR

PROJECT AND OBJECTIVES

HyTransit aimed to trial a fleet of six hybrid fuel cell buses in daily fleet service, together with one state-of-the-art HRS in Aberdeen, Scotland. By operating the vehicles rigorously on long inter-urban routes, the project aimed to prove that a hybrid fuel cell bus is capable of meeting the operational demands of an equivalent diesel bus, whilst offering significant benefits in terms of environmental performance. Beginning in January 2013, the project finished in March 2019, allowing for four full years of operation of the FCBs and the HRS.

NON-QUANTITATIVE OBJECTIVES

- Develop six A330 hybrid fuel cell buses specifically modified for long sub-urban routes
- The six FCBs deployed in Aberdeen were specially designed by Van Hool, with help from Stagecoach and Aberdeen City Council
- Initiate the first step of a large-scale roll-out of hydrogen buses in Scotland
- Following the success of HyTransit, Aberdeen City Council has committed to deploying more FCBs through

the JIVE project. In addition, other Scottish cities, such as Dundee, have committed to deploying FCBs

- Prove that a hybrid fuel cell bus is capable of meeting the operational performance of an equivalent diesel bus on demanding UK routes
- The project results can be evidenced to prove the capability of the FCBs. These results are also used by the project in dissemination work to spread the positive message
- Address the main commercial barrier to the technology (namely bus capital cost) by deploying state-of-the-art components
- The premium of fuel cell buses has reduced significantly over diesel buses since 2013. The premium is now c. €70 000/year, down from c. €170 000/year
- Disseminate the project results to the public and key stakeholders who will be responsible for decisions on the next steps towards commercialisation of the technology
- The HyTransit project has been widely disseminated across Europe.

PROGRESS AND MAIN ACHIEVEMENTS

- Kittybrewster HRS has exceeded expectations with the highest average availability (99.5 %) and utilisation (46 %) results seen to date across Europe
- Nearly 1.4 million kilometres have been driven by the fleet of buses and approximately 1.3 million passengers have used the service
- By using FCBs instead of conventional diesel vehicles, >400 000 litres of diesel has been saved and >1 000 tonnes of direct GHG emissions avoided.

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)
HRS						
AIP 2011 target for fleet	Availability	%	>85	78	✂	85
FC VEHICLES						
Project's own objectives	Availability of the hydrogen refuelling unit	%	>98	99.5	✓	98
	Cumulative amount of hydrogen dispensed	kg	>140 000	146 823		N/A
	Operating hours per bus	Hours	70 000	88 824		
	Number of passengers	Number	>1 000 000	1 302 487		



JIVE

JOINT INITIATIVE FOR HYDROGEN VEHICLES ACROSS EUROPE

Project ID:	735582
Call topic:	FCH-01-9-2016: Large Scale Validation of fuel cell bus fleets
Project total costs:	€110 375 045.24
FCH JU max. Contribution:	€32 000 000
Project start - end:	01/01/2017 - 31/12/2022
Coordinator:	ELEMENT ENERGY LIMITED, UK
Website:	www.fuelcellbuses.eu/projects/jive



BENEFICIARIES: REBELGROUP ADVISORY BV, IN-DER-CITY-BUS GMBH, ESWE VERKEHRSGESELLSCHAFT MBH, MAINZER VERKEHRSGESELLSCHAFT MBH, VERKEHRS-VERBUND MAINZ-WIESBADEN GESELLSCHAFT MIT BESCHRANKTER HAFTUNG, REGIONALVERKEHR KÖLN GMBH, EUE APS, DUNDEE CITY COUNCIL, WEST MIDLANDS TRAVEL LIMITED, SASA SPA AG SOCIETA' AUTOBUS SERVIZIO AREA SPA, HERNING KOMMUNE, WSW MOBIL GMBH, RIGAS SATIKSME SIA, TRENTO TRASPORTI SPA, EE ENERGY ENGINEERS GMBH, SPHERA SOLUTIONS GMBH, HYSOLUTIONS GMBH, ABERDEEN CITY COUNCIL, SÜEDTIROLER TRANSPORTSTRUKTUREN AG, HYCOLOGNE - WASSERSTOFF REGION RHEINLAND EV, LONDON BUS SERVICES LIMITED, PLANET PLANUNGSGRUPPE ENERGIE UND TECHNIK GBR, BIRMINGHAM CITY COUNCIL, FONDAZIONE BRUNO KESSLER, UNION INTERNATIONALE DES TRANSPORTS PUBLICS, HYDROGEN EUROPE

PROJECT AND OBJECTIVES

The JIVE project aims to assist the commercialisation of fuel cell buses (FCBs) as a zero-emissions public transport option across Europe. The project's goal is 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 9 locations. This will more than double the number of FCBs currently operating in Europe.

which means that they will lead to CO₂ abatement and not simply operate as a 'visible extra'.

FUTURE STEPS AND PLANS

- Nearly all the buses are expected to be operational by the end of 2021. The buses are currently being delivered to cities in batch and should enter into operation shortly after arrival
- By the end of 2021, enough operational data will have been analysed and key project findings communicated to demonstrate technological readiness. Even with the current data collection issues, it should be possible to present valid data at the next GA in September 2021.

PROGRESS AND MAIN ACHIEVEMENTS

- All the original 142 buses have been ordered from 3 different bus manufacturers
- In addition, 59 buses have entered into commercial operation.

NON-QUANTITATIVE OBJECTIVES

- Providing experience of the suitability of FCBs for wider roll-out. Through the publication of project deliverables, such as the Best Practice and Commercialisation Report 2, information flows have been established to interested observer parties
- Raise awareness of the readiness of fuel cell technology for wider roll-out – with a focus on bus purchasers and regulators. As before, a strong observer group within the JIVE consortium has been established which monitors discussions and best practice emerging from the project. This will ensure that the momentum for fuel cell bus uptake in Europe continues beyond the project
- Deliver positive environmental impacts by operating FC buses for extended periods. As per JIVE's objectives, all buses deployed thus far are replacing diesel technology,



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	Min. 44 000	
	Operating hours per fuel cell system	Hours	> 20 000	
	Availability	%	>90	
	Mean Distance Between Failures (MDBF)	km	>2 500	
	Specific fuel consumption	kg/100 km	< 9	
	Efficiency	%	Over 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
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:	€106 578 605.62
FCH JU max. Contribution:	€25 000000
Project start - end:	01/01/2018 - 31/12/2023
Coordinator:	ELEMENT ENERGY LIMITED, UK
Website:	www.fuelcellbuses.eu/projects/jive-2

BENEFICIARIES: OBCINA SOSTANJ, ELEMENT ENERGY, ENGIE ENERGIE SERVICES, CA DE LAUXERROIS, RHEINISCHE BAHNGESSELLSCHAFT AKTIENGESELLSCHAFT, SOCIETE PUBLIQUE LOCALE D'EXPLOITATION DES TRANSPORTS PUBLICS ET DES SERVICES A LA MOBILITE DE L'AGGLOMERATION PALOISE, STRAETO BS, OPENBAAR LICHAAM OV-BUREAU GRONINGEN EN DRENTHE, PAU BEARN PYRENEES MOBILITES, LANDSTINGET GAVLEBORG, REBELGROUP ADVISORY BV, REGIONALVERKEHR KOLN GMBH, DUNDEE CITY COUNCIL, WSW MOBIL GMBH, RIGAS SATIKSME SIA, MESTNA OBCINA VELENJE, KOLDING KOMMUNE, SPHERA SOLUTIONS GMBH, BRIGHTON & HOVE BUS AND COACH COMPANY LIMITED, RUTER AS, PROVINCIE ZUID-HOLLAND, PETROLEOS DE PORTUGAL - PETROGAL SA, VATGAS SVERIGE IDEELL FORENING, NOORD-BRABANT PROVINCIE, UNION INTERNATIONALE DES TRANSPORTS PUBLICS, HYDROGEN EUROPE

PROJECT AND OBJECTIVES

The JIVE 2 project started in January 2018. The two JIVE projects combined will deploy nearly 300 fuel cell buses in 22 cities across Europe by the early 2020s – the largest deployment in Europe to date.

NON-QUANTITATIVE OBJECTIVES

- Providing experience of suitability of FCBs for wider roll-out. Through the publication of project deliverables, such as the Best Practice and Commercialisation Report 2, information flows have been established to interested observer parties
- Raise awareness of the readiness of fuel cell technology for wider roll-out – with a focus on bus purchasers and regulators. As before, a strong observer group within the JIVE consortium has been established which monitors discussions and best practices emerging from the project. This will ensure that the momentum for fuel cell bus uptake in Europe continues beyond the project
- Deliver positive environmental impacts by operating FC buses for extended periods. As per the project objectives, all buses deployed thus far are replacing

diesel technology, which means that they will lead to CO₂ abatement and not simply operate as a 'visible extra'.

PROGRESS AND MAIN ACHIEVEMENTS

- To date, 110 of the 152 buses originally envisaged have been ordered from 4 different bus manufacturers
- In addition, 5 buses have been delivered.

FUTURE STEPS AND PLANS

- Half of the buses are expected to be delivered by the end of 2021
- By the end of 2021, enough operational data will have been analysed and key project findings communicated to demonstrate technological readiness. Even with the current data collection issues, it should be possible to present valid data at the next GA in September 2021.



QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	PARAMETER	UNIT	TARGET	SOA RESULT ACHIEVED TO DATE (BY OTHERS)
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	
	Mean Distance Between Failures (MDBF)	km	>2 500	
	Fuel consumption	kg/100 km	< 9	
	Efficiency	%	>42	
	Vehicle OPEX	%	Max. 100 more than diesel bus OPEX	
Vehicle CAPEX	Euro	<625 000	✓	

Project ID:	779589
Call topic:	FCH-01-7-2017 - Validation of Fuel Cell Trucks for the Collect of Urban Wastes
Project total costs:	€9 247 149.59
FCH JU max. Contribution:	€4 993 851
Project start - end:	01/01/2018 - 31/12/2021
Coordinator:	TRACTEBEL ENGINEERING, BE
Website:	h2revive.eu



BENEFICIARIES: GEMEENTE GRONINGEN, SAVER NV, SUEZ NEDERLAND HOLDING BV, AZIENDA SERVIZI MUNICIPALIZZATI DI MERANO SPA, SEAB SERVIZI ENERGIA AMBIENTE BOLZANO SPA, SWISS HYDROGEN SA, RENOVA AKTIEBOLAG, E-TRUCKS EUROPE, GEMEENTE GRONINGEN, GEMEENTE BREDA, SYMBIO, STAD ANTWERPEN, WATERSTOFNET VZW, POWERCELL SWEDEN AB, ELEMENT ENERGY LIMITED, PROTON MOTOR FUEL CELL GMBH, GEMEENTE AMSTERDAM, COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES

PROJECT AND OBJECTIVES

The REVIVE project will significantly advance the state of development of fuel cell refuse trucks by integrating fuel cell powertrains into 14 vehicles and deploying them at 8 sites across Europe. The first truck was deployed in Breda (NL) and is being tested in the field. The other 13 trucks will all be deployed in 2021.

NON-QUANTITATIVE OBJECTIVES

- Today we have 2 EU FC suppliers for the project: Proton Motor and PowerCell Sweden
- Demonstrate a route to high utilisation of HRS to support the roll-out of H2 mobility for light vehicles. Due to lack of deployment, this objective has not yet been achieved.

PROGRESS AND MAIN ACHIEVEMENTS

- In total, 14 trucks have been ordered and are being built
- First Proton Motor FC system has been delivered and successfully integrated
- First truck certification process has been completed and first REVIVE truck deployed.

FUTURE STEPS AND PLANS

- The consortium will ask for a project extension in order for most of the trucks to reach the 24-month period of operation. It will launch an amendment in Q2 2021
- Implementation of the data collection framework: finalise the data collection plan, roll out diesel

- data loggers to do a relevant comparison (TCO, LCA analysis), provide monthly reports
- Increase dissemination activities. In order to catch up with the delays in 2020, a plan for dissemination in 2021 will be developed.



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		
	Availability	%	90		
	Mean Distance Between Failures (MDBF)	km	3 500		
	FC power	kW	>40		45

Project ID:	875156
Call topic:	FCH-01-2-2019: Scaling up and demonstration of a multi-MW Fuel Cell system for shipping
Project total costs:	€13 179 056.25
FCH JU max. Contribution:	€9 975 477.50
Project start - end:	01/01/2020 - 31/12/2025
Coordinator:	MARITIME CLEANTECH, NO
Website:	shipfc.eu/



BENEFICIARIES: EIDESVIK SHIPPING AS, WÄRTSILÄ GAS SOLUTIONS NORWAY AS, SUSTAINABLE ENERGY AS, NORTH SEA SHIPPING AS, STAR BULK SHIPMANAGEMENT CO. (CYPRUS) LTD, WARTSILA NORWAY AS, CAPITAL-EXECUTIVE SHIP MANAGEMENT CORP, PERSEE, PROTOTECH AS, EQUINOR ENERGY AS, YARA INTERNATIONAL ASA, UNIVERSITY OF STRATHCLYDE, NATIONAL CENTER FOR SCIENTIFIC RESEARCH "DEMOKRITOS", FRAUNHOFER GESELLSCHAFT ZUR FÖRDERUNG DER ANGEWANDTEN FORSCHUNG EV

PROJECT AND OBJECTIVES

The ShipFC project'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. We also aim to prove the case for large-scale zero-emission fuel infrastructure through a realistic business model. Currently, the fuel cells are being scaled up and undergoing lab testing. The on-board fuel system design is in progress, as is the integration design for the FC power system. We are building our knowledge base for the development of a global green ammonia fuel infrastructure.

NON-QUANTITATIVE OBJECTIVES

- Prove viability of green ammonia fuel system by covering ship systems, bunkering and infrastructure. Development of ammonia fuel system is in the development phase, with several potential concepts having been identified and being further developed. Initial HAZID is being performed for the ammonia fuel system, which is subject to further iterations as the concepts are being further developed for a concept selection
- Integration of ammonia fuel cell and fuel systems in ship power systems. Integration activities have

started, with single line diagrams being developed and calculations being performed for the required battery pack. Power electronics are being designed to integrate the SOFC powertrain with the existing powertrain on board the vessel

- Show wider use and scale-up of the system to 20+ MW. Data collection and analysis of selected replicator vessels is being performed to identify the requirements of the larger vessels.

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
- Requirement specifications for SOFC have been developed.

FUTURE STEPS AND PLANS

- Scale-up and testing of SOFC. SOFC is currently undergoing lab-scale testing in preparation for large-scale tests. The full size 2 MW SOFC will be tested by November 2023.



QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	PARAMETER	UNIT	TARGET	TARGET ACHIEVED?
Project's own objectives	GHG reduction by use of ammonia fuel	%	70	✘
	Ammonia SOFC system power	MW	2	
	MW-scale SOFC operational experience	Hours	3 000	

Project ID:	779538
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:	€17 556 029.18
FCH JU max. Contribution:	€4 998 843
Project start - end:	01/09/2017 - 31/08/2022
Coordinator:	ELEMENT ENERGY LIMITED, UK
Website:	zefer.eu



BENEFICIARIES: LINDE GMBH, ELEMENT ENERGY, GREEN TOMATO CARS LIMITED, BREATH, SOCIETE DU TAXI ELECTRIQUE PARISIEN, AIR LIQUIDE ADVANCED TECHNOLOGIES SA, ITM POWER (TRADING) LIMITED, CENEX - CENTRE OF EXCELLENCE FOR LOW CARBON AND FUEL CELL TECHNOLOGIES, AIR LIQUIDE ADVANCED BUSINESS, VILLE DE PARIS, LINDE AG, BAYERISCHE MOTOREN WERKE AKTIENGESSELLSCHAFT, MAYOR'S OFFICE FOR POLICING AND CRIME

PROJECT AND OBJECTIVES

ZEFER aims to demonstrate viable business cases for fuel cell electric vehicles (FCEVs) in high-mileage fleet applications. The project will deploy 180 FCEVs as taxis, private hire vehicles and emergency service vehicles in three major European cities where their operational benefits and zero-emission credentials can be monetised. The vehicles will use existing HRS networks to increase local utilisation levels and improve the business case for HRS operators. As of March 2021, 117 vehicles had amassed >5.1 million kilometres and 3 HRS had been upgraded to cater to fleets.

NON-QUANTITATIVE OBJECTIVES

- Develop comprehensive understanding from the deployment project. Public deliverables have been produced, covering topics such as customer acceptance, the business case for FCEVs, and the technical performance of HRS and FCEVs subject to high utilisation
- Develop the confidence of investors and policymakers in FCEV and HRS roll-out. Analysis in ZEFER has proven that FCEVs and HRS are capable of meeting the demands of high-mileage fleet operations. This has led to fleet operators increasing the number of FCEVs in their fleet and attracting investors into joint ventures (HySetCo)
- Maintain and, if possible, increase SME participation in FCH JU projects to or over 25 %. 50 % of partners in ZEFER are SMEs. In fact, 84 % of project funding targets SMEs
- Reduce the production cost of fuel cell systems to be used in transport applications, while increasing their lifetime levels to make them competitive with conventional technologies. The project will demonstrate

the lifetime of fuel cells in FCEVs at utilisation levels well beyond those currently deployed. The bulk procurement of FCEVs is also expected to have reduced FCEV costs to their lowest level

- Increase the energy efficiency of hydrogen production, while reducing operating and capital costs so that the combined system is competitive with alternatives in the marketplace. ZEFER aims to reduce the cost of hydrogen at the pump to <€10/kg. This will be achieved by providing a stable demand for hydrogen at an HRS. The project will also trigger further cost reductions by creating a climate of investment in low-cost green production systems required to drive the delivered cost below this level.

PROGRESS AND MAIN ACHIEVEMENTS

- A total of 117 FCEVs have been deployed in everyday operation in Paris (57) and London (60), amassing over 5.1 million kilometres to date
- 75 % of HRS upgrades have been completed, leading to improvements in the technical performance and customer experience of HRS
- 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

- Deploy the final 60 FCEVs in high-mileage applications. With the Brussels deployment deemed unfeasible within the timeline of the ZEFER project, the consortium has agreed to reallocate the vehicles to another party/ location. The Project Officer has been kept up-to-date

on the reallocation proposals and is awaiting a formal proposal from the consortium

- Reinroduce FCEVs into service once COVID regulations allow. As noted above, the ZEFER partners have been significantly impacted by the COVID pandemic. Many have had to take their vehicles out of operation as government rules prohibit all but essential travel. It is hoped that as cases reduce, the vehicles can re-enter service. However, this is somewhat out of the control of the project partners
- Complete the HRS upgrades required in Paris, which have been delayed due to permit issues at the Paris-Ouest site. This is not expected to be resolved within the period of the project. Alternative upgrades are therefore being discussed with the Project Officer
- Continue data collection on the FCEVs and HRS to better understand how performance is impacted by long-term high utilisation levels. Data collection has been ongoing throughout the project. Some difficulties have been encountered with retrieving data from the Metropolitan Police Service (MPS) but this will soon be resolved as the MPS are fitting telematics to the vehicles
- Production of project reports analysing the business case for FCEVs in high-mileage applications. This will be supported by customer survey analysis. New iterations of the business case and customer acceptance reports are expected in Q2/Q3 2021
- Higher visibility dissemination work to inform policymakers and ensure that the fleet operation use case is expandable across other European regions. Roundtables with policymakers will be hosted by the project to increase awareness of the business case for FCEVs in fleet applications.

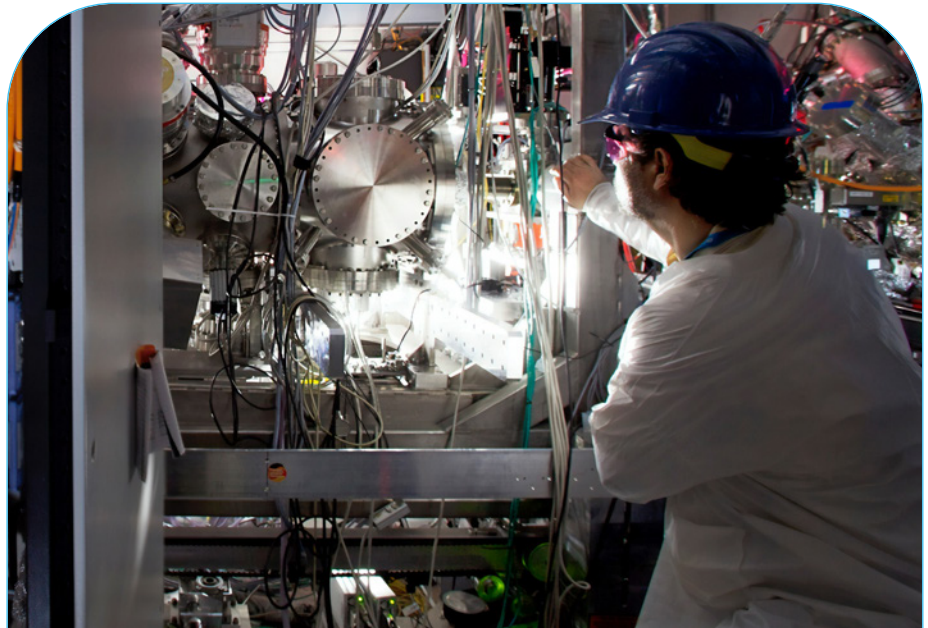
QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	PARAMETER	UNIT	TARGET	ACHIEVED TO DATE BY THE PROJECT	TARGET ACHIEVED?	SOA RESULT ACHIEVED TO DATE (BY OTHERS)	YEAR FOR SOA TARGET
Project's own objectives	Min. distance for vehicles	km /vehicle	90 000	~45 500 km per year pre-COVID for certain fleets	✘	FCEVs in taxi operation in H2ME drive on average ~45 000 km per year	2020
	Vehicle availability	%	>98	>99	✔	>99	
	Range	km	500	605	✔	756	
Project's own objective	HRS availability	%	>98	96	✘	98	2016
	Hydrogen purity	%	99.99	99.99	✔	99.99	2019
	Level of back-to-back vehicle refuelling	refuelling incidents/hour	6	6	✔	6	2020
	Cost of hydrogen	€/kg	≤10	10	✔	10	

PANEL 2
NEXT GENERATION
OF PRODUCTS –
TRANSPORT

Project ID:	875155
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:	€2 295 783.50
FCH JU max. Contribution:	€2 295 783.50
Project start - end:	01/01/2020 - 31/12/2022
Coordinator:	SINTEF AS, NO
Website:	https://camelot-fuelcell.eu

BENEFICIARIES: FCP FUEL CELL POWERTRAIN GMBH, JOHNSON MATTHEY FUEL CELLS LIMITED, PRETEXO, BAYERISCHE MOTOREN WERKE AKTIENGESELLSCHAFT, ALBERT-LUDWIGS-UNIVERSITAET FREIBURG, TECHNISCHE UNIVERSITAET CHEMNITZ, JOHNSON MATTHEY PLC



PROJECT AND OBJECTIVES

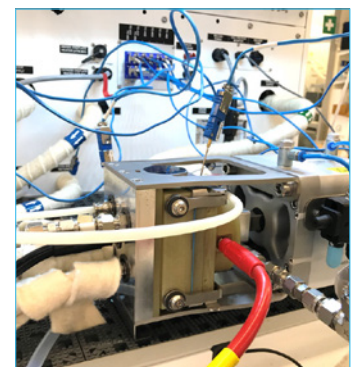
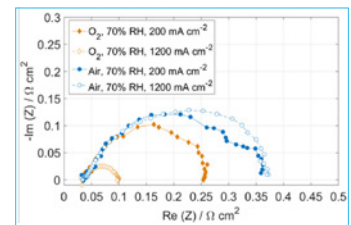
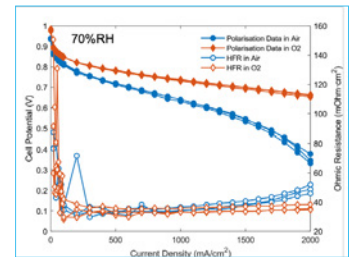
Fuel cell technology is advancing rapidly, providing energy-saving solutions in a wide range of applications including transport and mobility. However, there are limitations in fuel cell membrane electrode assembly (MEA, the core component in the electrochemical reaction) that must be overcome to improve performance. The CAMELOT project is a consortium of research institutes and universities, MEA suppliers and transport OEMs that aims to investigate ultra-thin and ultra-low loading layers required by future MEAs.

PROGRESS AND MAIN ACHIEVEMENTS

- Development of beyond state-of-the-art thin layer components for PEM technology
- Advanced characterisation of baseline materials to be used for model validation
- Development of membrane module for two-phase water transport.

FUTURE STEPS AND PLANS

- Project is currently on hold
- Restructuring of consortium is in progress.



QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	PARAMETER	UNIT	TARGET	TARGET ACHIEVED?
Project's own objectives	Membrane thickness	µm	<10	✘

Project ID:	736122
Call topic:	FCH-01-8-2016 - Development of innovative hydrogen compressor technology for small-scale decentralized applications for hydrogen refuelling or storage
Project total costs:	€2 496 830
FCH JU max. Contribution:	€2 496 830
Project start - end:	01/01/2017 - 28/02/2021
Coordinator:	EIFER EUROPAISCHES INSTITUT FÜR ENERGIEFORSCHUNG EDF KIT EWIV, DE
Website:	www.cosmhye.eu

BENEFICIARIES: STEINBEIS INNOVATION GMBH, LUDWIG-BOELKOW-SYSTEMTECHNIK GMBH, NEL HYDROGEN AS, MAHYTEC SARL, STEINBEIS ZI GMBH



PROJECT AND OBJECTIVES

The COSMHYC project aims to answer the needs identified by the MAWP of the FCH2 JU of increasing the energy efficiency of hydrogen production while reducing operating and capital costs, in order to make hydrogen a competitive fuel for transport applications. COSMHYC will develop and test an innovative compression solution from 1 to 1 000 bar based on a hybrid concept, combining a conventional compressor with an innovative compression technology.

NON-QUANTITATIVE OBJECTIVES

- Modular scalability. Design is intrinsically scalable
- No moving part in the innovative compressor
- Perform a cost of ownership assessment. Ongoing dedicated activities in the project.

PROGRESS AND MAIN ACHIEVEMENTS

- Rare-earth-free metal hydrides have been developed
- Techno-assessment of the relevant technology has been validated
- A prototype has been built and tested.

FUTURE STEPS AND PLANS

The project has finished.

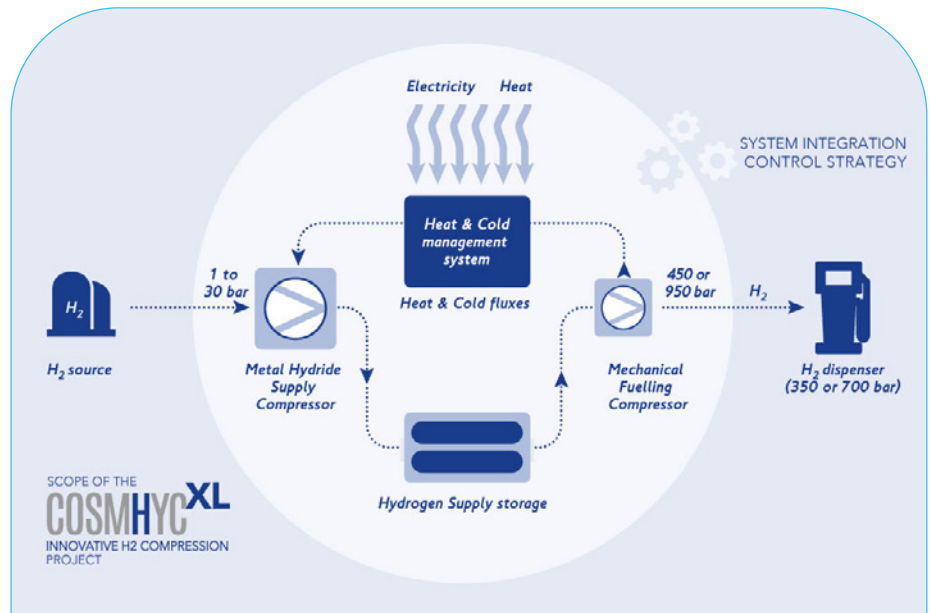


QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	PARAMETER	UNIT	TARGET	ACHIEVED TO DATE BY THE PROJECT	TARGET ACHIEVED?	SOA RESULT ACHIEVED TO DATE (BY OTHERS)	YEAR FOR SOA TARGET
AWP 2016	Noise	dB	<60	53	✓	85	2020
	TRL	-	5	5		3	2017
Project's own objectives	Specific costs	k€/kg*day	N/A	3.7		5-12	2015

Project ID: 826182
Call topic: FCH-01-7-2018 - Improvement of innovative compression concepts for large scale transport applications
Project total costs: €2 749 613.75
FCH JU max. Contribution: €2 749 613.75
Project start - end: 01/01/2019 - 31/12/2021
Coordinator: EIFER EUROPAISCHES INSTITUT FÜR ENERGIEFORSCHUNG EDF KIT EWIV, DE
Website: cosmhyec.eu/cosmhyc-xl-project

BENEFICIARIES: STEINBEIS 21 GMBH, MAHYTEC SARL, NEL HYDROGEN AS, LUDWIG-BOELKOW-SYSTEMTECHNIK GMBH



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 dedicated 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 diaphragm compressor.

NON-QUANTITATIVE OBJECTIVES

- Hybrid system allowing different configurations. Economic optimisation from LBST demonstrates that different refuelling applications will require only very slightly adapted configurations and intermediate storage capacities to minimise total costs
- Increase reliability. No moving part in the innovative compressor
- Cost of ownership assessment. Ongoing dedicated activities in the project.

PROGRESS AND MAIN ACHIEVEMENTS

- Optimisation of rare-earth-free hydrides with better performances than COSMHYC
- Economic analysis shows that the hybrid system allows different configurations (e.g. intermediate pressure levels or intermediate storage sizes)
- Modelling and draft designs are available for the new mechanical compressor and for the large-scale-oriented system integration.



FUTURE STEPS AND PLANS

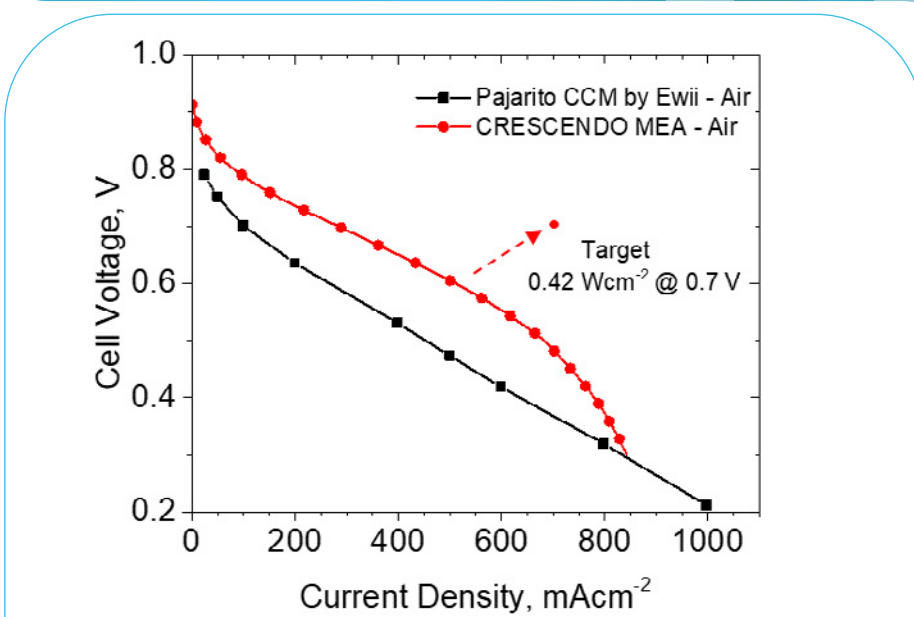
- Finalisation of design. Design has been drafted and main subsystems identified
- Construction of prototypes. Test site has been identified and is being prepared
- Long-term tests on prototypes have not yet started.



QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	PARAMETER	UNIT	TARGET	TARGET ACHIEVED?	SOA RESULT ACHIEVED TO DATE (BY OTHERS)	YEAR FOR 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	2019
	Noise	dB	<60		85	2017

Project ID:	779366
Call topic:	FCH-01-2-2017 - TTowards next generation of PEMFC: Non-PGM catalysts
Project total costs:	€2 739 602.5
FCH JU max. Contribution:	€2 739 602.5
Project start - end:	01/01/2018 - 30/06/2021
Coordinator:	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS, FR
Website:	www.crescendo-fuelcell.eu/



BENEFICIARIES: UNIVERSITE DE MONTPELLIER, JOHNSON MATTHEY FUEL CELLS LIMITED, PRETEXO, BAYERISCHE MOTOREN WERKE AKTIENGESELLSCHAFT, JOHNSON MATTHEY PLC, TECHNISCHE UNIVERSITAT BERLIN, COMMISSARIAT A L'ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES, IMPERIAL COLLEGE OF SCIENCE TECHNOLOGY AND MEDICINE, UNIVERSITA DEGLI STUDI DI PADOVA

PROJECT AND OBJECTIVES

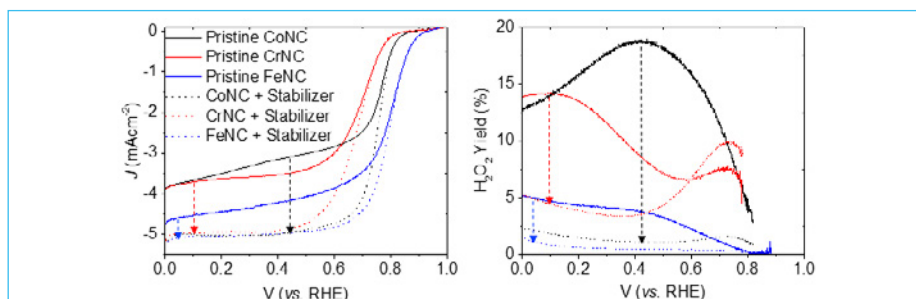
CRESCENDO aims to make progress in research on PGM-free fuel cell cathode catalysts, develop diagnostic methods to characterise their active site density and turnover frequency, and realise successful catalyst stabilisation approaches, as well as advance research on non-PGM and ultra-low PGM hydrogen oxidation catalysts. The reasons for the high losses with current PGM-free cathode catalyst layers have been analysed and the findings used to redesign the catalyst layer, with the objective of achieving 0.42 W/cm² at 0.7 V in air, and 1000 h operation with the scaled-up catalyst and final configuration of the MEA.

PROGRESS AND MAIN ACHIEVEMENTS

- Achieved 210+ mV improvement at 600 mA/cm² in H₂/air over commercial MEA comprising commercial non-PGM cathode
- Produced 30 g scaled-up non-PGM catalyst, associated with stabilisation additive and used in newly developed catalyst layers
- Demonstrated 170 mA/cm² (at 0.1 V with Ni-based bioinspired anode catalyst 36 A/mg Ni) anchored to functionalised carbon nanotubes.

FUTURE STEPS AND PLANS

- Optimise cathode catalyst layer with scaled-up catalyst. This is ongoing
- Evaluate MEAs with scaled-up project non-PGM cathode catalyst layers. Planned from M40
- Cost analysis. Planned from M42
- Demonstrate performance of MEA with PGM-free anode and PGM-free cathode after lockdown rules have been eased.

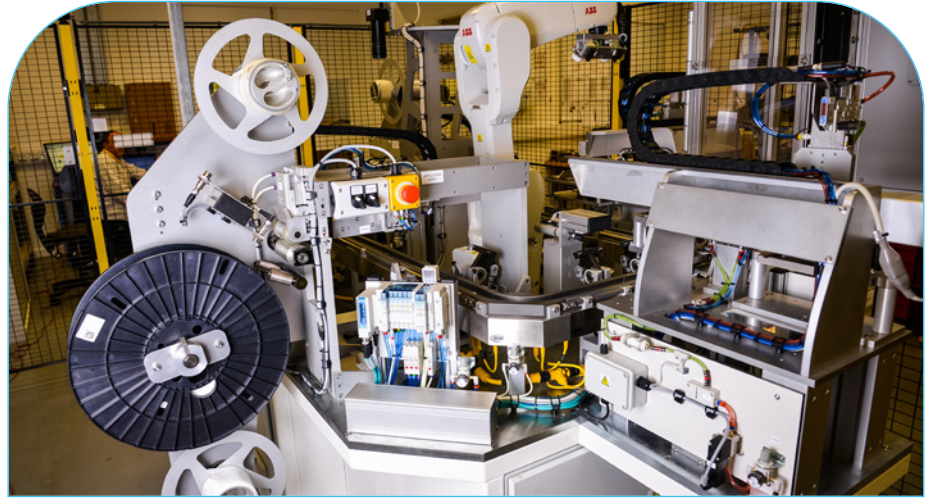


QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	PARAMETER	UNIT	TARGET	ACHIEVED TO DATE BY THE PROJECT	TARGET ACHIEVED?	SOA RESULT ACHIEVED TO DATE (BY OTHERS)	YEAR FOR SOA TARGET
AWP 2018	Current density at 0.7 V	mA/cm ²	600	400	✗	228	2020
	Durability at 1.5 A/cm ²	Hours	1000	Result due M45	✗	No data available at 1.5 A/cm ²	N/A
Project's own objectives for non-PGM anode catalyst	Mass activity at 0.9 V IR-free	A/mg	35	36	✓	No data available with bioinspired Ni catalyst	N/A

Project ID:	736290
Call topic:	FCH-01-1-2016 - Manufacturing technologies for PEMFC stack components and stacks
Project total costs:	€3 486 965
FCH JU max. Contribution:	€3 486 965
Project start - end:	01/01/2017 - 30/06/2020
Coordinator:	COMMISSARIAT A L'ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES, FR
Website:	digiman.eu/

BENEFICIARIES: INTELLIGENT ENERGY LIMITED, PRETEXO, FREUDENBERG PERFORMANCE MATERIALS SE & CO KG, TOYOTA MOTOR EUROPE NV, THE UNIVERSITY OF WARWICK



PROJECT AND OBJECTIVES

The project advances (MRL4>MRL6) the critical steps of the PEM fuel cell assembly processes and associated in-line QC and demonstrates a route to an automated volume process production capability within an automotive best practice context. This includes characterisation and digital codification of physical attributes of key materials (e.g. GDLs) to establish yield-impacting digital cause and effect relationships within the value chain Industry 4.0 standards. Main outputs are a proof of process and a blueprint design for beyond current state automotive PEM fuel cell manufacturing in Europe.

NON-QUANTITATIVE OBJECTIVES

- Inline digital detection and marking of surface non-uniformities via Vision line. Process set up and in operation. Automated surface assessment shows meaningful results and sufficient resolution
- Integration of inline non-destructive quality control tools. Digital optical QC has already been installed with Freudenberg Performance Material's production line
- Development of beyond state technologies, specific to PEMFC stack production. Innovative floatation methods for pick and place handling and mechanical pre-alignment of non-rigid and porous GDL materials have been developed
- Improvement, modification and adaptation of component production steps. Development of digital boundary limits to empirically derived homogeneity data have been developed
- Development of QA strategies for the transport sector compatible with IATF 16949. Characterisation of structural anomalies (heterogeneities and detection techniques have been completed).

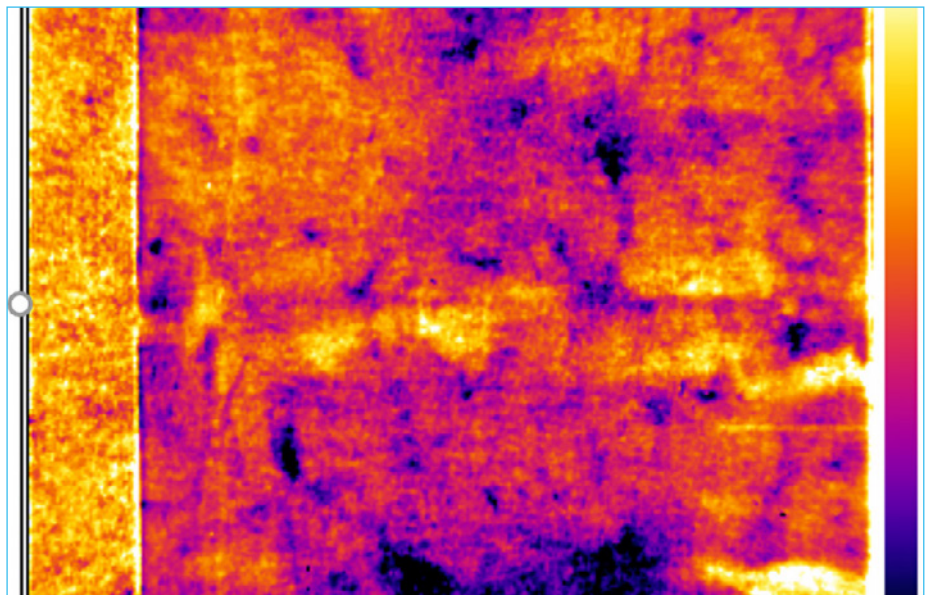
PROGRESS AND MAIN ACHIEVEMENTS

- KPIs have been agreed for: (i) fully automated stack assembly/test via automotive best practice; (ii) stack performance at handover to a production line
- Proof-of-process demonstrator equipment for the uplifted cell assembly automation has been manufactured and validated

- Deep characterisation of GDL properties has enabled the development of automatic scanning techniques for digital QC and characterisation.

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?
Project's own objectives	Stack weight	kg	2.9	2.9	✓
	Stack volume	l	2.85	2.85	
	Stack capacity	t	2.1	2.1	

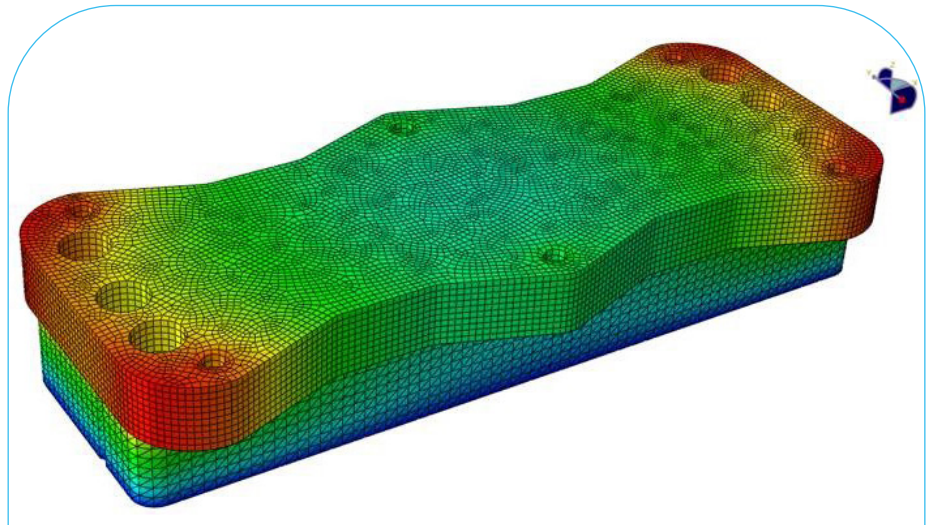


Disruptive pemfc stack with nOvel materiaLs,
Processes, arcHitecture and optimized INterfaces

DOLPHIN

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

Project ID:	826204
Call topic:	FCH-01-6-2018 - Game changer fuel cell stack for automotive applications
Project total costs:	€2 962 681
FCH JU max. Contribution:	€2 962 681
Project start - end:	01/01/2019 - 31/12/2022
Coordinator:	COMMISSARIAT A L'ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES, FR
Website:	www.dolphin-fc.eu/



BENEFICIARIES: CHEMOURS FRANCE SAS, CHEMOURS BELGIUM, CHEMOURS INTERNATIONAL OPERATIONS SARL, HEXCEL COMPOSITES GMBH & CO KG, DMG MORI ADDITIVE GMBH, SYMBIO, FAURECIA SYSTEMES D'ÉCHAPPEMENT SAS, HEXEL REINFORCEMENTS SAS, HEXCEL COMPOSITES LTD, ZENTRUM FÜR SONNENEnergie- UND WASSERSTOFF-FORSCHUNG BADEN-WÜRTTEMBERG, THE UNIVERSITY OF MANCHESTER

PROJECT AND OBJECTIVES

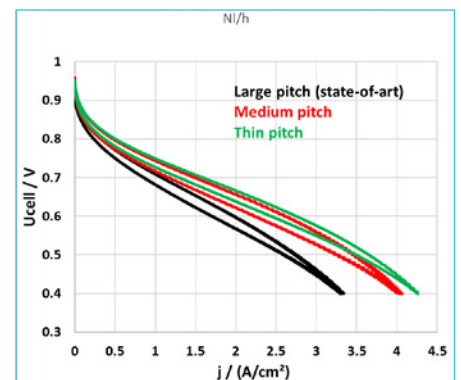
The overall aim of the project is to validate disruptive technologies for 100 kW light-weight and compact fuel cell stack designs, reaching outstanding (specific and volumetric) power density while simultaneously featuring enhanced durability (under automotive application conditions) compared to state of the art, and compatible with large scale/mass production of full power stacks. Validation of the DOLPHIN technologies will be supported by the design and manufacture of an automotive stack of 5 kW, representative of 100 kW power stacks.

PROGRESS AND MAIN ACHIEVEMENTS

- Increased performance thanks to reduction in rib-channel dimensions
- Manufacturing methods (printing, additive manufacturing) to produce flow fields with thin dimensions on metallic or composite thin sheets
- Reduction of mass and volume of terminal plates thanks to composite materials.

FUTURE STEPS AND PLANS

- Selection of most promising components to be tested in short stack and 5 kW stack (2021, 2022). Some materials have already been selected; tests for other have been delayed due to supply delays
- Performance and durability tests of 5 kW stack (2022). Test protocols have been defined
- Experimental validation of the interest in the different routes of the project to increase performance and durability. This is ongoing. Life Cycle Analysis will also be taken into consideration for the evaluation.



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 FOR SOA TARGET
AWP 2018	Weight-specific power density	kW/kg	4	N/A	✘	3.4	2017 by Auto-Stack Core
	Volume-specific power density	kW/l	5				
	Surface power density	W/cm ²	2	1.3		1.13	
	Durability	Hours	6 000	N/A		3 500	
	Stack cost	€/kW	20			36.8	

Project ID:	735606
Call topic:	FCH-01-1-2016 - Manufacturing technologies for PEMFC stack components and stacks
Project total costs:	€2 999 185
FCH JU max. Contribution:	€2 999 185
Project start - end:	01/03/2017 - 29/11/2020
Coordinator:	UNIRESEARCH BV, NL
Website:	www.fit-4-amanda.eu

BENEFICIARIES: UPS EUROPE SA, AUMANN LIMBACH-OBERFROHNA GMBH, PROTON MOTOR FUEL CELL GMBH, IRD FUEL CELLS A/S, TECHNISCHE UNIVERSITÄT CHEMNITZ, FRAUNHOFER GESELLSCHAFT ZUR FÖRDERUNG DER ANGEWANDTEN FORSCHUNG EV



PROJECT AND OBJECTIVES

The main target of the project was to industrialise stack production by building a global new and unique machine that allows the serial production of the centrepiece of the fuel cell system: the stack. The project is officially finished and the machine completed and delivered, but final tests and data have been delayed and are still ongoing due to technical issues and the COVID-19 pandemic.

- Design and development of an automated processing unit/system for the manufacturing of key/critical stack components, i.e. MEAs.

FUTURE STEPS AND PLANS

Finalisation of field tests which have already been planned between the PM and end users.



NON-QUANTITATIVE OBJECTIVES

- Feasibility study of commercial FC electrical vehicle that produces a summary of the conditions under which the fuel cell technology, especially the newly created stack, fits into an LCV from UPS
- Performance requirements are elaborated from the vehicle. Consolidate the technical requirements in detail for standard FC operation and need for special demands and find ways to integrate seamlessly to reduce costs.

PROGRESS AND MAIN ACHIEVEMENTS

- Development, manufacturing and testing of technology and machine system for the automatic assembly of PEMFC stacks
- Validation of designs, hardware, tools and software for the automated production of MEAs and automated stack assembly



QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	PARAMETER	UNIT	TARGET	TARGET ACHIEVED?
Project's own objectives	Production time for one stack (throughput time)	Hours	<0.5	✓
	Automated production process steps	%	90	✓
	Specific FC system cost	€/kW	100	✗

Project ID: 779576

Call topic: FCH-01-1-2017 - Development of fuel cell system technologies for achieving competitive solutions for aeronautical applications

Project total costs: €7 354 868.75

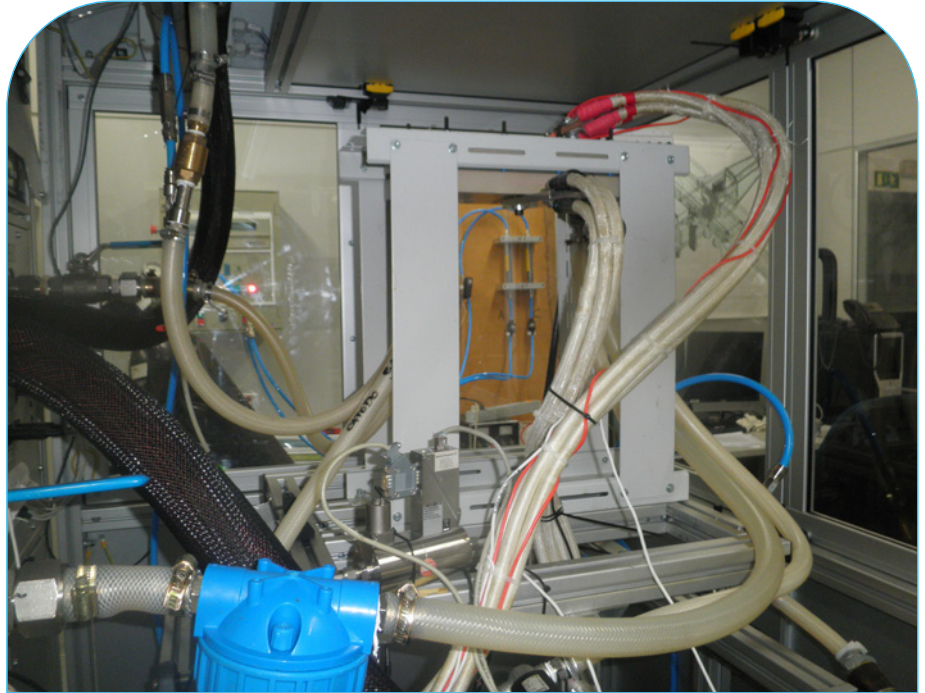
FCH JU max. Contribution: €5 063 023

Project start - end: 01/01/2018 - 30/09/2022

Coordinator: SAFRAN POWER UNITS, FR

Website: www.flhysafe.eu

Beneficiaries: COMMISSARIAT A L'ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES, DEUTSCHES ZENTRUM FUER LUFT- UND RAUMFAHRT EV, UNIVERSITAET ULM, ARTTIC, INSTITUTO NACIONAL DE TECNICA AEROESPACIAL ESTEBAN TERRADAS, SAFRAN AEROTECHNICS



PROJECT AND OBJECTIVES

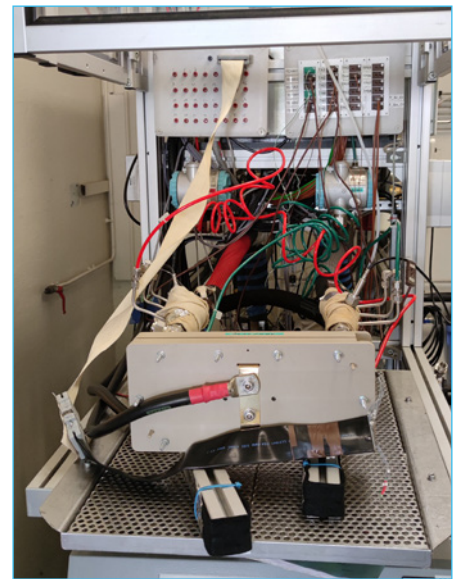
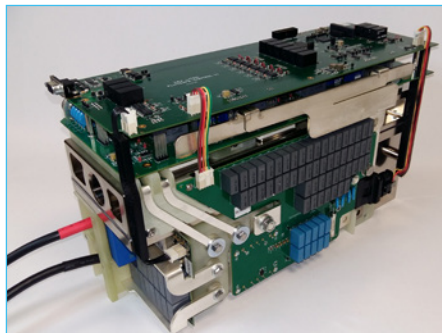
In the trend towards 'More Electric Aircraft' (MEA), fuel cell systems are considered one of the best options for efficient power generation. The main objective of FLHYSAFE is to demonstrate that a cost-efficient modular fuel cell system can replace the most critical safety systems and be used as an Emergency Power Unit aboard a commercial airplane and provide enhanced safety functionalities. Also, the project aims to virtually demonstrate that the system can be integrated, respecting both installation volumes and maintenance constraints, by using current aircraft designs.

PROGRESS AND MAIN ACHIEVEMENTS

- Emergency Power Unit system specification, functional analysis and system architecture (P&ID drawing)
- Short stack test campaigns (durability, start/stop study, oxidant)
- Integrated power converter design and manufacturing.

FUTURE STEPS AND PLANS

- FCS-a design, assembly and testing. Assembly is scheduled for S1 2021 and testing for S2 2021
- FCS-b design, assembly and testing. Design and assembly are scheduled for 2021 and testing for 2022.



QUANTITATIVE TARGETS AND STATUS

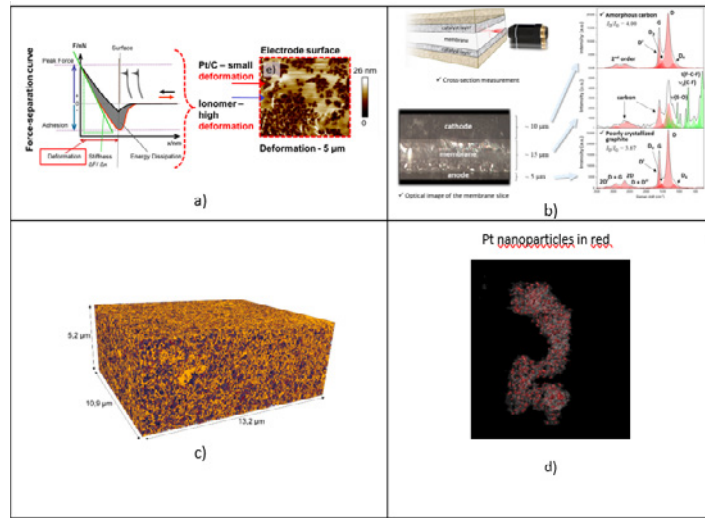
TARGET SOURCE	PARAMETER	UNIT	TARGET	TARGET ACHIEVED?
Project's own objectives	Weight (taking into account thermal management, electrical and power management but excluding hydrogen storage)	kg	150	✘
	Power density	W/kg	100	
	Volume	l	200	
	Efficiency at rated power	%	40	



FURTHER-FC

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

Project ID:	875025
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:	€2 735 031.25
FCH JU max. Contribution:	€2 199 567.35
Project start - end:	01/01/2020 - 29/02/2024
Coordinator:	COMMISSARIAT A L'ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES, FR
Website:	further-fc.eu/



BENEFICIARIES: CHEMOURS FRANCE SAS, THE CHEMOURS COMPANY FC, LLC, UNIVERSITE DE MONTPELLIER, HOCHSCHULE ESSLINGEN, TOYOTA MOTOR EUROPE NV, ECOLE NATIONALE SUPERIEURE DE CHIMIE DE MONTPELLIER, UNIVERSITY OF CALGARY, INSTITUT NATIONAL POLYTECHNIQUE DE TOULOUSE, DEUTSCHES ZENTRUM FUR LUFT- UND RAUMFAHRT EV, IMPERIAL COLLEGE OF SCIENCE TECHNOLOGY AND MEDICINE, PAUL SCHERRER INSTITUT, CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS

PROJECT AND OBJECTIVES

FURTHER-FC proposes complete experimental and modelling coupled platforms to better understand the performance limitations in the cathode catalyst layers (CCL) of low Pt loaded PEMFC. The concept starts with the design and manufacturing of customised CCL, which are to be intensively studied with the platforms to analyse their performance based on the knowledge of their structure and component distribution. Based on this, CCL improvements will be discussed and tested. So far, the first CCL have been produced and characterisation and modelling tools are currently being set up, improved, validated and applied.

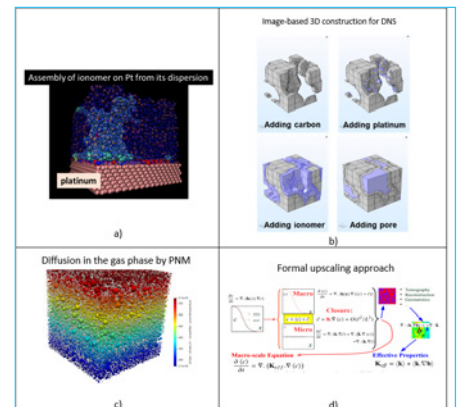
PROGRESS AND MAIN ACHIEVEMENTS

- Progress on the characterisation of catalyst layers by AFM, Raman and 3D FIB-SEM
- Progress on the modelling of catalyst layers, especially by direct numerical modelling

- Definition and validation of test protocols and differential cell hardware as a common basis between the partners.

FUTURE STEPS AND PLANS

- Characterise reference and customised CCL. Work has started on the reference and needs to be completed; work on the customised CCL has yet to be done
- Model transport mechanisms from the ionomer film to the single cell. Models are progressing, with first results from MD and DNS, and need to be completed. Inputs from in-operando experiments on the characterisations and validation are used as and when available.

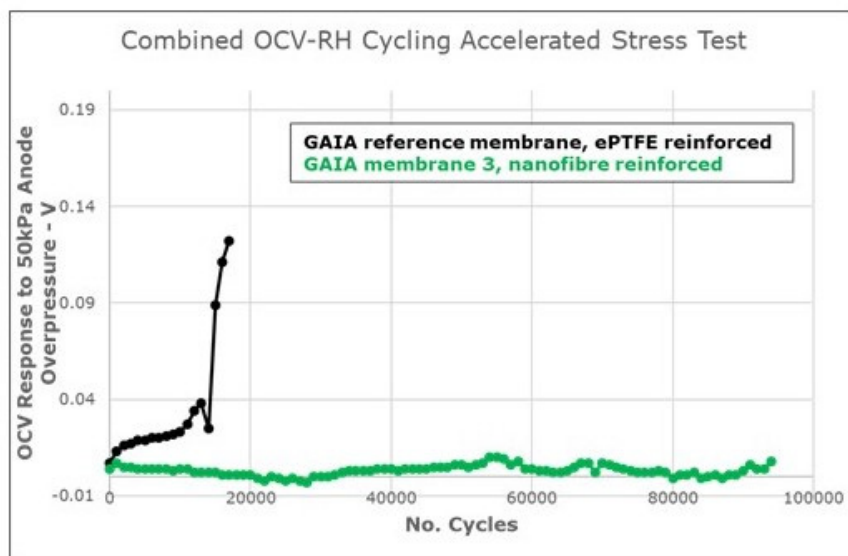


QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	PARAMETER	UNIT	TARGET	TARGET ACHIEVED?	SOA RESULT ACHIEVED TO DATE (BY OTHERS)	YEAR FOR SOA TARGET
MAWP (2014-2020)	Volumetric power density	kW/l	9.3	✂	4.1	2017 by Auto-Stack Core
	Weight power density	kW/kg	4		3.4	
	Surface power density	W/cm ²	1.8		1.13	
	Cost	€/kW	20		36.8	
	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	

Project ID:	826097
Call topic:	FCH-01-5-2018 - Next generation automotive MEA development
Project total costs:	€4 493 025
FCH JU max. Contribution:	€4 493 025
Project start - end:	01/01/2019 - 31/12/2021
Coordinator:	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS, FR
Website:	www.gaia-fuelcell.eu

BENEFICIARIES: DYNEON GMBH, UNIVERSITE DE MONTPELLIER, JOHNSON MATTHEY FUEL CELLS LIMITED, PRETEXO, 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



PROJECT AND OBJECTIVES

GAIA aims to develop the next generation of automotive MEAs, delivering 1.8 W/cm² at 0.6 V. The project intends to validate MEA performance and durability in full size cell short stacks, demonstrate the possibility of 6 000 hours lifetime, and provide a cost assessment that establishes that MEAs can achieve the cost target of 6 €/kW for a production rate of 1 million m²/year. Currently at M27, GAIA has validated its stack hardware and testing protocols, developed new carbon, catalyst, ionomer, membrane, gas diffusion and microporous layer components, and reached its first three milestones.

NON-QUANTITATIVE OBJECTIVES

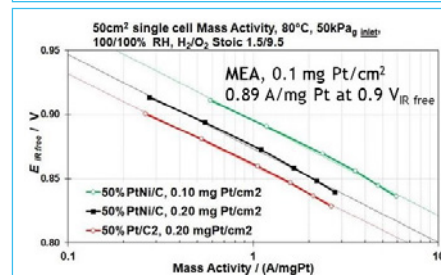
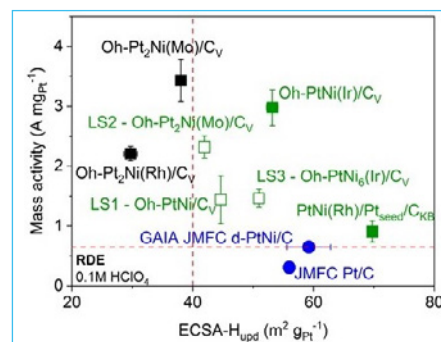
Outreach. Video on catalyst preparation and characterisation by RDE and catalyst integration into MEAs and testing/diagnostics, prepared by TUB and TUM (>1 460 views).

PROGRESS AND MAIN ACHIEVEMENTS

- Achieved 0.89 A/mg Pt in a 50 cm² fuel cell, 0.10 mg Pt/cm², giving 0.16 g Pt/kW, essentially reaching the project target
- Achieved 100 000 AST cycles (90 °C, OCV, wet/dry cycling) without failure with an MEA comprising an electrospun reinforced membrane, 5x target
- Generation 2 MEA provided improved performance in a short stack at all operation points, and improved stability at 105 °C compared with generation 1.

FUTURE STEPS AND PLANS

- Short stack testing with components specifically designed for performance to reach the performance target. CCMs prepared for delivery
- Short stack testing with components specifically designed for durability to reach the durability target. Planned for M29
- Implement new CCM coating methods. Benefit demonstrated in single cell testing
- Integrate most effective components in a short stack to achieve both performance and durability targets
- Cost analysis.



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 FOR SOA TARGET
AWP 2019	Power density at 0.6 V	W/cm ²	1.8	1.86	✓	No public data at 3 A/cm ² under call conditions	N/A
	Durability (voltage decay rate)	%	<10 % after 6 000 hours operation	<3 % after 2 500 hours automotive drive cycle testing		10 % after 500 hours automotive drive cycle testing	2019
	MEA cost	€/kW	6	Cost evaluation for later in year 3. Target production rate for membrane reinforcement contributes to reaching cost target	✗	13	2017

Project ID:	700101
Call topic:	FCH-01.2-2015 - Diagnostics and control for increased fuel cell system lifetime in automotive applications
PRD 2020 Panel:	2 - Next Generation of Products - Transport
Project total costs:	€3 260 297.50
FCH JU max. contribution:	€3 260 297.50
Project start - end:	01/05/2016 - 31/10/2019
Coordinator:	SINTEF AS, NO
Website:	www.giantleap.eu



BENEFICIARIES: VDL ENABLING TRANSPORT SOLUTIONS BV, VDL BUS CHASSIS BV, VDL BUS ROESELARE, VDL BUS & COACH BV, INSTITUT FRANCAIS DES SCIENCES ET TECHNOLOGIES DES TRANSPORTS, DE L'AMENAGEMENT ET DES RESEAUX, ELRINGKLINGER AG, ECOLE NATIONALE SUPERIEURE DE MECANIQUE ET DES MICROTECHNIQUES, BOSCH ENGINEERING GMBH, SVEUCILISTE U SPLITU, FAKULTET ELEKTROTEHNIKE, STROJARSTVA I BRODOGRADNJE, UNIVERSITE DE FRANCHE-COMTE, STIFTELSEN SINTEF

PROJECT AND OBJECTIVES

The project aimed to increase the reliability and availability of fuel cell buses, which was achieved with definition of diagnostic and prognostic algorithms, for both the stack and several balance-of-plant components, and a range-extender design with a system mounted on a trailer. Data on long-term tests has been published on public repositories. The project has been completed and an evolution of the prototype is currently in regular operation in the Netherlands.

PROGRESS AND MAIN ACHIEVEMENTS

- Published extensive data sets for fuel cell and BoP component testing
- Implemented and tested multiple diagnostic and prognostic algorithms
- Demonstrated the operation of a hydrogen range extender for battery-powered buses, now in regular operation.

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)	YEAR FOR SOA TARGET
Project's own objectives	Stack lifetime	Hours	12 000	15 200	✓	30 000	2020
MAWP 2014-2020	FC bus cost	€	650 000	540 000	✓	N/A	N/A
	Fuel consumption	kgH ₂ /100 km	8	7			



H2REF

DEVELOPMENT OF A COST EFFECTIVE AND RELIABLE HYDROGEN FUEL CELL VEHICLE REFUELLING SYSTEM

Project ID:	671463
Call topic:	FCH-01.5-2014 - Development of cost effective and reliable hydrogen refuelling station components and systems for fuel cell vehicles
PRD 2020 Panel:	2 - Next Generation of Products - Transport
Project total costs:	€7 127 941.25
FCH JU max. contribution:	€5 968 554
Project start - end:	01/09/2015- 31/12/2019
Coordinator:	CENTRE TECHNIQUE DES INDUSTRIES MECANIKES, FR
Website:	www.h2ref.eu



BENEFICIARIES: UNIVERSITE DE TECHNOLOGIE DE COMPIEGNE, LUDWIG-BOELKOW-SYSTEMTECHNIK GMBH, THE CCS GLOBAL GROUP LIMITED, HEXAGON RAUFOSS AS, H2NOVA, HASKEL FRANCE, HASKEL EUROPE LTD

PROJECT AND OBJECTIVES

The H2REF project, completed in 2019, addressed hydrogen compression and buffering for the refuelling of fuel cell electric light-duty vehicles. It encompassed the activities for advancing a novel cost-effective and reliable hydraulics-based compression and buffering system from TRL3 to 5.

The overall goal was to demonstrate a bladder accumulator technology applied to hydrogen refuelling, providing significant performance levels as currently achieved with existing solutions for 70 MPa refuelling at a significantly lower cost, and establish the knowledge base required for taking this innovation to the market.

NON-QUANTITATIVE OBJECTIVES

- Techno-economic analysis based on project result
- Completed cost comparison of CBM with benchmark
- Have the technology covered by the RCS framework
- CEN TC 54 has agreed to cover accumulators in composite materials and is developing a plan on how to proceed.

PROGRESS AND MAIN ACHIEVEMENTS

- CBM process developed, full-scale prototype system built, and 70 MPa hydrogen dispensing cycle successfully operated and evaluated (including H₂ purity)
- Suitable bladder material identified and accumulator developed and qualified for functional and endurance testing in CBM
- New hydrogen test area set up on Haskel's premises.

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?	COMMENTS
Project's own objectives	TRL	N/A	6	5	✂	N/A
	Unit cost	k€	300	440		For 50 units
	Capacity	kg/hour	30	15.9		With 75 kW motor, from 7 MPa
	Consumption	kWh/kg	1.5	5.1		Sources of energy losses identified



HEAVEN

HIGH POWER DENSITY FC SYSTEM FOR AERIAL PASSENGER VEHICLE FUELED BY LIQUID HYDROGEN

Project ID:	826247
Call topic:	FCH-01-4-2018 - Fuel cell systems for the propulsion of aerial passenger vehicle
Project total costs:	€4 600 881.68
FCH JU max. Contribution:	€3 995 305
Project start - end:	01/01/2019 - 31/12/2022
Coordinator:	FUNDACION AYESA, ES
Website:	heaven-fch-project.eu/

BENEFICIARIES: PIPISTREL VERTICAL SOLUTIONS DOO PODJETJE ZA NAPREDNE LETALSKE RESITVE, HZFLY GMBH, AIR LIQUIDE ADVANCED TECHNOLOGIES SA, ELRINGKLINGER AG, AIR LIQUIDE SA, DEUTSCHES ZENTRUM FUER LUFT- UND RAUMFAHRT EV



PROJECT AND OBJECTIVES

HEAVEN's goal is to design, develop and integrate the first global aircraft powertrain based on a high-power-density FC system and high energy density liquid hydrogen fuel system into an existing 2- to 4- seater aircraft for testing in-flight operation. HEAVEN will focus on demonstrating the airworthiness and economic viability of an FC and cryogenic hydrogen-based solution for the propulsion of passenger aircraft. In addition, HEAVEN will provide reliability figures for future certification and relevant data for the development of a zero-emission hydrogen-powered aircraft.

NON-QUANTITATIVE OBJECTIVES

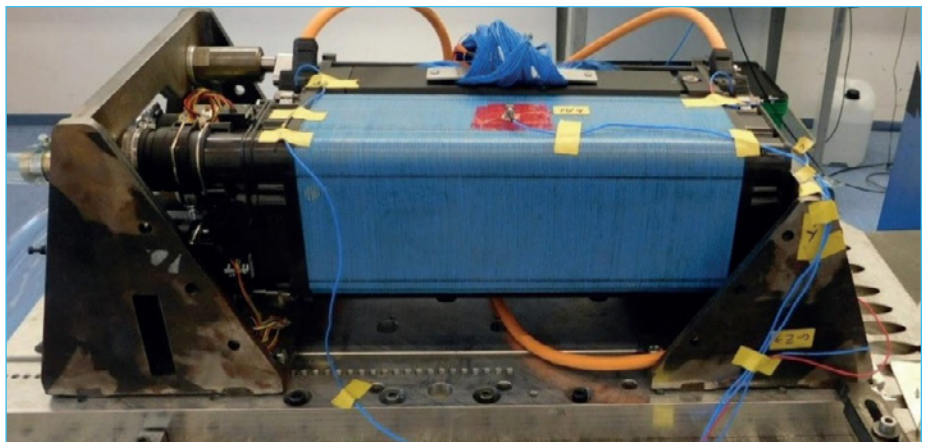
- Increase the credibility of the solution for the propulsion of passenger aircraft and UAVs
- Advance towards zero-emission hydrogen-powered regional commuter airliner.

PROGRESS AND MAIN ACHIEVEMENTS

- Conceptual design of the overall powertrain
- Full stack test system has been fully integrated in the test bench
- Aircraft safety studies are ongoing.

FUTURE STEPS AND PLANS

- Qualification and delivery: 2021-2022
- Ground/Flight tests: 2022-2023



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 incl. end plates)	✘
	FC power density in volume	kW/l	3.5 kW/l	4.1 kW/l (stack incl. end plates)	
	Air subsystem	%	> 50 %	Preliminary results in compliance with this value but not achieved yet	
	Power converter	kW/kg	8 kW/kg	Preliminary results in compliance with this value but not achieved yet	
	System lifetime	Hours	500 (stack)	N/A	

→ IN LINE →

INLINE DESIGN OF A FLEXIBLE, SCALABLE, HIGH-QUALITY PRODUCTION LINE FOR PEMFC MANUFACTURING

Project ID:	735367
Call topic:	FCH-01-3-2016 - PEMFC system manufacturing technologies and quality assurance
PRD 2020 Panel:	2 - Next Generation of Products - Transport
Project total costs:	€3 286 068.75
FCH JU max. contribution:	€3 286 068.75
Project start - end:	01/02/2017 - 31/01/2020
Coordinator:	PROFACTOR GMBH, AT
Website:	www.inline-project.eu



BENEFICIARIES: ELRINGKLINGER AG, FRONIUS INTERNATIONAL GMBH, KARLSRUHER INSTITUT FUER TECHNOLOGIE, OMB SALERI SPA

PROJECT AND OBJECTIVES

The project INLINE aimed to design a flexible, scalable, high-quality production line for PEMFC manufacturing. The three objectives were:

- redesign the media supply unit
- develop automated quality inspection methods to improve the end-of-line test
- ensure the scalability of the manufacturing process.

The project finished in January 2020. The final demonstration, including demonstration 3, was held in November 2019.

NON-QUANTITATIVE OBJECTIVES

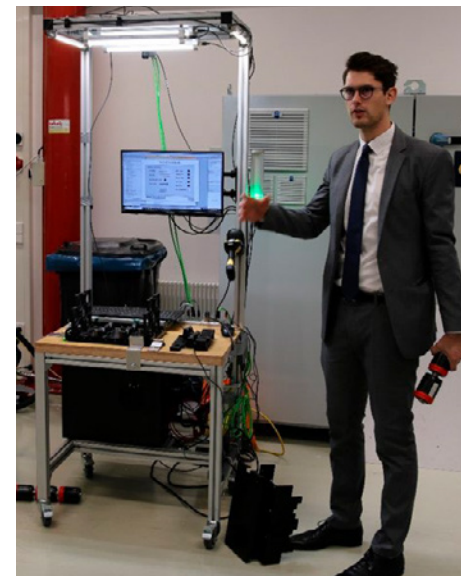
- Smart camera system
- The system enhances workers' safety in preventing short-circuits during mounting of the batteries in the accu pack
- Assisted assembly system
- The projection-based assembly instructions shorten workers' training time
- Semi-automated end-of-line test
- The built chamber and installed semi-automation provides a safety enhancement for the worker who executes the end-of-line test.

PROGRESS AND MAIN ACHIEVEMENTS

- Redesigned and integrated media supply unit
- Simulation of the full manufacturing process, including the newly developed systems and components, evaluated under different scenarios
- Final demonstrations of assisted assembly station and quality control sensors (endoscope sensor, smart camera sensor).

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?
Project's own objectives	Smart camera: detection rate	%	99	99	✓
	Simulation model: scalability factor		100	100	
	Endoscope sensor: detection rate				
	Screwing time	seconds	5	5	

Project ID: 735969

Call topic: FCH-01-4-2016 - Development of Industrialization-ready PEMFC systems and system components

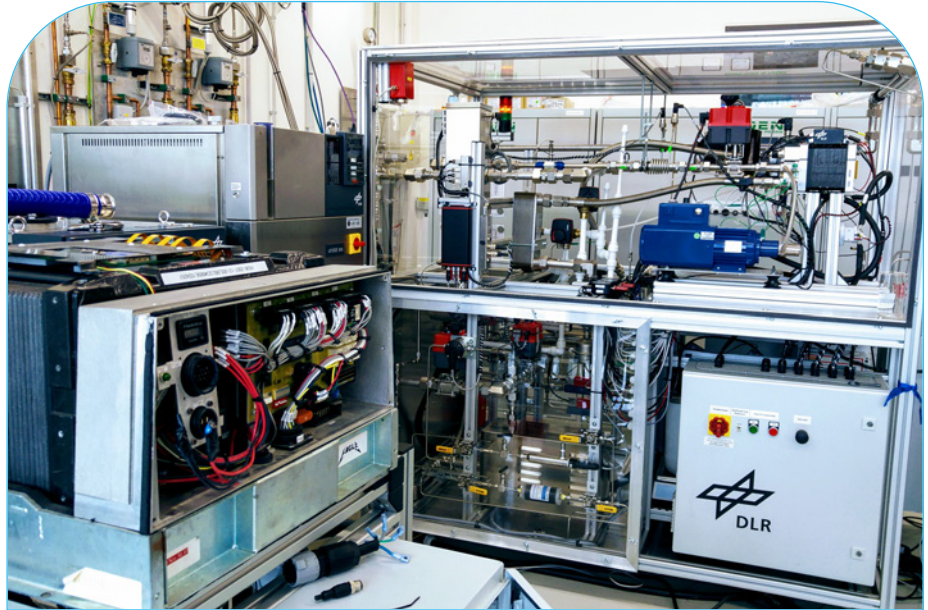
Project total costs: €6 156 288.75

FCH JU max. Contribution: €4 994 538.75

Project start - end: 01/01/2017 - 31/01/2021

Coordinator: FUNDACION AYESA, ES

Website: www.innbalance-fch-project.eu



BENEFICIARIES: DEUTSCHES ZENTRUM FUER LUFT-UND RAUMFAHRT EV, UNIVERSITAT POLITECNICA DE CATALUNYA, AVL LIST GMBH, VOLVO PERSONVAGNAR AB, STEINBEIS INNOVATION GGMBH, POWERCELL SWEDEN AB, CELEROTON AG, BROSE FAHRZEUGTEILE GMBH & CO. KOMMANDITGESELLSCHAFT WURZBURG, STEINBEIS 2I GMBH, CHINA-EURO VEHICLE TECHNOLOGY AKTIEBOLAG

PROJECT AND OBJECTIVES

The project aims to commercialise H₂-based electric vehicles by improving the efficiency and cost-effectiveness of automotive FC. INN-BALANCE integrates the latest trends in FC vehicle technology into the development of: a new air turbo compressor; combined H₂ injection and recirculation; advanced control and diagnosis devices; and a new concept of thermal management. These will add up to an innovative FCS and greatly improve the cost, efficiency and reliability of FC-powered vehicles. Overall, the achievements of INN-BALANCE in improving FC will benefit climate protection and energy security.

hydrogen system. Results will be made available to the general public

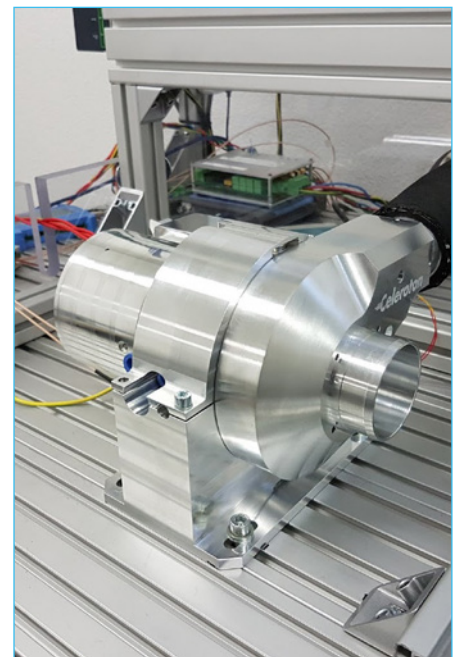
- Integrate the different hardware and software modules. Some adaptations are required to ensure the interoperability of the different components
- Vehicle testing and project findings will be presented at the final conference that will take place towards the end of project in autumn 2021. This event will be public and further information will be communicated on our social media channels and project webpage in the coming months.

PROGRESS AND MAIN ACHIEVEMENTS

- Tests of the INN-BALANCE modules at component level
- Commissioning and system-level tests in a PowerCell fuel cell test bed are currently being performed.

FUTURE STEPS AND PLANS

- A study on the improvement of manufacturing processes and cost reductions will be performed. An analysis will be carried out to see how the cost of single components affects the total cost of the



QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	PARAMETER	UNIT	TARGET	TARGET ACHIEVED?	SOA RESULT ACHIEVED TO DATE (BY OTHERS)	YEAR FOR SOA TARGET
Project's own objectives	Cold start	°C	-40	✘	-30	2015 (Toyota), 2019 (Hyundai)
	Peak energy efficiency*	%	85		60	2010
	Durability in automotive drive cycle	Hours	6 000		3 900	2015

*Ratio of DC output energy to the lower heating value of the input fuel (hydrogen). Peak efficiency occurs at less than 25 % rated power

Project ID: 700127

Call topic: FCH-01.1-2015 - Low cost and durable PEMFCs for transport applications

PRD 2020 Panel: 2 - Next Generation of Products - Transport

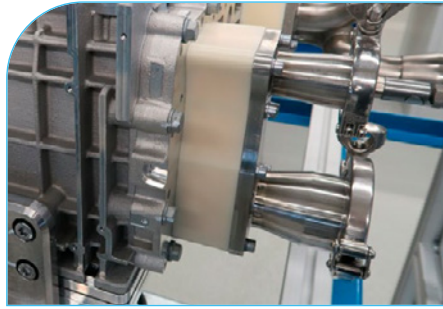
Project total costs: €6 878 070.01

FCH JU max. contribution: €6 877 869.75

Project start - end: 01/05/2016 - 31/10/2019

Coordinator: JOHNSON MATTHEY PLC, UK

Website: www.inspire-fuelcell.eu/



BENEFICIARIES: CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS, TECHNISCHE UNIVERSITAT BERLIN, TECHNISCHE UNIVERSITAT MUENCHEN, REINZ-DICHTUNGS GMBH, ALBERT-LUDWIGS-UNIVERSITAT FREIBURG, SGL CARBON GMBH, BAYERISCHE MOTOREN WERKE AKTIENGESELLSCHAFT, PRETEXO, JOHNSON MATTHEY FUEL CELLS LIMITED, UNIVERSITE DE MONTPELLIER, TEKNOLOGIAN TUTKIMUSKESKUS VTT OY

PROJECT AND OBJECTIVES

The objectives of INSPIRE were to develop and integrate the most advanced MEA components (electrocatalysts, membranes, GDLs and bipolar plates) into three generations of automotive stacks. The project developed and validated its third and final generation stack in 2019. The project met all its technical targets (including world-leading power and volumetric densities of 1.5 W/cm² and 4.8 kW/l respectively, and predicted durability >6 000 hours with <10% power degradation), and was within 10% of its cost target (below 50 €/kW for an annual production rate of 50 000 units).

NON-QUANTITATIVE OBJECTIVES

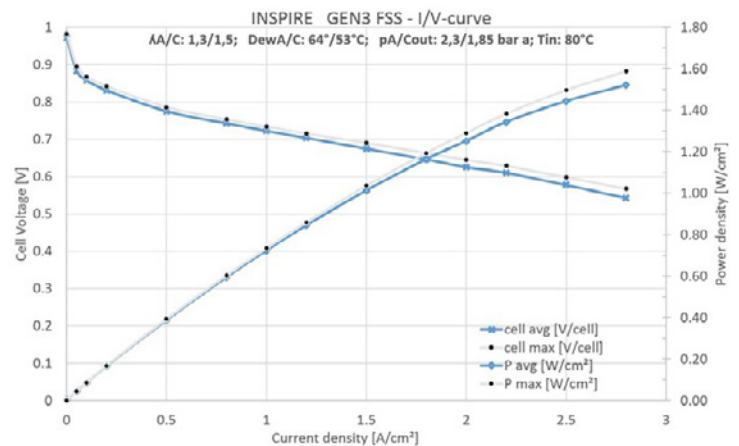
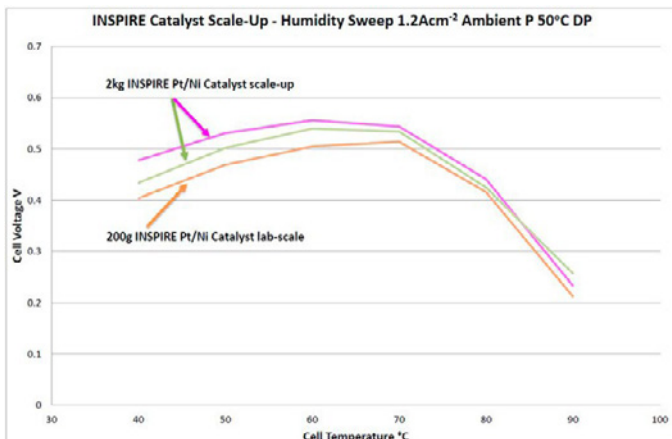
- Scale-up best performing catalyst for stack MEAs
- New catalysts met the project performance and durability targets and were scaled up for MEA optimisation and testing
- Develop two new generations of BPP for automotive stacks
- Final generation BPP and stack validated and still undergoing full durability assessment
- Dissemination of project results
- INSPIRE workshop held in 2019, bringing together several FCH JU H2020 projects focused on PEM fuel cell components.

PROGRESS AND MAIN ACHIEVEMENTS

- Areal power density of 1.5 W/cm²
- Cell volumetric power density of 4.8 kW/l
- Predicted durability of >6 000 hrs.

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)	YEAR FOR SOA TARGET
AWP 2015	Areal power density	W/cm ²	1.5	1.5	✓	1.3 (50 cm ² cell, 250 kPaabs, outlet, 94 °C, 65% RH)	2018
Project's own objectives	Catalyst	A/mg	0.6	0.6		0.6 (GM)	2016
MAWP 2014-2020	Performance loss over 6 000 hrs	%	10	10		5 605 hrs (NREL)	2015



MARANDA

MARINE APPLICATION OF A NEW FUEL CELL POWERTRAIN VALIDATED IN DEMANDING ARCTIC CONDITIONS

Project ID:	735717
Call topic:	FCH-01-5-2016 - Develop new complementary technologies for achieving competitive solutions for marine applications
Project total costs:	€3 704 757.5
FCH JU max. Contribution:	€2 939 457.5
Project start - end:	01/03/2017 - 28/02/2021
Coordinator:	TEKNOLOGIAN TUTKIMUSKESKUS VTT OY, FI projectsites.vtt.fi/sites/maranda/
Website:	

BENEFICIARIES: SWISS HYDROGEN SA, PERSEE, OMB SALERI SPA, POWERCELL SWEDEN AB, ABB OY, SUOMEN YMPARISTOKESKUS



PROJECT AND OBJECTIVES

The MARANDA project is developing an emission-free hydrogen-fuelled PEMFC-based hybrid powertrain system (3 x 82.5 kW AC) for marine applications. The system will be validated through both test bench experiments and on board the research vessel Aranda, including full-scale freeze start testing of the system. The project will increase the market potential of hydrogen fuel cells in the marine sector. General business cases for different actors in the marine and harbour or fuel cell business will be created. The project is currently in the system integration phase and the validation phase is being prepared.

NON-QUANTITATIVE OBJECTIVES

- The impact related to the development of RCS. MARANDA project has already made a significant contribution to the development of RCS
- Fuel cell systems should be able to withstand the shocks, vibrations, saline environment and ship motions commonly encountered on water as well as other requirements for marine application. FC system and hydrogen storage are designed to withstand these conditions

- Evaluation of the economic and environmental impact for a prospective customer. Report analysing the business aspects of hydrogen fuel cells for marine applications has been prepared
- The formulation of an initial go-to-market strategy. Report on the business analysis includes this
- Mapping opportunities for future demonstration actions. The work will be done in the final project year.

PROGRESS AND MAIN ACHIEVEMENTS

- Three FCS systems from Swiss Hydrogen have been assembled and all of them have been delivered to VTT for final integration
- The operation of the first FCS system was started (23 December 2021) and the first electricity was fed to the electricity grid
- Significant improvements in stack durability have been demonstrated by PowerCell Sweden.

FUTURE STEPS AND PLANS

- Restart of the first FC system operation at the durability test site (M49, March 2021). Before the restart, the safety analysis and education need to be completed
- Acceptance by the Finnish Transport Safety Agency (Trafi) of the installation of the FC system and hydrogen storage on Aranda (M51, May 2021). Final installations and the preparation of documents are ongoing
- Field trial started with target vessel (M52, June 2020)
- First FC system testing to be completed.
- Field trial with target vessel to be completed.



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	82.5	✓
	Freeze start capability	°C	-35	N/A	✗
	Stack durability	mV/1 000h	4.6	1.7	✓
	Fuel-to-electricity efficiency (AC)	%	42	45	✓

Project ID: 779550

Call topic: FCH-01-2-2017 - Towards next generation of PEMFC: Non-PGM catalysts

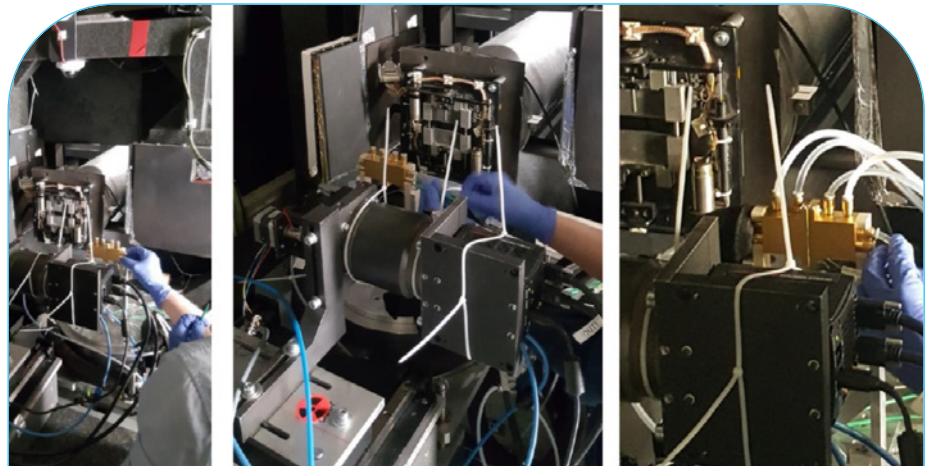
Project total costs: €2 829 016.88

FCH JU max. Contribution: €2 829 016.88

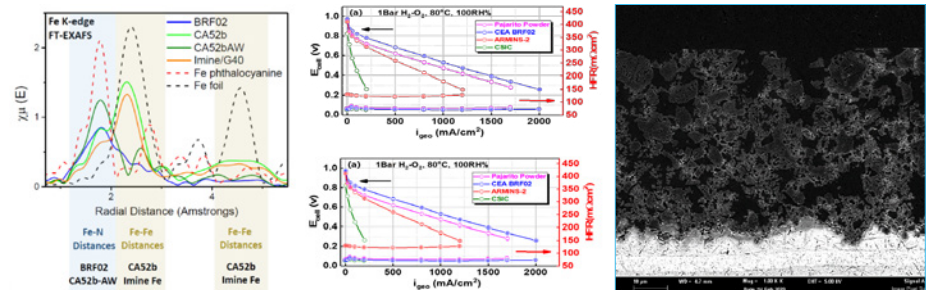
Project start - end: 01/02/2018 - 31/06/2021

Coordinator: COMMISSARIAT A L'ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES, FR

Website: www.pegasus-pemfc.eu/



BENEFICIARIES: AGENCIA ESTATAL CONSEJO SUPERIOR DE INVESTIGACIONES CIENTIFICAS, DEUTSCHES ZENTRUM FUER LUFT- UND RAUMFAHRT EV, ASSOCIATION POUR LA RECHERCHE ET LE DEVELOPPEMENT DES METHODES ET PROCESSUS INDUSTRIELS, TECHNISCHE UNIVERSITAET MUENCHEN, ECOLE NATIONALE SUPERIEURE DES MINES DE PARIS, IRD FUEL CELLS A/S, TOYOTA MOTOR EUROPE NV, HERAEUS FUEL CELLS GMBH



PROJECT AND OBJECTIVES

PEGASUS is exploring a promising route towards the removal of Pt and other critical raw materials (CRM) from PEMFC and their replacements by non-critical elements. The overall goal of this project is to demonstrate the experimental proof of concept for novel catalyst material structure for the oxygen reduction reaction (ORR). Today the project reports ORR activity for the developed PGM-free material at the highest level compared to the international state of the art. Nevertheless, there is still some way to go to be competitive with Pt-based material.

NON-QUANTITATIVE OBJECTIVES

- Studying water management and quantifying the water saturation in PGM-free cathode MEA. This has been achieved. Neutron imaging was performed

on the PEGASUS MEA. The profile of the water distribution in the MEA was determined

- Establishing diagnostic tools to quantify the key properties that govern transport losses in a PGM-free cathode. This was achieved, with ex situ quantification of electronic resistivity, in situ quantification of effective proton and O₂ resistance
- Quantifying and qualifying the nature of the active site. This was achieved through XEFAS experiments (X-ray) and pulse CO chemisorption/temperature programmed desorption experiments.

PROGRESS AND MAIN ACHIEVEMENTS

- The best catalyst synthesised in the project is twice as active under air as the commercial reference. It has been prepared in multigram batches

- A catalyst showing ORR activity equivalent to that of the commercial reference has been made using a preparation route which requires just a few steps
- Studies of the water management in MEA integrating the PEGASUS catalyst were performed through neutron imaging.

FUTURE STEPS AND PLANS

Assessment of the robustness of the PEGASUS materials. A degradation study, including accelerated stress tests, is in progress to assess the robustness of PEGASUS catalysts. Reduction of Pt loading. Development of PGM free catalysts (both for anode and cathode).

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		N/A
	catalyst activity (i geo @ 0.7 V under air)	mA/cm ²	600	50	✘	
	catalyst activity (i geo @ 0.7 V under air)	mA/cm ²	600	280		300
Project's own objectives	MEA performance @ 0.6 V under air	mA/cm ²	highest	420	✓	380
	Electronic resistivity	Ohm.cm	<5	<5		N/A
	Proton resistance	Ohm.cm ²	<0.1	0.14	✘	

Project ID: 779644

Call topic:

FCH-01-3-2017 - Improvement of compressed storage systems in the perspective of high volume automotive application

Project total costs: €3 996 943.75

FCH JU max. Contribution: €3 996 943.75

Project start - end: 01/01/2018 - 30/06/2021

Coordinator: OPTIMUM CPV, BE

Website: tahya.eu/

BENEFICIARIES: VOLKSWAGEN AG, TECHNISCHE UNIVERSITAET CHEMNITZ, BUNDESANSTALT FUER MATERIALFORSCHUNG UND -PRUEFUNG, RAIGI SAS, ANLEG GMBH, POLARIXPARTNER GMBH, ABSISKEY, AK GROUP



PROJECT AND OBJECTIVES

The TAHYA project, mainly led by industrial partners who are already involved in producing and manufacturing hydrogen solutions for the automotive and aviation industry, focuses on the development of a complete, competitive and innovative European H₂ storage system (a cylinder with a mounted on-tank-valve) for automotive applications that outperform the current Asian and US ones.

- Cost-competitive H₂ storage system for mass production
- RCS activities to propose updates to GRT13 and EC79 according to tests results obtained over the duration of the project.

FUTURE STEPS AND PLANS

The project will finish in June 2021. All objectives have been reached.

PROGRESS AND MAIN ACHIEVEMENTS

- Compatible H₂ storage system with high performances, safe and health, safety, environment responsible.



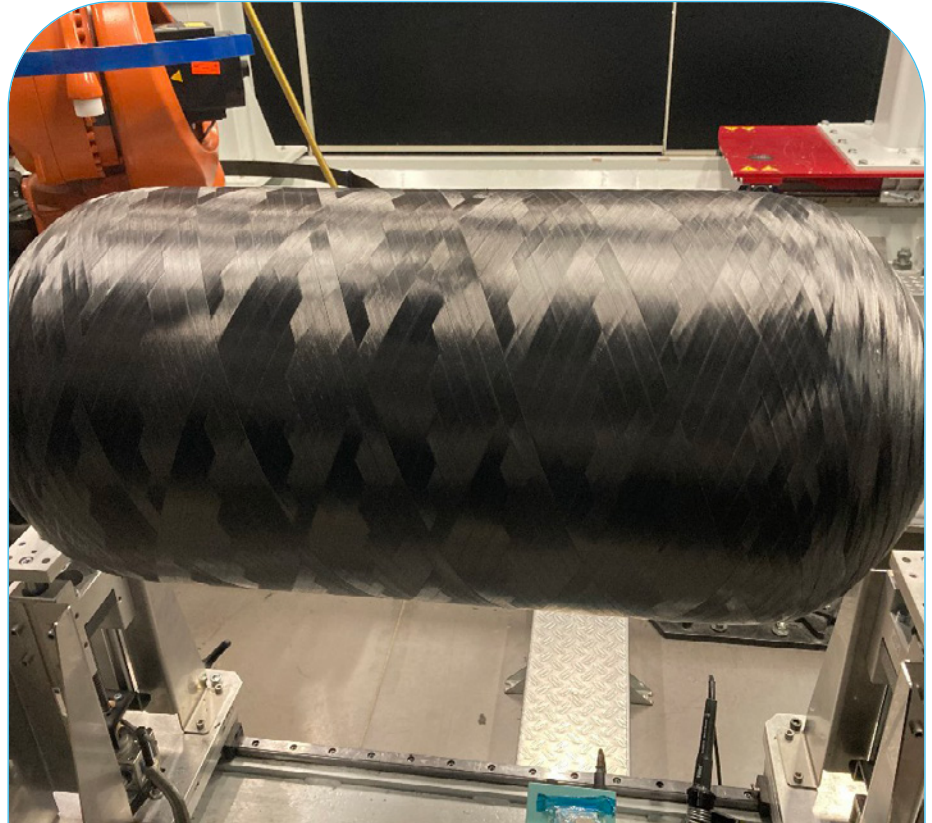


THOR

THERMOPLASTIC HYDROGEN TANKS OPTIMISED AND RECYCLABLE

Project ID:	826262
Call topic:	FCH-01-3-2018 - Strengthening of the European supply chain for compressed storage systems for transport applications
Project total costs:	€2 853 958.75
FCH JU max. Contribution:	€2 853 958.75
Project start - end:	01/01/2019 - 31/12/2021
Coordinator:	FAURECIA SYSTEMES D'ÉCHAPPEMENT SAS, FR
Website:	thor-fch2.eu/

BENEFICIARIES: COVESS NV, CETIM GRAND EST, ECOLE NATIONALE SUPERIEURE DE MECANIQUE ET D'AEROTECHNIQUE, SIRRIS HET COLLECTIEF CENTRUM VAN DE TECHNOLOGISCHE INDUSTRIE, RINA CONSULTING - CENTRO SVILUPPO MATERIALI SPA, UNIVERSITE DE POITIERS, AIR LIQUIDE SA, NORGES TEKNISK-NATURVITENSKAPELIGE UNIVERSITET NTNU, CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS



PROJECT AND OBJECTIVES

The project aims to develop recyclable tanks based on thermoplastic resins. It is studying the best design to improve the performance of the gas storage tank for hydrogen (modelling of the wrapping and correlation with tests to define an optimised tank design). Other goals are the study and definition of the production line and cost calculations, investigating the application of recycling technology for the end of life of carbon-fibre overwrapped pressure vessels and the fire behaviour of the thermoplastic tank.

NON-QUANTITATIVE OBJECTIVES

- Recyclability of the tanks
- 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

- Testing facilities in preparation for:
 - the EC79 test (such as thermal and mechanical tests at extreme temperatures)
 - fire behaviour
- Preparation of the optimised tank design for the first 64 l thermoplastic tank (winding pattern and bosses)
- First tanks have been manufactured. To be used for burst and ASR tests.

FUTURE STEPS AND PLANS

- Validate the type V H2 gas storage tank. Prototypes to be built and tested for modelling correlation
- Optimise design (performance, fire behaviour), with correlated soft, optimisation of the winding pattern and the tank design
- Definition of the production line with respect to the first results to prepare for the prototypes. Manufacturing the line layout.

QUANTITATIVE TARGETS AND STATUS

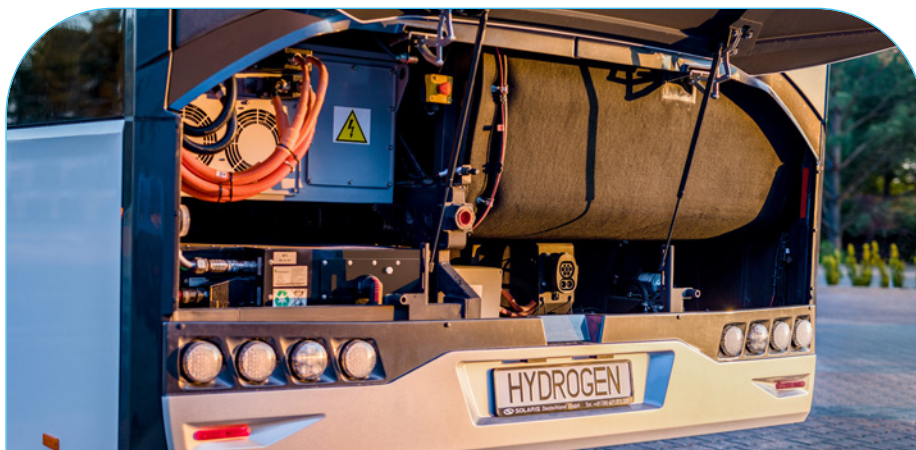
TARGET SOURCE	PARAMETER	UNIT	TARGET	ACHIEVED TO DATE BY THE PROJECT	TARGET ACHIEVED?
MAWP (2014-2020)	Volumetric capacity	kg/l	0.014	0.0141	✓
	Gravimetric capacity	%	5.4	4	✗
	Price	€/kg	400	N/A	✗



VIRTUAL-FCS

VIRTUAL & PHYSICAL PLATFORM FOR FUEL CELL SYSTEM DEVELOPMENT

Project ID:	875087
Call topic:	FCH-01-3-2019 - Cyber-physical platform for hybrid Fuel Cell systems
Project total costs:	€1 897 806.25
FCH JU max. Contribution:	€1 897 806.25
Project start - end:	01/01/2020 - 31/12/2022
Coordinator:	SINTEF AS, NO
Website:	www.sintef.no/projectweb/virtual-fcs/



BENEFICIARIES: BANKE APS, VIVARAIL LTD, COMMUNAUTE D'UNIVERSITES ET ETABLISSEMENTS UNIVERSITE BOURGOGNE - FRANCHE - COMTE, WESTCON POWER AND AUTOMATION AS, BALLARD POWER SYSTEMS EUROPE AS, ECOLE NATIONALE SUPERIEURE DE MECANIQUE ET DES MICROTECHNIQUES, SOLARIS BUS & COACH SPOLKA Z OGRANICZONA ODPOWIEDZIALNOSCIA, UNIVERSITE DE TECHNOLOGIE DE BELFORT - MONTBELIARD, UNIVERSITE DE FRANCHE-COMTE

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 PEM fuel cells and battery hybrid systems. The platform will be entirely open source, allowing everyone in both the industry and research to benefit from and contribute to the future development of the framework.

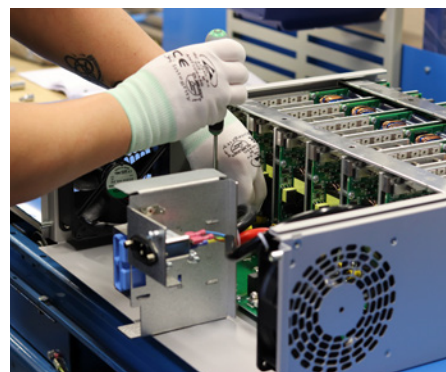
NON-QUANTITATIVE OBJECTIVES

- Improve accuracy of estimates of system lifetime. Improve lifetime by gaining insight into the governing degradation processes and improving EMS. Method: academic publications and used for internal development at partners
- Better a priori understanding of hybridisation strategies and EMS on the performance, reliability and durability, for reference cases representing typical transport industrial applications. Increase efficiencies of existing applications by tailored control strategies to adapt to demanding operating profile. Method: academic publications, advice to end users as part of the strategy, enhanced competitiveness of FC suppliers. Advertise competitiveness of end-user partner's solutions

- SME partners working in the maritime, rail, bus and heavy-duty industry will have better system models and understanding of the benefits of the FC system. There will be interaction with end users' sales strategies and IPR.

PROGRESS AND MAIN ACHIEVEMENTS

- Definition and details of a hybrid system design and parameters to be used for initial platform and model development
- Establish a working model of a fuel cell system to serve as a foundation for the further development and implementation of the Virtual-FCS platform
- A critical review of existing BoP models.



FUTURE STEPS AND PLANS

- First release the code and documentation: soon to be released
- Release of training materials: soon to be released
- Real-time system simulation (the next step) and emulation
- Prognostics model, the main focus in 2022
- Interaction with the physical system hardware, planned for the first half of 2022.



QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	TARGET	TARGET ACHIEVED?
Project's own objectives	10 % reduction in system lifetime costs by better component sizing	✘
	50 % reduction in time for new sizing system	
	25 % reduction in time for EMS development	
	25 % reduction in time for prototyping system	

**PANEL 3
TRIALS AND
DEPLOYMENT
OF FUEL CELL
APPLICATIONS –
ENERGY**



ALKAMMONIA

AMMONIA-FUELLED ALKALINE FUEL CELLS FOR REMOTE POWER APPLICATIONS

Project ID:	325343
Call topic:	SP1-JTI-FCH.2012.3.5 – System-level proof-of-concept for stationary power and CHP fuel cell systems at a representative scale
PRD 2020 Panel:	3 - Trials and Deployment of Fuel Cell Applications - Energy
Project total costs:	€2 884 512.59
FCH JU max. contribution:	€1 962 548
Project start - end:	01/05/2013 - 30/06/2018
Coordinator:	AFC ENERGY PLC, UK
Website:	alkammonia.eu/



BENEFICIARIES: PAUL SCHERRER INSTITUT, UNIVERSITAET DUISBURG-ESSEN, FAST - FEDERAZIONE DELLE ASSOCIAZIONI SCIENTIFICHE E TECNICHE, ACTA SPA, ZENTRUM FUR BRENNSTOFFZELLEN-TECHNIK GMBH, UPS SYSTEMS PLC, FUEL CELL SYSTEMS LTD

PROJECT AND OBJECTIVES

The ALKAMMONIA project has developed, and is testing, a proof-of-concept system focusing on diesel generator displacement opportunities, to provide power in remote areas. The project integrates three innovative and proven technologies: a highly efficient and low-cost alkaline fuel cell system, plus a novel ammonia fuel system consisting of a fuel delivery and cracker system for generation of hydrogen-rich gas. The project formally ended in 2018, but testing continues on the integrated system. The results will be shared with potential end-users.

NON-QUANTITATIVE OBJECTIVES

- Partner ZBT proceeded with the more strict and onerous process of TUV certification for the ammonia cracker
- Long-term testing of the integrated system is still in progress at AFCEN, despite the project formally ending. PSI LCA, total system cost and sustainability analyses have been completed and interim data provided.

PROGRESS AND MAIN ACHIEVEMENTS

- Successful short-term testing of the alkaline fuel cell balance-of-plant and stack
- Successful testing of the ammonia cracker and fuel delivery system
- Successful integration of sub-systems into the ALKAMMONIA system.

FUTURE STEPS AND PLANS

- Project finished
- Longevity testing of the integrated system, funded commercially
- Scale-up of ALKAMMONIA prototype to address EV charging and other diesel generator displacement opportunities.



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 FOR SOA TARGET
Project's own objectives	Cracker efficiency (based on LHV)	%	80	90	✓	N/A	N/A
	AFC stack weight	kg/kW	150	28	✓	200 kg, based on a 5 kWe stack	2013
	Projected cracker costs	€/kW	1 000	2 183	✗	N/A	N/A

Project ID:	735692
Call topic:	FCH-02-4-2016 - Cogeneration of hydrogen and electricity with high-temperature fuel cells (>50 kW)
Project total costs:	€6 868 158.75
FCH JU max. Contribution:	€3 999 896
Project start - end:	01/02/2017 - 31/07/2021
Coordinator:	FONDAZIONE BRUNO KESSLER, IT
Website:	www.ch2p.eu

BENEFICIARIES: DEUTSCHES ZENTRUM FUER LUFT- UND RAUMFAHRT EV, ECOLE POLYTECHNIQUE FEDERALE DE LAUSANNE, SHELL GLOBAL SOLUTIONS INTERNATIONAL BV, HYGEAR BV, HYGEAR Fuel Cell Systems BV, SOLIDPOWER SA, SOLIDPOWER SPA, HYGEAR TECHNOLOGY AND SERVICES BV, HYGEAR OPERATIONS BV



PROJECT AND OBJECTIVES

The CH2P project is developing an innovative technology prototype for HRS. The new system cogenerates hydrogen, heat and electricity using solid oxide cell technology fuelled by carbon-lean natural gas (NG) or biomethane. The CH2P system is a transition technology for an early infrastructure deployment of HRS, operating with higher efficiency, lower costs and reduced environmental footprint compared with conventional technologies. The CH2P system is currently under development.

NON-QUANTITATIVE OBJECTIVES

- Job creation. By contributing to transition technology for the hydrogen economy, CH2P will help create new employment opportunities in the EU
- Alternative fuels station. With one single technology, CH2P will be fed with natural gas or biogas and will deliver hydrogen and power, the

fuels of the European Directive on Alternative Fuels Infrastructure

- Cost model. CH2P will reach hydrogen generation costs far below 4 €/kg of hydrogen
- Use cases. CH2P can generate hydrogen for six different uses.

PROGRESS AND MAIN ACHIEVEMENTS

- The LSM1 was tested and validated at DLR in 2019
- Hydrogen purity. CH2P system produce 5N purity level, compliant with transport sector use, for on-board PEMFC
- Hydrogen cost estimate of 4.5 €/kg with a novel cost model.

FUTURE STEPS AND PLANS

- CH2P has been delayed and an amendment submitted to ask for a 9-month extension, with

the project ending in April 2022. The amendment process is ongoing and will help mitigate delays due to the COVID-19 pandemic and technical challenges

- The full 20 kg H₂/day system, the alpha version, will be tested completely by HyGear by September 2021. The alpha system is close to finalisation and is expected to be shipped from SOLIDpower to HyGear in the coming months
- The second 20 kg H₂/day module will be built with improved components (gamma system), allowing operation in electrolysis mode (not tested in this project). The gamma system should be ready for shipment from SOLIDpower to HyGear in July 2021
- The full 40 kg H₂/day system will integrate the gamma and alpha modules into a modular and flexible prototype. The assembly, planned for November 2021, represents a key milestone for CH2P
- The full system will be tested in a real operating environment.

QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	PARAMETER	UNIT	TARGET	ACHIEVED TO DATE BY THE PROJECT	TARGET ACHIEVED?
AWP 2016	System size	kg H ₂ /day	20	80 %	✘
	Flexible cogeneration of H ₂ and power	%	50 + 50	80 %	✘
	System efficiency	%	65	79	✔

Project ID:	303458
Call topic:	SP1-JTI-FCH.2011.3.6 - Field demonstration of large stationary fuel cell systems for distributed generation and other relevant commercial or industrial applications
Project total costs:	€10 343 142.60
FCH JU max. Contribution:	€4 590 095
Project start - end:	01/05/2012 - 30/09/2020
Coordinator:	BALLARD POWER SYSTEMS EUROPE AS, DK
Website:	www.cleargen.eu



BENEFICIARIES: AQUIPAC SAS, BUDAPESTI MUSZAKI ES GAZDASAGTUDOMANYI EGYETEM, CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS, HYDROGENE DE FRANCE, JEMA ENERGY SA, LINDE GAS MAGYARORSZAG ZARTKORUEN MUKODO RESZVENYTARSASAG, LOGAN ENERGY LIMITED

PROJECT AND OBJECTIVES

The main objectives of the CLEARgen demo project are:

- the development and construction of a large-scale fuel cell system, purpose-built for the European market
- the validation of the technical and economic readiness of the fuel cell system at megawatt scale
- the field demonstration and development of a megawatt-scale system at a European chemical production plant.

The demonstration site was chosen for its ability to provide a strong reference and to convince future operators of the relevance of large-scale stationary fuel cell applications.

PROGRESS AND MAIN ACHIEVEMENTS

- Delivery of a European-compliant ClearGen™ fuel cell system

- Fuel purification system design produced and installed
- Fuel cell system and components installed and ready for operation.

FUTURE STEPS AND PLANS

- Commissioning of PSA was delayed due to coronavirus travel restrictions, which prevented the commissioning team from Xebec, Canada, from travelling
- Commissioning of the fuel cell system was delayed due to coronavirus travel restrictions, which prevented the commissioning team from Ballard, Canada, from travelling
- System operation was delayed
- Monitoring and reporting were delayed.



QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	PARAMETER	UNIT	TARGET	ACHIEVED TO DATE BY THE PROJECT	TARGET ACHIEVED?
AIP 2011	Lifetime (between FC refurbishment)	Hours	40 000	N/A	✘
	Performance loss	%	<3	N/A	✘
	Service and maintenance cost	€ cents/kW	4.5	N/A	✘
Project's own objectives	Electrical efficiency	%	48	50	✔
	Cost	Euro	300 000	300 000	✔
	Availability	%	90-95 %	N/A	✘

Project ID: 779481

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

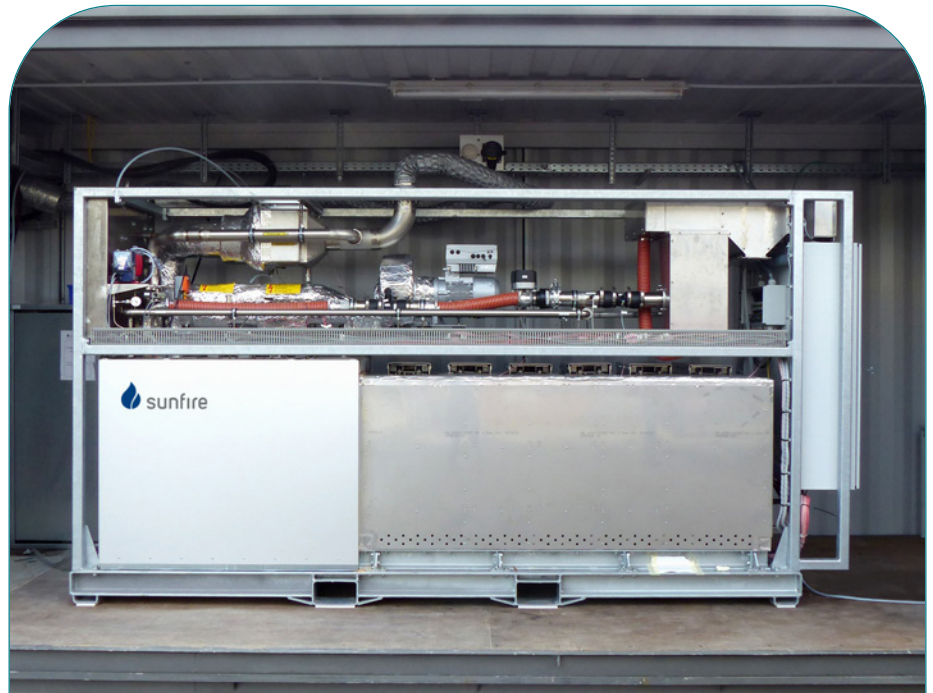
Project total costs: €10 277 897.50

FCH JU max. Contribution: €7 486 954.75

Project start - end: 01/01/2018 - 31/08/2022

Coordinator: TEKNOLOGIAN TUTKIMUSKESKUS VTT OY, FI

Website: www.comsos.eu



BENEFICIARIES: POLITECNICO DI TORINO, SOLIDPOWER SA, SOLIDPOWER SPA, SUNFIRE GMBH, CONVION OY, ENERGY MATTERS BV

PROJECT AND OBJECTIVES

The key objective of the ComSOS project is to validate and demonstrate fuel cell-based combined heat and power (CHP) 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: SOLIDpower, Sunfire and Convion.

PROGRESS AND MAIN ACHIEVEMENTS

- Convion C60 product design has been refined for serial manufacturing
- The design phase of the SOLIDpower BG-60 unit is almost complete
- First Sunfire CHP has been shipped to Taiwan and installed for customer use.

FUTURE STEPS AND PLANS

- Assembly and testing of the beta prototype of the BG-60 unit. FAT test will be finalised in 2021
- Manufacturing of both Convion units and their FAT tests will be done in 2021
- The commissioning and installation of two additional Sunfire units will be done in 2021.



QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	PARAMETER	UNIT	TARGET	ACHIEVED TO DATE BY THE PROJECT	TARGET ACHIEVED?
MAWP Addendum (2018-2020)	SME participation	%	25	50	✓
	NOx emission	mg/kWh	40	<40	
	Electrical efficiency	%	42-55	> 50	

Project ID:	671473
Call topic:	FCH-02.9-2014 -Significant improvement of installation and service for fuel cell systems by Design-to-Service
PRD 2020 Panel:	3 - Trials and Deployment of Fuel Cell Applications - Energy
Project total costs:	€3 636 797.50
FCH JU max. contribution:	€2 953 790.75
Project start - end:	01/09/2015 - 31/03/2020
Coordinator:	DLR-INSTITUT FÜR VERNETZTE ENERGIESYSTEME EV, DE
Website:	www.project-d2service.eu/



BENEFICIARIES: BALLARD POWER SYSTEMS EUROPE AS, BOSAL EMISSION CONTROL SYSTEMS NV, ZENTRUM FUER BRENNSTOFFZELLEN-TECHNIK GMBH, SOLIDPOWER SPA, BRITISH GAS TRADING LIMITED, ENERGY PARTNER SRL

PROJECT AND OBJECTIVES

The project aimed to simplify fuel cell systems for both residential and commercial applications by making servicing and maintenance easy, fast and safe. The primary objective was to significantly reduce costs and labour for maintenance work, to promote the distribution of energy-efficient fuel-cell-based micro CHP, supplemental power and back-up power technology. Two different fuel cell technologies – PEMFC and SOFC – were employed in different systems that were improved. The project ended in March 2020.

PROGRESS AND MAIN ACHIEVEMENTS

- System layout improvement and component simplification for easier component exchange, standardisation and better durability
- Remote monitoring system improvement for earlier failure detection and avoidance of expensive service visits
- Elaboration of guidelines for designing easily understandable service manuals to allow non-specialised technicians to perform routine service tasks.

FUTURE STEPS AND PLANS

Project finished: catalyst investigations and the reactor qualification for lifetime desulphurisation with a possible operating time of 60 000 hours.



QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	PARAMETER	UNIT	TARGET	ACHIEVED TO DATE BY THE PROJECT	TARGET ACHIEVED?
AWP 2014	Service time /presence time of maintenance technician (SOFC)	Hours	<4	4	✓
	Total down time for servicing (SOFC)	Hours	<48	<0.5/<0.5/48*	✓
	Service interval (SOFC)	1/a	<1	1	✓
	Service costs	€/(kW*a)	<600	850	✗

* Cold BoP/annual Service/Stack replacement



DEMOSOFC

DEMONSTRATION OF LARGE SOFC SYSTEM FED WITH BIOGAS FROM WWTP

Project ID:	671470
Call topic:	FCH-02.11-2014 - Large scale fuel cell power plant demonstration in industrial/commercial market segments
Project total costs:	€5 905 336.25
FCH JU max. Contribution:	€4 492 561
Project start - end:	01/09/2015 - 31/10/2020
Coordinator:	POLITECNICO DI TORINO, IT
Website:	demosofc.wordpress.com/



BENEFICIARIES: CONVION OY, IMPERIAL COLLEGE OF SCIENCE TECHNOLOGY AND MEDICINE, RISORSE IDRICHE SPA, SOCIETA METROPOLITANA ACQUE TORINO SPA, TEKNOLOGIAN TUTKIMUSKESKUS VTT OY

PROJECT AND OBJECTIVES

The DEMOSOFC project demonstrates the technical and economic feasibility of operating a 110 kW_e SOFC system in a wastewater treatment plant. The final plant layout includes only 2 SOFC modules (1 x 58 kW_e and 1 x 44 kW_e). The first SOFC module was activated in October 2017 and the second in October 2018. More than 14 100 hours of on-site operation have been reached (SOFC 1 operation, followed by SOFC 2 operation, and finally some months of SOFC 1 and 2 running in parallel).

NON-QUANTITATIVE OBJECTIVES

- Training end-user (SMAT) technicians on the new fuel cell system. Three training courses have been held
- Visits to the demo sites organised with a standardised format, for people from all over the world
- Technical experience. Build technical knowledge, customer and investor confidence. Lessons learned for replicating detailed engineering, construction, installation and management in the long run.

Definition of optimal detailed engineering at minimum cost

- A complete FMEA of the demo: this was developed and offers lessons and experience for the future
- Dissemination via press releases, webinars, social media (Facebook, Twitter, etc.), website, workshops at demo site and elsewhere, conferences, public events and technical papers.

PROGRESS AND MAIN ACHIEVEMENTS

- High electrical efficiency, always higher than 50 %, with peaks at 56 %
- Zero emissions to atmosphere, NO_x, SO_x, VOC and PM below detection limits
- >14 100 hours of on-site operation (7 100+ for SOFC 1 and 10 200+ for SOFC 2).

FUTURE STEPS AND PLANS

The project finished at the end of October 2020.



QUANTITATIVE TARGETS AND STATUS

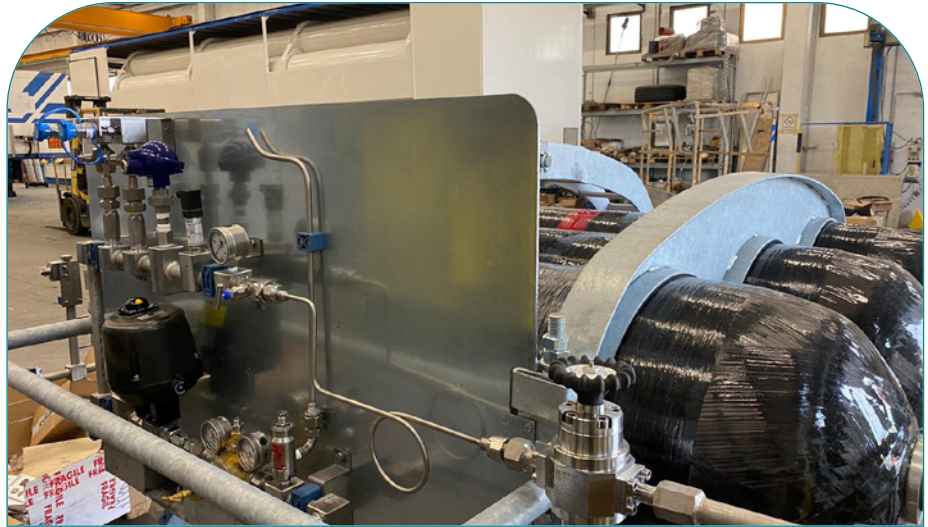
TARGET SOURCE	PARAMETER	UNIT	TARGET	ACHIEVED TO DATE BY THE PROJECT	TARGET ACHIEVED?
MAWP (2014-2020)	Electrical efficiency	% LHV	42-60	50-56	✓
	NO _x emissions	mg/kWh	<40	<160	✗
	Availability of the plant	%	97	60	✗
	Thermal efficiency	% LHV	24-42	30-35	✓
	Lifetime	Years of plant operation	8-20	3.5	✗



EVERYWH2ERE

MAKING HYDROGEN AFFORDABLE TO SUSTAINABLY OPERATE EVERYWHERE IN EUROPEAN CITIES

Project ID:	779606
Call topic:	FCH-02-10-2017 - Transportable FC gensets for temporary power supply in urban applications
Project total costs:	€6 762 324.46
FCH JU max. Contribution:	€4 999 945.76
Project start - end:	01/02/2018 - 31/01/2023
Coordinator:	RINA CONSULTING SPA, IT
Website:	www.everywh2ere.eu/



BENEFICIARIES: FRIEM SPA, LINDE GAS ITALIA SRL, DELTA1 GUG (HAFTUNGSBESCHRANKT), 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, FUNDACION PARA EL DESARROLLO DE LAS NUEVAS TECNOLOGIAS DEL HIDROGENO EN ARAGON, ICLEI EUROPEAN SECRETARIAT GMBH (ICLEI EUROPASEKRETARIAT GMBH), PARCO SCIENTIFICO TECNOLOGICO PER L'AMBIENTE ENVIRONMENT PARK TORINO SPA, ACCIONA CONSTRUCCION SA

PROJECT AND OBJECTIVES

EVERYWH2ERE's goal is to integrate PEMFC subsystems and intrinsically safe pressurised hydrogen storage technologies into FC-based transportable gensets that are easy to install and transport. Eight FC containerised 'plug and play' gensets (4 x 25 kW - 4 x 100 kW) will be realised and tested at construction sites, music festivals and urban public events all around Europe. The first two prototypes have been realised and are being commissioned. Environmental, economic, safety and regulatory aspects have been analysed to inform and promote the demonstration campaign and the project's road-to-market strategy.

NON-QUANTITATIVE OBJECTIVES

- Higher social acceptance of FCH technology
- Demonstration of FC-based gensets at events, festivals, etc. gives strong visibility to FCH technologies
- Easier permitting

- Development of an HSE guideline (with a mini-HAZOP) to facilitate permitting and maybe a future dedicated regulation/technical norms.

PROGRESS AND MAIN ACHIEVEMENTS

- Realisation of the first two FC-based transportable gensets (1 x 25 kW and 1 x 100 kW) and of related hydrogen storage bundles
- Assessment of the cost of the system and potential related market value proposition/business model
- Assessment of the environmental footprint (via LCA/LCC).

FUTURE STEPS AND PLANS

- Demonstration of gensets
- Enhancement of LCA and LCC analysis
- Refinement of the gensets' executive design
- Testing of ejector solutions
- Finalisation of a road-to-market strategy



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 FOR SOA TARGET
Project's own objectives	LCOE of the genset <i>Identification of replication market with contractual costs in a range of +/-10 % compared to current power supply solutions</i>	€/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 <i>Noise emission of the full genset (not only the FC SuSy)</i>	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 <i>CAPEX of the system</i>	€/kW	5 500	6 850	✗	No FC-based gensets today (according to stakeholders a 1 500-2 000 €/kW may be acceptable)	2025

Project ID:	700339
Call topic:	FCH-02.9-2015 - Large scale demonstration μ CHP fuel cells
Project total costs:	€84 462 140.62
FCH JU max. Contribution:	€33 932 752.75
Project start - end:	01/06/2016 - 31/08/2021
Coordinator:	THE EUROPEAN ASSOCIATION FOR THE PROMOTION OF COGENERATION VZW, BE
Website:	www.pace-energy.eu



BENEFICIARIES: ELEMENT ENERGY, REMEHA GMBH, REMEHA NV, VIESSMANN ELEKTRONIK GMBH, VIESSMANN WERKE ALLENDORF GMBH, BOR 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-WARME ENERGIESYSTEMEGMBH, EWE AKTIENGESELLSCHAFT, VAILLANT GMBH, ELEMENT ENERGY LIMITED, HEXIS AG, FACHHOCHSCHULE ZENTRALSCHWEIZ - HOCHSCHULE LUZERN, DANMARKS TEKNISKE UNIVERSITET

PROJECT AND OBJECTIVES

The PACE project will deploy more than 2 800 next-generation FC micro-cogeneration units in 10 European countries by 2021. The focus is on private homes and small enterprises. The project brings together the five leading European suppliers. Manufacturers are supported by associations, consultancies and the research community, who provide specific expertise.

NON-QUANTITATIVE OBJECTIVES

Operability of units: the commissioned units are in operation more than 99 % of the time.

PROGRESS AND MAIN ACHIEVEMENTS

- Manufacturers have put models with improved performance on the market
- To date, 2 183 units have been sold and 1,688 installed
- Targeted lobbying activities have led to favourable market conditions in certain countries.

FUTURE STEPS AND PLANS

Complete the deployment of 2 800 units. More than 1 000 units still need to be sold and commissioned by the end of December 2021.



QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	PARAMETER	UNIT	TARGET	ACHIEVED TO DATE BY THE PROJECT	TARGET ACHIEVED?
Project's own objectives	Decrease of FC micro-cogeneration unit cost	%	30	N/A	✂
	Number of commissioned units	-	2 800	1 688	
	Number of manufactured units*	-	1 000	>1 000	✓

*per manufacturer per year



REMOTE

REMOTE AREA ENERGY SUPPLY WITH MULTIPLE OPTIONS FOR INTEGRATED HYDROGEN-BASED TECHNOLOGIES

Project ID:	779541
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:	€6 753 851.25
FCH JU max. Contribution:	€4 995 950.25
Project start - end:	01/01/2018 - 31/12/2021
Coordinator:	POLITECNICO DI TORINO, IT
Website:	www.remote-euproject.eu/

BENEFICIARIES: SINTEF AS, ENGIE EPS ITALIA SRL, TRONDERENERGI AS, ORIZWN ANONYMH TECHNIKI ETAIREIA, POWIDIAN, IRIS SRL, HYDROGENICS EUROPE NV, ENEL GREEN POWER SPA, BALLARD POWER SYSTEMS EUROPE AS, ETHNIKO KENTRO EREVNAS KAI TECHNOLOGIKIS ANAPTYXIS, STIFTELSEN SINTEF



PROJECT AND OBJECTIVES

REMOTE will demonstrate the technical and economic feasibility of fuel cell-based H₂ energy storage solutions (integrated P2P, non-integrated P2G + G2P systems, customised P2P systems), deployed in 3 demos, based on renewables (solar, wind, hydro) in isolated micro-grid or off-grid remote areas. The analysis of the technical, economic and regulatory framework for the demos was completed in 3.5 years (March 2021). The design, engineering, plan for O&M and permitting procedures have been assessed for all the demos. Two demos have been installed (Norway, Greece) and are now running.

NON-QUANTITATIVE OBJECTIVES

- Gain experience of P2P systems throughout the value chain. Validate real demonstration units in representative applications of isolated micro-grid or off-grid areas, to enable suppliers, end users and other stakeholders to gain wide experience for the future deployment of these energy solutions
- Identify gaps in regulations. The lessons learnt from the demo plants' design, installation and operation will help identify gaps in regulations, allowing full-scale exploitation of H₂-based energy storage in the energy market (not only for islands or remote areas)

- Creation of know-how for next-generation P2P. Through the demo's design, installation and operation, REMOTE will create fundamental know-how for the next generation of fully integrated P2P chains based on fuel cells and H₂ technologies adapted to the market and society's needs, leading to scientific advances in the management of off-grid and isolated micro-grids
- The project will help us understand in detail the complete LCA of RES-fed H₂-based P2P systems in remote areas, in terms of metrics such as global GHG reduction, thanks to the adoption of H₂ as a local RES storage system on a seasonal level.

FUTURE STEPS AND PLANS

- Operation and full analysis of demo in Norway: finalise the installation of the electrolyser to have the full plant running
- Operation and full analysis of demo in Greece: finalise the connection to the local load to have the full plant running
- The new demo 1 site has been selected and the new partners are developing the detailed engineering and permitting procedures. Construction and commissioning will follow.

PROGRESS AND MAIN ACHIEVEMENTS

- Demo 4 started operating in Norway at the end of 2020 with stored H₂. In May, it started running with the electrolyser
- Demo 2 started operating in Greece in autumn 2020 with a temporary load, to be replaced with the real local load
- The new demo 1 in the Canary Islands (Spain) has been defined and is now subject to detailed engineering.



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 FOR SOA TARGET
MAWP Addendum (2018-2020) (target year 2020)	Rated efficiency electrolyser (PEM)	kWh/kg	55,5	50.5 (rated value, to be measured on demo)	✓	50	2020
	Lifetime	years of plant operation	8 - 20	15 (fuel cell) - 20 (surrounding equipment) estimated	✓ (estimation)	N/A	N/A
	Electrolyser footprint (PEM)	m ² /MW	100	273	✗	10	2018-2020
	Rated efficiency electrolyser (alkaline)	kWh/kg	50	50.6 (rated value, to be measured on demo)	✓	N/A	N/A
	Rated efficiency fuel cell (PEM)	%LHV	42-60	45	✓	51	2018

Project ID:	824953
Call topic:	FCH-02-3-2018 - Robust, efficient long term remote power supply
Project total costs:	€4 220 093.75
FCH JU max. Contribution:	€2 999 190.26
Project start - end:	01/01/2019 - 31/12/2022
Coordinator:	TEKNOLOGIAN TUTKIMUSKESKUS VTT OY, FI
Website:	rorepower.com

BENEFICIARIES: 3E ENERGY OY, SUNFIRE FUEL CELLS GMBH, SUNFIRE GMBH, SOLIDPOWER SPA, EUROPEAN FUEL CELL FORUM AG



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 gas and oil infrastructure in remote regions with harsh climate conditions (from -40 °C to +50 °C), and to supply power to telecommunication towers (e.g. telecom base stations or microwave transceivers), especially in emerging countries.

FUTURE STEPS AND PLANS

- Finalise certification of fuel cell units according to IEC EN62882-3-100 and CSA/ANSI FC1 before Q3/2021
- Produce the first BG-Remote system prototype (container). These units will be delivered to Finland in Q2-Q3/2021
- SOLIDpower BG-Remote (LNG) units will be delivered to Sardinia in Q2-Q3/2021



PROGRESS AND MAIN ACHIEVEMENTS

- The 12 RoRePower units have been installed at customer sites
- Sunfire-Remote 400 and 900 passed the design freeze process and are on the market
- Sunfire-Remote 400 Gen. 2 provides nominal power after 15 000 hours of operation and 30 on-off cycles.

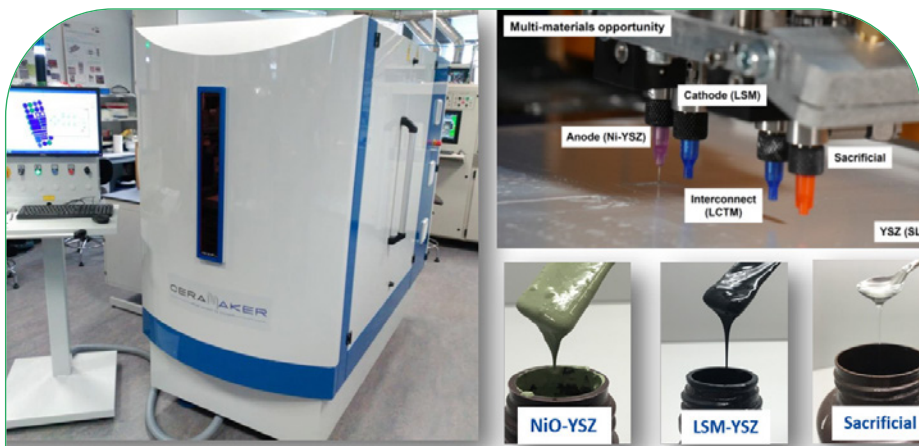


QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	PARAMETER	UNIT	TARGET	ACHIEVED TO DATE BY THE PROJECT	TARGET ACHIEVED?
AWP 2019	Electrical efficiency	%	>35	>35	✓
	Start-up temperature for propane	°C	-30	-30	✓
	Long-term desulphurisation	Months	15	15	✓

**PANEL 4
NEXT GENERATION
OF PRODUCTS –
ENERGY**

Project ID:	700266
Call topic:	FCH-02.6-2015: Development of cost effective manufacturing technologies for key components or fuel cell systems
Project total costs:	€2 191 133.75
FCH JU max. Contribution:	€2 180 662.5
Project start - end:	01/07/2016- 30/04/2020
Coordinator:	FUNDACIO INSTITUT DE RECERCA DE L'ENERGIA DE CATALUNYA, ES
Website:	www.cell3ditor.eu/



BENEFICIARIES: 3DCERAM, SAAN ENERGI AB, PROMETHEAN PARTICLES LTD, HYGEAR Fuel Cell Systems BV, FRANCISCO ALBERO SA, UNIVERSIDAD DE LA LAGUNA, DANMARKS TEKNISKE UNIVERSITET

PROJECT AND OBJECTIVES

The main goal of the Cell3Ditor project was the development of a 3D printing technology for the industrial production of SOFC components by covering research and innovation in all the stages of the industrial value chain. Cell3Ditor technology was demonstrated by the end of the project, with the release of printable feedstock (electrolyte, electrodes and interconnects), a hybrid printing machine (now commercialised) and enhanced corrugated SOFC cells with 60 % increase in performance (using conventional materials).

NON-QUANTITATIVE OBJECTIVES

- Development of new materials for the 3D printing of ceramics. The project has delivered new ceramic slurries, adding to the list of materials available for 3D printing: 8YSZ, LSM, Ni-YSZ, LCTM (interconnector)
- Development of 3D printing processes for SOFC stacks manufacturing. The proof of concept of the 3D printing process for SOFCs has been provided and new processes have been created.

PROGRESS AND MAIN ACHIEVEMENTS

- Printable feedstock for electrolyte (YSZ), electrodes (Ni-YSZ, LSM-YSZ) and interconnects (LTO)
- Hybrid printing machine able to print complete cells and stacks released
- New families of 3D-printed SOFC cells with enhanced performance and long durability.

FUTURE STEPS AND PLANS

The project has finished. While the final goal of producing a 3D printed stack has not been attained, printing and co-sintering processes have been developed. Button cells have been printed and tested successfully.



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 FOR SOA TARGET
Project's own objectives	Power density Increment of specific power of cells	mW/cm	260	410	✓	0.2	2004
	Global Warming Potential (GWP)	kg CO ₂ /kW	1 230	93	✓	1 230	2015
	Material use	kg/kW	25.84	7.6	✓	25.84	2015



EMPOWER

EUROPEAN METHANOL POWERED FUEL CELL CHP

Project ID:	875081
Call topic:	FCH-02-7-2019: Development of highly efficient and flexible mini CHP fuel cell system based on HTPEMFCs
Project total costs:	€1 499 876.25
FCH JU max. Contribution:	€1 499 876.25
Project start - end:	01/01/2020 - 31/12/2022
Coordinator:	TEKNOLOGIAN TUTKIMUSKESKUS VTT OY, FI
Website:	www.empower-euproject.eu/

BENEFICIARIES: BLUE WORLD TECHNOLOGIES APS, THT CONTROL OY, CATATOR AB, UNIVERSIDADE DO PORTO



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 PEM fuel cell technology. The project will enhance the system efficiency to target the mini-CHP market and provide a cost-competitive and low-carbon option. The CHP unit developed will be capable of fast start-up and fast dynamic response to help integration of intermittent power production from renewable energy sources. Currently, the subsystems of the CHP are being built and tested by project partners.

NON-QUANTITATIVE OBJECTIVES

- Increase visibility and awareness of the potential of renewable methanol. Open communication and dissemination of project results will lead to increased visibility and awareness of the potential of renewable methanol

- Develop a business plan for the use of renewable methanol in CHP as well as other applications. A preliminary market potential study will be done in spring 2021 and updated by the end of the project
- Support knowledge exchange and production ramp-up through identification of stakeholders, information and linkage. An industrial webinar was arranged in January 2021 and there will be an industrial workshop by the end of 2021
- The main goal is the production of affordable and secure electricity with a low-carbon footprint.

PROGRESS AND MAIN ACHIEVEMENTS

- A new, compact concept for HTPEM fuel cell stack compression with bands instead of rods has been tested
- An MCU was planned and built for the 5-kW power unit, including controls for safety, fuel supply system, cooling and power electronics

- A complete gas-phase reformer was designed and constructed. Commissioning and evaluation are under way. The work is progressing over time.

FUTURE STEPS AND PLANS

- Develop, manufacture and characterise a highly efficient methanol reformer in spring 2021
- Develop, manufacture and characterise a highly efficient HTPEM fuel cell in summer 2021
- Characterise and integrate reformer with the HTPEM fuel cell in autumn 2021
- Integrate, commission and demonstrate the system in a laboratory environment in winter 2021
- Integrate, commission and demonstrate the system in a relevant end-user environment in spring/summer 2022
- Conduct a system scale-up study (50 kW), environmental analysis and business analysis in 2022.

QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	PARAMETER	UNIT	TARGET	TARGET ACHIEVED?
Project's own objectives	Rated stack electrical efficiency (LHV reformat gas)	%	55	✗
	Fuel processing efficiency	%	85	
MAWP Addendum (2018-2020)	CHP electrical efficiency (LHV methanol)	%	37-67	
	CAPEX	€/kWh	5 500	



GRASSHOPPER

GRID ASSISTING MODULAR HYDROGEN PEM POWER PLANT

Project ID:	779430
Call topic:	FCH-02-7-2017 - Development of flexible large fuel cell power plants for grid support
Project total costs:	€4 387 063.75
FCH JU max. Contribution:	€4 387 063.75
Project start - end:	01/01/2018 - 30/06/2021
Coordinator:	INEA INFORMATIZACIJA ENERGETIKA AVTOMATIZACIJA DOO, SI
Website:	www.grasshopperproject.eu/



BENEFICIARIES: POLITECNICO DI MILANO, NEDSTACK FUEL CELL TECHNOLOGY BV, ABENGOA INNOVACION SOCIEDAD ANONIMA, ZENTRUM FUR BRENNSTOFFZELLEN-TECHNIK GMBH, JOHNSON MATTHEY FUEL CELLS LIMITED

PROJECT AND OBJECTIVES

The GRASSHOPPER project aims to create a next-generation MW-size fuel cell power plant (FCPP), which is more cost-effective and flexible in power output. The FCPP will be demonstrated in the field as a 100 kW sub-module pilot plant, implementing newly developed stacks with improved MEAs and BoP system components. The new stack design has been developed with increased power density and is undergoing short stack testing. The pilot plant is undergoing FAT testing and will run on H₂ soon. A dynamic simulation model of the pilot plant has been developed to study further optimisation strategies.

NON-QUANTITATIVE OBJECTIVES

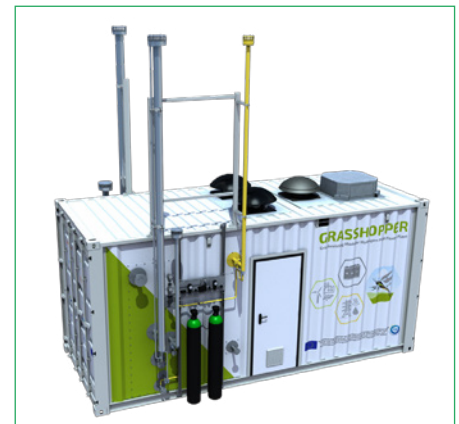
Operation flexibility and grid stabilisation capability via fast response. Operation strategy defined taking into account response time requirements for grid stabilisation.

PROGRESS AND MAIN ACHIEVEMENTS

- The pilot power plant is in the commissioning phase
- Both short stack and single cell testing with the new 6H MEAs and cell plates show performance close to the target of 0.68 V @ 1 A/cm²
- Grasshopper MEAs show excellent durability in AST testing.

FUTURE STEPS AND PLANS

- Assembly of the full stacks for the 100-kW plant. All parts for building the short stacks have arrived. Sealing application and cell plate manufacturing are ongoing for the full stacks
- Testing, relocation and start-up of the pilot plant. FAT testing is ongoing and the pilot plant will soon start testing with hydrogen
- Stack design verification and optimisation, pending full results from short stacks and first full stack
- Cost analysis of stacks and the system.



QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	PARAMETER	UNIT	TARGET	TARGET ACHIEVED?	SOA RESULT ACHIEVED TO DATE (BY OTHERS)	YEAR FOR SOA TARGET
Project's own objectives	MEA cost reduction	%	65	✂	MEA cost price of electricity 0.04 €/kWh	2018
	Stack efficiency	%	55		55	
MAWP Addendum (2018-2020)	System electrical efficiency	%	50		50	
	System CAPEX	€/kWe	1 500		3 000	
AWP 2017	Stack lifetime	Hours	20 000	16 000		

Project ID:	671403
Call topic:	FCH-02.5-2014 -Innovative fuel cell systems at intermediate power range for distributed combined heat and power generation
PRD 2020 Panel:	4 - Next Generation of Products - Energy
Project total costs:	€3 998 081.25
FCH JU max. contribution:	€3 998 081.25
Project start - end:	01/09/2015 - 31/10/2019
Coordinator:	TEKNOLOGIAN TUTKIMUSKESKUS VTT OY, FI
Website:	www.innosofc.eu/



BENEFICIARIES: ENERGY MATTERS BV, CONVION OY, ELCOGEN OY, ELRINGKLINGER AG, FORSCHUNGSZENTRUM JULICH GMBH, AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE, L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE

PROJECT AND OBJECTIVES

The INNO-SOFC project is developing an innovative 50 kW SOFC system and related value chain, from interconnects and stacks to end-users and application analysis. The project is based on the products of industrial partners and motivated by their interest in improving their products and consolidating an efficient value chain through collaboration. The INNO-SOFC system has been transported to the Lempäälä smart grid.

NON-QUANTITATIVE OBJECTIVES

- A public modelling tool was created to analyse different business cases
- Published in <https://blueterra.nl/en/project/inno-sofc/>

PROGRESS AND MAIN ACHIEVEMENTS

- INNO-SOFC system FAT approved and transported to the Lempäälä smart grid
- Stack long-term testing lasted 12 000 hours with <0.4 % degradation rate
- A public modelling tool was created to analyse different business cases: <https://blueterra.nl/en/project/inno-sofc/>

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)	YEAR FOR SOA TARGET
Project's own objectives	System CAPEX	€/kW	4 000	N/A	✘	9 000	2018
	System lifetime	Hours	30 000	N/A	✘	N/A	N/A
	Stack degradation rate	%/kh	<0.5	<0.4	✔	0	2019

Project ID:	735918
Call topic:	FCH-02-5-2016 - Advanced monitoring, diagnostics and lifetime estimation for stationary SOFC stacks and modules
PRD 2020 Panel:	4 - Next Generation of Products - Energy
Project total costs:	€3 146 056.25
FCH JU max. contribution:	€2 498 948.75
Project start - end:	01/01/2017- 31/12/2019
Coordinator:	COMMISSARIAT A L'ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES, FR
Website:	insight-project.eu/



BENEFICIARIES: ABSISKEY, TEKNOLOGIAN TUTKIMUSKESKUS VTT OY, SOLIDPOWER SPA, BITRON SPA, SOLIDPOWER SA, ABSISKEY CP, UNIVERSITA DEGLI STUDI DI SALERNO, AVL LIST GMBH, INSTITUT JOZEF STEFAN, ECOLE POLYTECHNIQUE FEDERALE DE LAUSANNE, DANMARKS TEKNISKE UNIVERSITET

PROJECT AND OBJECTIVES

The INSIGHT project aims to develop a monitoring, diagnostic and lifetime tool for SOFC stacks. Monitoring is based on two advanced techniques (EIS and THD), in addition to conventional stack signal. Durability tests with faults added on purpose generate the data required to develop and validate the algorithms. Fault-mitigation logics will be developed to avoid stack failures and slow down their degradation. Low-cost hardware, consisting of a single board able to embed the tool, will be developed and integrated in a commercial microCHP, which will be tested in the field.

NON-QUANTITATIVE OBJECTIVES

- Methodology for fault detection/isolation and mitigation
- Fault detection and isolation algorithm and complete fault signature matrix (which correlates the variation of the features and the fault accounted for). The tool then proposes mitigation action to the system controller
- Modification of the DC/DC converter for excitation
- The DC/DC converter of the EnGen 2 500 micro-CHP system has been modified, and the Bitron Box, developed to embed the monitoring, diagnostic and lifetime tools, has been developed, manufactured and interfaced with the EnGen 2 500.

PROGRESS AND MAIN ACHIEVEMENTS

- Non-linear perturbation techniques (THD and PRBS) have been found as quick analysis tools, with an answer consistent with conventional EIS measurements
- MDLT (hardware and software) tool developed and interfaced with modified DC/DC converter of the EnGen 2 500 system from SolidPower
- 6 200 hours of in-field system tests, and validation of the MDLT tool under these conditions for fuel starvation fault.

FUTURE STEPS AND PLANS

- The project has finished.

QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	PARAMETER	TARGET	ACHIEVED TO DATE BY THE PROJECT	TARGET ACHIEVED?	SOA RESULT ACHIEVED TO DATE (BY OTHERS)
Project's own objectives	Perform test with faults added on purpose	Test 3 faults	All tested	✓	Evaluation of C deposition
	Develop monitoring, diagnostic and lifetime tool (MDLT)	Tool developed	7 tools delivered to partners for testing		No other similar tool for SOFC, as far as open literature is concerned
	Implement the MDLT on board	Implementation done	6 200 hours of in-field tests		N/A
AWP 2016	Lifetime	Prolong lifetime by 5 %	Achieved. Earlier detection of fuel starvation with the tool: the tool is able to detect issues only 10 % above nominal conditions, while with classical signals it is detected 'only' 22 % above nominal conditions.	✓	No other similar tool for SOFC, as far as open literature is concerned
	Cost	System cost increase due to additional hardware for MDLT less than 3 %	The share of the MDLT tool is 2 % if board prototype cost is considered, and 1.3 % for series production, thus reaching the targets set		No other similar tool for SOFC, as far as open literature is concerned

Project ID: 826323

Call topic: FCH-02-6-2018 - Cost-effective novel architectures of interconnects

Project total costs: €2 335 997.50

FCH JU max. Contribution: €2 335 997.50

Project start - end: 01/01/2019 - 31/12/2021

Coordinator: DANMARKS TEKNISKE UNIVERSITET, DK

Website: www.lowcost-ic.eu



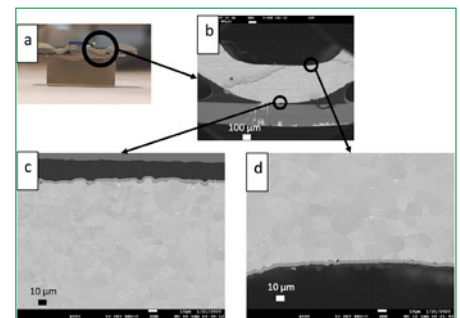
BENEFICIARIES: TECNO ITALIA SRL, SUNFIRE GMBH, SOLIDPOWER SPA, BORIT NV, APERAM STAINLESS FRANCE SA, AKTIEBOLAGET SANDVIK MATERIALSTECHONOLOGY, AVL LIST GMBH, CHALMERS TEKNISKA HOEGSKOLA AB, FORSCHUNGSZENTRUM JULICH GMBH

PROJECT AND OBJECTIVES

The overall objective of LOWCOST-IC is to contribute to the successful upscaling of 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
- minimizing interconnect development and production costs – by introducing cheaper high-volume steel, applying state-of-the-art large-scale roll-to-roll manufacturing methods for SOC manufacturing and developing a novel interconnect shape design route.

- Produce new interconnects with optimised geometry for Sunfire. Further mechanical investigations have shown that the original design approach did not work. New approach is ongoing. Borit will produce the interconnects as soon as the design is finished
- Cost target for large-scale manufacturing of SOC stack interconnects will be investigated. Current production methods have been analysed. Now the impact of scale will be considered
- Develop new coatings to minimise ASR increase from Si scale. Various Si scavengers have been tested and this work will continue.

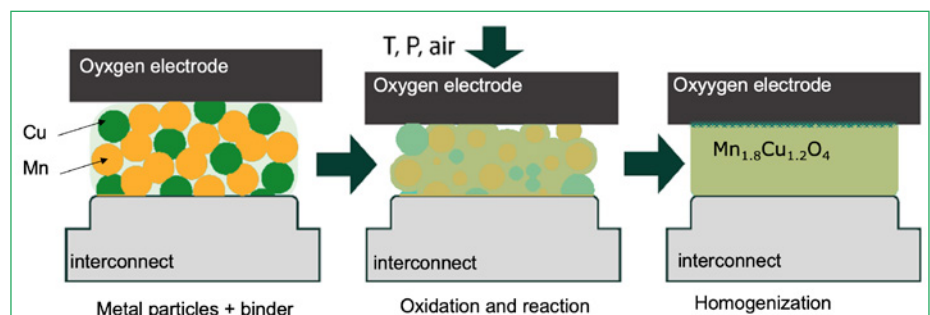


PROGRESS AND MAIN ACHIEVEMENTS

- One new improved contact layer developed based on previously proposed contact layers
- Stack tested with roll-to-roll manufactured coatings from Sandvik
- New 3D fast multiphysics model adapted to Sunfire's stack design for further studies.

FUTURE STEPS AND PLANS

- Testing of second-generation contact layers in stacks. Contact layers have been tested in the lab with promising results



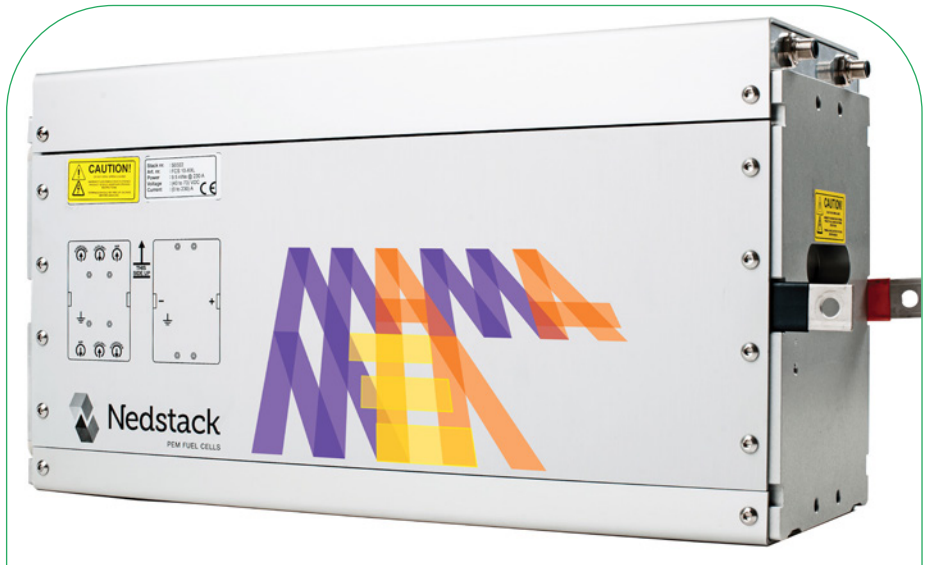
QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	PARAMETER	UNIT	TARGET	ACHIEVED TO DATE BY THE PROJECT	TARGET ACHIEVED?	SOA RESULT ACHIEVED TO DATE (BY OTHERS)	YEAR FOR SOA TARGET
Project's own objectives	Fracture energy	J/m ²	5.1	12	✓	1.7	2013
	Area-specific resistance at 750 °C	mOhm.cm ²	15	12	✓	15	2019
	Area-specific resistance 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
Call topic:	FCH-02-8-2017 - Step-change in manufacturing of fuel cell stack components
Project total costs:	€3 189 816
FCH JU max. Contribution:	€3 189 816
Project start - end:	01/01/2018 - 30/06/2021
Coordinator:	TECHNISCHE UNIVERSITAET CHEMNITZ, DE
Website:	www.mama-mea.eu



BENEFICIARIES: SYSTEM SPA, JOHNSON MATTHEY FUEL CELLS LIMITED, INEA INFORMATIZACIJA ENERGETIKA AVTOMATIZACIJA DOO, NEDSTACK FUEL CELL TECHNOLOGY BV, UNIVERSITA DEGLI STUDI DI MODENA E REGGIO EMILIA, FRAUNHOFER GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG EV

PROJECT AND OBJECTIVES

MAMA-MEA is developing an innovative additive layer deposition process integrating all main CCM components (membrane, catalyst layers, sealing) using a single, continuous roll-to-roll manufacturing process for the PEMFC industry to considerably increase the volume manufacturing rate, while also increasing key material utilisation and reducing materials and costs. The aim is to increase the MRL of the additive manufacturing process from 3 to 6. Techniques for the deposition of each layer were down-selected from mature technologies used in other industries. Design of the MAMA-MEA production line is ongoing.

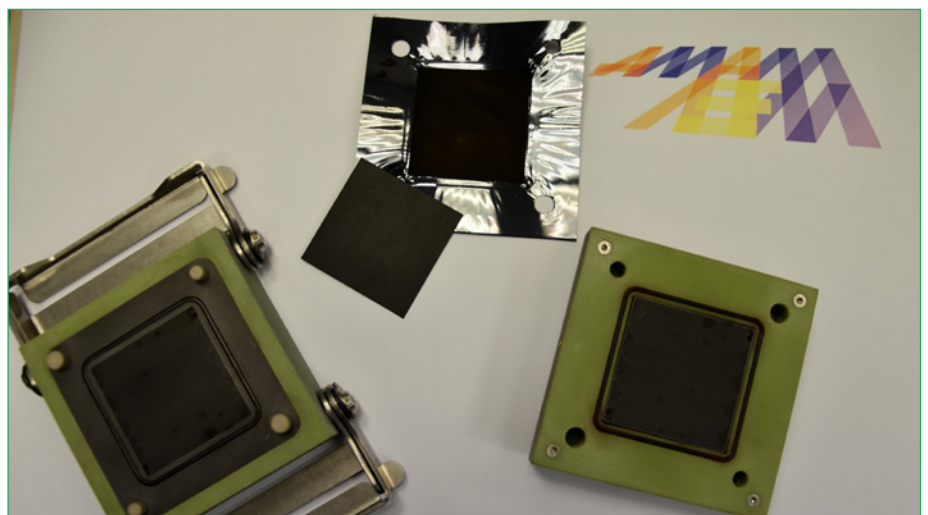
PROGRESS AND MAIN ACHIEVEMENTS

- Evaluation and selection of inkjet inks suitable for the deposition of seal frames. Generation of samples with improved print quality for testing
- Produced MEAs for two stacks through an additive layer manufacturing process using a prototype direct coating line that performs on a par with the benchmark

- Additive layer trial CCMs assembled into two rainbow stacks were tested by NFCT in-house and then run for a longer period in a test facility.

FUTURE STEPS AND PLANS

- JMFC's production facility: under the current situation, construction is not guaranteed.



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	



NewSOC

NEXT GENERATION SOLID OXIDE FUEL CELL AND ELECTROLYSIS TECHNOLOGY

Picture of the 3D printed large area cells



Project ID: 874577

Call topic: FCH-02-6-2019 - New materials, architectures and manufacturing processes for Solid Oxide Cells

Project total costs: €4 999 726.25

FCH JU max. Contribution: €4 999 726.25

Project start - end: 01/01/2020 - 30/06/2023

Coordinator: DANMARKS TEKNISKE UNIVERSITET, DK

Website: www.newsoc.eu/

Beneficiaries: TEKNOLOGIAN TUTKIMUSKESKUS VTT OY, SUNFIRE GMBH, CERES POWER LIMITED, SOLIDPOWER SPA, AKTSIA SELTS ELCOGEN, FUNDACIO INSTITUT DE RECERCA DE L'ENERGIA DE CATALUNYA, HEXIS AG, ETHNIKO KENTRO EREVNAS KAI TECHNOLOGIKIS ANAPTYXIS, INSTYTUT ENERGETYKI, UNIVERSITA DEGLI STUDI DI SALERNO, ECOLE POLYTECHNIQUE FEDERALE DE LAUSANNE, POLITECNICO DI TORINO, NEDERLANDSE ORGANISATIE VOOR TOEGEPAST NATUURWETENSCHAPPELIJK ONDERZOEK TNO, COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES, IDRYMA TECHNOLOGIAS KAI EREVNAS

PROJECT AND OBJECTIVES

NewSOC aims to significantly improve the performance, durability and cost competitiveness of solid oxide cells and stacks compared to state of the art. In order to achieve these goals, NewSOC proposes 12 innovative concepts in the following areas: (i) structural optimisation and innovative architectures, (ii) alternative materials, and (iii) innovative manufacturing to reduce critical raw materials and the environmental footprint, while improving performance and lifetime. Despite the huge challenges due to the pandemic, we achieved progress in all areas.

NON-QUANTITATIVE OBJECTIVES

- Develop a modelling tool for microstructure optimisation. Achieved and used for improving the Ni-YSZ electrode
- Reduction of CRM materials in the SOC manufacturing (Co in the oxygen electrode). Achieved by the development of an LSF electrode
- Understanding of the underlying mechanisms under SOFC/SOEC and H₂O/CO₂ co-electrolysis operation. Understanding gained for individual CO₂ electrolysis and the contribution of the RWGS reaction to the production rate of CO during H₂O/CO₂ co-electrolysis.

PROGRESS AND MAIN ACHIEVEMENTS

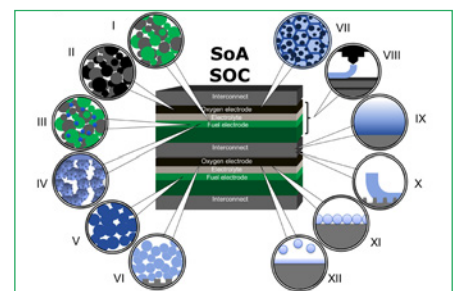
- First-generation SOC with highly active oxygen electrodes with honeycomb structures manufactured and electrochemically tested at temperatures ranging from 650-750 oC
- Cells with optimised Ni-YSZ fuel electrode microstructure developed and tested, demonstrating intact Ni with no depletion after 900-1 000 h SOE operation
- 3D printed large-area electrolytes (58 cm²) were electrochemically characterised in symmetrical and full cell configuration.

FUTURE STEPS AND PLANS

- Delivery of cells developed in WP2. Integration of highly active honeycomb structured oxygen electrodes into industrial half SOC for experimental verification and stack integration
- Delivery of cells developed in WP3. Integration of two optimized electrodes into a full cell for test and stack integration
- Durability improvement of cells with Ni-based fuel electrodes (WP2). Testing of cells with infiltrated,

more tolerant and durable Ni/YSZ (Ni/GDC) fuel electrodes in rev SOC mode and SOE mode

- More tolerant and active fuel electrodes (WP2). Identification of materials and reference mapping with the target parameters, followed by electrode integration into full cells and short stacks
- Improvement of the electrochemical performance of the 3D printed large-area cells, including electrolyte and porous electrodes (WP4). Development of structures that help to hold the large electrolyte membrane and allow for an electrolyte with reduced thickness; development of optimum electrode pore structure.



QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	PARAMETER	UNIT	TARGET	ACHIEVED TO DATE BY THE PROJECT	TARGET ACHIEVED?
Project's own objectives	ASR	Ohm.cm ² at 650°C	0.4	0.7	✘
	ASR	Ohm.cm ² at 650°C	0.4	0.86	
	Electrolysis current for operation with degradation rate below 1%/1 000 h	A/cm ²	0.75-1	Nearly 5% obtained at 725 °C and -1 A/cm ²	
	Thermal cycling stability of IC/coating/modified sealing/IC joined samples	Ohm.cm at 850°C	>1 x 10 E6 5 thermal cycles	>1 x E6 3 thermal cycles	



Project ID: 779537

Call topic: FCH-02-9-2017 - Development of next-generation SOFC stack for small stationary applications

Project total costs: €2 996 873.75

FCH JU max. Contribution: € 2,996,873.75

Project start - end: 01/01/2018 - 30/06/2021

Coordinator: SAINT-GOBAIN CENTRE DE RECHERCHES ET D'ETUDES EUROPEEN, FR

Website: oxigen-fch-project.eu/

BENEFICIARIES: SINTEF AS, SOCIETE EUROPEENNE DES PRODUITS REFRACTAIRES, EIFER EUROPAISCHES INSTITUT FUR ENERGIEFORSCHUNG EDF KIT EWIV, ICI CALDAIE SPA, SAINT GOBAIN RECHERCHE SA, ENGIE, STIFTELSEN SINTEF, FRAUNHOFER GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG EV, COMMISSARIAT A L'ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES

PROJECT AND OBJECTIVES

OxiGEN aims to develop an innovative SOFC platform, including an all-ceramic stack design and a modular hotbox, thanks to its higher durability and simpler design for micro-CHP.

The objectives are:

- Define the most suitable hotbox functional specifications for residential and commercial segments (completed)
- Develop a higher power stack and modular hot box to build a 1-kWe prototype and assess the performances and durability targets (in progress)
- Propose material-based solutions for future long-term improvements (in progress)
- Study the cost of ownership of the solution.

NON-QUANTITATIVE OBJECTIVES

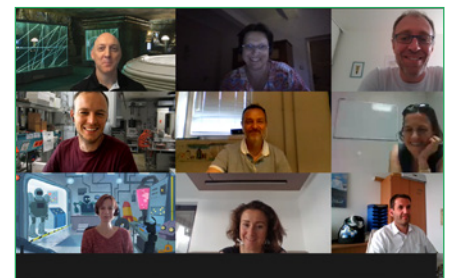
- Definition of market specifications for residential and small commercial applications and boundary limits of the hot box (completed)
- Stack design (completed)
- Hot box design (completed)
- GEN 3 short stack (in progress).

PROGRESS AND MAIN ACHIEVEMENTS

- Definition of market specifications for residential and small commercial applications and hot box boundary limits (ENGIE/SG/CEA)
- GEN 1 stack and hot box manufacturing (SG/IKTS) and pre-test at ICI Caldaie and GEN 1 short stack test at CEA
- Novel electrolyte development for better cell performances (SINTEF).

FUTURE STEPS AND PLANS

- Manufacturing of hot box with stack reaching DC efficiency of at least 55 % and a lifetime of about 2 500 h. Ongoing but with difficulties.
- Assessment of durability and performance of the stack and hot box combination.
- GEN 3 short stack with new materials in electrolyte and anode functional layers to improve the stack's performance.



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 FOR SOA TARGET
Project's own objective: short stack	DC electrical efficiency	%	59	50	✂	47	2016
Project's own objective: electrolyte	Conductivity	%	>30	30	✓	N/A	2016
Project's own objective: system efficiency	DC efficiency	%	55	0	✂	N/A	N/A

Project ID:	735160
Call topic:	FCH-02-6-2016 -Development of cost-effective manufacturing technologies for key components or fuel cell systems
Project total costs:	€2 110 015
FCH JU max. Contribution:	€2 110 015
Project start - end:	01/02/2017 – 31/07/2020
Coordinator:	TEKNOLOGIAN TUTKIMUSKESKUS VTT OY, FI
Website:	www.qsofc.eu/

BENEFICIARIES: MUKO MASCHINENBAU GMBH, HAIKU TECH EUROPE BV, ELCOGEN OY, ELRINGKLINGER AG, AKTIASELTS ELCOGEN, AKTIEBLAGET SANDVIK MATERIALSTECHONOLOGY, AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE



PROJECT AND OBJECTIVES

The qSOFC project focuses on SOFC stack cost reduction and quality improvement by replacing manual labour in all key parts of the stack manufacturing process with automated manufacturing and quality control. This will lead to a stack cost of 1 000 €/kW and create a further cost reduction potential down to 500 €/kW at mass production (2 000 MW/year). During the qSOFC project, key steps in cell and interconnect manufacturing and quality assurance have been optimised to enable mass manufacturing.

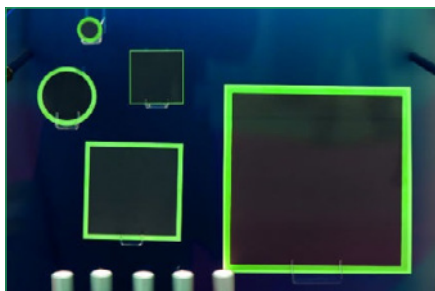
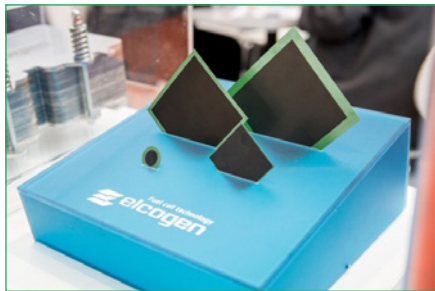
NON-QUANTITATIVE OBJECTIVES

- Cell mass-manufacturing process compliance with REACH regulations. New REACH-compliant compositions for mass manufacturing identified, tested and validated
- Development of stack quality assurance testing unit. Unit constructed and put into production use
- Optical inspection system developed and validated for cells. Technology can be utilised for cells and possibly other applications.

PROGRESS AND MAIN ACHIEVEMENTS

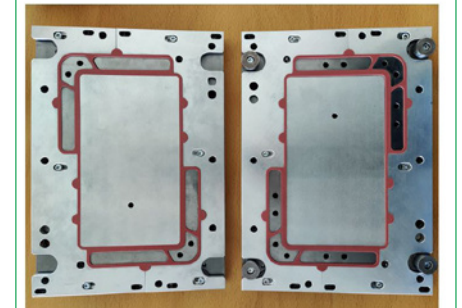
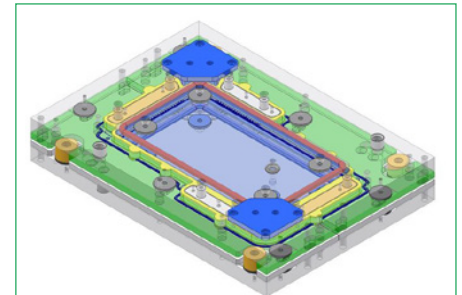
- Automated machine vision inspection system for cell manufacturing quality assurance
- Novel stack conditioning procedures have been developed, leading to about 70 % reduction in stack conditioning time and conditioning cost

- Cell manufacturing process has been modified to allow high-speed manufacturing necessary for mass production.



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)	YEAR FOR SOA TARGET
Project's own objectives	Cell layer QC time	Second/cell layer	10	10	✓	N/A	N/A
	Stack production yield	%	99.5	100	✓	99.5	2015
	Production rate	Hours/stack	24	17	✓	24	2014
	Energy per conditioning cycle	kWh/cycle	300	213	✓	300	2015



RUBY

ROBUST AND RELIABLE GENERAL MANAGEMENT TOOL FOR PERFORMANCE AND DURABILITY IMPROVEMENT OF FUEL CELL STATIONARY UNITS

Project ID: 875047

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: €2 999 715

FCH JU max. Contribution: €2 999 715

Project start - end: 01/01/2020 - 31/12/2023

Coordinator: UNIVERSITA DEGLI STUDI DI SALERNO, IT

Website: www.rubypoint.eu/



BENEFICIARIES: COMMUNAUTE D'UNIVERSITES ET ETABLISSEMENTS UNIVERSITE BOURGOGNE - FRANCHE - COMTE, TEKNOLOGIAN TUTKIMUSKESKUS VTT OY, SOLIDPOWER SPA, BITRON SPA, BALLARD POWER SYSTEMS EUROPE AS, EIFER EUROPAISCHES INSTITUT FUR ENERGIEFORSCHUNG EDF KIT EWIV, FONDAZIONE BRUNO KESSLER, UNIVERSITE DE FRANCHE-COMTE, INSTITUT JOZEF STEFAN, ECOLE POLYTECHNIQUE FEDERALE DE LAUSANNE, COMMISSARIAT A L'ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES

PROJECT AND OBJECTIVES

RUBY aims to develop and implement a tool able to perform integrated monitoring, diagnostic, prognostic and control functions for the production of μ -CHP and backup (BUP) systems, based on SOFC and PEMFC. The tool's key feature is the electrochemical impedance spectroscopy (EIS)-based advanced monitoring of both SOFC and PEMFC stacks. RUBY is working on the hardware integration with stack diagnostic and control algorithms as well as with fault detection algorithms for BOP. One-year tests will be conducted in a real-life environment for μ -CHP and for BUP installed in a controlled real field.

NON-QUANTITATIVE OBJECTIVES

Analysis of historical data from the previous project. Data collection and elaboration for potential machine learning of the models.

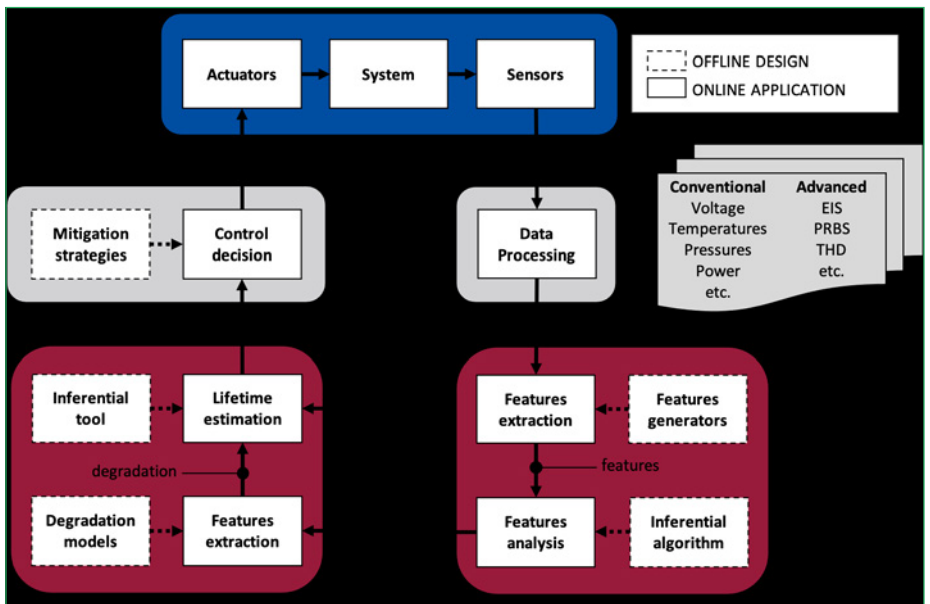
PROGRESS AND MAIN ACHIEVEMENTS

- Database of system and stack measurement of conventional and EIS spectra shared among partners
- Test benches ready for system installation at partner premises
- PEMFC and SOFC stack delivered and under testing.

FUTURE STEPS AND PLANS

- EIS technique validated in laboratory. Main faults confirmed in laboratory with EIS

- Integrate RUBY tool into FCS. Tool integration completed for both FC technologies
- Validation test campaign started and checked at all test sites. Check the progress of the test campaign against the plan.



QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	PARAMETER	UNIT	TARGET	TARGET ACHIEVED?	SOA RESULT ACHIEVED TO DATE (BY OTHERS)	YEAR FOR SOA TARGET
Project's own objectives	Lifetime SOFC performance enhancement	Years	14	✘	10	2019
	Lifetime PEMFC performance enhancement	Years	15		12	
	Maintenance costs SOFC reduction of the on-site maintenance interventions	€ cents/kWh	3.5		6	
	Maintenance costs PEMFC reduction of the on-site maintenance interventions	€/year	452		617	



Project ID: 826234

Call topic: FCH-02-7-2018 - Efficient and cost-optimised biogas-based cogeneration by high temperature fuel cells

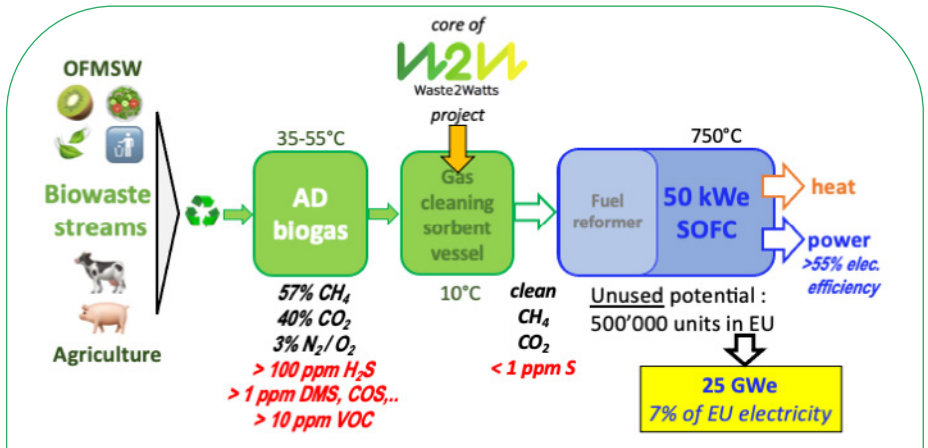
Project total costs: €1 681 602.50

FCH JU max. Contribution: €1 681 602.50

Project start - end: 01/01/2019 - 31/12/2021

Coordinator: ECOLE POLYTECHNIQUE FEDERALE DE LAUSANNE, CH

Website: waste2watts-project.net/



BENEFICIARIES: EREP SA, ETUDES ET APPLICATIONS D'ENERGIES RENOUVELABLES ET D'EPURATION, BOKOMP 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 A L'ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES, PAUL SCHERRER INSTITUT

PROJECT AND OBJECTIVES

WASTE2WATTS aims to develop biogas cleaning technologies to make the gas compatible with solid oxide fuel cells (SOFC). It is characterising a series of solid sorbents (mainly based on activated carbon) in terms of how effectively they remove the sulphur contaminants H₂S, CH₃SH, CH₃SCH₃, COS as a function of the gas matrix and temperature. The project is testing SOFC cells and stacks from two suppliers, and reforming catalysts, with representative gas mixtures (based on calculations of the SOFC-CHP system layout) including contaminants. It is also exploring cleaning based on deep gas cooling and preparing a 6-kWe SOFC demo with agro-biogas.

NON-QUANTITATIVE OBJECTIVES

- Biogas policy. There is a clear need for bio-waste exploitation support, especially in agriculture, and for small-scale applications (25-50 kWe)

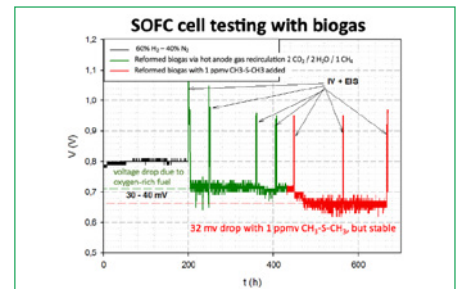
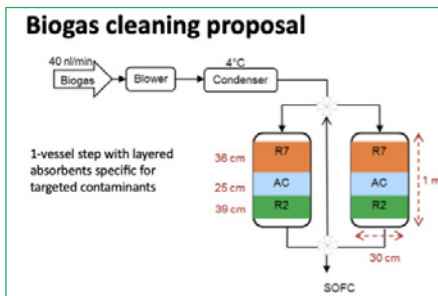
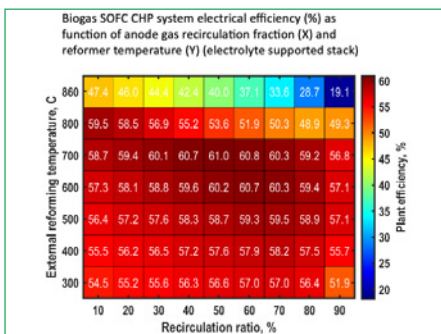
- Scale question. There is a scale segment (25-50 kWe) which would be favourable for exploitation with SOFCs, especially for farm clusters
- Sorbent question. Sorbents as a state-of-the-art solution for wet multi-contaminant ambient biogas cleaning have a low retention capacity and high OPEX
- Dry reforming capability. It is possible to reform recirculated biogas with low steam and high CO₂ content on a specific catalyst.

PROGRESS AND MAIN ACHIEVEMENTS

- There is a huge biogas resource in agriculture in Europe for use by small-scale SOFC (50 kWe, 0.5 M units or 25 GWe, 1 500 PJ = 8 % of EU natural gas)
- There is no easy or cheap way of using known commercial solid sorbents to clean biogas of all sulphur compounds to very low levels for SOFCs
- There are system layouts for biogas SOFC-CHP allowing to achieve >50 % electrical efficiency based on currently known performances.

FUTURE STEPS AND PLANS

- A new funding proposal for a pilot installation on a farm to operate a 6 kWe SOFC on agro-biogas is in preparation
- More research is being performed on the use of sorbents with wet biogas, including commercial solutions
- Clarify cleaning by deep cooling. More research is ongoing to clarify the feasibility (cost, performance) of deep cooling (-100 °C) of biogas to remove contaminants
- Reforming catalysts and solid oxide cells/stacks with contaminants. Thorough characterisation on cells and stacks continues, especially with contaminants, and especially for longer test durations
- Establishing a biogas installation with an advisory board SME partner. A project is in preparation with the SME partner to supply small-scale agro-biogas installations (with ICE). This installation is likely to succeed and will provide a basis for follow-up work.



QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	PARAMETER	UNIT	TARGET	ACHIEVED TO DATE BY THE PROJECT	SOA RESULT ACHIEVED TO DATE (BY OTHERS)
Project's own objectives	Biogas pollutant matrix	ppmv	<0.5 ppmv	COS is transparent to tested sorbents	Not known
	Biogas pollutant matrix	ppmv	<0.5 ppmv	DMS is the most relevant and tricky sulphur contaminant to deal with	Not known
	Sorbent capacity	g pollutant retained per g sorbent	0.1 g/g	Contaminant retention capacity of commercial sorbents is poor, especially for wet gas and contaminant mixtures	Steam added to biogas
	Gas cleaning cost	€/kWe	<1 000 €/kWe	Cost target will be difficult to meet on a small scale if biogas must be deep-chilled (4 °C)	1 000 €/kWe

**PANEL 5
HYDROGEN
FOR SECTORAL
INTEGRATION**

Project ID: 875024

Call topic: FCH-02-4-2019: New Anion Exchange Membrane Electrolysers

Project total costs: €1 999 995

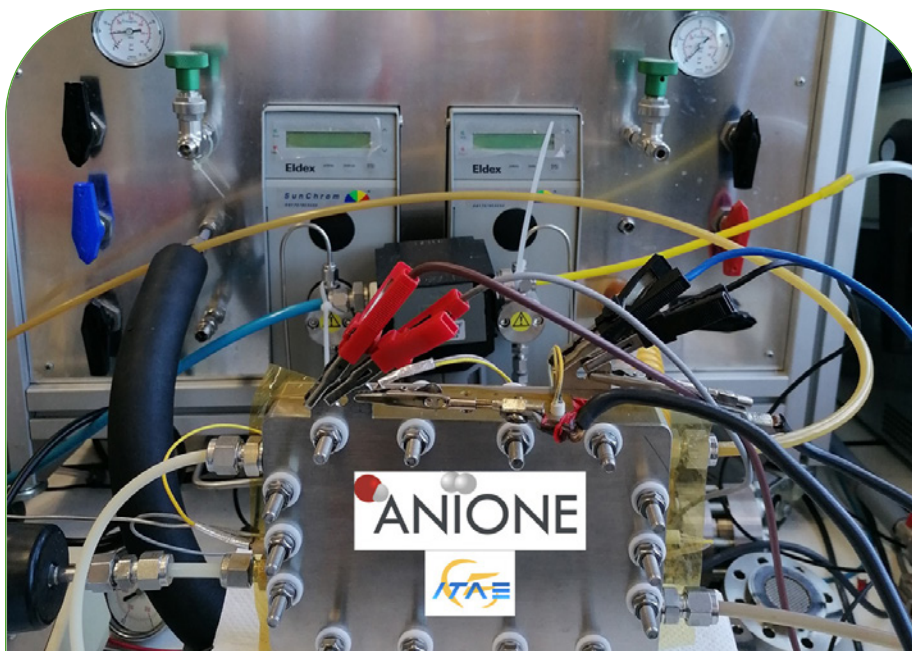
FCH JU max. Contribution: €1 999 995

Project start - end: 01/01/2020 - 31/12/2022

Coordinator: CONSIGLIO NAZIONALE DELLE RICERCHE, IT

Website: anione.eu/

BENEFICIARIES: POCELL TECH LTD, UNIVERSITE DE MONTPELLIER, PV3 TECHNOLOGIES LTD, HYDROGENICS EUROPE NV, IRD FUEL CELLS A/S, UNIRESEARCH BV, CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS



PROJECT AND OBJECTIVES

ANIONE aims to develop a high-performance, cost-effective and durable anion exchange membrane (AEM) water electrolysis technology. The approach uses 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 electro-catalysts and membrane-electrode assemblies showing promising performance and stability.

NON-QUANTITATIVE OBJECTIVES

- Enhanced oxygen evolution catalyst. Development of an advanced non-CRM, Ni-Fe-based catalyst for the oxygen evolution reaction, showing a reduced overpotential and enhanced stability
- Enhanced hydrogen evolution catalyst. Development of an advanced non-CRM, Ni-based catalyst for the hydrogen evolution reaction, showing a reduced overpotential and enhanced stability
- Advanced cost-effective membrane. Development of cost-effective advanced AEMs with proper hydroxide ion conductivity and stability

- Process implementation. Development of an AEM electrolysis operating mode showing enhanced stability
- AEM electrolysis hardware components. Implementation of advanced AEM electrolysis components in terms of diffusion layers and current collectors.

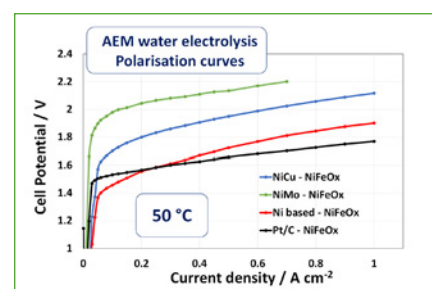
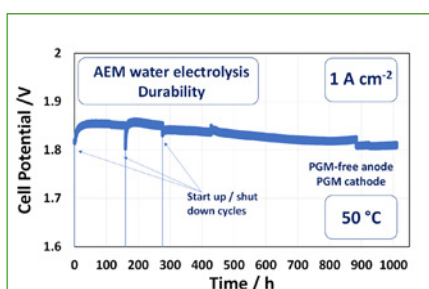
- Development of an advanced non-CRM, Ni-based catalyst for the hydrogen evolution reaction, showing a reduced overpotential of 120 mV at 1 A cm⁻²
- Development of cost-effective advanced AEMs with hydroxide ion conductivity better than 50 mS cm⁻¹.

PROGRESS AND MAIN ACHIEVEMENTS

- Development of an advanced non-CRM, Ni-Fe-based catalyst for the oxygen evolution reaction, showing a reduced overpotential of 170 mV at 1 A cm⁻²

FUTURE STEPS AND PLANS

- Further improvement of AEM membrane conductivity
- Large-area MEA testing with improved membranes
- Stack assembling and testing. Promising results have been achieved with new AEM membranes. These need to be consolidated in terms of low hydrogen crossover and MEA performance and stability.



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 FOR SOA TARGET
Project's own objectives and AWP 2019	Cell voltage at 1 A cm ⁻² (cell performance at 45 °C)	V	2	1.85	✘	1.67	2020
	Degradation rate: voltage increase at 1 A cm ⁻²	mV/h	<0.025	<0.005	✔	2	2020
	Voltage efficiency	% vs. HHV	74 %	80 %	✔	88 %	2020
	Membrane conductivity	mS cm ⁻¹	50 mS cm ⁻¹	20	✘	80	2021

BIG HIT

BUILDING INNOVATIVE GREEN HYDROGEN SYSTEMS IN AN ISOLATED TERRITORY: A PILOT FOR EUROPE

Project ID:	700092
Call topic:	FCH-03.2-2015 - Hydrogen territories
Project total costs:	€7 748 848
FCH JU max. Contribution:	€5 000 000
Project start - end:	01/05/2016 - 30/04/2022
Coordinator:	FUNDACION PARA EL DESARROLLO DE LAS NUEVAS TECNOLOGIAS DEL HIDROGENO EN ARAGON, ES
Website:	www.bighit.eu



BENEFICIARIES: CALVERA MAQUINARIA E INSTALACIONES SL, THE 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

PROJECT AND OBJECTIVES

This 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 per year of renewable power and 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

- LCA study has been completed. First report has been submitted, final report at the end of the project will include operational data
- Business model study for integrated energy systems based on hydrogen technologies across the islands. First report has been submitted, final report at the end of the project will include operational data
- Social LCA. First report has been submitted, final report at the end of the project will include operational data

- Hydrogen Territories Platform (HTP) has been launched. Two webinars have already been presented and 3 more are planned in 2021
- First analysis of project lessons learnt about the connection of electrolysers in power grids with high penetration of RES (optimal model) and marinisation of electrolysers, among other things.

PROGRESS AND MAIN ACHIEVEMENTS

- Main project equipment already built: 5 H2 trailers (250 kg H2 storage), H2 catalytic boiler (30 kW), 1 MW electrolyser; 5 H2 FC vans, 75 kW FC (cog)
- Operation of the hydrogen production site, logistics (MEGC moving H2 across the islands), H2 boiler and H2 FC vans
- Lessons learnt about: (i) connection of electrolyser in power grids with high penetration of RES (optimal model); and (ii) marinisation of electrolysers.

FUTURE STEPS AND PLANS

- Project and data analysis will run until April 2022. Problem with green hydrogen production using curtailed power to be solved (due to low curtailment)

- Consolidation of the Hydrogen Territories Platform, a tool to replicate the BIG HIT model in other locations and share lessons learnt and experiences (learning by doing approach). Four webinars are planned for 2021
- Final report on business models, LCA and S-LCA, including operational data, will be presented by the end of the project
- Main project results, conclusions and lessons learnt. To be presented at the final event in April 2022 in Orkney.



QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	PARAMETER	UNIT	TARGET	ACHIEVED TO DATE BY THE PROJECT	TARGET ACHIEVED?	
DEMONSTRATION OF A HYDROGEN CATALYTIC BOILER (THERMAL STATIC APPLICATION)						
MAWP Addendum (2018-2020)	Power	kW	40	30 kW commissioned; 10 kW FAT completed	✘	
	FUEL CELL LIGHT DUTY VEHICLES (INCLUDING CARS) AVAILABILITY – FC VANS IN BIG HIT					
	Availability	%	98	98	✔	
HRS DURABILITY						
	Time	Years	10	3rd year of operation	✘	



BIONICO

BIOGAS MEMBRANE REFORMER FOR DECENTRALISED HYDROGEN PRODUCTION

Project ID:	671459
Call topic:	FCH-02.2-2014 - Decentralised hydrogen production from clean CO ₂ -containing biogas
PRD 2020 Panel:	5 - Hydrogen for Sectoral Integration
Project total costs:	€3 396 640
FCH JU max. contribution:	€3 147 640
Project start - end:	01/09/2015 - 31/12/2019
Coordinator:	POLITECNICO DI MILANO, IT
Website:	www.bionicoproject.eu



BENEFICIARIES: TECHNISCHE UNIVERSITEIT EINDHOVEN, JOHNSON MATTHEY PLC, FUNDACION TECNALIA RESEARCH AND INNOVATION, ICI CALDAIE SPA, ABENGOA HIDROGENO SA, QUANTIS, RAUSCHERT KLOSTER VEILSDORF GMBH, ABENGOA RESEARCH SL, ENC POWER LDA, ENC ENERGY SGPS SA

PROJECT AND OBJECTIVES

The BIONICO project aimed to develop, build and demonstrate at a real biogas plant (TRL6) the use of a novel catalytic membrane reactor (CMR) for producing high-purity hydrogen from Biogas in a single step. The project achieved the targets set for component development (membrane and catalyst), energy-economic-environmental performance, laboratory experiments and reactor construction. Unfortunately, the reactor demonstration failed because of a severe auxiliary components failure that damaged the reactor, stopping the activity.

PROGRESS AND MAIN ACHIEVEMENTS

- A novel CMR for H₂ production was designed and constructed with T25 membranes and a catalyst
- A new type of membrane, thin Pd-Ag membranes (>40 cm long), was successfully prepared onto finger-like asymmetric alumina 14/7 mm
- A novel reforming catalyst was developed for the biogas composition identified in the project.

FUTURE STEPS AND PLANS

- The project has finished
- Demonstrate the catalytic membrane reactor performance in long-term tests
- Demonstrate membrane stability over long periods.



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 FOR SOA TARGET
MAWP 2014-2020	Overall efficiency	%	72	71.9	✓	65	2014
AWP 2014	Perform hydrogen production in a single step	Step	1	1	✓	4	2016
	Demonstrate BIONICO concept at a landfill plant delivering 100 kg/day	kg/day	100	N/A	✗	No system exists	N/A



BIOROBURplus

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

Project ID:	736272
Call topic:	FCH-02-2-2016 - Development of compact reformers for distributed bio-hydrogen production
Project total costs:	€3 813 536.24
FCH JU max. Contribution:	€2 996 248.74
Project start - end:	01/01/2017 - 30/06/2021
Coordinator:	POLITECNICO DI MILANO, IT
Website:	www.bioroburplus.org

BENEFICIARIES: ACEA PINEROLESE INDUSTRIALE SPA, ENGICER SA, DBI - GASTECHNOLOGISCHES INSTITUT GGMBH FREIBERG, KARLSRUHER INSTITUT FUER TECHNOLOGIE, HYSYTECH SRL, PARCO SCIENTIFICO TECNOLOGICO PER LAMBIENTE ENVIRONMENTO 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 CNRS



PROJECT AND OBJECTIVES

The BioRoburplus project is developing a pre-commercial oxidative steam reformer for the production of green hydrogen from biogas with no preliminary removal of CO₂. The plant will produce 50 Nm³/h (107 kg/day) of hydrogen with a purity of 99.9 % and an energy efficiency of 81 % on an HHV basis. The plant has been constructed, installed and the commissioning is currently ongoing at the ACEA site. A dedicated TRL6 demo campaign, using real biogas from a municipal organic-waste anaerobic digester, will run until the end of the project.

NON-QUANTITATIVE OBJECTIVES

- Dissemination and training activities. News about the installed plant is continuously posted on social media to attract interested parties/potential clients
- Improve the efficiency of hydrogen production through better heat integration of the components. Different schemes have been evaluated
- Assess component and system sustainability (LCA, HAZOP, REACH). 'Exploitation plant and Market penetration study. An LCA analysis of the general system is being carried out. REACH and HAZOP analysis of the

BioRoburplus process has been completed. Exploitation plan and decision support schemes for BioRoburplus system implementation are ongoing

- Manufacturing of supports and catalyst coating process. Final catalyst formulation has been coated on the support structure
- Development of a compact and cost-effective fuel processor for distributed H₂ production that offers easy scalability. The BioRoburplus subunits were carefully developed to achieve the project's objectives. The plant can be scaled up, which is important for exploiting most of the decentralised application opportunities and reducing the final H₂ costs. The techno-economic analysis showed that to reduce the cost of H₂ and make it competitive, it is necessary to increase the production volume; mass production and a demand for green hydrogen is needed.

PROGRESS AND MAIN ACHIEVEMENTS

- A TRL6 demo unit for green H₂ production from biogas with a high degree of integration has been manufactured, installed and 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 commissioning of the TRL6 demo plant is expected to be completed by April 2021
- Start the testing campaign using real biogas at the ACEA site in the coming weeks. It will run until June 2021
- Test the performance and stability of the structured catalyst developed. The performances and stability of the catalyst selected for the biogas reforming will be demonstrated in the final testing campaign in the coming weeks
- Collect and analyse the experimental data to complete the LCA and the techno-economic analysis and to drive future scale-up of the technology. Each component is being tested and the data analysed. The data from the test campaign will be used to assess the performance of the plant and identify potential improvements.

QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	PARAMETER	UNIT	TARGET	TARGET ACHIEVED?	SOA RESULT ACHIEVED TO DATE (BY OTHERS)	YEAR FOR SOA TARGET
Project's own objectives	Nominal H ₂ production capacity	Nm ³ /h	50	✘ (still ongoing)	50 Nm ³ /h with an overall efficiency of the conversion of biogas to green hydrogen of 65 %	2016
	Overall plant efficiency based on HHV	%	≥80	✘ (still ongoing)	Overall plant efficiency of 65 % for a processor with a nominal production rate of 50 Nm ³ /h of hydrogen	
	Reformer outlet CO concentration a dry-basis	%	<8	✓ Experimental test at lab scale. To be demonstrated at TRL6 level	10	
AWP 2016	H ₂ purity	%	99.99	✘ (still ongoing)	BioRobur delivered 50 Nm ³ /h of 99.9 % hydrogen from biogas	

Project ID:	875088
Call topic:	FCH-02-4-2019 - New Anion Exchange Membrane Electrolysers
Project total costs:	€1 999 906.25
FCH JU max. Contribution:	€1 999 906.25
Project start - end:	01/01/2020 - 31/12/2022
Coordinator:	SINTEF AS, NO
Website:	www.channel-fch.eu

BENEFICIARIES: ENAPTER SRL, EVONIK CREAVIS GMBH, SHELL GLOBAL SOLUTIONS INTERNATIONAL BV, EVONIK OPERATIONS GMBH, NORGE TEKNISKNATURVITENSKAPELIGE UNIVERSITET NTNU, FORSCHUNGSZENTRUM JULICH GMBH



PROJECT AND OBJECTIVES

The main objective of CHANNEL is to develop a low-cost and efficient electrolyser stack and balance of plant (BoP) that will become a game-changer for the electrolyser industry. The concept is to construct an AEM electrolyser unit using low-cost materials, advanced anion exchange membranes and ionomers, non-PGM electrocatalysts, as well as low-cost porous transport layers, current collectors and bipolar plates. To date, we have developed non-PGM catalysts and optimised AEM membranes and ionomers, in addition to a preliminary stack design and selection of stack components.

NON-QUANTITATIVE OBJECTIVES

- Design a preliminary 2 kW stack. A report has been submitted
- Characterisation of porous transport layers based on nickel and stainless steel. This has been completed
- Training students: two students from the University of St Andrews have been working on the project to date

- Journal publication: we have one publication on catalyst development
- Contribute to the AEM test protocol harmonisation workshop, attended with the NEWELY and ANIONE consortiums.

PROGRESS AND MAIN ACHIEVEMENTS

- We have developed highly active hydrogen evolution reaction (HER) and oxygen evolution reaction (OER) electrocatalysts
- Optimised properties for both AEM ionomers and membranes
- Submitted a preliminary stack design for the 2-kW demonstrator/prototype.

FUTURE STEPS AND PLANS

- Further optimisation of the membranes and ionomers to enhance mechanical and chemical properties, which is ongoing

- We are publishing a journal article (in progress) based on modelling of the transient P2D AEM model and simulation of electrode catalyst loading and composition as a function of KOH concentration, temperature and cell current density. This offers additional insights into the drivers of AEM cell performance and assists optimisation activities
- A plan to implement the model in the open-source system modelling to allow others in the research community to utilise the platform to make informed decisions about how best to optimise AEM electrolyser technologies
- Demonstration of the preliminary AEM stack prototype before end of 2021. The design of the preliminary stack has been finalised. Partners are in the process of providing materials, such as electrodes, porous transport layers, membranes, etc.

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 FOR SOA TARGET
Project's own objectives	OER catalyst performance	mV	<300 mV (at 10 mA/cm ² 1 M KOH)	237 mV (1 M KOH) 270 mV (0.1 M KOH)	✓	Ir-based catalyst (250 mV at 10 mA/cm ²)	2019
	HER catalyst performance	mV	<150 mV (at -0.2 V vs RHE)	60 mV in 1 M KOH, 120 mV in 0.1 M KOH	✓		
	OER catalyst stability	mV	<25 mV degradation over 1 000 h in RDE	33 mV	✗	N/A	N/A
	HER catalyst stability	mV	<25 mV degradation over 1 000 h in RDE	26 mV	✗		
AWP 2019	Membrane OH-conductivity (T=RT)	mS/cm	50	<45	✗	ca. 120 (50-micron membrane from Sustainion) 40-45 mS/cm FAA-3 (Fumatech)	2020
	Ionomer OH conductivity, T = 60 °C	mS/cm	20	>60	✓	N/A	N/A



Demo4Grid

DEMONSTRATION OF 4MW PRESSURIZED ALKALINE ELECTROLYSER FOR GRID BALANCING SERVICES

Project ID:	736351
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:	€7 736 682.5
FCH JU max. Contribution:	€2 932 554.38
Project start - end:	01/03/2017 - 31/08/2023
Coordinator:	DIADIKASIA BUSINESS CONSULTING SYMVOULOI EPICHEIRISEON AE, EL
Website:	www.demo4grid.eu/



BENEFICIARIES: FEN SUSTAIN SYSTEMS GMBH, MPREIS WARENVERTRIEBS GMBH, INSTRUMENTACION Y COMPONENTES SA, FUNDACION PARA EL DESARROLLO DE LAS NUEVAS TECNOLOGIAS DEL HIDROGENO EN ARAGON, IHT INDUSTRIE HAUTE TECHNOLOGIE SA

PROJECT AND OBJECTIVES

The main aim of Demo4Grid is the commercial setup and demonstration of a technical solution utilising 'above state-of-the-art' pressurized alkaline electrolyser (PAE) technology for providing grid balancing services in real operational and market conditions. The final 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

- Engineering documents, analysis of RCS and safety requirements are in place
- A project-specific business model has been updated
- Civil engineering works for the electrolysis building are being finalised, the KOH storage tank has been installed the first electrolysis BoP skids have been received.

FUTURE STEPS AND PLANS

- The PAE will be delivered at the demo site by October 2021. The hall of the electrolysis building is ready for installation and pipework. The first electrolysis BoP skids (pre-heating unit) have been received and

- lifted into place. The installation of the HVAC on the first floor of building is progressing
- The PAE will be commissioned by mid-November 2021.

- The PAE will be fully operational by mid-December 2021.



QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	PARAMETER	UNIT	TARGET	TARGET ACHIEVED?	SOA RESULT ACHIEVED TO DATE (BY OTHERS)	YEAR FOR SOA TARGET
Project's own objectives	H ₂ production electrolysis, hot start from min. to max. power	s	2	✘	60	2015
	Start-up time KPIs from cold to minimum part load for alkaline electrolysers	min	20		20	
	Minimum part load operation targets for alkaline electrolysers	% (full load)	20		30	
	Ramp up	% (full load)/s	7		7	
	Ramp down	% (full load)/s	10		10	



DJEWELS

DELFIJL JOINT DEVELOPMENT OF GREEN WATER ELECTROLYSIS AT LARGE SCALE

Project ID:	826089
Call topic:	FCH-02-1-2018 - Demonstration of a large scale (min. 20MW) electrolyser for converting renewable energy to hydrogen
Project total costs:	€43 929 750
FCH JU max. Contribution:	€10 999 999
Project start - end:	01/01/2020 - 31/12/2025
Coordinator:	NOURYON INDUSTRIAL CHEMICALS BV, NL
Website:	djewels.eu

BENEFICIARIES: BIOMETHANOL CHEMIE NEDERLAND BV, INDUSTRIE DE NORA SPA-IDN, HINICIO SA, MCPHY ENERGY, NV NEDERLANDSE GASUNIE



PROJECT AND OBJECTIVES

The Djewels project aims to demonstrate the operational readiness of a 20 MW electrolyser for the production of renewable fuels (renewable methanol) in real-life industrial and commercial conditions. It will take the technology from TRL 7 to TRL 8 and lay the foundations for the next scale-up step, towards a 100 MW electrolyser at the same site. The project is currently in the engineering phase (20 MW) and piloting phase (1 MW stack) in Les Renardières (FR).

NON-QUANTITATIVE OBJECTIVES

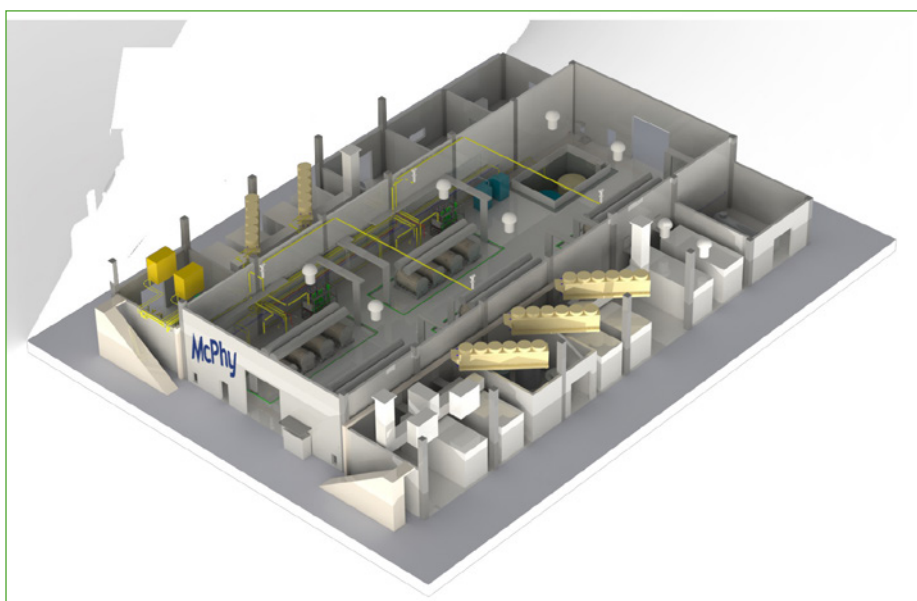
- Safety performance
- Completion of HAZOP.

PROGRESS AND MAIN ACHIEVEMENTS

- Constructions of the 1 MW stack testing facility is complete
- Finalisation of HAZOP.

FUTURE STEPS AND PLANS

- Finish stack testing and optimisation. This is delayed and anticipated to be completed in summer 2021
- Investment decision in summer 2021
- Construction to be completed in 2024.



QUANTITATIVE TARGETS AND STATUS

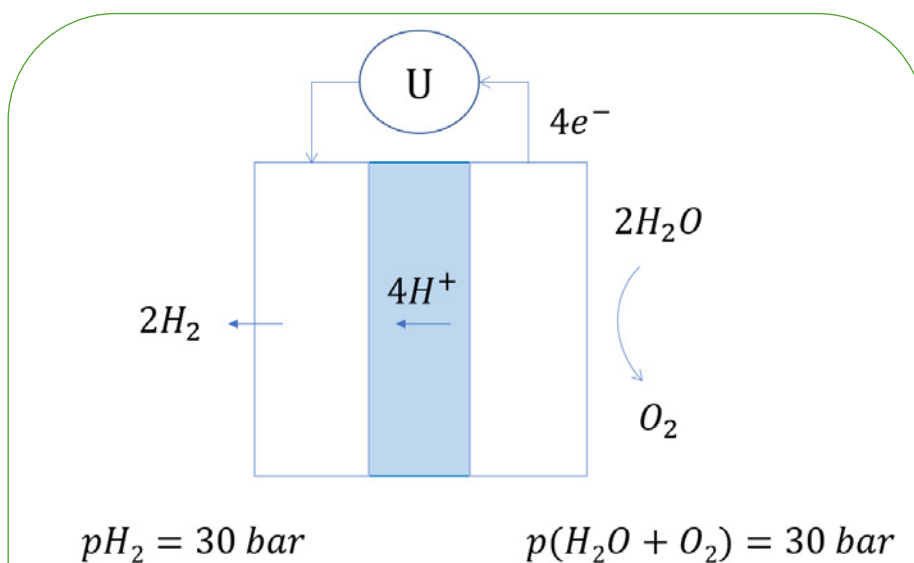
TARGET SOURCE	PARAMETER	UNIT	TARGET	TARGET ACHIEVED?
MAWP Addendum (2018-2020)	Energy consumption	kWh/kg	<52.8	✘
	Efficiency degradation	%/year	0.72	
	Flexibility with degradation below 2 %/year	% of nominal power	3-110	
Project's own objectives	Nominal capacity	MW	20	



GAMER

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

Project ID:	779486
Call topic:	FCH-02-2-2017 - Game changer High Temperature Steam Electrolysers
Project total costs:	€2 998 951.25
FCH JU max. Contribution:	€2 998 951.25
Project start - end:	01/01/2018 - 31/12/2021
Coordinator:	SINTEF AS, NO
Website:	www.sintef.no/projectweb/gamer/



BENEFICIARIES: AGENCIA ESTATAL CONSEJO SUPERIOR DE INVESTIGACIONES CIENTIFICAS, STIFTELSEN SINTEF, UNIVERSITETET I OSLO, SHELL GLOBAL SOLUTIONS INTERNATIONAL BV, COORSTEK MEMBRANE SCIENCES AS, CRI EHF, MC2 INGENIERIA Y SISTEMAS SL

PROJECT AND OBJECTIVES

The GAMER project will develop a novel cost-effective tubular proton ceramic electrolyser (PCE) stack that will produce pure dry pressurised hydrogen. The electrolyser system will be thermally coupled to renewable or waste heat sources in industrial plants to achieve higher AC electrical efficiency. The project will establish the science and technology for the high-volume production of novel tubular cells and will develop designs of system and balance of plant components supported by advanced modelling and simulation work, flowsheets of integrated processes.

NON-QUANTITATIVE OBJECTIVES

- Dissemination activities. Four papers are under preparation, and we participated in a seminar

- Process integration studies, producing a report that addresses the benefits and challenges of electrolysis integration in industrial plants
- Exploitation activities. Two spin-off projects have been established
- Technical activities. Factory acceptance test of the testing rig with BoP
- Assembly of single engineering units (SEUs) for qualification: 13 have been delivered to the project.

PROGRESS AND MAIN ACHIEVEMENTS

- Production of several SEUs was successfully tested in pressurised electrolysis mode at 600 °C
- Building of the testing equipment with the necessary BoP and power electronics
- Operation of SEU in pressurised electrolysis mode at 600 °C at up to 10 bar.

FUTURE STEPS AND PLANS

- Scale up production of SEUs: in progress
- Building of furnace and SEU assembly in the prototype demonstrator: in progress
- Publication of results. Several drafts are available
- Finalisation of LCA studies. Draft deliverable under review by partners
- Installation and commissioning of prototype. Planned for mid-2021
- Testing of prototype. Planned for/to perform after task 5.

QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	PARAMETER	UNIT	TARGET	ACHIEVED TO DATE BY THE PROJECT	TARGET ACHIEVED?	SOA RESULT ACHIEVED TO DATE (BY OTHERS)
Project's own objectives	Tubular electrochemical SEU resistance at 3 bar	ohm.cm ²	2-4	2-4	✓	2.8
	Faradaic efficiency of the SEU at 3 bar at 0.1 mA/cm ² at 600 °C	%	80+	80	✓	No other project makes SEU
	Maximum decrease of the voltage after 500 h at 600 °C at 100 mA/cm ²	%	<5	1.4	✓	No other project makes SEU



Project ID: 826350

Call topic: FCH-02-2-2018 - Demonstration of large scale steam electrolyser system in industrial market

Project total costs: €5 882 492.50

FCH JU max. Contribution: €3 999 993.25

Project start - end: 01/01/2019 - 31/12/2022

Coordinator: SALZGITTER MANNESMANN FORSCHUNG GMBH

Website: www.green-industrial-hydrogen.com/

BENEFICIARIES: PAUL WURTH SA, SUNFIRE GMBH, SALZGITTER FLACHSTAHL GMBH, TENOVA SPA, COMMISSARIAT A L'ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES

PROJECT AND OBJECTIVES

GrInHy2.0 is about the manufacturing and operation of the world's biggest high-temperature electrolyser with a capacity of 720 kW AC and an electrical efficiency of 84 % LHV. While the technology's Carbon Direct Avoidance potential for the future European steel industry is being assessed, the electrolyser will produce more than 100 tons of 'green' hydrogen based on steam from industrial waste heat in >13 000 operational hours for today's steel production in Salzgitter. In December 2020, the system injected hydrogen for the first time and is currently being validated for operational procedures.

NON-QUANTITATIVE OBJECTIVES

- Assessing the CO₂ avoidance potential of hydrogen for the European steel industry
- First calculations show the CDA potential of hydrogen in DRP replacing carbon-reducing agents. The results will be used for a future roll-out study.

PROGRESS AND MAIN ACHIEVEMENTS

- The system's 'electrolyser' and 'hydrogen processing unit' have been manufactured and the installation site is being completed

- First-time injection was about 100 Nm³/h during commissioning
- The long-term stack test at the CEA labs has started.

FUTURE STEPS AND PLANS

- Start of system operation in September 2020
- Production of at least 100 tonnes of hydrogen by the end of 2021
- Reaching the objectives of 13 000 operational hours and a system availability of 95 % in early 2022
- Completion of 20 000 hours of continuous stack testing in October 2022.

QUANTITATIVE TARGETS AND STATUS

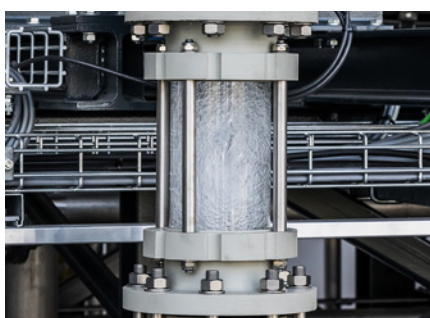
TARGET SOURCE	PARAMETER	UNIT	TARGET	ACHIEVED TO DATE BY THE PROJECT	TARGET ACHIEVED?	SOA RESULT ACHIEVED TO DATE (BY OTHERS)	YEAR FOR SOA TARGET
AWP 2018	Hydrogen production rate	kg/h	18	9		3.6	2017
	Total production of 'green' hydrogen	t	100	1	✂	N/A	
	Electrical efficiency based on LHV	%	84	-		78	
	CAPEX	€/(kg/d)	4 500	4 500	✓	12 000	
	Demonstration of hot start from min. to max. power	min	5			10	2018
	Hours of operation	Hours	13 000	-		10 000	2019
	Availability	%	95		✂	66	
Project's own objectives	Cost of hydrogen	€/kg	7			N/A	N/A
	Hours of continuous stack testing	Hours	20 000	4 500		8 700	2019



H2FUTURE
Green Hydrogen

H2Future

HYDROGEN MEETING FUTURE NEEDS OF LOW CARBON MANUFACTURING VALUE CHAINS



Project ID: 735503

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: €17 852 540.38

FCH JU max. Contribution: €11 997 820.01

Project start - end: 01/01/2017 - 30/06/2021

Coordinator: VERBUND Solutions GmbH, AT

Website: www.h2future-project.eu

BENEFICIARIES: SIEMENS ENERGY AUSTRIA GMBH, SIEMENS ENERGY GLOBAL GMBH & CO. KG, K1-MET GMBH, VOESTALPINE STAHL GMBH, AUSTRIAN POWER GRID AG, SIEMENS AKTIENGESELLSCHAFT OESTERREICH, SIEMENS AKTIENGESELLSCHAFT, STICHTING ENERGIEONDERZOEK CENTRUM NEDERLAND, NEDERLANDSE ORGANISATIE VOOR TOEGEPAST NATUURWETENSCHAPPELIJK ONDERZOEK TNO, VERBUND ENERGY4BUSINESS GMBH

PROJECT AND OBJECTIVES

The main goals of the H2FUTURE project are to design and install a 6 MW PEM electrolyser system at the voestalpine steel plant in Linz and to execute a two-year demonstration operation of the electrolyser system with ambitious efficiency targets. The plant started production at the end of 2019. During commissioning the plant was pre-qualified for grid-balancing services such as primary, secondary or tertiary reserves. The pilot test phase was executed from March to September 2020.

NON-QUANTITATIVE OBJECTIVES

- Project communication. In order to keep everyone well informed, there were more meetings between project participants than planned
- Range and scalability. The load range of the plant exceeded the targeted values.

PROGRESS AND MAIN ACHIEVEMENTS

- Finalisation of the pilot test phase in the scheduled time
- Plant has provided primary and secondary reserve to the electricity grid
- Plant has been in quasi-commercial operation since 15 October 2020.

FUTURE STEPS AND PLANS

- Application for project extension until the end of 2021 due to some project delays. The remaining project duration time was too short for the planned 3 000 operational hours
- Catch up with open deliverables. Some deliverables have been delayed.



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	%	77-82	
	Range and scalability	%	20-100	

Project ID:	779469
Call topic:	FCH-02-4-2017 - Highly flexible electrolyzers balancing the energy output inside the fence of a wind park
Project total costs:	€7 613 404.45
FCH JU max. Contribution:	€4 997 738.63
Project start - end:	01/01/2018 - 31/12/2021
Coordinator:	SINTEF AS, NO
Website:	www.haeolus.eu

BENEFICIARIES: VARANGER KRAFTHYDROGEN AS, VARANGER KRAFTMARKED AS, VARANGER KRAUFTUTVIKLING AS, VARANGER KRAFTENTERPRENOR AS, VARANGER KRAFT AS, VARANGER KRAFTNETT AS, VARANGER KRAFTVIND AS, COMMUNAUTE D'UNIVERSITES ET ETABLISSEMENTS UNIVERSITE BOURGOGNE - FRANCHE - COMTE, NEW NEL HYDROGEN AS, KES KNOWLEDGE ENVIRONMENT SECURITY SRL, HYDROGENICS EUROPE NV, UNIVERSITA DEGLI STUDI DEL SANNIO, ECOLE NATIONALE SUPERIEURE DE MECANIQUE ET DES MICROTECHNIQUES, UNIVERSITE DE TECHNOLOGIE DE BELFORT - MONTBELIARD, FUNDACION TECNALIA RESEARCH & INNOVATION, UNIVERSITE DE FRANCHE-COMTE, STIFTELSEN SINTEF



PROJECT AND OBJECTIVES

The project will demonstrate the operation of a 2.5 MW electrolyser in conjunction with a wind park. The objectives are to deploy and demonstrate several operational concepts (re-electrification, mini-grid, fuel production) and remote operation, enabling higher wind power uptake in power grids. The project has been delayed by a number of issues, including the COVID-19 pandemic. The installation of the system was expected in May 2021 and operation within the project will then continue until the end of 2023 (pending amendment of the grant agreement).

NON-QUANTITATIVE OBJECTIVES

- Model-predictive controllers for multiple use cases, developed with corresponding test protocols
- Public studies on wind-hydrogen plants for techno-economic analysis, business case and impact on energy systems. LCA study awaits operational data
- Stimulate the 'Hydrogen valley' in Finnmark (NO). Several initiatives have started (biogas upgrade, maritime hydrogen and ammonia), with good contact with local authorities.

PROGRESS AND MAIN ACHIEVEMENTS

- Synthesised control algorithms and testing protocols for multiple use cases of hydrogen-wind systems
- Analysed several techno-economic aspects of the specific project plant and similar plants in multiple EU countries, including impact on energy systems
- Identified multiple opportunities for hydrogen and by-product valorisation in the region (biogas upgrade, ammonia production, maritime propulsion, etc.).

FUTURE STEPS AND PLANS

- System deployment, installation and start-up is expected in May 2021, depending on pandemic developments
- Demonstration of all three use cases
- Dissemination actions (site visit, industrial fair presence, etc.) compatible with pandemic developments.



QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	PARAMETER	UNIT	TARGET	ACHIEVED TO DATE BY THE PROJECT	TARGET ACHIEVED?
MAWP Addendum (2018-2020) and AWP 2017	CAPEX	M€/tpd	3	1.33	✓
	Efficiency	kWh/kg	52	51.88	✓
Project's own objectives	Degradation	%/year	1.5	N/A	✗



HEAVENN

HYDROGEN ENERGY APPLICATIONS FOR VALLEY ENVIRONMENTS IN NORTHERN NETHERLANDS



Project ID:	875090
Call topic:	FCH-03-1-2019 - H2 Valley
Project total costs:	€98 998 216.18
FCH JU max. Contribution:	€20 000 000
Project start - end:	01/01/2020 - 31/12/2025
Coordinator:	STICHTING ENERGY VALLEY, NL

BENEFICIARIES: STICHTING NEW ENERGY COALITION, TOTAL NEDERLAND NV, GEMEENTE HOOGEVEEN, HYDROGEN IRELAND NATURAL RESOURCES ASSOCIATION COMPANY LBG, NEDERLANDSE PARTICULIERE RIJNVAART-CENTRALE COOPERATIE UA, UVO VERVOER BV, LENTEN SCHEEPVAART BV, BYTESNET GRONINGEN BV, EWE GASSPEICHER GMBH, ENERCY 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, EBN BV 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, HINICIO SA, NOURYON INDUSTRIAL CHEMICALS BV, FUNDACION PARA EL DESARROLLO DE LAS NUEVAS TECNOLOGIAS DEL HIDROGENO EN ARAGON, NV NEDERLANDSE GASUNIE, THE EUROPEAN MARINE ENERGY CENTRE LIMITED, RIJKSUNIVERSITEIT GRONINGEN

PROJECT AND OBJECTIVES

HEAVENN is a large-scale demo project that brings together core elements – production, distribution, storage and local end-use of H₂ – in a fully integrated and functioning ‘H₂ Valley’ (H₂V) that can serve as a blueprint for replication across Europe and beyond. The main goal is to make use of green hydrogen across the entire value chain, while developing replicable business models for wide-scale commercial deployment of H₂ across the entire regional energy system. HEAVENN aims to become a Hydrogen Valley blueprint for other regions to replicate.

NON-QUANTITATIVE OBJECTIVES

- RCS certification. Relevant green H₂ value chains will be tested against the CertiHy protocol
- The safety issues will be covered by the permitting procedures
- Education and training on technologies and acceptance via the GWB project, specifically for SMEs.

- Decision made on the minimum design capacity of the Shell electrolyser in Emmen (2 with a minimum 4 MW size)
- Underground storage activities initiated with first test setups in the Zuidwending salt dome.

PROGRESS AND MAIN ACHIEVEMENTS

- First (15 of 105) passenger vehicles acquired for cluster 4 to participant in Green Planet. Now awaiting the opening of the Green Planet fuelling station

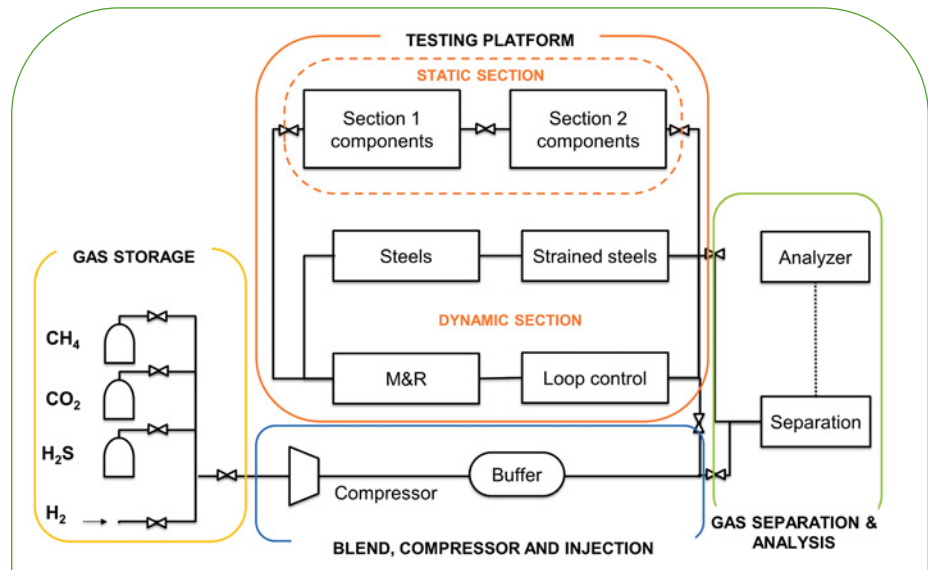
FUTURE STEPS AND PLANS

Catch-up actions: make an inventory of delays due to COVID-19 and define mitigating measures to address time, scope and budget.

QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	PARAMETER	UNIT	TARGET	TARGET ACHIEVED?	SOA RESULT ACHIEVED TO DATE (BY OTHERS)	YEAR FOR SOA TARGET	
MAWP Addendum (2018-2020)	FCH PASSENGER CARS						
	FC system cost	€/kWh	60	✘	100	2019	
	Maintenance	€/km	0.03		0.04		
	Availability	%	98		98	2017	
	Durability	Hours	5 000		4 000		
	H ₂ PRODUCTION (ELECTROLYSIS) – PEM						
	Energy commission consumption	kWh/kg	50	✘	55	2020	
	CAPEX	€/kWh	<900		900		
	O&M	€/kg d/y	41		41		
	STORAGE, DISTRIBUTION AND H ₂ SUPPLY						
	Large storage system cost	€/kg	0.8	✘	N/A	2024	
	Release energy use	kWh/kg	10		10		
	HRS						
	CAPEX	k€/day		4-2	✘	7	2017

Project ID:	875091
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:	€2 107 672.50
FCH JU max. Contribution:	€2 107 672.50
Project start - end:	01/01/2020 - 31/12/2022
Coordinator:	FUNDACION PARA EL DESARROLLO DE LAS NUEVAS TECNOLOGIAS DEL HIDROGENO EN ARAGON, ES
Website:	www.higgsproject.eu/



BENEFICIARIES: REDEXIS GAS SA, EUROPEAN RESEARCH INSTITUTE FOR GAS AND ENERGY INNOVATION, HSR HOCHSCHULE FUR TECHNIK RAPPERSWIL, DVGW DEUTSCHER VEREIN DES GAS- UND WASSERFACHES - TECHNISCH-WISSENSCHAFTLICHER VEREIN EV, FUNDACION TECNALIA RESEARCH & INNOVATION

PROJECT AND OBJECTIVES

HIGGS aims to fill the gaps in our knowledge of the impact of high levels of hydrogen on high-pressure natural gas infrastructure, its components and its management. Several activities will be developed to reach this goal, including mapping technical, legal and regulatory barriers and enablers, testing materials/components, techno-economic modelling and preparing a set of conclusions as a pathway towards enabling the injection of hydrogen in high-pressure gas grids. The inventory of materials, equipment and RCS is partly finished and the testing platform has been designed.

NON-QUANTITATIVE OBJECTIVES

- Draw up RCS recommendations
- Determine a pathway for the stepwise integration of hydrogen in the EU gas network
- Develop a techno-economic model and study the role of technologies for integrating H₂/CH₄ and sector coupling at EU level.

PROGRESS AND MAIN ACHIEVEMENTS

- Admixture system and testing platform designed to enable dynamic and static testing
- List of materials, equipment and components from natural gas transmission grid selected for testing
- Mapping of RCS at EU level is partly finished.

FUTURE STEPS AND PLANS

- Commission and assemble the admixture system and testing platform. Civil works have started
- Test campaigns on materials, components and equipment carried out with different hydrogen concentrations blended with methane, including separation processes for admixtures up to 15 % H₂ injected. The test campaigns are expected to start in summer 2021
- Characterise materials before and after hydrogen exposure in order to evaluate the effect of injecting this gas. Not yet started
- RSC review at European and national level to be assembled, reviewed and compiled in a

- comprehensive report comprising diagrams and graphs, for distribution on the website and for presentations and papers. The first overview report will be ready by June 2021 and results will be reviewed and updated throughout the project
- Baseline definition and studies of cases of blending hydrogen into natural gas. Simulation of these cases and analysis of techno-economic aspects. Literature review of international hydrogen strategies. Data acquisition for the techno-economic model (grid structure and parameters) and its boundary conditions in a European context
- Develop and describe a pathway towards integrating hydrogen into the EU gas networks, including proposals at national level (EU 26+). This is ongoing work and will deliver four reports, which are all public. The main and final report, published by the end of 2022, will be the pathway description. The results will 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	%	Not defined	Not started	✘
	H ₂ compatibility of materials and equipment in transmission networks	%	Not defined	Not started	
	H ₂ incorporated in standards through CEN technical committees	-	Recommendations	N/A	
	Scalable separation technology	TRL	4-6	3	

Project ID:	671384
Call topic:	FCH-02.10-2014 - Demonstrating the feasibility of central large scale electrolysers in providing grid services and hydrogen distribution and supply to multiple high value markets
Project total costs:	€15 803 441.25
FCH JU max. Contribution:	€7 999 370.8
Project start - end:	01/10/2015 - 30/09/2020
Coordinator:	AIR LIQUIDE ADVANCED BUSINESS, FR
Website:	www.hybalance.eu



BENEFICIARIES: LUDWIG-BOELKOW-SYSTEMTECHNIK GMBH, HYDROGENICS EUROPE NV, COPENHAGEN HYDROGEN NETWORK AS, FORDONSGAS SVERIGE AB, NEAS ENERGY AS, CEMTEC FONDEN, AIR LIQUIDE GLOBAL E&C SOLUTIONS FRANCE

PROJECT AND OBJECTIVES

HyBalance demonstrates the link between energy storage in the form of hydrogen and the deployment of hydrogen mobility solutions. The production of green hydrogen based on wind power using electrolysis is a well-known and proven technology, but the HyBalance project implements advanced key technologies. It not only validates highly dynamic PEM electrolysis technology and the innovative hydrogen delivery processes involved, but also demonstrates these in a real-life industrial environment.

PROGRESS AND MAIN ACHIEVEMENTS

- Commissioning of the plant and supply of hydrogen to industrial and clean mobility customers
- PEM electrolysis technology achieved a high level of availability, efficiency, reactivity and flexibility during the plant operation
- The Danish Transmission System Operator Energinet.dk homologated the plant to provide grid services on all energy markets.

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)	YEAR FOR SOA TARGET
MAWP (2014-2020)	Cost goal	€/kW	1 570	1 810	✘	1 200	2020
AIP 2014	Efficiency	kWhel/kg H ₂	57.5	56.5	✘	55.3 - 52.2	2018 - 2019
	System lifetime	Hours	20 000	>16 000	✘	>10 200	N/A



HyCARE

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

Project ID: 826352

Call topic: FCH-02-5-2018 - Hydrogen carriers for stationary storage of excess renewable energy

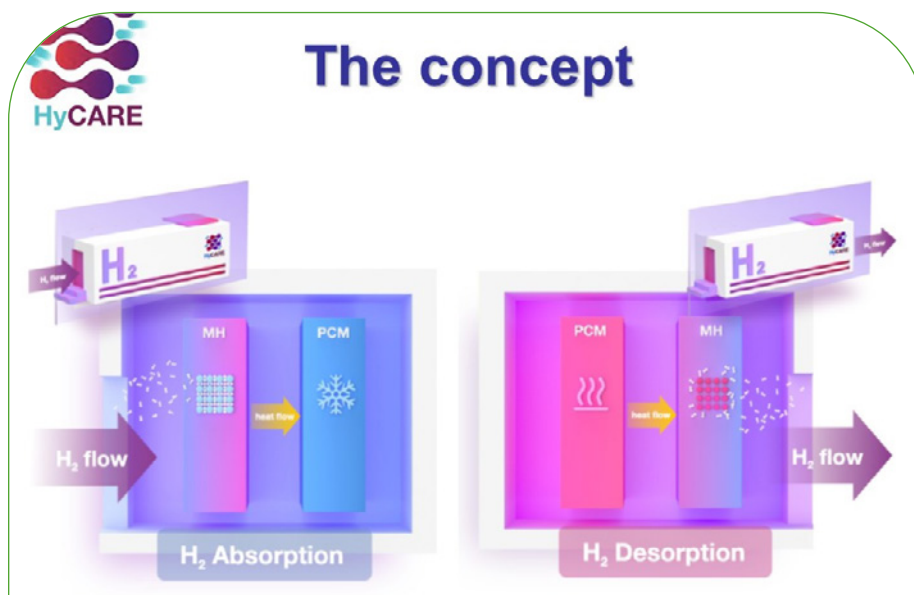
Project total costs: €1 999 230

FCH JU max. Contribution: €1 999 230

Project start - end: 01/01/2019 - 31/12/2021

Coordinator: PARCO SCIENTIFICO TECNOLOGICO PER LAMBIENTE ENVIRONMENT PARK TORINO SPA

Website: hycare-project.eu/



BENEFICIARIES: STUEHFF GMBH, TECNodelta SRL, GKN SINTER METALS ENGINEERING GMBH, PARCO SCIENTIFICO TECNOLOGICO PER LAMBIENTE ENVIRONMENT PARK TORINO SPA, INSTITUTT FOR ENERGITEKNIKK, HELMHOLTZ-ZENTRUM GEESTHACHT ZENTRUM FUR MATERIAL- UND KUSTENFORSCHUNG GMBH, FONDAZIONE BRUNO KESSLER, ENGIE, CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS

PROJECT AND OBJECTIVES

The main objective of the HyCARE project is to develop a demonstration of a hydrogen storage tank using a solid-state hydrogen carrier at large scale. The tank will be based on an innovative concept, combining hydrogen and heat storage, in order to improve the energy efficiency of the whole system. The tank developed will be installed at the site of ENGIE Lab CRIGEN. The main steps of the project are up and running properly, but other activities have been delayed due to the pandemic. The project will now end in 2022 rather than 2021.

NON-QUANTITATIVE OBJECTIVES

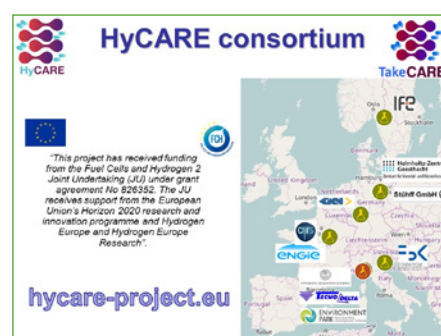
- Safety: low T and P for storing hydrogen using carriers
- Improving the energy efficiency of the hydrogen storage using heat storage via PCM.

PROGRESS AND MAIN ACHIEVEMENTS

- The composition of the MH has been defined and characterised. The PCM has been selected. Materials are available for the demonstrator
- MH and PCM tank design have been finalised. A draft of P&ID of the demonstrator is available. A prototype system has been built and tested
- The site for the demonstrator has been decided. EL and FC have been commissioned. TEA and LCA have been set up. Dissemination and exploitation are active.

FUTURE STEPS AND PLANS

- Set up and test the final demonstrator. This is under way, with the conclusions now delayed by 6 months and expected for June 2022
- The results obtained will be analysed by TEA and LCA and their potential for exploitation will be explored.

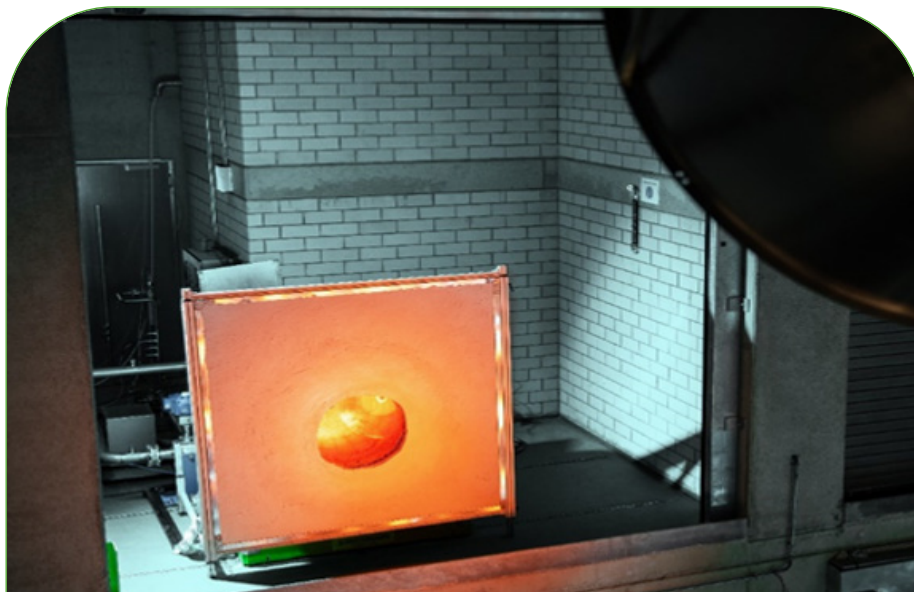


QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	PARAMETER	UNIT	TARGET	ACHIEVED TO DATE BY THE PROJECT	TARGET ACHIEVED?
Project's own objectives	Volumetric capacity of H ₂ carrier	kg H ₂ per unit of volume of carrier	N/A	Reversible capacity at 55 °C between 1-25 bar equal to 69.3	✗
	Gravimetric capacity of H ₂ carrier	Gravimetric capacity of the H ₂ carrier in weight %		Reversible capacity at 55 °C between 2-20 bar is equal to 1.4	✗
	Hydrogen storage capacity	Maximum amount of H ₂ in kg that can be stored in the system		44 reversibly (55 °C, 1-25 bar)	✗
	Max. tank pressure	Pressure rating of the H ₂ carrier tank in bar	<50	40	✓
	Cyclability	Number of full cycles until reaching 2 % reduction in the gravimetric capacity of the H ₂ carrier	250	250	✓



Project ID:	826379
Call topic:	FCH-02-4-2018 - Thermochemical Hydrogen Production from Concentrated Sunlight
Project total costs:	€2 999 940
FCH JU max. Contribution:	€2 999 940
Project start - end:	01/01/2019 - 31/12/2022
Coordinator:	ETHNIKO KENTRO EREVNAS KAI TECHNOLOGIKIS ANAPTYXIS, EL
Website:	www.hydrosol-beyond.certh.gr/



BENEFICIARIES: HYGEAR OPERATIONS BV, HYGEAR HYDROGEN PLANT BV, HYGEAR TECHNOLOGY AND SERVICES BV, ENGICER SA, ABENGOA INNOVACION SOCIEDAD ANONIMA, HYGEAR FUEL CELL SYSTEMS BV, HYGEAR BV, SCUOLA UNIVERSITARIA PROFESSIONALE DELLA SVIZZERA ITALIANA, CENTRO DE INVESTIGACIONES ENERGETICAS, MEDIOAMBIENTALES Y TECNOLOGICAS-CIEMAT, DEUTSCHES ZENTRUM FÜR LUFT- UND RAUMFAHRT EV, COMMISSARIAT A L'ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES

PROJECT AND OBJECTIVES

Hydrosol-beyond is a 4-year project that focuses on two sets of activities running in parallel. The first is the investigation, design and development of novel concepts that will be integrated in the existing plant (super heat exchanger, N₂ minimisation and purification). Secondly, tasks and activities at the Solar Platform of Almeria (ES) to perform solar experiments.

NON-QUANTITATIVE OBJECTIVES

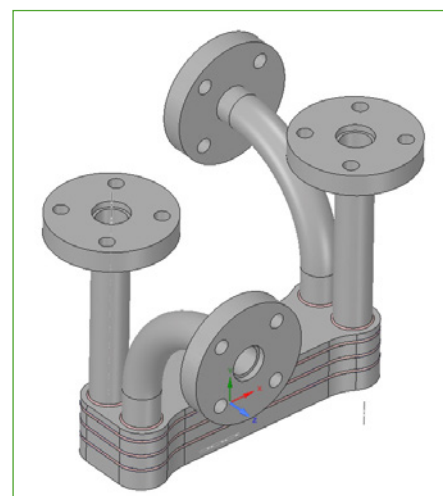
Development of a novel high-temperature heat exchanger. The design of a hybrid (metal/ceramic) capable of operating at temperatures over 1 000 °C, has been determined and the manufacture of a small-scale prototype is in progress.

PROGRESS AND MAIN ACHIEVEMENTS

- An overview of the improved plant concept was provided, containing new concepts for improving the plant performance
- A redesign of the reactor provides more stable embedding of the quartz window in the front flange
- Definition of specifications and completion of detailed refined process flowsheet layout and piping and instrumentation diagram of the solar plant.

FUTURE STEPS AND PLANS

- The integration of the novel heat exchanger in the existing solar platform. The manufacture and validation of a small-scale apparatus is in progress. The results will be used to develop the full-scale heat exchanger and integrate it in the solar plant
- The development of the nitrogen purification unit and a scaled-up PSA system capable of removing oxygen from the effluent N₂/O₂ stream
- On field Experiments

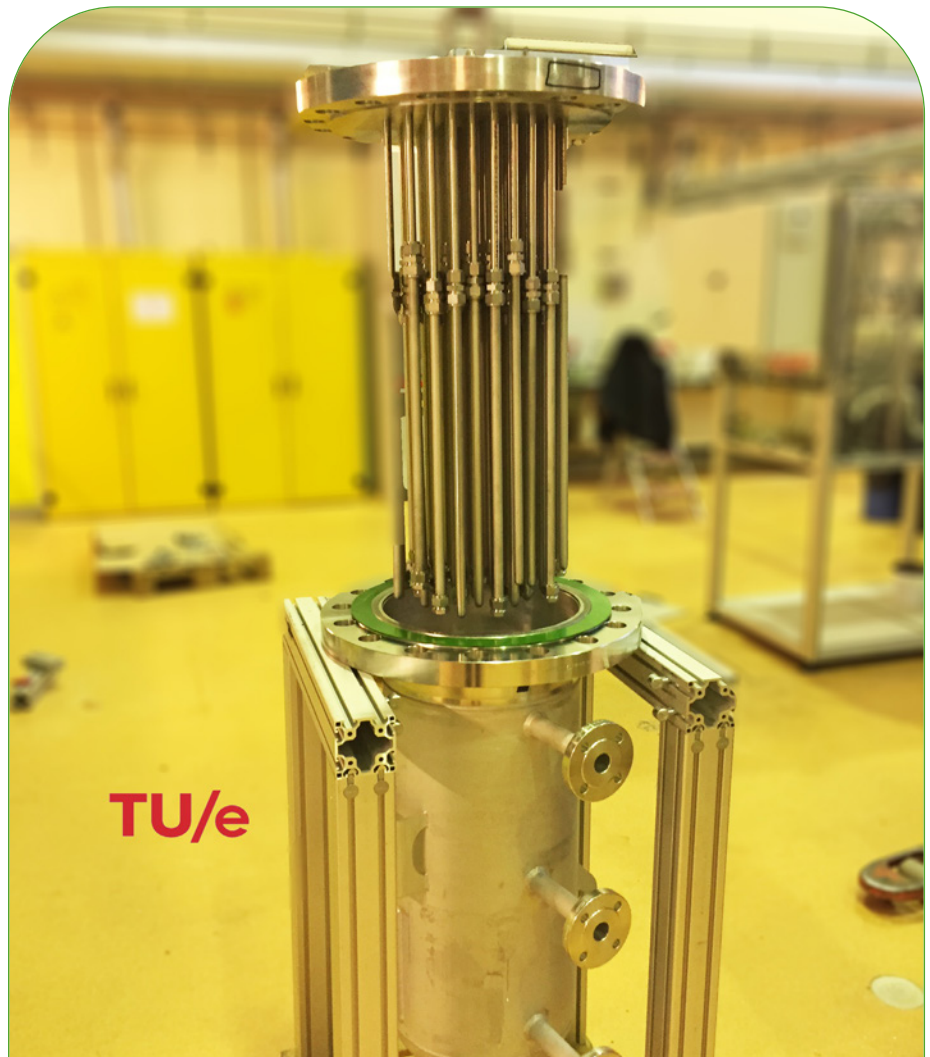


QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	PARAMETER	UNIT	TARGET	ACHIEVED TO DATE BY THE PROJECT	TARGET ACHIEVED?	SOA RESULT ACHIEVED TO DATE (BY OTHERS)	YEAR FOR SOA TARGET
Project's own objectives	Hydrogen production: H ₂ yield	kg/week	9.6	0.025		3.2	
	Redox material lifetime	cycles	1 000	245	✂	600	2019
	Heat recovery: parasitic losses	%	60	N/A		N/A	

Project ID:	700355
Call topic:	FCH-02.5-2015 - Development of technology to separate hydrogen from low-concentration hydrogen streams
Project total costs:	€ 3,167,710
FCH JU max. Contribution:	€ 2,527,710
Project start - end:	01/05/2016 - 30/04/2020
Coordinator:	TECHNISCHE UNIVERSITEIT EINDHOVEN, NL
Website:	www.hygrid-h2.eu

BENEFICIARIES: FUNDACION TECNALIA RESEARCH & INNOVATION, SAES GETTERS S.P.A., HYGear BV, HyGear Fuel Cell Systems B.V., QUANTIS, HYET HYDROGEN BV, HYGear TECHNOLOGY AND SERVICES BV, NORTEGAS ENERGIA DISTRIBUCION SOCIEDAD ANONIMA



PROJECT AND OBJECTIVES

The key objective of the HyGrid project is the design, scale-up and demonstration at 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 is on 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 power and cost of <5 kWh/kg H₂ and <1.5 €/kg H₂. A pilot has been designed for >25 kg/day of hydrogen.

NON-QUANTITATIVE OBJECTIVES

Training for PhD students. One student has already finalised their PhD and found a job in a research centre to work on topics similar to HyGrid.

PROGRESS AND MAIN ACHIEVEMENTS

- All prototype components are finished and being installed/debugged
- Two patent applications on 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

Finalise debugging and test the complete system. The components are available and being integrated. The software is being finalised.

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 H ₂	1.5	1.5	
	Prototype unit	TRL	5	5	
	Pure hydrogen production	kg/day	25	12	✗



HySTOC

HYDROGEN SUPPLY AND TRANSPORTATION USING LIQUID ORGANIC HYDROGEN CARRIERS

Project ID:	779694
Call topic:	FCH-02-6-2017 - Liquid organic hydrogen carrier
Project total costs:	€2 499 921.25
FCH JU max. Contribution:	€2 499 921.25
Project start - end:	01/01/2018 - 31/03/2022
Coordinator:	HYDROGENIOUS LOHC TECHNOLOGIES GMBH, DE
Website:	hystoc.eu/

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-UNIVERSITAET ERLANGEN-NUERNBERG



PROJECT AND OBJECTIVES

The HySTOC project aims to demonstrate the feasibility of LOHC-based distribution of high purity hydrogen (ISO 14687:2-2012) to an HRS in Finland, in an unprecedented field test. The H₂ is produced and supplied by the project partner Woikoski in Kokkola, Finland. Here the H₂ is placed in the StorageBox of the project partner Hydrogenious, from where it is transferred to the LOHC. The hydrated material is then transported to the project partner VTT in Espoo, where it is placed in the ReleaseBox from Hydrogenious. In the dehydrogenation process, the H₂ is released from the LOHC in the ReleaseBox.

NON-QUANTITATIVE OBJECTIVES

- Gain further experience in the development, assembly, commissioning, operation, costs, etc. of the LOHC hydrogenation unit
- Gain further experience in the development, assembly, commissioning, operation, costs, etc. of the LOHC dehydrogenation unit
- Gain further experience in LOHC logistics
- Analyse H₂ gas from the LOHC.

PROGRESS AND MAIN ACHIEVEMENTS

- StorageBox was developed, built, assembled, commissioned. Currently, it is located in Kokkola and operated by project partners Woikoski and Hydrogenious
- ReleaseBox was developed, built, assembled and is almost commissioned. Currently, it is located in Espoo and final commissioning will be by VTT, HyGear and Hydrogenious
- LOHC is transported between Kokkola (Woikoski) and Espoo (VTT) in IBC containers on a truck.

FUTURE STEPS AND PLANS

- The LOHC hydrogenation unit to be operated by Woikoski and Hydrogenious
- Completion of commissioning and operation of the LOHC dehydrogenation unit to be performed by VTT and Hydrogenious
- LOHC logistics will be further improved by Woikoski
- The re-released hydrogen will be analysed by VTT
- Hydrogen refuelling station: interface clarification by Woikoski, VTT and Hydrogenious. Implementation of the

HRS at the VTT site. Testing of the LOHC dehydrogenation unit at an HRS operated by Woikoski. The hydrogen refuelling with the HRS has been changed to be implemented by a simpler system with lower pressure (200 bar). This system is currently under development. The hydrogen produced will, however, be tested with a real FC vehicle.



QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	PARAMETER	UNIT	TARGET	ACHIEVED TO DATE BY THE PROJECT	TARGET ACHIEVED?
REDUCTION OF HYDROGEN STORAGE COSTS					
Project's own objectives	Absolute material costs SB	€/(kg/d)	336 000	350 000	✘
	Absolute material costs RB	€/(kg/d)	400 000	380 000	
ACCESSIBLE TO MOBILE APPLICATIONS					
	Hydrogen quality	-	ISO14687-2	ISO14687-2	✔

Project ID: 735533

Call topic:

FCH-03-1-2016 - Development of innovative hydrogen purification technology based on membrane systems

PRD 2020 Panel:

5 - Hydrogen for Sectoral Integration

Project total costs: €2 088 195

FCH JU max. contribution: €1 999 925

Project start - end: 01/01/2017- 31/12/2019

Coordinator: INSTITUT JOZEF STEFAN, SI

Website: www.memphys.eu



BENEFICIARIES: IMPERIAL COLLEGE OF SCIENCE, TECHNOLOGY AND MEDICINE, FORSCHUNGSZENTRUM JULICH GMBH, BORIT NV, DUALE HOCHSCHULE BADEN-WUERTTEMBERG, HYET HYDROGEN BV

PROJECT AND OBJECTIVES

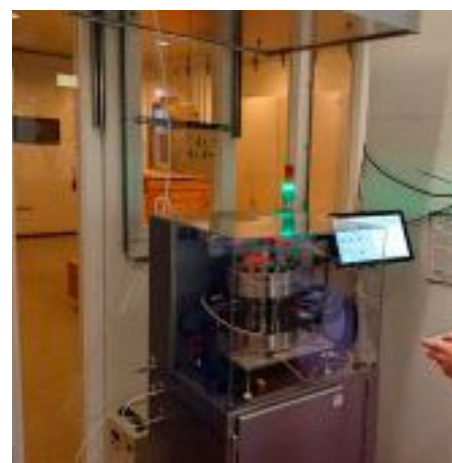
Project MEMPHYS targeted the development of a stand-alone hydrogen purification system based on electrochemical hydrogen purification (EHP). The focus was on high contaminant tolerance at low cost, making the system suitable for different applications. MEMPHYS targeted a 5 kg H₂/day system with an energy consumption of <5 kWh/kg H₂, a hydrogen recovery rate of >90%, producing high-purity hydrogen at a system cost of <1 500 €/kg H₂/day with a pressure of 200 bar. The project ended in December 2019.

PROGRESS AND MAIN ACHIEVEMENTS

- Targeted recovery rate and efficiency targets were reached in short-stack tests
- Extensive experimentation was performed and comparable measurement results were achieved in the partner's laboratories at different institutions
- A study to determine the optimum catalyst, fluid dynamic model and balance-of-plant components was conducted.

FUTURE STEPS AND PLANS

- Project finished by 31 December 2020. However, several partners expressed the intention to continue providing support to industrial partner HyET
- Building up of a 5 kg/day system in 2020
- Further development of diagnostic algorithms by partner JSI in 2020.



QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	PARAMETER	UNIT	TARGET	ACHIEVED TO DATE BY THE PROJECT	TARGET ACHIEVED?
Project's own objectives	Energy consumption of EHP stack	kWh/kg H ₂	3	3	✓
	Recovery rate EHP short stack	%	>90	90	
	Recovery rate single cell	%	>90	90	
	Energy consumption at targeted recovery rate	kWh/kg H ₂	3	5	✗

Project ID:	875123
Call topic:	FCH-02-2-2019 - Multi-megawatt high-temperature electrolyser for valorisation as energy vector in energy intensive industry
Project total costs:	€9 751 722.50
FCH JU max. Contribution:	€6 993 725.39
Project start - end:	01/01/2020 - 31/12/2024
Coordinator:	COMMISSARIAT A L'ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES, FR
Website:	multiplhy-project.eu



BENEFICIARIES: NESTE ENGINEERING SOLUTIONS BV, NESTE NETHERLANDS BV, ENGIE ENERGIE SERVICES, NESTE ENGINEERING SOLUTIONS OY, PAUL WURTH SA, SUNFIRE GMBH, NESTE OYJ, ENGIE

PROJECT AND OBJECTIVES

MULTIPLHY aims to install and integrate the world's first high-temperature electrolyser (HTE) system at multi-megawatt scale at a biorefinery in Rotterdam (NL), demonstrating the EU's technological and industrial leadership in the application of solid oxide electrolyser cell (SOEC) technology. A key element of the project is the manufacturing and demonstration of a multi-MW high-temperature electrolyser and its operation in a biorefinery. The results enable MULTIPLHY to promote the SOEC-based high-temperature electrolyser from TRL7 to 8.

PROGRESS AND MAIN ACHIEVEMENTS

- A first HyLink Gen 2.0 'Proof of Concept' module has been developed, manufactured and commissioned. The first electrolysis operation mode ran successfully
- System integration and operating concept have been defined. The approved layout of the HTE and HPU systems fits into the mandatory plot at the refinery
- A testing protocol enabling the benchmarking of stacks comprising cells of different technologies has been defined.

FUTURE STEPS AND PLANS

Execute project tasks as planned. Tasks are on track.

QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	PARAMETER	UNIT	TARGET	TARGET ACHIEVED?	SOA RESULT ACHIEVED TO DATE (BY OTHERS)	YEAR FOR SOA TARGET
AWP 2019	Electrical consumption	kWh/kg	39	✘	39.7	2017
	Production loss	h=%/1 000 h	<1.2		1.9	
	Downtime	%	5		Not available	N/A



NEPTUNE

NEXT GENERATION PEM ELECTROLYSER UNDER NEW EXTREMES

Project ID:	779540
Call topic:	FCH-02-1-2017 - Game changer Water Electrolysers
Project total costs:	€1 927 335.43
FCH JU max. Contribution:	€1 926 221.25
Project start - end:	01/02/2018 - 31/10/2021
Coordinator:	ITM POWER (TRADING) LIMITED, UK
Website:	www.neptune-pem.eu

BENEFICIARIES: CONSIGLIO NAZIONALE DELLE RICERCHE, ENGIE, SOLVAY SPECIALTY POLYMERS ITALY SPA, IRD FUEL CELLS A/S, PRETEXO



PROJECT AND OBJECTIVES

The NEPTUNE project addresses challenges associated with reducing capital costs and increasing production rates and output pressures of water electrolysis to the levels required to achieve large-scale application of PEM electrolysers. NEPTUNE is developing a set of breakthrough solutions at material, stack and system levels to increase hydrogen pressure to 100 bar and current density to 4 A cm⁻² for the base load, while keeping the nominal energy consumption <50 kWh/kg H₂. The novel solutions will be validated by demonstrating a robust and rapid-response electrolyser.

NON-QUANTITATIVE OBJECTIVES

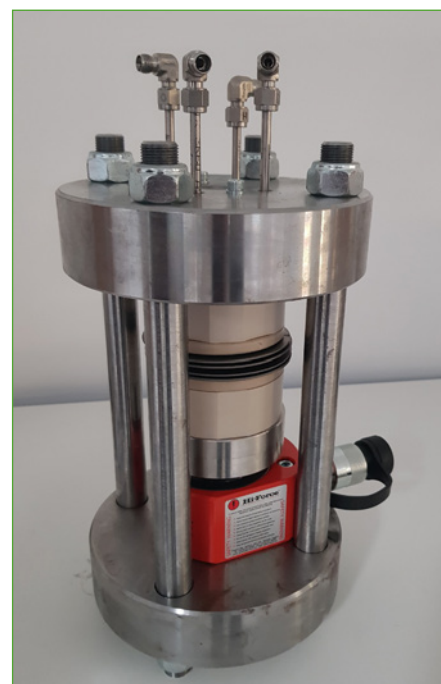
Extension of protocols for testing electrolysis systems under the new operating conditions (high temperature and pressure). Public deliverable report published.

PROGRESS AND MAIN ACHIEVEMENTS

- Design and build a new simplified balance of plant for PEM electrolysis to extend operating conditions
- MEA degradation rate achieved at 80 °C, 4.4 μV/h/cell at 4 A cm⁻² in a test >2 000 h (single cell level)
- At 90 °C, cell voltages of 1.74 V and 1.98 V at 4 and 8 A cm⁻², respectively, with noble metal loading 0.34 mg cm⁻² anode and 0.1 mg cm⁻² cathode.

FUTURE STEPS AND PLANS

- Demonstration of advanced cost-effective PEM electrolysis stack operating at high temperature and with high differential pressure.
- Validation of PEM electrolysis stack durability in endurance tests and dynamic operating conditions.
- Techno-economic assessment and life cycle analysis on the advanced PEM electrolyser. Goal and scope defined.

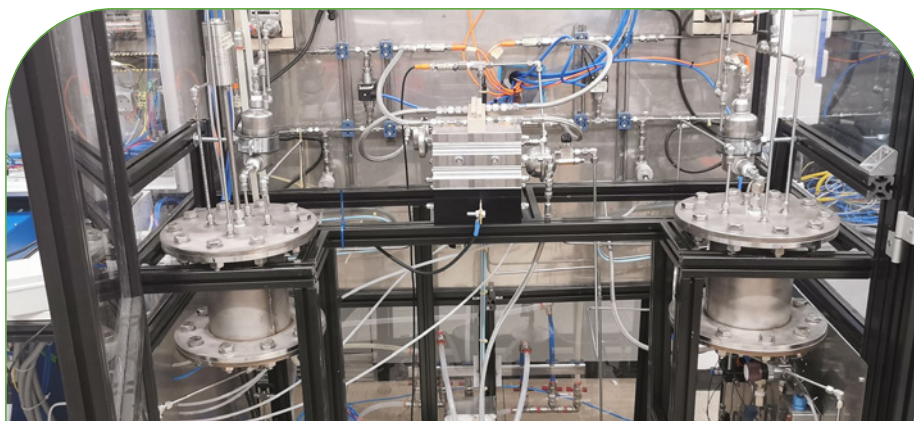


QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	PARAMETER	UNIT	TARGET	ACHIEVED TO DATE BY THE PROJECT	TARGET ACHIEVED?	SOA RESULT ACHIEVED TO DATE (BY OTHERS)	YEAR FOR 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 h for LT 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
Call topic:	FCH-02-4-2019 - New Anion Exchange Membrane Electrolysers
Project total costs:	€2 597 413.75
FCH JU max. Contribution:	€2 204 846.25
Project start - end:	01/01/2020 - 31/12/2022
Coordinator:	DEUTSCHES ZENTRUM FÜR LUFT- UND RAUMFAHRT EV, DE
Website:	www.newely.eu

BENEFICIARIES: MEMBRANENZSARL, PROPULS GMBH, CUTTING-EDGE NANOMATERIALS CENMATUGHAFTUNGSBESCHRANKT, AIR LIQUIDE FORSCHUNG UND ENTWICKLUNG GMBH, KOREA INSTITUTE OF SCIENCE AND TECHNOLOGY, WESTFALISCHE HOCHSCHULE GELSENKIRCHEN, BOCHOLT, RECKLINGHAUSEN, DLR-INSTITUT FÜR VERNETZTE ENERGIESYSTEME EV, USTAV MAKROMOLEKULARNÍ CHEMIE AV CRVVI, FONDAZIONE BRUNO KESSLER, VYSOKÁ ŠKOLA CHEMICKO-TECHNOLOGICKÁ V PRAZE, AIR LIQUIDE SA, COMMISSARIAT A L'ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES

PROJECT AND OBJECTIVES

The NEWELY project aims to redefine anion exchange membrane water electrolysis (AEMWE), surpassing the current state of alkaline WE and bringing it one step closer to proton exchange membrane WE in terms of efficiency but at lower cost. The three main challenges of AEMWE – membrane, catalyst and stack – are addressed by 3 SMEs and a large hydrogen company supported by 7 renowned R&D centres. With a prototypic 5-cell stack at elevated pressure in a 2 000-hour endurance test, twice the performance of the state of the art of AEMWE will be validated. This will impact the cost of green hydrogen.

NON-QUANTITATIVE OBJECTIVES

TEA (Techno- Economic Assessment) + LCA (life cycle assessment) demonstrate reduction of CAPEX and OPEX for AEMWE rel. PEMWE and AWE.

PROGRESS AND MAIN ACHIEVEMENTS

- MEA with NiFe anode and Mo2C cathode and commercial AEM/ionomer achieves 2 V at 2 A cm⁻² in 0.1 M KOH. Degradation rate of 500 μV/h at constant 1 A cm⁻²
- First publication of the project is a review paper on commercial AEMs
- Construction of the AEMWE test station for stacks.

FUTURE STEPS AND PLANS

- MEA preparation at 25 cm² and 200 cm² with project materials and targeted performance. First MEAs prepared, with testing of the 25 cm² MEA next step
- First sketch completed of the stack design and construction
- Stack has not yet been in operation at increased pressure
- Long-term testing of the stack to demonstrate the required stability
- Data collection has started for LCA and cost analysis

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 FOR SOA TARGET	
MAXIMUM AEMWE STACK SIZE REALISED IN THE PROJECT								
Project's own objectives and MAWP Addendum (2018-2020)	Stack power	kW	2	0.014	✗	2.4	2021	
	Cell area	cm ²	200	4	✗	N.A		
	Pressure	bar (rel.)	≤40	0	✓	≤35		
	Energy consumption @ power Corresponding to cell voltage @ current	kWh/kg @ W cm ⁻² Corresponding to V @ A cm ⁻²	53.6 @ 2 Corresponding to 2 @ 1	53.6 @ 3.6 Corresponding to 2 @ 1.8	✓	53.6 @ 0.7 Corresponding to 2 @ 0.35	2020	
	NON-PGM CATALYSTS							
		Added overpotentials anode + cathode	mV	415	232	✗	250	2020
	Current density	mA cm ⁻²	1	1	✓	1		
MAWP Addendum (2018-2020) and AWP 2019	Stable operation for 2000 h, cell voltage gap after 2000 h operation Extrapolated to efficiency degradation @ rated power and considering 8000 h operations/year	mV Extrapolated to %/year	50 Extrapolated to 7.2	No test yet	✗	<2	2021	
	Chemically, thermally and mechanically stable AEM ionomer and membrane with conductivity	mS cm ⁻¹	≥50	>60	✓	80	2021	
	Area-specific resistance (ASR)	Ω cm ²	≤0.07	0.08	✗	0.045		

Project ID: 735218

Call topic: FCH-02-3-2016 - Development of processes for direct production of hydrogen from sunlight

Project total costs: €2 499 992.5

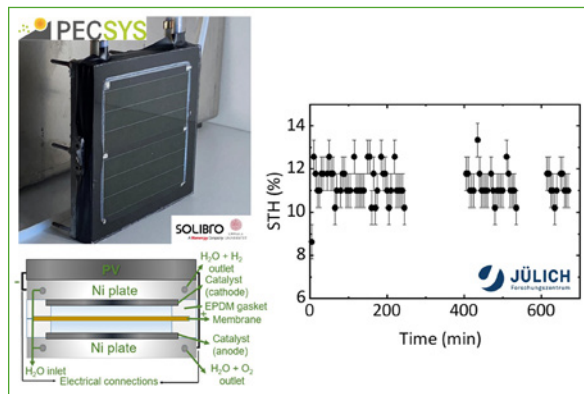
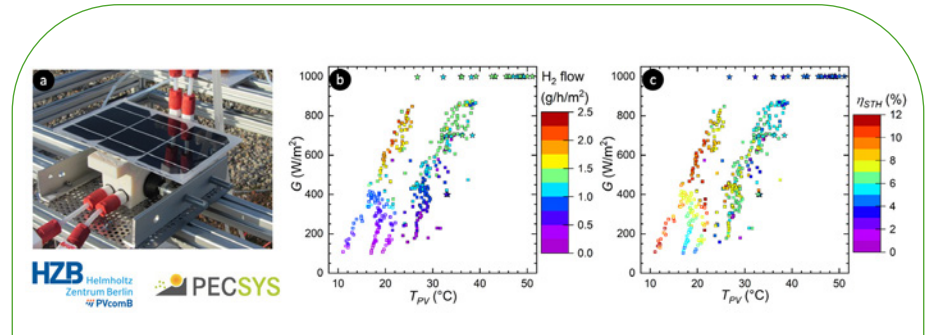
FCH JU max. Contribution: €2 499 992.5

Project start - end: 01/01/2017 - 31/12/2020

Coordinator: HELMHOLTZ-ZENTRUM BERLIN FÜR MATERIALIEN UND ENERGIE GMBH, DE

Website: <https://www.helmholtz-berlin.de/projects/pecsys/>

BENEFICIARIES: UPPSALA UNIVERSITET, FORSCHUNGSZENTRUM JÜLICH GMBH, CONSIGLIO NAZIONALE DELLE RICERCHE, SOLIBRO RESEARCH AB, ENEL GREEN POWER SPA, 3SUN SRL



PROJECT AND OBJECTIVES

The PECSYS project demonstrated a solar-driven electrochemical hydrogen generator using a solar collection area >10 m². The best thermally integrated devices achieved solar-to-hydrogen (STH) conversion efficiencies of 13 % (100 cm²) and 5.1 % (2 600 cm²). The final 10 m² demonstrator installed at Jülich (DE) consisted of an array of CuInGaSe and silicon heterojunction photovoltaic modules directly electrically coupled to an electrolyser stack. The demonstrator was continuously operated for 9 months, during which 22 kg of hydrogen were generated with an average STH efficiency of 10 %.

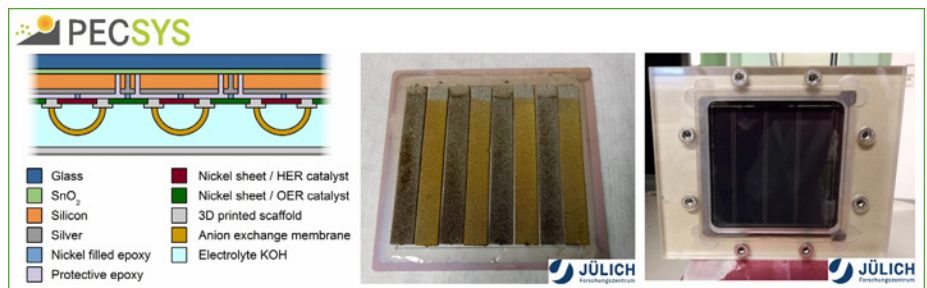
PROGRESS AND MAIN ACHIEVEMENTS

- A CIGS PV integrated electrolyser with 100 cm² area achieved a STH conversion efficiency of 13 % at a rate of 2.2 g H₂/h/m²

- A 10 m² array of PV modules directly connected to detached PEM electrolysers achieved a STH conversion efficiency of 10 % at a rate of 2.3 g/h/m²
- NiMo and NiFe catalysts grown on up to 125 cm² areas, for H₂ and O₂ evolution, respectively, achieved overpotentials of 94 mV and 200 mV at 10 mA/cm².

FUTURE STEPS AND PLANS

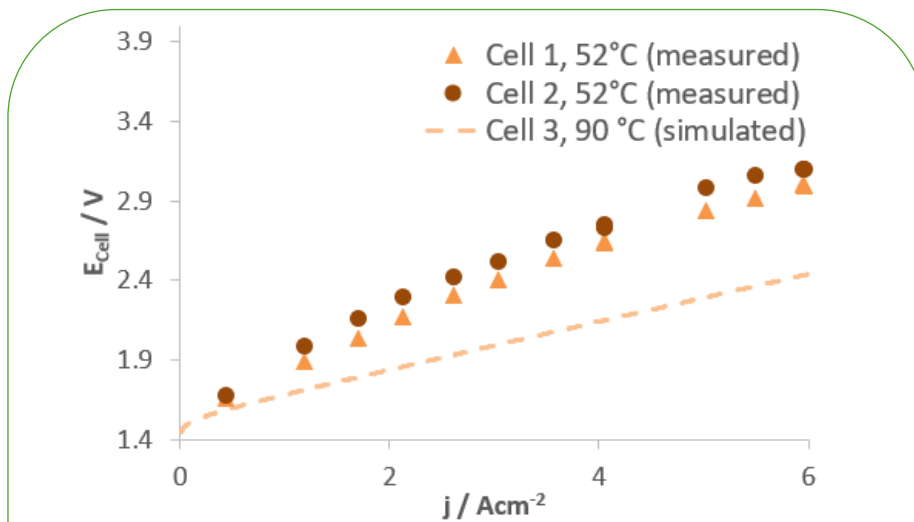
The project has finished.



QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	PARAMETER	UNIT	TARGET	ACHIEVED TO DATE BY THE PROJECT	TARGET ACHIEVED?	SOA RESULT ACHIEVED TO DATE (BY OTHERS)
Project's own objectives	Hydrogen production rate	g/h/m ²	1.6	2.3	✓	1.2
	Solar collection area	m ²	10	10	✓	1.5
	Operation with less than 10 % drop in efficiency	Hours	1 825	2 680	✓	10

Project ID:	779478
Call topic:	FCH-02-1-2017: Game changer Water Electrolysers
Project total costs:	€1 999 088.75
FCH JU max. Contribution:	€1 999 088.75
Project start - end:	01/01/2018 - 30/06/2021
Coordinator:	DEUTSCHES ZENTRUM FUER LUFT- UND RAUMFAHRT EV, DE
Website:	pretzel-electrolyzer.eu/



BENEFICIARIES: IGAS ENERGY GMBH, ADAMANT AERODIASTIMIKES EFARMOGES ETAIREIA PERIORISMENIS EFTHYNIS, SOLUCIONES CATALITICAS IBERCAT SL, GKN SINTER METALS FILTERS GMBH RADEVORMWALD, WESTFALISCHE HOCHSCHULE GELSENKIRCHEN, BOCHOLT, RECKLINGHAUSEN, GKN SINTER METALS ENGINEERING GMBH, ECOLE NATIONALE SUPERIEURE DES MINES DE PARIS, ETHNIKO KENTRO EREVNAS KAI TECHNOLOGIKIS ANAPTYXIS, UNIVERSITATEA POLITEHNICA TIMISOARA, ASSOCIATION POUR LA RECHERCHE ET LE DEVELOPPEMENT DES METHODES ET PROCESSUS INDUSTRIELS

PROJECT AND OBJECTIVES

The overall goal of PRETZEL is to develop an innovative polymer electrolyte membrane electrolyser (PEMEL) that provides significant increases in efficiency and operability to satisfy emerging market demands and becomes a game-changing electrolyser. A central objective is the development of a novel PEMEL system with a maximum of 25 kW electrical power consumption that generates 4.5 m³ h⁻¹ H₂ at rated power, at an output pressure of 100 bar and feed water temperature of maximum 90 °C. The components have been tested, are currently being manufactured and the system will be tested over 2 000 h.

NON-QUANTITATIVE OBJECTIVES

- An assessment of additional commercial opportunities that are available with the game-changing electrolyser compared to current electrolysers. Will be implemented.

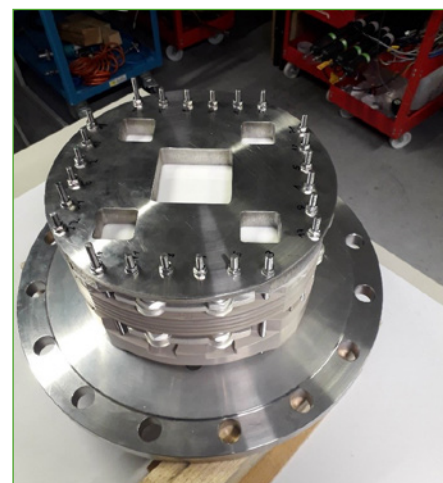
- Enabling additional commercial roll-out of electrolysers post-2025.

PROGRESS AND MAIN ACHIEVEMENTS

- Coatings for stainless steel BPP and PTLs were developed and tested up to a current density of 6 A cm⁻², achieving an unprecedented cell efficiency of 77 %
- Ti-based PTL allows operation up to 6 A cm⁻² at 90 °C, eliminating mass transport limitations completely and passing the durability AST
- The first 100 bar H₂ pressure test in a 5 Nm³ h⁻¹ PEMWE system from iGas was carried out successfully with a stack containing the developed PTLs.

FUTURE STEPS AND PLANS

Completion of 2 000-hour test of PEMWE system at 90 °C, 100 bar up to 6 A cm⁻². Not started yet.



QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	PARAMETER	ACHIEVED TO DATE BY THE PROJECT
MAWP (2014–2020) and AWP 2017	Reducing PEM electrolyser CAPEX costs: new cost-effective current collectors for PEM electrolysers for hydrogen generation from renewable energies	500 cm ² manufactured PCD are ready for implementation and testing in high pressure stack
	Increase energy efficiency of hydrogen production: increase of 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. Catalyst with adequate metal content and aerogel support for 500 cm ² MEA production produced
	Development and validation of game-changing PEM electrolyser meeting the targets of 2023: 210 cm ² high-pressure stack with all components tested	Cell parts and CAD design of high-pressure electrolyser stack are finalised and manufactured. The design is based on prototypes of our partners using the principle of hydraulic cell compression, which was developed in publicly funded projects VOMPELS (EFRE-0800099) and MoDePEM (EFRE-0400094)
AWP 2017	Step change improvements: 100 bar, rapid response (<1 s hot start), 4 A cm ⁻² nominal current density and overload of 6 A cm ⁻² , temperature T>80 °C	Initial cell test performing polarisation curve up to 6 A cm ⁻² at 90 °C and 100 bar 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 potential users of the gases produced



QualyGridS

STANDARDIZED QUALIFYING TESTS OF ELECTROLYSERS FOR GRID SERVICES

Project ID: 735485

Call topic: FCH-02-1-2016: Establish testing protocols for electrolyzers performing electricity grid services

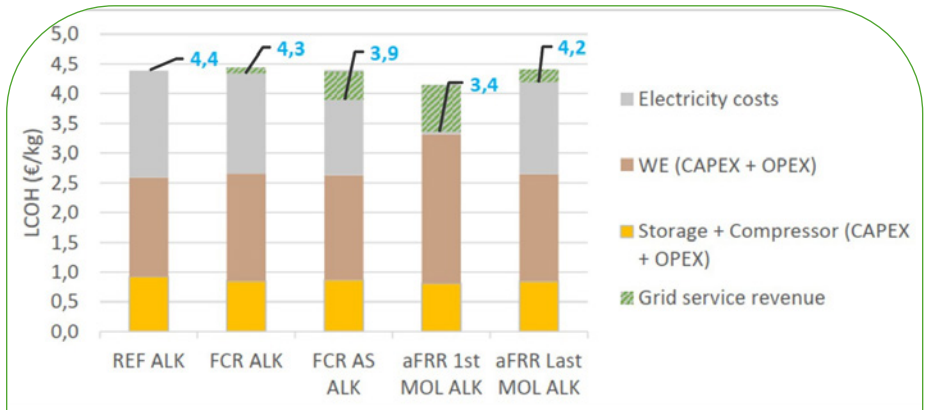
Project total costs: €2 811 262.5

FCH JU max. Contribution: €1 996 795

Project start - end: 01/01/2017 - 30/06/2020

Coordinator: DEUTSCHES ZENTRUM FUER LUFT- UND RAUMFAHRT EV, DE

Website: www.qualygrids.eu



BENEFICIARIES: COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES, DANMARKS TEKNISKE UNIVERSITET, IHT INDUSTRIE HAUTE TECHNOLOGIE SA, STICHTING KONINKLIJK NEDERLANDS NORMALISATIE INSTITUUT, FACHHOCHSCHULE ZENTRALSCHWEIZ - HOCHSCHULE LUZERN, FUNDACION PARA EL DESARROLLO DE LAS NUEVAS TECNOLOGIAS DEL HIDROGENO EN ARAGON, EUROPEAN FUEL CELL FORUM AG, ITM POWER (TRADING) LIMITED, NEW NEL HYDROGEN AS

PROJECT AND OBJECTIVES

The overall objective of the QualyGridS project was to establish standardised testing protocols for electrolyzers to perform electricity grid services. Alkaline and PEM electrolyzers are both considered in this project. A variety of different grid services are addressed as well as multiple hydrogen end users. The protocols developed were applied to alkaline and PEM electrolyser systems, using electrolyser sizes from 10 kW to 300 kW. In addition, a techno-economic analysis of business cases was performed, covering the grid and market situations in the most relevant regions of Europe.

NON-QUANTITATIVE OBJECTIVES

- AWP 2016: development of standardised protocols for electrolyzers to provide grid services. Achieved

100 %. QualyGridS protocols are the basis of the ISO Technical Report

- AWP 2016: definition of specific KPIs for dynamic operation to provide grid services. Achieved 100 %
- Evaluation of business cases, sensitivities and a roadmap. Achieved 100 %. The evaluations led to the publication of final recommendations.

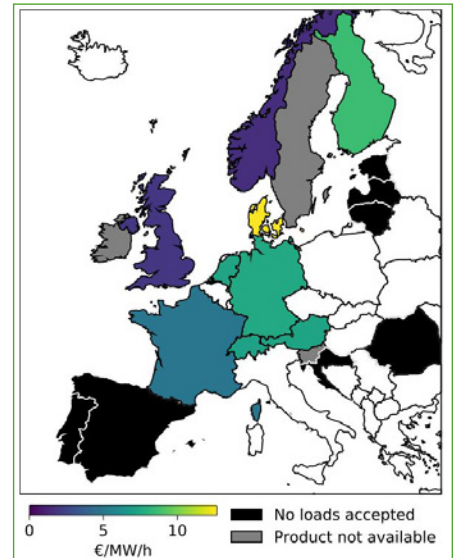
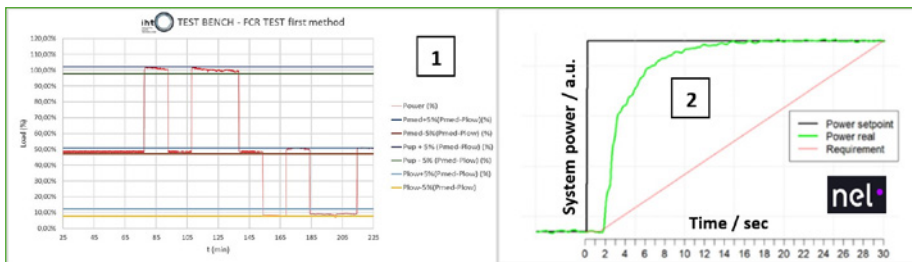
PROGRESS AND MAIN ACHIEVEMENTS

- Testing protocols for electrolyzers performing grid services presented to ISO TC 197 Hydrogen technologies, approved as new working group to submit an ISO Technical Report
- Business case definition and detailed business case evaluation done, including recommendations

- 2 PEM and 3 alkaline electrolyser systems have been tested for their ability to perform grid services by running the project's testing protocols.

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)	YEAR FOR SOA TARGET
Project's own objectives	Number of electrolyzers that have performed test run	-	5	5 systems up to 300 kW performed the test run	✓	N/A	N/A
MAWP (2014-2020)	Cost of hydrogen	(€/kg)	4.5-7.0	Cost reduction by performing a FRR for the evaluated scenario can be as high as 24 %	✗	12	2017
AWP 2016	Development of standardised protocols for electrolyzers to provide grid services across EU countries	Number of drafts and reviews of these drafts	3	3	✓	Draft harmonised testing protocols by JRC, including input from QualyGridS project, no standard	2020



Project ID: 779579

Call topic: FCH-02-5-2017: Demonstration of large electrolysers for bulk renewable hydrogen production

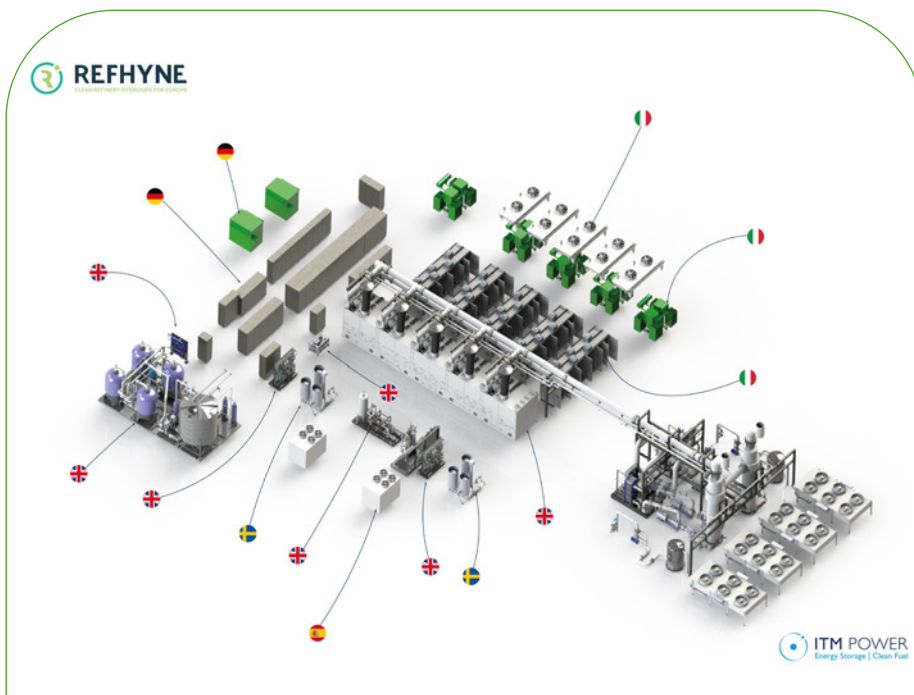
Project total costs: €19 759 516.50

FCH JU max. Contribution: €9 998 043.50

Project start - end: 01/01/2018 - 31/12/2022

Coordinator: SINTEF AS, NO

Website: www.refhyne.eu



BENEFICIARIES: SHELL ENERGY EUROPE LIMITED, SHELL DEUTSCHLAND OIL GMBH, SPHERA SOLUTIONS GMBH, ITM POWER (TRADING) LIMITED, ELEMENT ENERGY LIMITED, STIFTELSEN SINTEF

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, demonstrate 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 being installed and the plant is expected start operation around mid-2021.

NON-QUANTITATIVE OBJECTIVES

- 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 an evidence base for changes to existing policies. This will include a specific analysis focused towards policymakers recommending changes to existing policies. The first results are just in and will soon be released

- Assessment of the legislative and RCS implications of these systems. REFHYNE will produce a detailed assessment of the consenting process for the system and of any issues related to safety or codes and standards.

PROGRESS AND MAIN ACHIEVEMENTS

- Finalised detailed design of the electrolyser system plant and its adaptation to the refinery

- Permit application approved by the local authorities
- Refinery building and infrastructure ready for integration of electrolysers.

FUTURE STEPS AND PLANS

- Demonstration of the 10 MW PEM electrolyser in a refinery setting. Expected to be inaugurated in mid-2021
- Techno-economic assessment of the electrolyser system and concept. Framework and models are in place, thus assessments will begin once system operating data are available
- Environmental analysis of the electrolyser system and concept. Framework and models are in place, thus analysis will begin once system data are available.

QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	PARAMETER	UNIT	TARGET	TARGET ACHIEVED?	SOA RESULT ACHIEVED TO DATE (BY OTHERS)	YEAR FOR SOA TARGET
MAWP Addendum (2018-2020)	H ₂ production	kWh/kg	52	✘	57-60	2017
	H ₂ production	M€/t/d	2		8	
	H ₂ production	%	1.5		2-4	
	H ₂ production	%	0-100		5-100	
	H ₂ production	s	2		60	

Project ID:	779577
Call topic:	FCH-02-3-2017: Reversible Solid Oxide Electrolyser (rSOC) for resilient energy systems
Project total costs:	€2 999 575.48
FCH JU max. Contribution:	€2 999 575.25
Project start - end:	01/01/2018 - 31/12/2020
Coordinator:	COMMISSARIAT A L'ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES, FR
Website:	www.reflex-energy.eu/



BENEFICIARIES: SYLFEN, TEKNOLOGIAN TUTKIMUSKESKUS VTT OY, ENGIE SERVIZI SPA, AKTISIELTS ELCOGEN, GREEN POWER TECHNOLOGIES SL, PARCO SCIENTIFICO TECNOLOGICO PER L'AMBIENTE ENVIRONMENT PARK TORINO SPA, UNIVERSIDAD DE SEVILLA, ENGIE, DANMARKS TEKNISKE UNIVERSITET

PROJECT AND OBJECTIVES

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

NON-QUANTITATIVE OBJECTIVES

- Techno-economic assessment is ongoing
- Inventory of RCS applicable to rSOC systems drawn up for France and Italy.

PROGRESS AND MAIN ACHIEVEMENTS

- Project performance target and durability target achieved in rSOC operation at cell scale
- Enlarged cells (200 cm²) integrated successfully in the small and large stack with same performance as regular size cells
- Power electronics manufactured and fulfils efficiency requirement of >95 %.

FUTURE STEPS AND PLANS

- Finalise modules and system assembly: ongoing and planned for M40
- Install and operate the system in-field: planned for M42.



QUANTITATIVE TARGETS AND STATUS

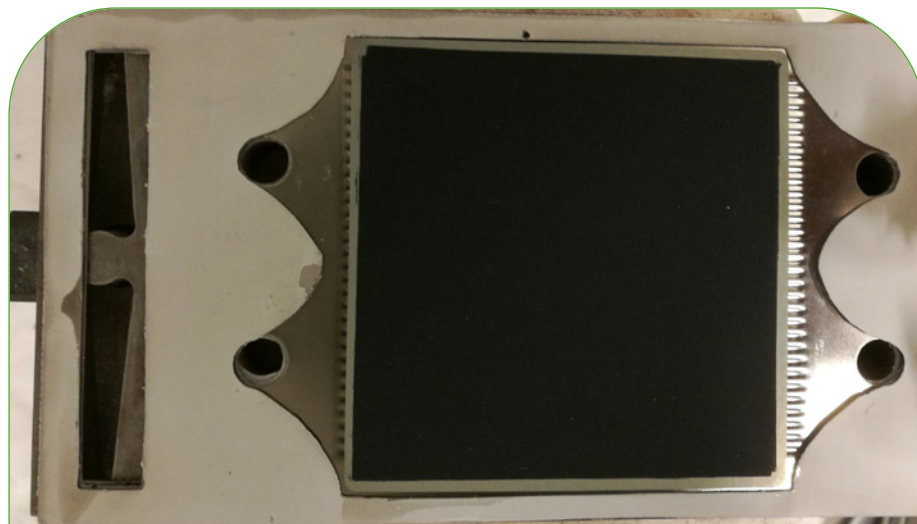
TARGET SOURCE	PARAMETER	UNIT	TARGET	ACHIEVED TO DATE BY THE PROJECT	TARGET ACHIEVED?	SOA RESULT ACHIEVED TO DATE (BY OTHERS)	YEAR FOR SOA TARGET
Project's own objective	Current density in SOEC mode	A/cm ²	-1.2	-1.25	✓	-1.15 A/cm ² at 750 °C - 1 A/cm ² at 800 °C	2015-2016
	Durability in SOEC step during rSOC operation at 0.58 A/cm ² and SC=68 %	%/kh	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	2020
	Power electronic efficiency	%	95	96	✓	88	2019
AWP	SC=80 %	%	80	85	✓	70	2015



SElySOs

DEVELOPMENT OF NEW ELECTRODE MATERIALS AND UNDERSTANDING OF DEGRADATION MECHANISMS ON SOLID OXIDE HIGH TEMPERATURE ELECTROLYSIS CELLS

Project ID:	671481
Call topic:	FCH-02.1-2014: Research in electrolysis for cost-effective hydrogen production
Project total costs:	€2 939 655
FCH JU max. Contribution:	€2 939 655
Project start - end:	02/11/2015 - 01/05/2020
Coordinator:	IDRYMA TECHNOLOGIAS KAI EREVNAS, EL
Website:	selysos.iceht.forth.gr



BENEFICIARIES: PROTOTECH AS, PYROGENESIS SA, ETHNIKO KENTRO EREVNAS KAI TECHNOLOGIKIS ANAPTYXIS, VYSOKA SKOLA CHEMICKO-TECHNOLOGICKA V PRAZE, FORSCHUNGSZENTRUM JULICH GMBH, CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS

PROJECT AND OBJECTIVES

SElySOs focused on the understanding of degradation and lifetime fundamentals of both SOEC electrodes in order to minimise their degradation and improve their performance and stability, mainly under H₂O electrolysis and to a certain extent under H₂O/CO₂ co-electrolysis conditions. The project investigated: (i) modified SoA Ni-based cathode cement; (ii) alternative perovskite-type cathode materials; (iii) the O₂ electrode in detail; and (iv) the development of a theoretical model to describe the performance and degradation of the SOEC H₂ electrode.

NON-QUANTITATIVE OBJECTIVES

- New materials and component design less prone to degradation. During the project's last year, a series of modified Ni-based and Ni-free electrodes and a series of new air electrodes were investigated under various SOEC H₂O electrolysis and H₂O/CO₂ co-electrolysis conditions. The results obtained were quite promising and specific electrodes were further examined, as larger size cells, for their long-term stability and in short stack tests, under SOEC operation
- Understanding of degradation mechanisms under dynamic operation. Mathematical modelling was developed for both of the SOEC H₂O electrolysis and H₂O/CO₂ co-electrolysis processes. One key objective

achieved was the correlation of the model/s with experimental data from the measurements performed as part of the project

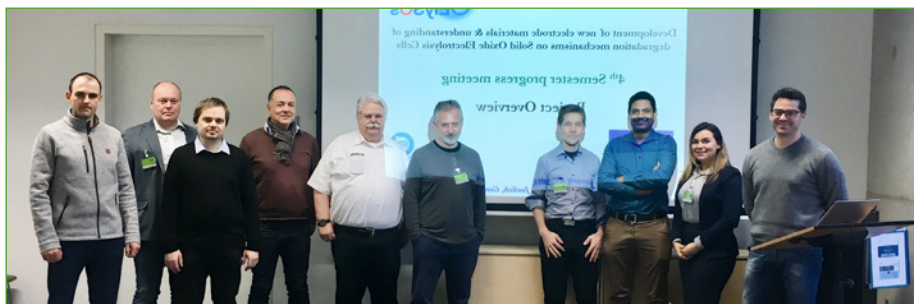
- Development of improved and robust SOEC systems (cells /stack(s)). The newly developed electrodes were further investigated for their performance and tolerance in the form of complete cells. The latter were also investigated, in parallel, through long-term stability measurements of single large-area cells and the manufacture and testing of short stacks.

PROGRESS AND MAIN ACHIEVEMENTS

- Development of promising modified Ni-based and Ni-free cathodes and of new air electrodes with improved and tailored performance under SOEC operation
- Advanced operando analysis of Ni-based and Ni-free electrodes, which provided useful insights into their surface state during SOEC operation
- Thermodynamic and electrochemical modelling of the H₂O and H₂ and CO₂ system by combining theoretical and experimental data, under SOEC operation.

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)	YEAR FOR SOA TARGET
Project's own objective	Decrease the area-specific resistance on the fuel electrode compared to the SoA	Ohm * cm ²	N/A	0.4 for an Au-Mo-Ni/GDC modified fuel electrode and LSCoF as air electrode	✂	1.6 for Ni/GDC as fuel electrode and LSCoF as air electrode	2019
	Increase in the current density	A/cm ²	1	0.59 for an Au-Mo-Ni/GDC modified fuel electrode and LSCoF as air electrode		0.22 for Ni/GDC as fuel electrode and LSCoF as air electrode	
	Decrease of the catalyst (fuel electrode) loading per H ₂ capacity	g/(kg H ₂ /day)	N/A	18.5 for an Au-Mo-Ni /GDC modified fuel electrode and LSCoF as air electrode		50.3 for Ni/GDC as fuel electrode and LSCoF as air electrode	

Project ID: 875148

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: €3 746 753.75

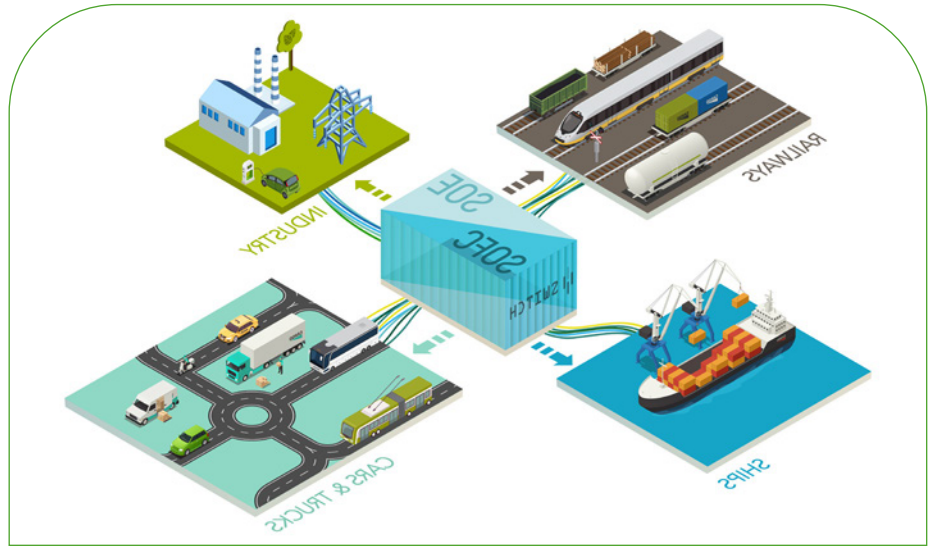
FCH JU max. Contribution: €2 992 521

Project start - end: 01/01/2020 - 31/12/2022

Coordinator: FONDAZIONE BRUNO KESSLER, IT

Website: switch-fch.eu/about/

BENEFICIARIES: SWECO CONSULTING SPOLKA Z OGRANICZONA ODPOWIEDZIALNOSCIA, SOLIDPOWER SA, HYGEAR BV, SHELL GLOBAL SOLUTIONS INTERNATIONAL BV, ECOLE POLYTECHNIQUE FEDERALE DE LAUSANNE, DEUTSCHES ZENTRUM FUR LUFT- UND RAUMFAHRT EV



PROJECT AND OBJECTIVES

The 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). The goals of the project are to increase green H₂ production from renewable sources to secure hydrogen supply and to reduce the overall technology costs for H₂ production.

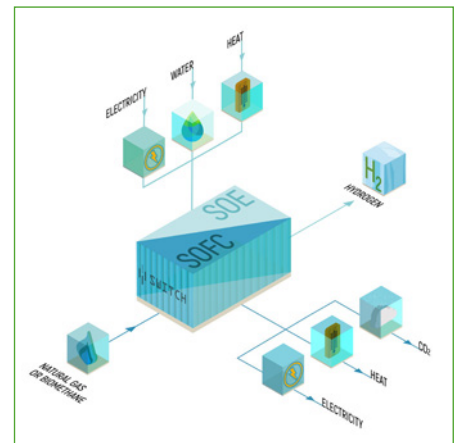
NON-QUANTITATIVE OBJECTIVES

- Reliability and stability of power and hydrogen supply. The cogeneration potential with high dynamic behaviour offers a system able to deliver a reliable and stable production of hydrogen and power to facilitate demand-side management, securing the form of energy needed and connecting the generation profile to the proper end user
- Modularity. Development and validation of a 50 kg H₂/day technology, realised by integrating modules composed of high-reliability stack modules provided by SP
- Hydrogen purity level. Hydrogen will be purified between the range 99.7% to 99.99 % and with a water content of less than 5 ppm, in compliance with ISO 14687
- In-field testing. The final SWITCH system prototype will be installed in a test-bench infrastructure and in a real-life operational environment, with an operation time of 5 000 hours in a relevant environment for in-field testing

- Life-cycle analysis (LCA) and life-cycle cost analysis (LCC) will help to evaluate the benefits of the SWITCH technology in comparison with SoA SMR and other H₂ production technologies (electrolysis).

PROGRESS AND MAIN ACHIEVEMENTS

- Definition of the demand profiles for hydrogen and power related to four potential use cases at hydrogen refuelling stations
- Technical specifications of the SWITCH system: general description, proposed layout and utilities specification, operating modes for each module
- Results of multi-period and multi-objective optimisation analysis used to design SWITCH to operate efficiently in multiple modes that satisfy variable demand.



FUTURE STEPS AND PLANS

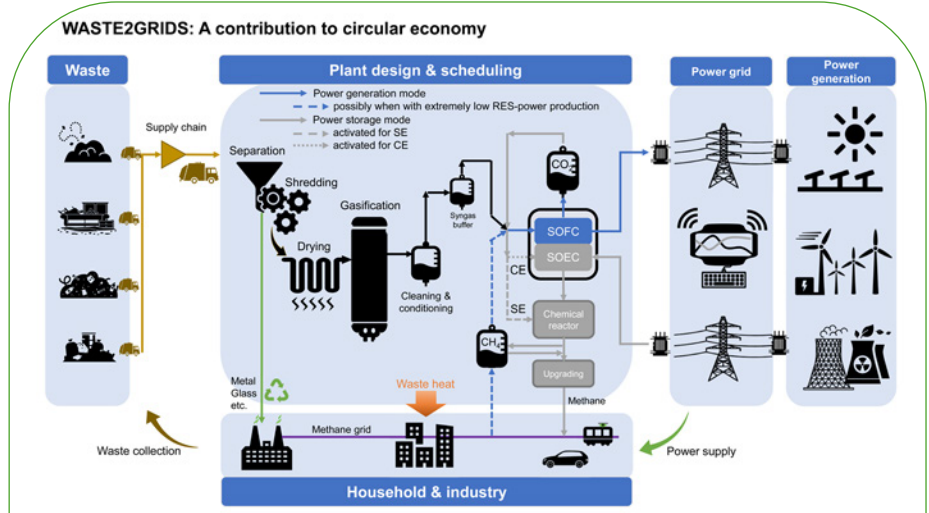
- 250 hours of LSM experimental analysis in electrolysis and polygeneration mode to test start-up and shutdown cycles. In February 2021, the LSM was delivered to DLR for testing and the test rig and test procedures were defined
- Definition of the PFD and finalisation of the design basis. HyGear and SOLIDpower are working on the final definitions of the requirement for each component.
- Definition of the P&ID of the complete system. Once the PFD has been completed by HyGear and SOLIDpower, it will be converted to a P&ID. The deadline is the end October 2021
- Realisation of the system: the Factory Acceptance Test is expected to start in May 2022.



QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	PARAMETER	UNIT	TARGET	TARGET ACHIEVED?	SOA RESULT ACHIEVED TO DATE (BY OTHERS)	YEAR FOR SOA TARGET
Project's own objective	Electrolyser conversion efficiency	%	85	✂	80	2021
	Fuel cell conversion efficiency	%	75		80	
	Hydrogen price	€/kg	5		11.2	2020
	Stack lifetime	Hours	10 000		3 000	2021
	Low switching time	min	30		-	-

Project ID:	826161
Call topic:	FCH-02-8-2018: Waste-stream based power balancing plants with high efficiency, high flexibility and power-to-X capability
Project total costs:	€528 750
FCH JU max. Contribution:	€528 750
Project start - end:	01/01/2019 - 31/12/2020
Coordinator:	ECOLE POLYTECHNIQUE FEDERALE DE LAUSANNE, CH
Website:	www.waste2grids-project.net/



BENEFICIARIES: SOLIDPOWER SA, AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE, L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE, DANMARKS TEKNISKE UNIVERSITET

PROJECT AND OBJECTIVES

The overall objective is to identify the most promising industrial pathways of waste gasification and solid-oxide technology integrated plants, which provide grid-balancing services by switching among: (i) power generation (PowGen) mode, converting waste to electricity for the grid, (ii) power storage (PowSto) mode, using the grid electricity to convert waste into methane, and (iii) power neutral (PowNeu) mode, converting waste into methane with no grid interaction. The goals are to perform a preliminary investigation into the long-term techno-economic feasibility of the plants and to identify promising business cases with the necessary preconditions.

NON-QUANTITATIVE OBJECTIVES

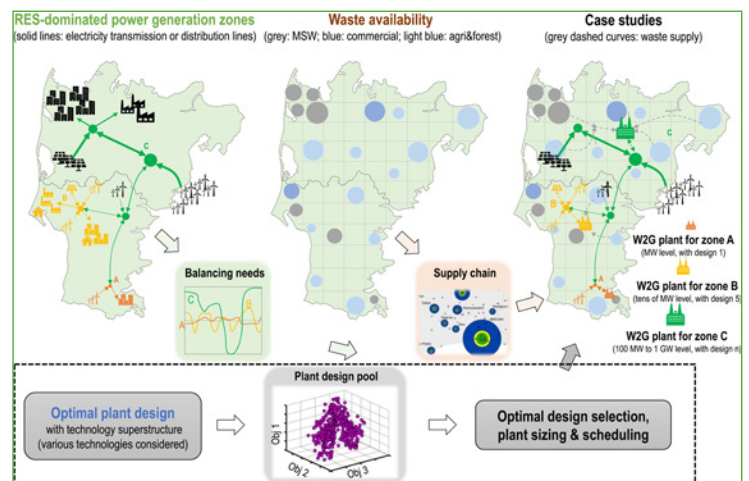
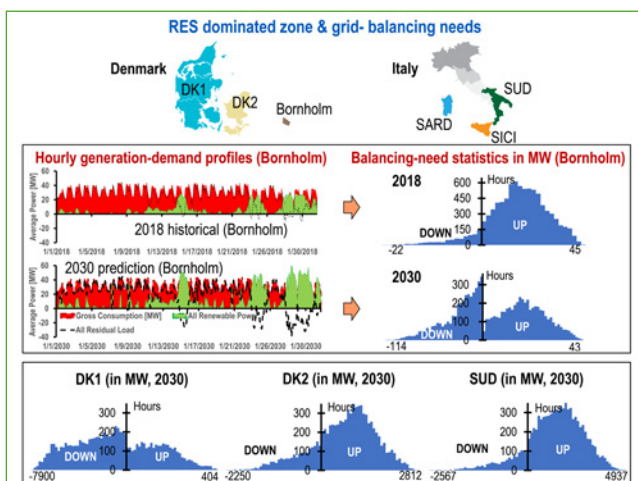
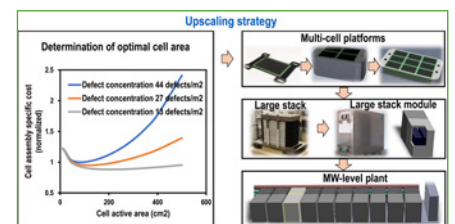
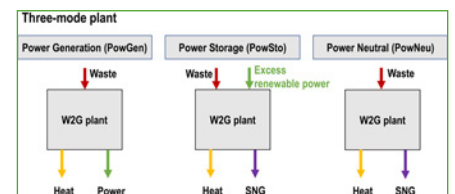
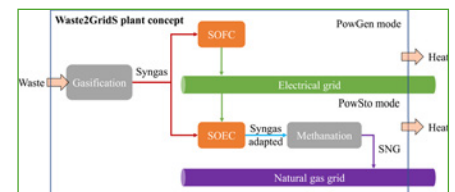
- Grid flexibility needs. Theoretical flexibility needs for 2030 were identified with the multi-timescale data-driven method developed. Four of the six zones identified are interested, i.e. DK1, DK2 and Bornholm in Denmark and SUD in Italy
- Waste availability prediction. For the four RES-dominated zones, the following were quantified for 2030: the sustainable potentials of organic waste

and residual biomass, including agriculture residues (straw and pruning), forest (net increment and residues), MSW (organic, wood and paper fraction) and bio-waste

- Multiple design evaluation. The optimal conceptual plant design has been drawn up with various combinations of technologies, resulting in an efficiency up to 50-60 % for PowGen mode, 72-76 % for PowSto mode and 47-55 % for PowNeu mode
- Promising business cases. At least two business cases have been identified with specific locations, plant design, sizes and scheduling.

PROGRESS AND MAIN ACHIEVEMENTS

- Proposed a novel concept of a triple-mode grid balancing plant enabled by biomass gasification and reversible solid-oxide cell technology
- Proposed a sequential optimisation method for thermo-economic feasibility that takes into account grid flexibility needs, waste availability and plant design
- Identification of business cases of the triple-mode concept and the necessary prerequisites.



**PANEL 6
SUPPORT FOR
MARKET UPTAKE**



AD ASTRA

HARNESSING DEGRADATION MECHANISMS TO PRESCRIBE ACCELERATED STRESS TESTS FOR THE REALIZATION OF SOC LIFETIME PREDICTION ALGORITHMS

Project ID:	825027
Call topic:	FCH-04-3-2018: Accelerated Stress Testing (AST) protocols for Solid Oxide Fuel Cells (SOFC)
Project total costs:	€3 008 426
FCH JU max. Contribution:	€3 008 426
Project start - end:	01/01/2019 - 31/12/2021
Coordinator:	AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE, L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE, IT
Website:	www.ad-astra.eu



BENEFICIARIES: SUNFIRE GMBH, SOLIDPOWER SPA, EIFER EUROPAISCHES INSTITUT FUR ENERGIEFORSCHUNG EDF KIT EWIV, INSTITUTE OF ELECTROCHEMISTRY AND ENERGY SYSTEMS, UNIVERSITA DEGLI STUDI DI SALERNO, ECOLE POLYTECHNIQUE FEDERALE DE LAUSANNE, UNIVERSITA DEGLI STUDI DI GENOVA, DANMARKS TEKNISKE UNIVERSITET, COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES

PROJECT AND OBJECTIVES

Accelerated stress tests deliberately stress a test material, component or product for a short period of time to assess the stability of new materials without having to use them in an operational system over a long-term period. The 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 next.

NON-QUANTITATIVE OBJECTIVES

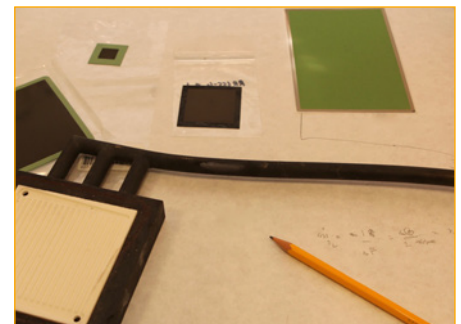
A Comprehensive Review article has been submitted to the *Journal of Electrochemical Science Advances* as open access. The submission is under peer evaluation.

PROGRESS AND MAIN ACHIEVEMENTS

- 160 samples from in-field and laboratory tests have been delivered and analysed
- Online database set up for the collection of all data (sample identity details, test conditions, measurement results) in an indexed archive
- First model for transfer functions developed from AST conditions to real-life operation.

FUTURE STEPS AND PLANS

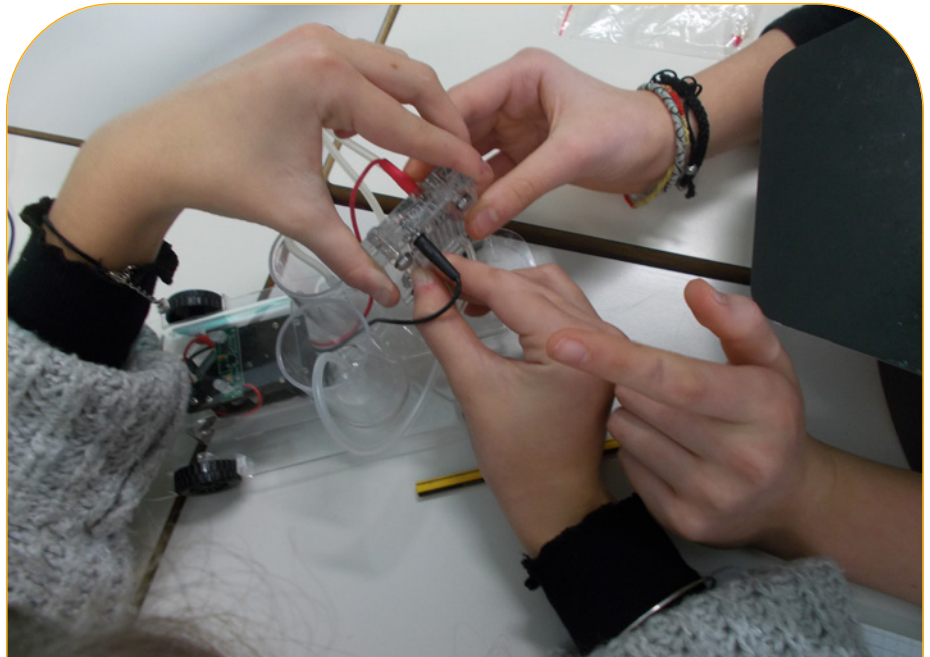
- Finalisation of a second round of experiments and evaluation of results. Deliverable 3.2 will reflect this and is being assembled
- Definition of experimental campaign for validation of selected AST procedures. Deliverable 2.2 will incorporate results from D3.2 and present this
- Inclusion of experimental data in the tailored degradation models. Deliverable 5.2 will present this phase.



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 WP 2, 3 and 4	2 for WP3, 1 for WP4, 3 for WP5	
AWP 2018	Submission of NWIP to IEC for standardisation	1	Contributions from project to Ad Hoc Group received	

Project ID:	826246
Call topic:	FCH-04-4-2018: Strengthening public acceptance and awareness of FCH technologies by educating pupils at schools
Project total costs:	€502 499
FCH JU max. Contribution:	€502 499
Project start - end:	01/01/2019 - 30/06/2021
Coordinator:	UNIVERSITA DEGLI STUDI DI MODENA E REGGIO EMILIA, IT
Website:	fchgo.eu



BENEFICIARIES: STEINBEIS 2I GMBH, INEUROPA SRL, ZURCHER HOCHSCHULE FUR ANGEWANDTE WISSENSCHAFTEN, UNIWERSYTET MIKOLAJA KOPERNIKA W TORUNIU, LIBERA UNIVERSITA DI BOLZANO, DANMARKS TEKNISKE UNIVERSITET

PROJECT AND OBJECTIVES

FCHgo aims to explain the functioning and application of FCH technologies to young people by providing an educational toolkit with a narrative approach and a website as a connection point for all users. A set of classrooms lessons from six countries will be available, designed for pupils from 8 to 18. FCHgo has also launched the first edition of a new annual award for the best idea/solution for using FCH. The final version of the FCHgo toolkit is now available, having been tested in classrooms and validated.

NON-QUANTITATIVE OBJECTIVES

- Educational Programme Delivery Model (EPDM). The final version of the EPDM consists of an educational toolkit comprising a set of guidelines, lessons, toys, plays and videos to support educational activities in European schools. The EPDM is currently available in five languages

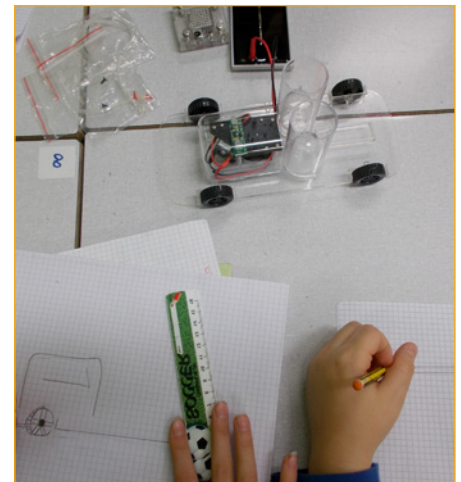
- Launch of the FCHgo award, offering all European students the opportunity to propose their best ideas for future FCH applications. The award is up and running.

PROGRESS AND MAIN ACHIEVEMENTS

- Final version of the FCHgo EPDM available
- Testing of the EPDM has been completed in all partners countries
- FCHgo award activities are under way.

FUTURE STEPS AND PLANS

First edition of the FCHgo award. Award submissions closed on 31 March 2021 and the prizes were awarded in June 2021. More editions of this annual award have been scheduled.



QUANTITATIVE TARGETS AND STATUS

PARAMETER	UNIT	TARGET	ACHIEVED TO DATE BY THE PROJECT	TARGET ACHIEVED?
Participation in educational activities	Pupils	800	1 842	✓
Website visitors	Number of visitors	3 000	5 966	✓
Number of likes/followers in social networks	Number of likes/followers	1 000	1 142	✓
Participation in external events	Events	10	12	✓



HYDRAITE

HYDROGEN DELIVERY RISK ASSESSMENT AND IMPURITY TOLERANCE EVALUATION

Project ID:	779475
Call topic:	FCH-04-1-2017: Limiting the impact of contaminants originating from the hydrogen supply chain
Project total costs:	€3 499 867.50
FCH JU max. Contribution:	€3 499 867.50
Project start - end:	01/01/2018 - 31/12/2020
Coordinator:	TEKNOLOGIAN TUTKIMUSKESKUS VTT OY, FI
Website:	hydraite.eu



BENEFICIARIES: COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES, STIFTELSEN SINTEF, NPL MANAGEMENT LIMITED, ZENTRUM FÜR SONNENENERGIE- UND WASSERSTOFF-FORSCHUNG BADEN-WURTEMBERG, POWERCELL SWEDEN AB, ZENTRUM FÜR BRENNSTOFFZELLEN-TECHNIK GMBH, SINTEF AS

PROJECT AND OBJECTIVES

The HYDRAITE project aims to solve the issue of hydrogen quality for transportation applications. It involves studying the effects of contaminants that originate from the hydrogen supply chain, on fuel cell systems in automotive applications. An HRS sampling campaign has been conducted. The project has developed in-line monitoring of hydrogen quality at the HRS as well as a sampling strategy and methodology for new impurities, gas, particles and liquids. Three European H₂ laboratories have been established, capable of measuring all contaminants according to ISO 14687 standards.

NON-QUANTITATIVE OBJECTIVES

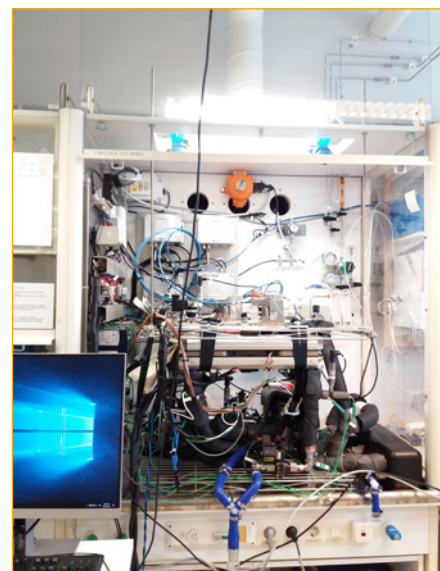
- Recommendations for revision of ISO standard 14687. Similar measurement set-ups of six partners are ready, methodology has been validated, FC measurements have started with CO, CO₂, sulphur, ionic liquids, freon and toluene
- Recommendations for FC stack contaminant measurements in automotive-type operation. Recommendations will derive from the successful measurement campaigns
- Technical data on fuel composition from HRS. The first HRS measurement campaign has been completed, external analysis completed, internal analysis and inter-laboratory comparison are ongoing. The second SC was realised in spring 2021
- In-line monitoring of hydrogen fuel quality. The concept of a PEM-based sensor and HRS in-line quality monitoring has been established.
- Three European laboratories to measure the ISO contaminants. Three laboratories with analytical methods compliant with ISO 14687 have been set up.

PROGRESS AND MAIN ACHIEVEMENTS

- Three European hydrogen quality laboratories have been established, capable of full analysis according to EN 17124
- The first HRS sampling campaign was conducted, with 10 gas and particle samples collected from 8 different stations in Germany, Sweden and Norway
- Validating the methodology for studying the effect of impurities on FC stacks.

FUTURE STEPS AND PLANS

- FC measurements will be made as planned in the DoA by 6 project partners and the results reported
- Recommendations will be formulated based on the experience and results from FC measurement campaigns
- The second HRS measurement campaign will be conducted.
- Reporting of the analytical solutions and development of an in-line sensor for hydrogen fuel monitoring
- Three European H₂ quality laboratories will have their third and final inter-comparison.



3 analytical laboratories ready for Hydrogen quality ISO 14687



Project ID:	875089
Call topic:	FCH-04-1-2019: Training of Responders
Project total costs:	€1 000 000
FCH JU max. Contribution:	€1 000 000
Project start - end:	01/01/2020 - 31/12/2022
Coordinator:	UNIVERSITY OF ULSTER, UK
Website:	hyresponder.eu/

BENEFICIARIES: FIRE SERVICE COLLEGE LIMITED, INTERNATIONAL FIRE ACADEMY, MINISTRY OF THE INTERIOR OF THE CZECH REPUBLIC, UNIVERSITETET I SOROST-NORGE, LANDES-FEUERWEHRVERBAND TIROL, PERSEE, CRISIS SIMULATION ENGINEERING SARL, ECOLE NATIONALE SUPERIEURE DES OFFICIERS DE SAPEURS-POMPIERS (ENSOSP), SERVICE PUBLIC FEDERAL INTERIEUR, AYUNTAMIENTO DE ZARAGOZA, ASSOCIATION COMITE NATIONAL FRANCAIS DU CTIF (COMITE TECHNIQUE INTERNATIONAL DE PREVENTION ET D EXTINCTION DU FEU), DLR-INSTITUT FUR VERNETZTE ENERGIESYSTEME EV, AIR LIQUIDE SA, DEUTSCHES ZENTRUM FUR LUFT- UND RAUMFAHRT EV, UNIVERSITA DEGLI STUDI DI ROMA LA SAPIENZA, COMMISSARIAT A L'ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES

PROJECT AND OBJECTIVES

The aim of HyResponder is to develop and implement a sustainable train the trainer programme in hydrogen safety for responders throughout Europe. Updated operational, virtual reality and educational training will reflect the state of the art in hydrogen safety. The European Emergency Response Guide will be revised. The materials for responders will be translated and available in 8 languages via a purpose-built e-platform. The translated materials will be utilised by trainers to deliver workshops in 10 countries across Europe, enhancing the reach and impact of the programme.

NON-QUANTITATIVE OBJECTIVES

- Expansion of national networks beyond those specified in the project. This is ongoing through the SAB
- Development of training packages at different levels. A plan is in place and an example has been completed for feedback.

PROGRESS AND MAIN ACHIEVEMENTS

- Identified new safety aspects and scenarios of technologies, systems and infrastructures pertinent to responders, specifically LH2 (D1.1, 1.3)
- Revised the international curriculum in hydrogen safety for responders and produced a draft of updated training materials (WP2 outputs)
- Identified a stratification approach for the training materials to reflect four learning levels and requirements with partner and SAB input.

FUTURE STEPS AND PLANS

- Delivery of the train the trainer event. Plans in place to deliver this virtually, with the preliminary list of trainers identified
- Delivery of 10 regional workshops. Draft schedule prepared for 2022, to be submitted as a milestone in April 2021
- Training package with three sets of training materials (lectures, operational, VR). Plans are in place, the first draft of lectures is complete, materials to be available in June 2021 and revised based on feedback. They will be publicly available in 2022

- Translation of training package to be completed from June 2021 to December 2022
- Development of e-platform incorporating training materials and online tools. The draft structure is under preparation and the platform basis will be in place by the end of 2021. It will be publicly available at the end of 2022
- Recognition of the training package across Europe. Training materials are being reviewed with this in mind.



QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	PARAMETER	TARGET	TARGET ACHIEVED?
Project's own objectives	Training events (1 train the trainer, 10 national)	11	✗
	Three sets of training materials (lectures, operational, VR)	3	
	Revised EERG	1	
	E-platform for responders	1	



HyTunnel-CS

PNR FOR SAFETY OF HYDROGEN DRIVEN VEHICLES AND TRANSPORT THROUGH TUNNELS AND SIMILAR CONFINED SPACES

Project ID:	826193
Call topic:	FCH-04-1-2018: PNR for safety of hydrogen driven vehicles and transport through tunnels and similar confined spaces
Project total costs:	€2 500 000
FCH JU max. Contribution:	€2 500 000
Project start - end:	01/03/2019 - 28/02/2022
Coordinator:	UNIVERSITY OF ULSTER, UK
Website:	hytunnel.net



BENEFICIARIES: INTERNATIONAL FIRE ACADEMY, UNIVERSITETET I SOROST-NORGE, SERVICE PUBLIC FEDERAL INTERIEUR, PRO-SCIENCE - GESELLSCHAFT FÜR WISSENSCHAFTLICHE UND TECHNISCHE DIENSTLEISTUNGEN MBH, KARLSRUHER INSTITUT FUER TECHNOLOGIE, FUNDACION PARA EL DESARROLLO DE LAS NUEVAS TECNOLOGIAS DEL HIDROGENO EN ARAGON, HEALTH AND SAFETY EXECUTIVE, STICHTING KONINKLIJK NEDERLANDS NORMALISATIE INSTITUUT, NATIONAL CENTER FOR SCIENTIFIC RESEARCH 'DEMOKRITOS', UNIVERSITA DEGLI STUDI DI ROMA LA SAPIENZA, DANMARKS TEKNISKE UNIVERSITET, COMMISSARIAT A L'ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES

PROJECT AND OBJECTIVES

This pre-normative research project focuses on the safety of hydrogen-driven vehicles in underground infrastructure. The project will synthesise analytical, numerical and experimental research to produce recommendations for: (i) intervention strategies and tactics for first responders; (ii) the safer use of hydrogen vehicles in underground transportation systems; and (iii) RCS. HyTunnel-CS will reduce over-conservatism in infrastructure safety design for hydrogen accidents and save costs on underground systems. The outcomes could be directly implemented in relevant RCS.

NON-QUANTITATIVE OBJECTIVES

The risk to FCEVs entering tunnels to be equal or below that of fossil fuel vehicles. Approach the issue by considering the tunnel-vehicle as a system in experimental, theoretical and numerical studies.

PROGRESS AND MAIN ACHIEVEMENTS

- Analytical, numerical, small- and medium-scale experimental research programmes are being fulfilled as planned

- Large-scale experimental programme on hydrogen release, fires and explosions, including in a real tunnel (CEA), has commenced
- Progress communicated at the Stakeholders Workshop (220+ participants), Emergency Services Workshop (158 participants) and a meeting with car OEMs (28 participants).

FUTURE STEPS AND PLANS

- Analytical and numerical campaign: finalisation of the remaining analytical studies, validation of CFD simulations against large-scale experimental programme results. The work is expected to finish after completion of large-scale experimental campaigns in September 2021
- Experimental campaign: fulfilling experimental programme on hydrogen releases, fires and deflagrations. Mitigating delays in the large-scale experimental programme: expected to be completed in/by September 2021
- Communication campaign with results communicated via a dissemination conference scheduled for M36 (February 2022)

- Recommendations for inherently safer use of hydrogen vehicles (M34), for RCS (M35), response to hydrogen accidents (M36). Development of all recommendations is on track.

Spalling of concrete Hydrogen burners



QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	PARAMETER	TARGET	ACHIEVED TO DATE BY THE PROJECT	TARGET ACHIEVED?
Project's own objectives	Modelling and simulation campaigns	43	21	✘
	Two seminars (M6, M30), two workshops (both M15), dissemination conference (M36)	5	3	
AWP 2018	Experimental campaigns	20	13	
	Recommendations for inherently safer use of hydrogen vehicles in underground traffic systems	1	0	
	Recommendations for RCS	1	0	
	Harmonised recommendations on response to hydrogen accidents	1	0	





ID-FAST

INVESTIGATIONS ON DEGRADATION MECHANISMS AND DEFINITION OF PROTOCOLS FOR PEM FUEL CELLS ACCELERATED STRESS TESTING

Project ID: 779565

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

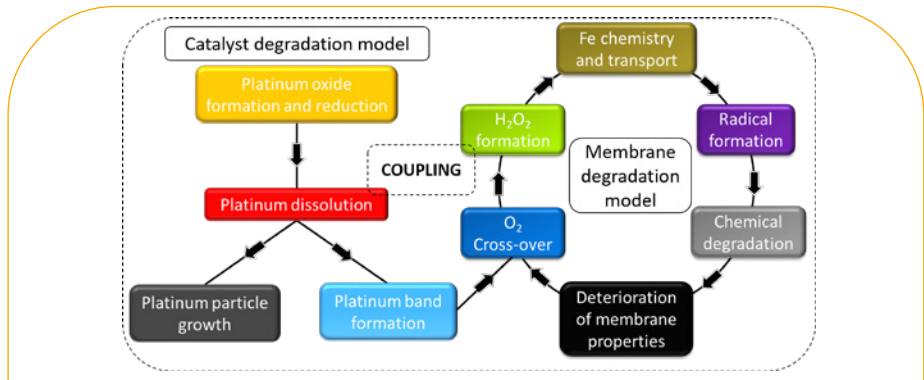
Project total costs: €2 748 195

FCH JU max. Contribution: €2 748 195

Project start - end: 01/01/2018 - 31/12/2021

Coordinator: COMMISSARIAT A L'ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES, FR

Website: id-fast.eu



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

PROJECT AND OBJECTIVES

ID-FAST aims to support the deployment of PEMFC by developing specific accelerated stress tests that can be linked to real-world durability. The core focus is on understanding degradation and validation of new ASTs relating in-/ex-situ and modelling data. Post-mortem analyses after ageing and models give insights into the mechanisms involved. Experiments and simulations using single or coupled mechanisms and various stressors have led to proposals for accelerating protocols applied in single cells. Validation with different MEAs, stress tests on stacks and the proposal of transfer functions linking AST to real-life conditions will conclude the project.

NON-QUANTITATIVE OBJECTIVES

- Identification of real ageing mechanisms and impact of conditions. Mechanisms identified, including local issues from post-mortem analyses of stack components aged following real ageing profiles.
- Development of models and coupling of mechanisms for simulation of ASTs. Coupling of the mechanisms

involved within the cathode catalyst layers achieved.

- The simulation was conducted with a model coupling membrane degradation and bipolar plate corrosion
- Development and validation of specific and combined AST protocols. Operando ASTs for single components tested with multiple stressors as well as specific ASTs based on the project reference drive cycles
- Proposal of transfer functions relating accelerated to real degradation. Comparison between real ageing conditions and accelerated conditions has started for some mechanisms and further analyses of combined protocols are needed
- Support standardisation efforts on fuel cell testing related to ASTs. Contribution to working group AHG11 of IEC TC105 started in 2019, dedicated to AST for fuel cells, in collaboration with the SOFC project AD ASTRA.

PROGRESS AND MAIN ACHIEVEMENTS

- Identification of main stressors and acceleration mechanisms for MEA components with specific ageing tests in cells or stacks and post-mortem analyses

- Simulation including multi-mechanism degradation modes based on models coupling cathode catalyst layer phenomena or membrane and metallic ions
- Definition of operando single component AST and AST with multiple stressors based on ID-FAST drive cycles towards further combined AST and validation.

FUTURE STEPS AND PLANS

- Complete the testing plan, including ageing tests in single cells and stacks to finalise AST development and then the validation process with different core components. Tests in progress at several partners. The focus and selection of the most relevant ageing tests will be considered throughout 2021 to achieve major outcomes
- Finalise the definition of combined ASTs based on experiments/models and the related transfer functions to link accelerated and real ageing. This is in progress and be done by coupling experimental and simulation results of performance losses and the impact of stressors during ageing following drive cycle profiles.

QUANTITATIVE TARGETS AND STATUS

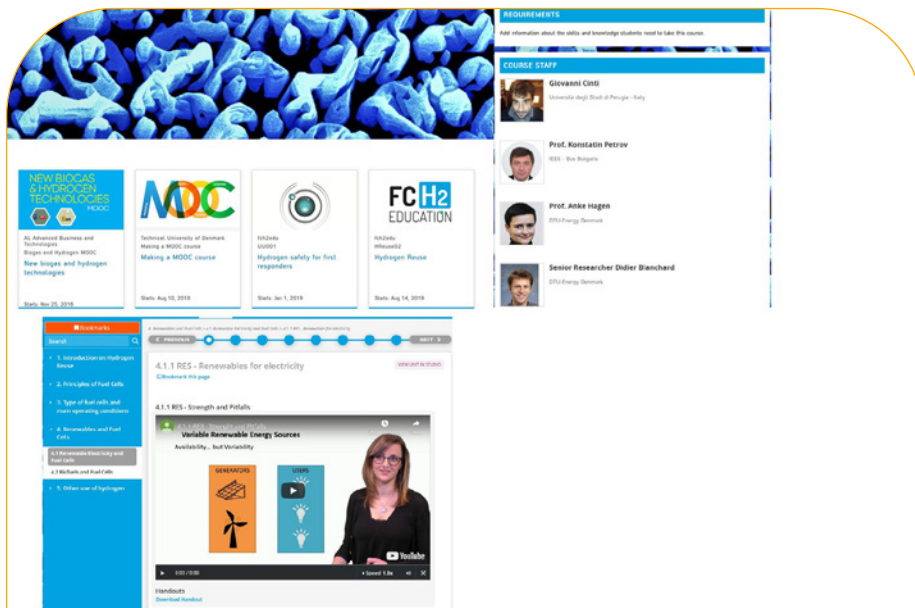
TARGET SOURCE	PARAMETER	UNIT	TARGET	TARGET ACHIEVED?	SOA RESULT ACHIEVED TO DATE (BY OTHERS)	YEAR FOR SOA TARGET
Project's own objectives	Accelerated degradation rate	µV/h	>100 µV/h	✗	Limited SoA on combined AST representative of the real world	N/A
	Acceleration factor		2 to 10 involving multiple stressors	✓ (involving multiple stressors)	Limited SoA on combined AST representative of the real world	N/A
	ASTs		New (different component or combined protocols)	✓	Single mechanism AST available for CCM components	<2018
	Ageing protocols	-	New (more representative of real ageing)	✓	e.g. FC-DLC	<2018
	Reducing gaps in the understanding of degradation		Improvement	✓ (progress on mechanisms and coupling)	Analyses of MEA degradation mechanisms (exp. and model)	<2020
	Transfer function linking real ageing and accelerated ageing		Relation defining the relative impact of real and accelerated ageing on the degradation rates	✗	Limited SoA on combined AST representative of the real world	N/A



NET-Tools

NOVEL EDUCATION AND TRAINING TOOLS BASED ON DIGITAL APPLICATIONS RELATED TO HYDROGEN AND FUEL CELL

Project ID:	736648
Call topic:	FCH-04-1-2016: Novel Education and Training Tools
Project total costs:	€ 1 596 007.5
FCH JU max. Contribution:	€1 596 007.5
Project start - end:	01/03/2017 - 30/11/2020
Coordinator:	KARLSRUHER INSTITUT FUER TECHNOLOGIE, DE
Website:	www.h2fc-net.eu



BENEFICIARIES: ELEMENT ENERGY, PERSEE, ELEMENT ENERGY LIMITED, INSTITUTE OF ELECTROCHEMISTRY AND ENERGY SYSTEMS, UNIVERSITA DEGLI STUDI DI PERUGIA, UNIVERSITY OF ULSTER, NATIONAL CENTER FOR SCIENTIFIC RESEARCH 'DEMKRITOS', DANMARKS TEKNISKE UNIVERSITET

PROJECT AND OBJECTIVES

NET-Tools aimed to develop a functional e-platform which operates as a gateway for the FCH community. The e-platform provides FCH relevant e-learning content compiled and provided under different categories. These categories are e-laboratory, e-learning and e-repository. While e-laboratory and e-learning are dedicated to FCH-related education, the e-repository offers additional opportunities to publish FCH-related information or research results. The e-platform is in operation and the e-laboratory provides e-tools. The e-platform is in operation and the e-laboratory provides all the e-tools and e-learning examples. The project has finished.

NON-QUANTITATIVE OBJECTIVES

- Deliver courses based on NET-Tools e-learning. The first course in the Bulgarian Institute of Science (BAS), Sofia, had 12 candidates and 10 certificates were awarded. The second course was in Buenos Aires, Argentina

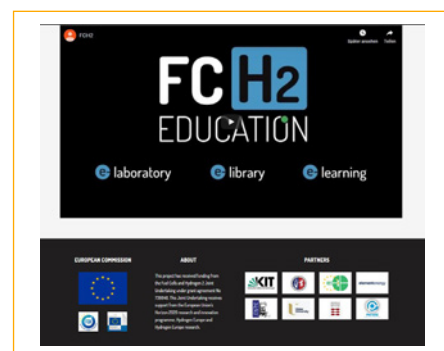
- Collection of e-tools. Compilation of calculation tools based on peer-reviewed publications
- Flying teachers. Two webinars presented instead of physical meetings
- Educational Schools. Specific project events to introduce the NET-Tools e-platform: the 1st Educational School was held in Bulgaria and the 2nd Educational School in Denmark
- Development of MOOCs.

PROGRESS AND MAIN ACHIEVEMENTS

- Technical realisation and structuring of the e-platform and its categories e-laboratory, e-learning and e-repository
- The programming of a set of e-tools that are included in the e-laboratory. The e-tools can be used for educational purposes and simple calculations
- The development of e-learning materials available under the e-learning category.

FUTURE STEPS AND PLANS

- Course content may be added to the e-learning category on the e-platform on a free basis, depending on the willingness of external contributors
- Additional e-tools for calculation and educational use may be added to the e-laboratory on a free basis, depending on the willingness of external contributors.



QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	PARAMETER	TARGET	ACHIEVED TO DATE BY THE PROJECT	TARGET ACHIEVED?
Project's own objective	E-tools	35	35	✓
	E-courses	3	3	
	Public project events	5	5	
	E-newsletter	6	6	
	Persons in collaboration	100	50	✗



Project ID: 779613

Call topic: FCH-04-4-2017: PNR for a safe use of liquid hydrogen

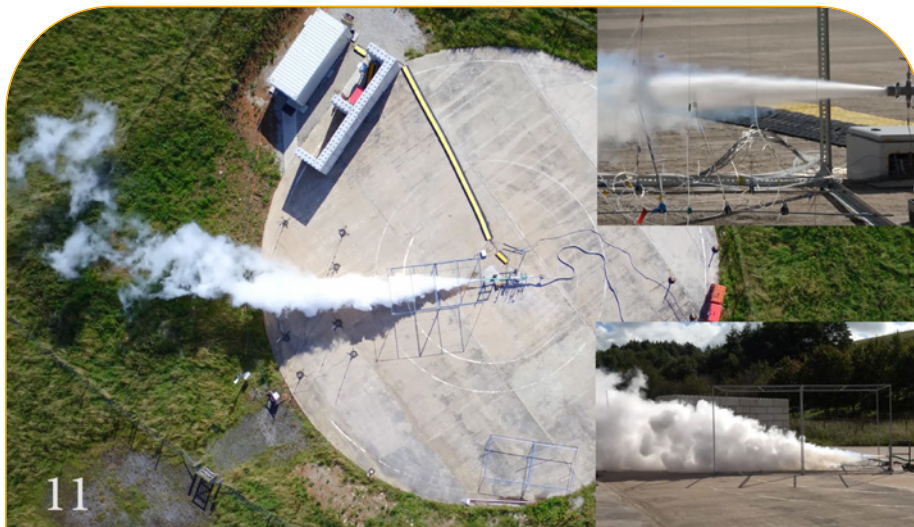
Project total costs: €1 905 862.50

FCH JU max. Contribution: €1 724 277

Project start - end: 01/01/2018 - 31/05/2021

Coordinator: KARLSRUHER INSTITUT FUER TECHNOLOGIE, DE

Website: www.preslhy.eu



BENEFICIARIES: INTERNATIONAL ASSOCIATION FOR HYDROGEN SAFETY, PRO-SCIENCE - GESELLSCHAFT FUR WISSENSCHAFTLICHE UND TECHNISCHE DIENSTLEISTUNGEN MBH, HEALTH AND SAFETY EXECUTIVE, UNIVERSITY OF ULSTER, INSTITUT NATIONAL DE L'ENVIRONNEMENT ET DES RISQUES INERIS, AIR LIQUIDE SA, THE UNIVERSITY OF WARWICK, NATIONAL CENTER FOR SCIENTIFIC RESEARCH 'DEMOKRITOS'

PROJECT AND OBJECTIVES

PRESLHY conducts pre-normative research for the safe use of cryogenic LH2 in non-industrial settings. In a preparatory phase, the state of the art was summarised and the experimental programme was adjusted to the outcome of a research priorities workshop. The central part of the project consists of three phenomena-oriented work packages addressing release, ignition and combustion with analytical approaches, experiments and simulations. The results will improve the general understanding and provide recommendations for SDOs.

PROGRESS AND MAIN ACHIEVEMENTS

- Organised 3 measurement data workshops and the LH2 session at the Research Priorities Workshop in 2020
- Experimental programme was accomplished, white paper and chapter on LH2 safety published
- Initiation of TF2 in the ISO TC 197 WG 29 for revising ISO TR 15916:2015 with respect to LH2 safety.

FUTURE STEPS AND PLANS

Integration of the project results into the revision of ISO TR 15916:2015 via the ISO TC 197 WG29 TF2 coordinated by the project coordinator. Revision has been formally initiated and it is planned to conclude in 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	3	✓
	Number of workshops with SDOs invited	1	4	
	Consortium partners involved in SDOs	1	5	
	Review of standard initiated	1	1	
Dissemination	Peer reviewed journal publications	1	3	

Project ID: 874997

Call topic: FCH-04-2-2019: Refuelling Protocols for Medium and Heavy-Duty Vehicles

Project total costs: €3 167 077.50

FCH JU max. Contribution: €1 494 417.00

Project start - end: 01/01/2020 - 31/12/2021

Coordinator: LUDWIG-BOELKOW-SYSTEMTECHNIK GMBH, DE

Website: prhyde.eu/



Nadine van der Schoot
ZBT GmbH

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, AIR LIQUIDE SA, COMMISSARIAT A L'ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES

PROJECT AND OBJECTIVES

The project aims to investigate the refuelling protocol requirements and provide data for compressed (gaseous) hydrogen refuelling protocols developed for 35, 50 and 70 MPa nominal working pressures. This will help facilitate the future standardisation of fuelling protocols for medium- and heavy-duty vehicles.

PROGRESS AND MAIN ACHIEVEMENTS

- Webinars in first year
- Publication of deliverables to date
- Survey of interested stakeholders outside of consortium.



Nadine van der Schoot
ZBT GmbH

QUANTITATIVE TARGETS AND STATUS

PARAMETER	TARGET	ACHIEVED TO DATE BY THE PROJECT	TARGET ACHIEVED?
Meetings with standards organisation groupings	4	2	✂
Number of reports sent to standards developing organisations	15	9	
Publicly accessible workshops/webinars	5	3	

Project ID: 779730

Call topic: FCH-04-3-2017: European Higher Training Network in Fuel Cells and Hydrogen

Project total costs: €1 248 528.75

FCH JU max. Contribution: €1 248 528.75

Project start - end: 01/11/2017 - 31/10/2020

Coordinator: THE UNIVERSITY OF BIRMINGHAM, UK

Website: www.teachy.eu



BENEFICIARIES: KARLSRUHER INSTITUT FUER TECHNOLOGIE, NATIONAL TECHNICAL UNIVERSITY OF UKRAINE IGOR SIKORSKY KYIV POLYTECHNIC INSTITUTE, UNIVERSITATEA POLITEHNICA DIN BUCURESTI, VYSOKA SKOLA CHEMICKO-TECHNOLOGICKA V PRAZE, INSTITUT POLYTECHNIQUE DE GRENOBLE, UNIVERSITY OF ULSTER, ECOLE POLYTECHNIQUE FEDERALE DE LAUSANNE, TECHNISCHE UNIVERSITEIT DELFT, POLITECNICO DI TORINO, UNIVERSITE LIBRE DE BRUXELLES, DANMARKS TEKNISKE UNIVERSITET

PROJECT AND OBJECTIVES

As the FCHT industry gradually emerges into the markets, the need for trained staff becomes more pressing. TeachHy2020, or TeachHy for short, specifically addresses the supply of undergraduate and graduate education (BEng/ BSc, MEng/MSc, PhD, etc.) in fuel cell and hydrogen technologies (FCHT) across Europe. TeachHy2020 will take a

lead in building a repository of university grade educational material, and design and run an MSc course in FCHT that is accessible to students from all parts of Europe.

- CPD modules established and trialled at several universities.

PROGRESS AND MAIN ACHIEVEMENTS

- MSc blended learning programme content established
- First MSc programme to start in October 2021

FUTURE STEPS AND PLANS

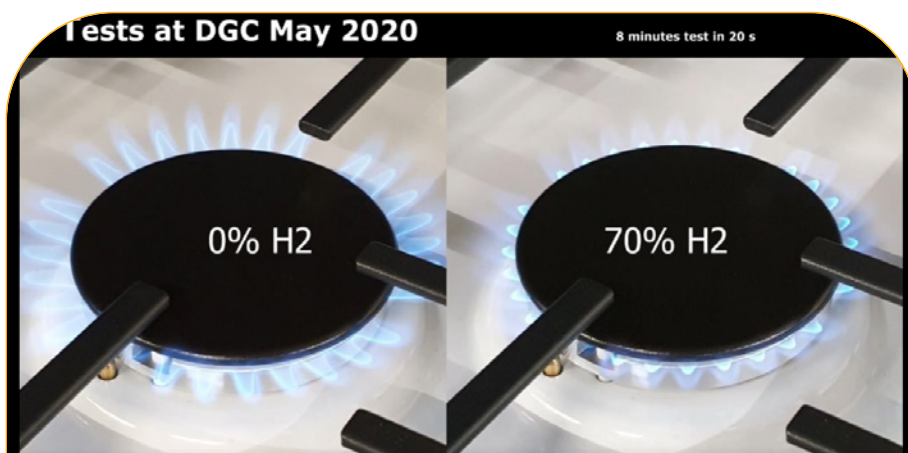
Forming a business entity to further support and manage the MSc programme material post-project. This is in progress.



QUANTITATIVE TARGETS AND STATUS

PARAMETER	UNIT	TARGET	TARGET ACHIEVED?
Start of MSc course	Date	October 2019	✘
Modules translated into different languages	Number of modules	12	✘
Minimum of 12 modules established on LMS	Number of modules	12	
Used MSc modules for CPD delivery	Modules run	-	✔

Project ID:	874983
Call topic:	FCH-04-3-2019: Hydrogen admixtures in natural gas domestic and commercial end uses
Project total costs:	€2 468 826.25
FCH JU max. Contribution:	€2 468 826.25
Project start - end:	01/01/2020 - 31/12/2022
Coordinator:	ENGIE, GR
Website:	thyga-project.eu/



BENEFICIARIES: DANSK GASTEKNISK CENTER AS, BDR THERMEA GROUP BV, GERG LE GROUPE EUROPEEN DE RECHERCHES GAZIERES, GAS.BE, GASWARME-INSTITUT ESSEN EV, DVGW DEUTSCHER VEREIN DES GAS- UND WASSERFACHES - TECHNISCH-WISSENSCHAFTLICHER VEREIN EV, ELECTROLUX ITALIA SPA, COMMISSARIAT A L'ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES

PROJECT AND OBJECTIVES

The THyGA project is investigating the amounts 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: domestic and commercial gas appliances (space heating, hot water, cooking and catering), which account for more than 40 % of the EU's gas consumption.

NON-QUANTITATIVE OBJECTIVES

Participation of external partners in the project. Some laboratories and manufacturers expressed a wish to use the THyGA protocol to do their own tests and contribute to the project's analysis.

PROGRESS AND MAIN ACHIEVEMENTS

- WP2 made an extensive assessment of the theoretical impact of H2NG blends on natural gas appliances (combustion and non-combustion impacts)
- Development of a generic protocol to assess the impact of H2NG blends on all appliances that will be tested during the project
- Test of around 15 appliances by end of March 2021 (the target is 100 appliances by 2022).

FUTURE STEPS AND PLANS

- Completion of the test campaign. So far, around 10 % of the test objectives have been attained and the goal is to achieve the 100 tests within the project timeline (by end of 2022)
- Support of the stakeholders on standardisation. THyGA has already begun exchanging information with technical committees and plans to develop a common work programme to support standardisation and certification with respect to H2NG for appliances
- Mitigation approaches. The objective is to identify the technical possibilities of mitigation to improve the acceptable rate of H2 that appliances can deal with (in terms of safety, efficiency, power, etc.).

QUANTITATIVE TARGETS AND STATUS

TARGET SOURCE	TARGET	ACHIEVED TO DATE BY THE PROJECT	SOA RESULT ACHIEVED TO DATE (BY OTHERS)	YEAR FOR SOA TARGET
Project's own objectives	Understanding the actual theoretical and experimental knowledge on the impact of H2NG blends on combustion	2 deliverables published on theoretical calculation and bibliography study	Several studies and test reports	2020
	Understanding the actual theoretical and experimental knowledge on the impact of H2NG blends on materials	Bibliography review and preparation of test rig	Several studies and test reports	
	Segmentation of the types of appliances	Segmentation validated with stakeholders	Similar approaches on segmentation	
	Test of up to 100 appliances	N/A	N/A	N/A

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