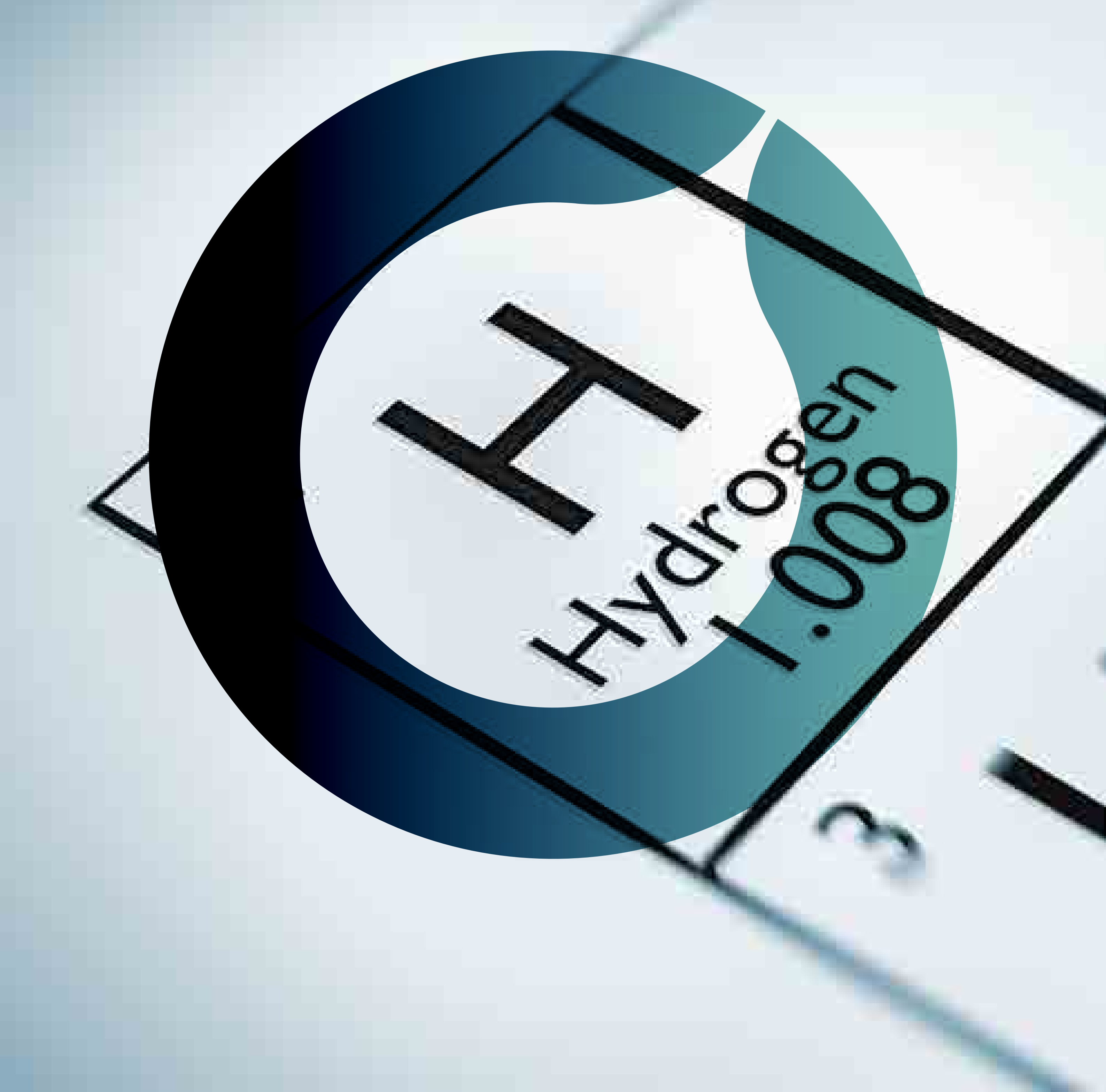
FUEL CELLS AND HYDROGEN
JOINT UNDERTAKING

PROGRAMME REVIEW
REPORT 2017



The FCH-JU Programme Office has asked the Joint Research Centre of the European Commission to develop an improved programme review methodology and to perform the full review for the year 2017. This report is an edited version of the full 2017 Programme Review Report produced by the JRC. The Joint Research Centre (JRC) performed the 2017 Programme Annual Review Assessment under the Framework Contract approved by the FCH-JU Governing Board on 23/12/2015.

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Design: EU-Turn, Brussels

Print ISBN 978-92-9246-327-4 ISSN 2443-602X doi:10.2843/703121
PDF ISBN 978-92-9246-328-1 ISSN 2443-6038 doi:10.2843/701136

FCH JOINT UNDERTAKING

Publicly available

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CONTENTS

LIST OF ACRONYMS

AFC	Alkaline fuel cell
APU	Auxiliary power unit
AWP	Annual work programme
CAPEX	Capital up-front expenditure (investment)
CGH_2	Compressed gas hydrogen
CHP	Combined heat and power
CO_2	Carbon dioxide
DC	Direct current
EIS	Electrochemical Impedance Spectroscopy
EU	European Union
FP7	European Union's Seventh Framework Programme for Research and Technological Development
FC	Fuel cell
FCEV	Fuel cell electric vehicle
FCH	Fuel cell and hydrogen
FCH JU	Fuel Cells and Hydrogen Joint Undertaking: FCH1 JU (2008-2014); FCH2 JU (2014-2020)
GDL	Gas diffusion layer
GHG	Greenhouse gas
H_2	Hydrogen
H2020	Horizon 2020
HFP	European Hydrogen and Fuel cell Platform
HHV	Higher heating value
HRS	Hydrogen refuelling station
HT	High temperature
ICE	Internal combustion engine
KPI	Key performance indicator
kW	Kilowatt
LCA	Life cycle assessment
MAIP	FCH JU's Multi-Annual Implementation Plan (2008-2013)
MAWP	FCH 2 JU's Multi-Annual Work Plan (2014-2020)

MEA	Membrane electrode assembly
MHV	Materials handling vehicles
MW	Megawatt
NOx	Nitrogen oxides
OEM	Original equipment manufacturer
P2H	Power to hydrogen
PEM	Proton exchange membrane
PEMFC	Proton exchange membrane fuel cell
PM	Particulate matter
PNR	Pre-normative research
PoC	Proof-of-concept
RCS	Regulations, codes and standards
SET-Plan	Strategic Energy Technology Plan
SME	Small and medium-sized enterprise
SoA	State of the art
SOFC	Solid oxide fuel cell
SOx	Sulphur oxides
TCO	Total cost of ownership
TRL	Technology readiness level TRL 1 – basic principles observed TRL 2 – technology concept formulated TRL 3 – experimental PoC 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)
USA	United States of America

INTRODUCTION 01

1.1 FUEL CELL AND HYDROGEN TECHNOLOGIES CONTRIBUTING TO EU GOALS

The European Union (EU) is a signatory of the Paris Agreement, which came into force in November 2016. The aim of the agreement is to enhance implementation of the United Nations Framework Convention on Climate Change by, for instance, limiting temperature increases to below 2°C above pre-industrial levels and actually aiming to remain within a 1.5°C rise.

Prior to this, the EU had already been active in targeting reductions in carbon dioxide (CO_2) emissions by setting increasingly ambitious objectives, the latest figures being those included in the 2030 Energy Strategy published in 2015:

- 40 % reduction in greenhouse gas emissions compared to 1990 levels;
- 27 % share of renewable-energy consumption[1];
- 27 % energy savings compared to a 'business as usual' scenario.

In parallel, the EU is aware of its extreme dependence on oil and gas imports and has set targets to reduce the related risks. This is voiced in the European Commission's 2014 Energy Security Strategy, which again puts the focus on the need for improved energy efficiency, as well as the necessity of increasing the EU's own energy production, to diversify supply sources and routes, to consolidate its internal energy system, and to protect its critical infrastructure.

Last, but not least, the EU aims to reduce air pollution, with the latest objectives set out in the 2013 Clean Air Policy Package.

Fuel cell and hydrogen (FCH) technologies can play a major role in achieving these goals for climate change, energy efficiency, pollution mitigation and internal energy sourcing. Fuel cells (FCs) produce electricity more efficiently than internal combustion engines (ICEs), reducing CO_2 emissions when fuelled with traditional fuels, and eliminating them altogether when fuelled with hydrogen, while releasing very limited amounts of nitrogen oxides (NOx), sulphur oxides (SOx) and particulate matter (PM) pollutants.

Although the production of hydrogen (H_2) itself, traditionally from hydrocarbons, does release CO_2, a hydrogen FC-powered engine will still emit less CO_2 globally than its ICE counterpart. Better still, the development of technologies for producing hydrogen from renewable energies would make hydrogen fuel cell power units totally carbon neutral. Furthermore, such so-called 'green hydrogen' can act as a store for renewable electricity and allow offsetting potential power grid instability caused by the fluctuating nature of renewable electricity production.

The European Commission had already identified this potential in 2004 when it set up the European Hydrogen and Fuel Cell Platform (HFP). In 2008, this was transformed into the FCH JU, which became the FCH 2 JU in 2014. In parallel, since the onset of the Strategic Energy Technology Plan (SET-Plan), FCH technologies have been listed among the eight technologies with a potentially important role in a successful European sustainable energy system.

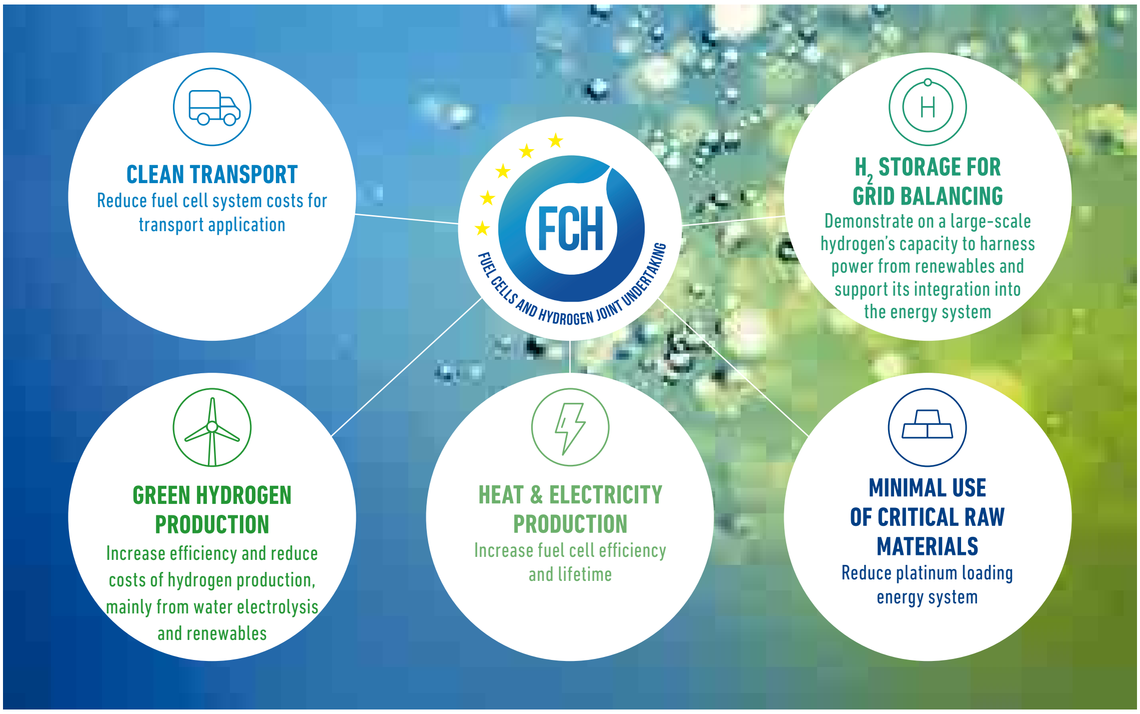
FCH technologies as a strategic option for transport has been further evidenced by the Alternative Fuels Directive[2] as well as the Clean Mobility package launched by the European Commission in November 2017[3].

1. Target valid during the conduction of the review, for the revised targets please visit: https://ec.europa.eu/energy/en/topics/renewable-energy
2. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32014L0094
3. https://ec.europa.eu/transport/modes/road/news/2017-11-08-driving-clean-mobility_en

1.2 THE ROLE OF THE FCH JU

The overall objective of the FCH JU is to implement an optimal research and innovation programme at EU level in order to develop a portfolio of clean and efficient solutions that exploit the properties of hydrogen as an energy carrier and fuel cells as energy converters to the point of market readiness. This will enable support for EU policies on sustainable energy and transport, climate change, the environment and industrial competitiveness as embodied in the Europe 2020 strategy, job creation, and also help achieve the EU's overarching objective of smart, sustainable and inclusive growth. The core objectives are illustrated in Figure 1.

Figure 1: The core objectives of the FCH JU programme



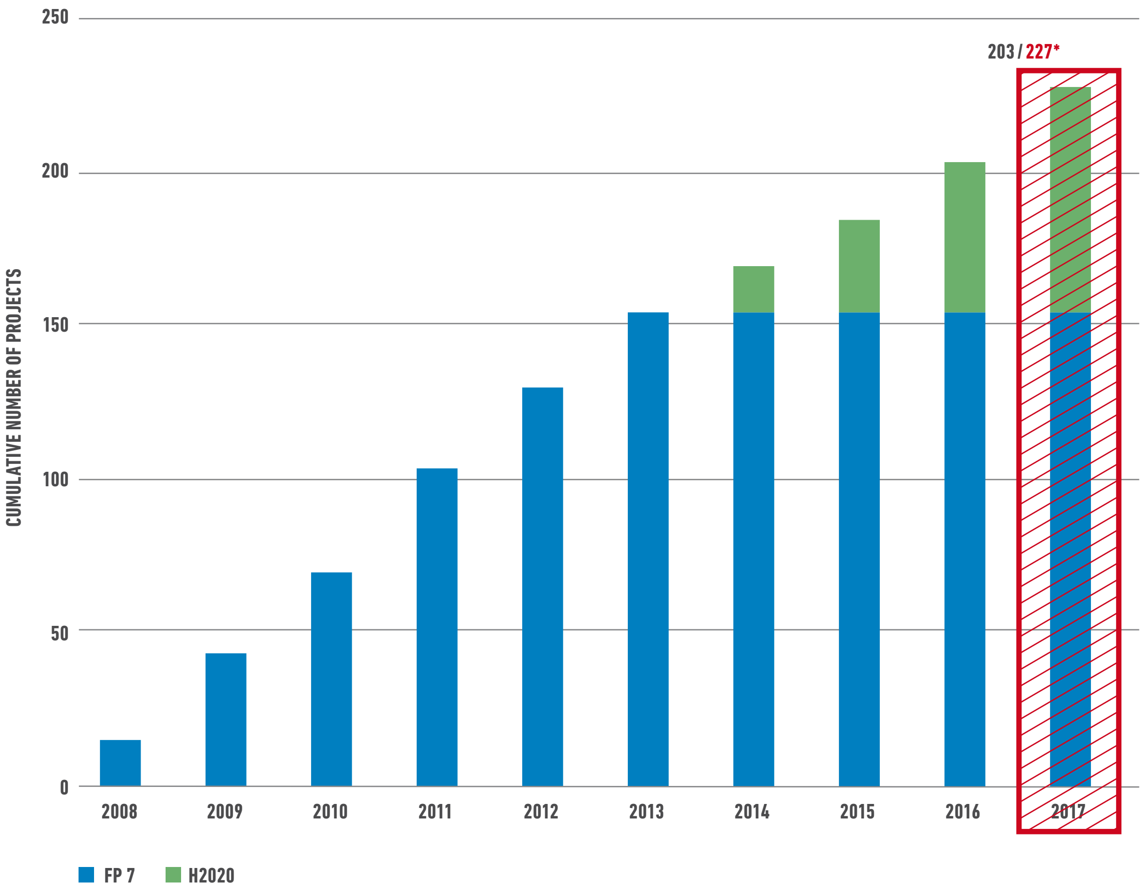
The overall direction of the programme is guided by the multi-annual plans: MAIP (Multi-Annual Implementation Plan) for 2008-2013 under the FP7 (Seventh Framework Programme of the European Community for Research and Technological Development, including demonstration activities) and MAWP (Multi-Annual Work Plan) for 2014-2020 under the Horizon 2020 - the Framework Programme for Research and Innovation (2014-2020). These plans specify targets for FCH technologies in Europe in the form of specific key performance indicators (KPIs) covering cost, durability and performance. Project-specific targets were also considered and are relevant for the review process. The progress of the programme is judged to a great extent by progress towards achieving all these targets, and for the current review, the relevant ones are those for 2017.

Compared to the MAIP, the programme described in the MAWP places greater emphasis on near market pre-commercialisation activities and particularly on increasing numbers of units in demonstration projects. These serve several broad aims: to provide real world performance data on statistically significant numbers of units; to contribute to increased scale of manufacturing and consequent cost reduction; to collect experience on usefulness and added value of applicable standards and regulations and to increase public awareness of the benefits of FCH technologies. The shift in emphasis in the programme is reflected in an increase in the technology readiness levels (TRLs) required of the projects. For example, research and innovation projects are expected to normally have a starting TRL of 3 to 5 and demonstration projects a starting TRL of 6 to 8.

1.3 PURPOSE AND SCOPE OF PROGRAMME REVIEW 2017

The purpose of the periodic Programme Review is to ensure that the FCH JU programme is aligned with the strategy and objectives set out in the founding Regulation[4] and in the multi-annual programme and annual work programmes. The cumulative number of projects supported by the FCH JU programme since its start in FP7 is shown in Figure 2.

Figure 2: Cumulative number of projects in the FCH JU programme



* Projects included in Programme Review 2017 covering calls 2008-2016 /Projects signed on 01/08/2017

The consecutive Programme Reviews have included all projects that were operational for all or part of the period June-October of the preceding year. The 2017 review therefore covers 87 projects, of which 58 were initiated under FP7, and 29 under Horizon 2020 (H2020). All data and statistics quoted here are as reported by the cut-off date of June 2017.

The Programme Review is performed on a project basis. Considering the FCH JU programme structure (Figure 3) which consists of two main pillars (Transport and Energy) and of cross-cutting activities relevant to both, the projects have been assigned to six «review panels». The panels coverage of projects is schematically shown in Figure 3.

4. COUNCIL REGULATION (EU) No 559/2014 of 6 May 2014

Figure 3: The overall structure of the FCH JU programme and the panels for the 2017 review

Each panel focuses on a specific subject area. The Transport pillar distinguishes between projects mainly concerned with technology validation and others mainly dealing with research, grouped in two separate panels. For the Energy pillar, projects dealing with stationary heat and power generation are similarly split in two panels, whereas all projects dealing with hydrogen production, distribution and storage are clustered in a single panel. In the review, projects with activities relevant to both the Transport and the Energy pillar (overarching) are associated to the panel that best reflects the main focus of the project. Cross-cutting projects are covered in a dedicated panel.

REVIEW PROCESS

From its start in 2011 and until 2016, the Programme Review has been carried out by external experts from research and industry, both European and non-European, as well as by members of the FCH JU Scientific Committee.

As follow-up to a recommendation[5] by the Internal Audit Service of the Commission, the 2017 programme review was performed following a different procedure than the one applied in the previous years. Upon proposal by the PO and following endorsement by the Governing Board, the JRC was entrusted with the 2017 programme review as part of its activities under the multiannual Framework Contract between FCH JU and JRC. Subsequent to the signature of a Declaration of Confidentiality and Conflict of Interest, all activities related to the review have been performed in the JRC Petten establishment.

Although the 2017 review covers similar aspects as the previous reviews, it pays particular attention to the added value, effectiveness and efficiency of FCH JU activities. Specific recommendations covering these aspects are formulated to better meet the overall FCH JU programme objectives and targets.

PRESENTATION OF THE REVIEW FINDINGS

This Programme Review Report summarises the findings from the assessment of the projects in the six panels. For each panel, because of the wide range in scope, activities and applications of the projects belonging to it, projects covering similar or related topics are brought together in a number of focus areas. This grouping is followed by a historical overview of the related budget evolution for the panel.

The panel review identifies the strengths of the panel and areas that would benefit from additional focus and proposes a set of actions for follow-up.

5. Final Audit Report on Performance management of the Fuel Cells and Hydrogen 2 Joint Undertaking (FCH 2 JU) activities (IAS Audit Report: IAS.A2-2016-FCH 2 JU-003, Ares(2016)6677840 - 29/11/2016)

02 TRANSPORT PILLAR

2.1 OBJECTIVES

The aim of the transport pillar is to accelerate the commercialisation of FCH technologies in transport through a programme including both demonstration and research projects.

FCH technologies play an important role in reducing emissions, including greenhouse gases (GHGs), local emissions such as SOx, NOx, particulate matter (PM), as well as noise from Europe's transport activities, especially road transport. On a well-to-wheel basis, the use of 'green' hydrogen significantly reduces the carbon emissions associated with transport. FCH technologies also contribute to enhanced energy security through higher conversion efficiencies and reduced fuel import dependence.

2.2 BUDGET

The FCH JU's MAIP set out a budget of between 32 % and 36 % of total spending for transportation and refuelling infrastructure activities (excluding off-road vehicles) for the period 2008-2013. The second phase of the FCH JU has set a target for the same activities at 47.5 % of the total budget for 2014-2020 in the MAWP (the multi-annual plan)[6].

Table 1: FCH JU financial contribution (€ M) for the two main activity areas in the Transport pillar

TRANSPORT PILLAR / ACTIVITY AREAS	€ M
Technology validation in transport applications	252.6
Research activities for transport applications	88.7
Total	**341.3**

2.3 TECHNOLOGY VALIDATION (DEMONSTRATION)

The overarching aim is to reduce fuel cell system costs for transport applications while increasing their lifetime and reducing the use of critical raw materials such as platinum group metals.

2.3.1 FOCUS AREAS AND ACHIEVEMENTS

Focus areas

Demonstration projects focus on the following areas:

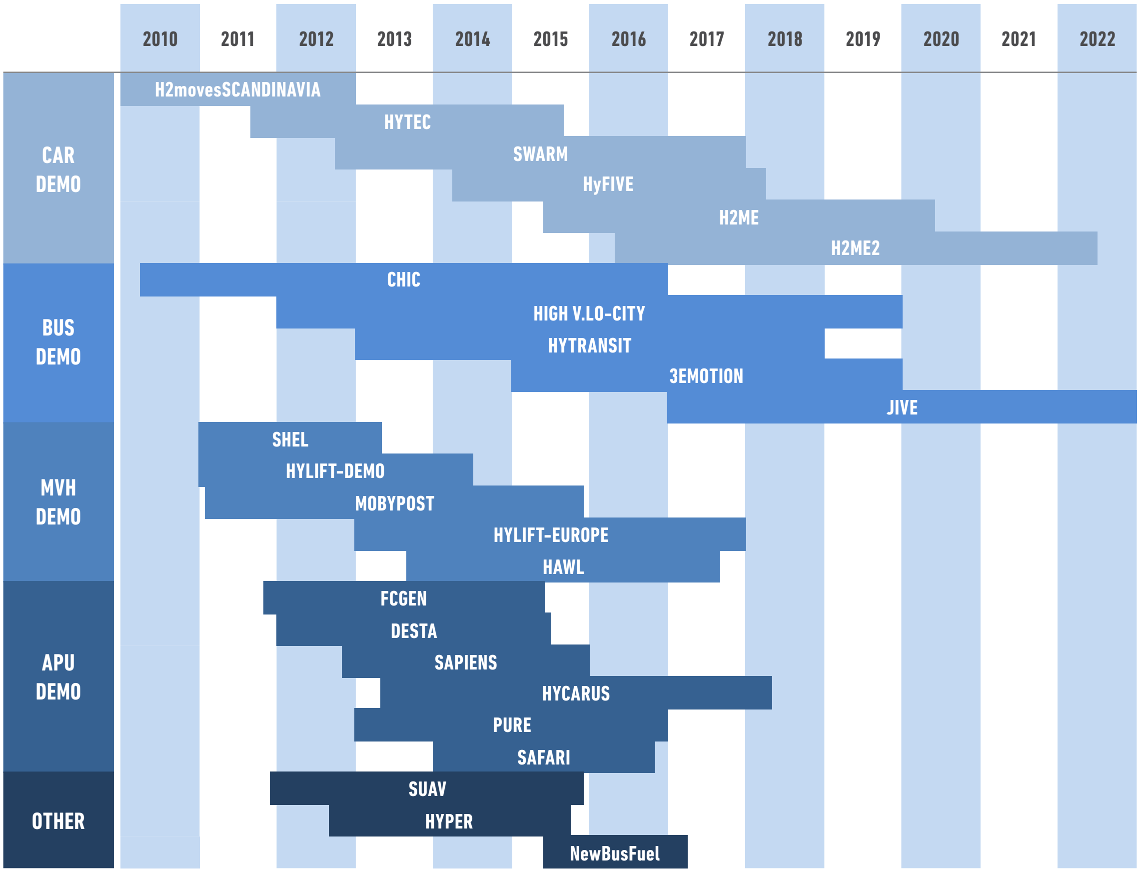
- **Cars and related refuelling infrastructure** – increase the number of fuel cell vehicles deployed in Europe, reduce vehicle costs and demonstrate market readiness as well as develop necessary infrastructure refuelling networks at a competitive cost;
- **Buses and related refuelling infrastructure** – deploy increasing numbers of fuel cell buses across Europe, improve fuel economy and availability and reduce cost per vehicle as well as develop necessary infrastructure for refuelling at a competitive cost;
- **Materials handling vehicles (MHVs)** – achieve system cost reductions, increase numbers of units deployed in Europe and prove the business case;
- **Auxiliary power units (APUs)** – validate the technology and identify markets over a range of road, air and marine applications;
- Other related projects that not easily grouped in the above focus areas.

6. Valid during the period of the conduction of the review, recently amended.

Activities by FCH JU are complemented and enhanced by the opportunity to work alongside the leading hydrogen mobility initiatives on fuel cell cars, buses and hydrogen refuelling stations (HRS) in EU Member States.

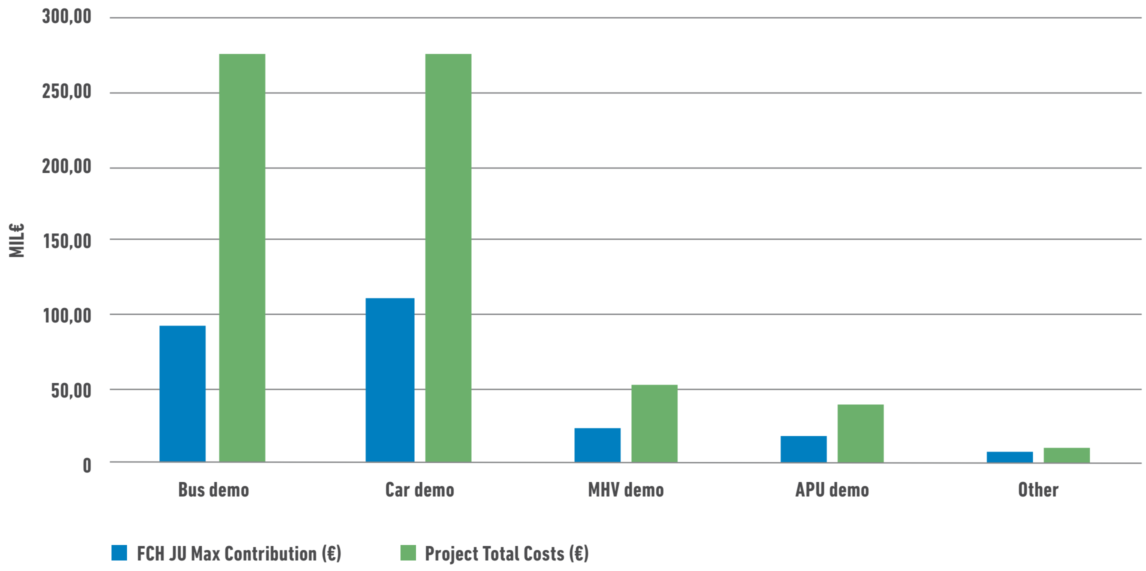
The present review covers thirteen projects across these five categories: SWARM, HyFIVE, H2ME, H2ME2 (cars and related infrastructure), CHIC, HIGH V.LO-CITY, HYTRANSIT, 3EMOTION (buses and related infrastructure), HYLIFT-EUROPE, HAWL (MHVs), HYCARUS, PURE (APUs), and NewBusFuel (other).

Figure 4: Technology Validation projects in the Transport pillar reviewed in Panel 1



In the calls between 2008 and 2016, the FCH JU supported 25 projects relevant to this panel with a total FCH JU contribution of €252.6 million and a contribution from partners of €402.3 million. The distribution of total budgets over the five focus areas is shown in Figure 5 and indicates that nearly half of FCH JU funding supports car demonstrations, whereas approximately 80% covers on-road vehicles (cars and buses). The FCH JU funding contribution to the projects covered in the present review amounts to about 40% of the total funding for this pillar and primarily addresses road transport.

Figure 5: FCH JU funding for Panel 1 (transport demo) from the start of the multi-annual programme up to now



Achievements

The FCH JU-backed demonstration activities involving **cars** concern over 1,600 vehicles with more than 350 currently deployed (the others are being planned for within the ongoing projects). Of those, at least 220 cars were in operation during 2016 and have now accumulated a total of almost 2 million km driven since the first day of their deployment. In 2016, at least 760 thousand km were driven. The 2016 average vehicle availability reached 99.26 %.

The 2017 targets for tank-to-wheel efficiency (42 %) and availability (higher than 98 %) have been met, while those for fuel cell system cost (150 €/kW), mid-executive class vehicle cost (€70 000) and fuel cell system lifetime (5,000 hours) are still to be reached.

A major success of the FCH JU car demonstration programme is bringing together Europe's four most ambitious national initiatives on hydrogen mobility for Germany, Scandinavia, France and the UK, into the two projects of the Hydrogen Mobility Europe initiative (H2ME and H2ME2). The initiative will significantly expand the activities in each country by deploying over 1400 fuel cell hydrogen vehicles and 49 state-of-the-art refuelling stations across eight countries. The scale in the deployment is expected to result in total cost of ownership (TCO) reductions for both FCEVs (both passenger vehicles and range-extended vans) and HRS.

Another asset of the programme is the increased attention that is being paid in recent projects to the demonstration of the benefits that electrolytic production of hydrogen at the refuelling station can offer in terms of balancing the electricity grid. The associated revenue generation from provision of energy services by aggregated electrolyser-HRS systems at MW scale may in future contribute to reducing the cost of hydrogen at the nozzle.

To meet the refuelling requirements for further uptake, a network of hydrogen refuelling stations is being created across Europe. The total number of HRS under the Transport Demo panel will be 89, out of them 39 are deployed (14 already confirmed in 2016).

The FCH JU-backed **HRS network** for cars refuelling covers to date seven countries and in 2016 delivered 11,800 kg[7] of hydrogen at 95.3% availability. Most of these installations meet the targets for station capital up-front expenditure (CAPEX) of 1-2.5 M€ (200-1,000 kg/day).

However, the hydrogen cost target is not yet consistently achieved, depending largely on the electricity price. The price of hydrogen at the pump ranges from 8 €/kg (from hydrocarbons) to 12 €/kg (from renewables).

The latest projects H2ME and H2ME2 are expected to set the HRS state of the art and the cumulative expertise acquired on legal and permitting aspects, and on safety. Their outcomes should be exploited for EU-wide harmonisation of legislation.

In terms of targets, the successful projects achieve the promised objectives at a quite reasonable level; while others fall short in reaching the set of expected goals. One of the main identified causes for this shortcoming is the delay evidenced for some of the demo activities, likely caused by under-estimation of some technical and legal/administrative difficulties during the project planning.

Demonstrations with **buses** concern 200 vehicles in 21 cities (42 vehicles in seven cities currently in operation) with a technology which is now close to commercial reality, at TRL 8. Considering the 41 bus demonstrations reported in TRUST, they have accumulated a total driven distance of over 5 million km since the FCH JU started. From 2016 reported data on FCH JU-backed bus demos, 1.6 million km were driven with an average bus availability of 82 %. There were over 8,000 refuelling operations consuming 159 tons of hydrogen for buses which proved to be able to meet their daily duty cycle. The 2017 targets for FC system Lifetime, FC System cost, and for vehicle cost (based on procurement prices) have been met, while those for availability (90 %) and fuel consumption are still ongoing as most buses have not yet been able to operate the targeted number of hours.

Fuel consumption is highly dependent on the city where buses are operating: even if the average fuel consumption of 9.86 kg hydrogen per 100 km is achieved, the reported fuel consumption for buses ranges between 14 kg hydrogen per 100 km and 7.7 kg hydrogen per 100 km.

An FCH JU-backed hydrogen refuelling station network for buses consisting of seven stations in seven cities has been deployed. It reached an average availability rate of 97% since the start of operation.

The bus demo projects have provided further positive evidence on the performance and functionality of hydrogen fuel cell buses and associated refuelling infrastructure, steadily reducing barriers for their commercialisation in the near term. This was mainly achieved through major progresses in FC lifetime (exceeding the expected targets) and increased availability of high-capacity refuelling systems, which now seems at par with those of a diesel refuelling infrastructure. Operational experience has been acquired with different bus drive trains and with different means of hydrogen production.

At a European level, FCH bus deployment activities can be considered as a flagship. The success of bus demo projects is demonstrated by the fact that in different cities, bus operators have joined the projects after their start. This evidences a growing involvement of regions and a steadily increase in private contribution to the financing of the demo projects.

The ongoing demo projects will benefit from the findings of the dedicated desk-top project NEWBUSFUEL which addressed the current knowledge gap between technologies and engineering solutions capable of refuelling a large number of buses at a single bus depot, together with the associated safety implications (particularly for the required large volumes of stored hydrogen).

7. This number does not match the 10,200 kg of hydrogen reported above for cars, because some FCH JU-backed HRS are also open to the public and not simply restricted to FCH JU-backed projects.

Materials Handling Vehicles (MHVs) projects HyLIFT-Europe and HAWL have been evaluated as part of the 2017 programme review. Demonstrations of MHVs will involve 283 forklifts, covering twelve different MHVs models, deployed in ten sites. From those, 116 have already been demonstrated and 92 reported in the TRUST exercise for 2016. Eight fuel cell systems and six vehicles models from three MHVs suppliers have been certified in Europe.

These vehicles are technically mature enough for commercialisation, but are still held back by unfavourable business cases. They have accumulated approximately 452,000 h of operation in total and 391,200 h in 2016 alone. The 2017 targets for lifetime (10,000 h) and availability (95%) have been achieved. The cost of on-board hydrogen storage (1,000 €/kg hydrogen), the fuel cell efficiency (50 %) and the fuel cell system cost (1,500 €/kW at 10 kW scale) remain to be proven.

In contrast to previous **APU** demo projects, the two projects analysed for the 2017 review deal with proton exchange membrane (PEM) technology: LT PEM for aviation applications (HYCARUS), and high temperature (HT) PEM for maritime applications, in particular use in an on-board recreational yacht (PURE).

For the airborne application (HYCARUS), the exploitation of the by-products from operating the fuel cell system (namely heat and oxygen-depleted air) to increase overall efficiency and reduce costs, has been analysed but not implemented due to economic reasons.

For the finished project dealing with the maritime application (PURE), the emphasis has been on tailoring catalyst materials and membrane electrode assemblies (MEAs) for the application requirements, in particular the use of sulphur-containing fuel. This has been successful, also because of previous findings from finished projects (both FCH JU and other EC programmes), but at the expense of reaching the objectives for the prototype HT PEM system in terms of size and weight.

Both projects have paid due attention in adapting existing regulations, codes and standards (RCS) to the specific APU applications and have interacted with RCS developing bodies active in the respective application domains. The outcome of these efforts, e.g. hazard analysis and safety assessment approaches, should be made public beyond the projects themselves.

2.3.2 REVIEW FINDINGS

This section presents an assessment overview of projects in Panel 1.

Strengths:

- Partners participating in demonstration projects show a significant commitment to FCH technology and a clear interest for its commercialisation.
- Regulatory issues have been identified and solved for 70 MPa refuelling and for placing hydrogen fuelling points on petrol forecourts.
- H2ME, CHIC, HIGH V.LO-CITY, HY-FIVE, HyTransit stand out for their relationships/interactions with national and regional programmes.
- There is a large potential for cross-fertilisation of achievements and lessons learned (e.g. hazards analysis and safety assessment) between demonstration projects.

Additional focus needed:

- Increase the number of projects on aeronautic and water-borne applications to reach the critical mass required for subsequent impact.
- Increase efforts to establish reliable approaches for cost estimation (TCO) and for life cycle assessment (LCA) evaluations for both vehicles and infrastructure.
- Ensure security in the supply of spare parts throughout the full project duration.

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

Follow-up actions

- Homogenise to the maximum extent possible reporting requirements and templates to collect information on the operation of cars, buses and fuelling infrastructure in terms of efficiency, reliability, environmental footprint and cost.
- Exchange operational experience with USA (in particular California), Japan, Korea, China.
- Strengthen cross-fertilisation between car and bus demos
- Formalise feedback from demo projects into research.
- Investigate the feasibility of expanding results from bus demos to heavy duty vehicles.

2.4 RESEARCH AND INNOVATION

2.4.1 FOCUS AREAS AND ACHIEVEMENTS

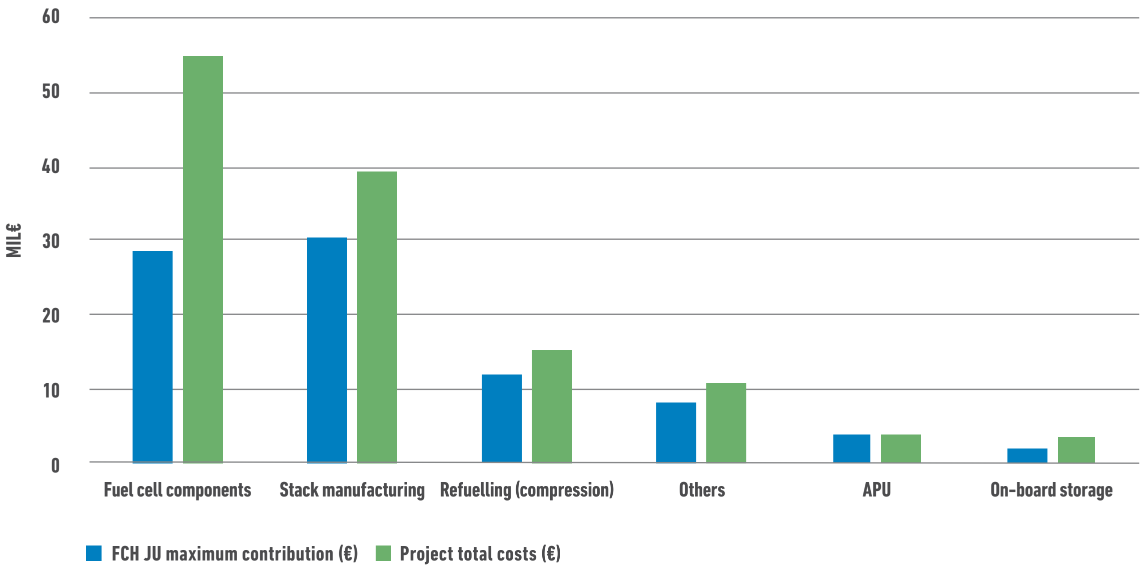
Focus areas

Research and innovation projects in transport focus on delivering better-performing fuel cells and hydrogen refuelling station (HRS) systems whilst also lowering costs. The projects portfolio covers the following research areas:

- **Membrane electrodes assembly (MEA) –** activities to develop and improve fuel cell membranes for transport;
- **Catalysts –** improvements to raise performance levels and reduce costs;
- **Gas diffusion layer (GDL) –** optimisation of gas distribution at the electrodes surface;
- **Bipolar plates –** development of materials for better performance and reduction of costs;
- **Methodologies and tools –** creation and development of modelling and other tools to help industry undertake projects;
- **Manufacturing and process development –** activities to support the near-term production of components and subsystems;
- **System and balance-of-plant (BoP) components –** development and improvement of components for better performance and/or reduced cost for on-board storage, APU and diagnostics;
- **Advanced refuelling –** projects to develop more cost-effective and increasingly efficient hydrogen refuelling technologies and storage options.

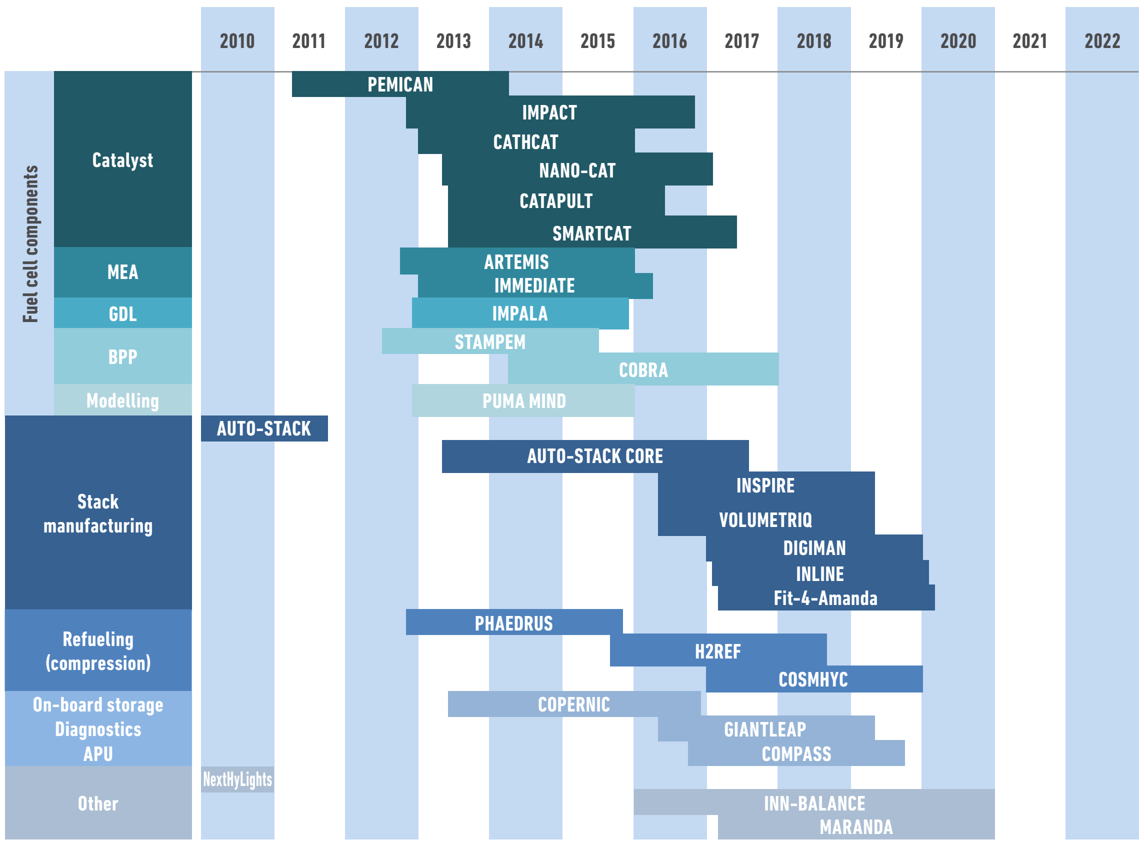
Between 2008 and 2016, the FCH JU supported 28 projects with a total FCH JU contribution of €88.7 million and a contribution from partners of €42.1 million.

Figure 6: FCH JU funding for Panel 2 (transport research) from the start of the multi-annual programme up to now



The present review covers eleven projects: IMPACT, NANO-CAT, SMARTCAT, COBRA (Fuel cell components), AUTO-STACK CORE, INSPIRE, VOLUMETRIQ (Stack manufacturing), H2REF (Refuelling / compression), COPERNIC (On-board storage), GIANTLEAP (Diagnostics), and COMPASS (APU).

Figure 7: Research projects in the Transport pillar reviewed in Panel 2 (Time Frame 2010-2022)



Achievements

In general, the four reviewed projects on **fuel cell components** (IMPACT, NANO-CAT, SMARTCAT, COBRA) have made significant progress at individual component level, although not all targets are met. In the future, the setting of targets could be more selective and realistic, and account for the effects of the most important interactions between individual performance improvement measures.

These four projects perform well in reaching their relevant targets, and slightly lower on project impact, but fall short for contributions to cross-cutting areas. This indicates that additional efforts may be required in this respect, particularly with regard to training of researchers. Confirming the trend reported in the 2016 review, projects have shown evidence of added-value interaction, either with earlier projects, or with still ongoing ones.

The three projects on **stack manufacturing** (AUTO-STACK CORE, VOLUMETRIQ, INSPIRE) focus on delivering mature state-of-the-art stack components (MEA, bipolar plates) and stacks that meet automotive performance (technical as well as operational, e.g. cold start) specifications and that can be produced with consistent high quality in large volumes.

Considerable progress has been achieved since the start of the projects. For AUTOSTACK-CORE all targets with the exception of power density under the reference conditions established by the project, have been met. For VOLUMETRIQ and INSPIRE which have started later, all intermediate milestones have been met, also through effective cross-fertilisation of results between both projects.

All three projects have exceeded the initial project expectations. Starting from TRL 2, the final TRL 5 of AUTOSTACK-CORE exceeds the planned TRL 4 at project end. In the case of VOLUMETRIQ, for an assumed 50,000 units/year, the project-specific cost target of 100 €/kW for the fuel cell system, more ambitious than the 150 €/kW target in the call, is claimed achievable by increased power density, reduced scrap / rejection rates and by attaining TRL 7 in supply chain development. INSPIRE targets a specific stack cost of 50 €/kW.

The success of AUTOSTACK-CORE is demonstrated by the fact that automotive original equipment manufacturers (OEMs) and tier-1 suppliers are currently evaluating the stack for use in vehicles and that the stack is offered as prototype by a commercial company outside the EU (for trucks based in USA). The project has also triggered a follow-up in a German-funded project to further increase robustness and manufacturability of the FC stack.

The successful implementation of these automotive R&I projects stems also from the very strong commitment of automotive OEMs involved, either directly as project partners, or indirectly via their active membership in the industrial advisory boards of the individual projects.

To measure projects' progress and allow for an objective comparison of claimed project achievements FCH JU should continue to implement appropriate harmonised protocols and test methods using the actual prototypes and products developed in the projects.

The project on refuelling, H2Ref, aims at developing a cost effective and reliable **refuelling** station system. The low cost of the new compression system, together with the use of optimised approaches for pre-cooling and dispensing from HyTransfer is expected to result in substantial cost decrease and increased operational performance of 70 MPa HRSs.

The project COPERNIC focused on **on-board storage,** aimed at performance improvements and cost reduction of type IV composite compressed gas hydrogen (CGH_2) tanks by using enhanced materials, innovative components, improved composite design and quality, and higher productivity and manufacturing throughput. All targets have been met and resulted in a cheaper storage system with enhanced safety. Project results and achievements are being actively exploited.

New materials and improved components have enabled integrated on-board hydrogen storage tank systems to meet the 2017 KPIs for volumetric capacity (0.022 kg/l) and gravimetric capacity (4 %). The introduction of low cost robotic manufacturing methods succeeded in bringing down the storage system cost at mass production while achieving the 2017 target (800 €/kg hydrogen). Further reductions in cost are anticipated through optimisation of the storage system design for the mass production processes.

The newly started project on **diagnostics,** GIANTLEAP, aims at validating advanced online diagnostics of the FC and BoP components (humidifiers, compressors) and associated prognostic methods and control algorithms to increase reliability of the FC system and optimise its lifetime. The project goals on cost reduction and desired TRLs are challenging. Also, the project COMPASS, focusing on **APU,** aims at developing an advanced solid oxide fuel cell (SOFC) APU system for integration into battery electric vehicles..

2.4.2 REVIEW FINDINGS

This section presents an assessment overview of projects in Panel 2, focus areas on FC components and on stack manufacturing.

Strengths:

- There is evidence of a potential for focused and added-value interactions between related projects.
- A number of consortia adequately combine availability of all required competences, skills, and required hardware infrastructure among project members.
- Harmonised test procedures are increasingly being used.

Additional focus needed:

- Consider expanding the project portfolio to also include R&I into high temperature PEMFCs.
- Consider strengthening the project portfolio to also include R&I into reducing use of PGM.
- Quantify more exhaustively the impact of fuel impurities (individual and jointly) on short-term performance and on longer-term endurance.
- Spend more efforts to reliably predict FC stack and system behaviour on the basis of results obtained from tests on individual FC components.
- Include the generation of the necessary set of experimental data to be used as input into LCA.

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

Follow-up actions:

- Make consistent use of harmonized approaches for accelerated testing to characterize long-term performance of FC components and stacks.
- Enhance the exploitation of research outcomes of finished projects in the formulation of follow-up projects, either in research or in demonstration.
- Explore the possibility of exploiting material development efforts in fields other than FC electrochemical energy conversion devices, e.g. electrolysers or flow-batteries.
- Ensure the presence of a stack manufacturer and integrator in the consortium or advisory board for future projects dealing with development of FC components.

03 ENERGY PILLAR

3.1 OBJECTIVES

The objective of the Energy pillar is to accelerate the commercialisation of FCH technologies for stationary fuel cells and for the production of green or low-carbon hydrogen as an energy vector in Europe. The FCH JU programme supports activities in three main areas:

- Stationary fuel cells (power and heat) demonstrations and proof-of-concept (PoC) activities to prove technology capability and readiness;
- Stationary fuel cells (power and heat) research and innovation for improving performance, durability and cost;
- Hydrogen production pathways from renewable energy sources, handling, distribution and storage technologies.

3.2 BUDGET

To date (November 2017), 117 projects in the Energy pillar have received financial contributions from the FCH JU totalling more than €350 million. The distribution of projects in the three main activity areas is shown in Table 2, with about €144.5 million for stationary fuel cell demonstration and proof of concept (PoC) projects, €88.4 million for stationary fuel cell Research and Innovation Actions, and €117.8 million for hydrogen production, distribution and storage[8].

Table 2: FCH JU financial contribution (€ M) for the three main activity areas in the Energy pillar

ENERGY PILLAR / ACTIVITY AREAS	€ M
Technology validation in stationary applications	144.5
Research activities for stationary applications	88.4
Hydrogen production, distribution and storage: research and validation	117.8
Total	**350.7**

8. These figures include the full budget of over-arching project (BIG HIT) which draws half of its €5 million funding from the transport pillar and one project (HYUNDER) dedicated to hydrogen storage and financed with €1.7 million in FP7 under a cross-cutting budget. These projects have been allocated to panel 5: Hydrogen production, storage and distribution, as it is most appropriate there.

3.3 TECHNOLOGY VALIDATION IN STATIONARY FUEL CELL APPLICATIONS

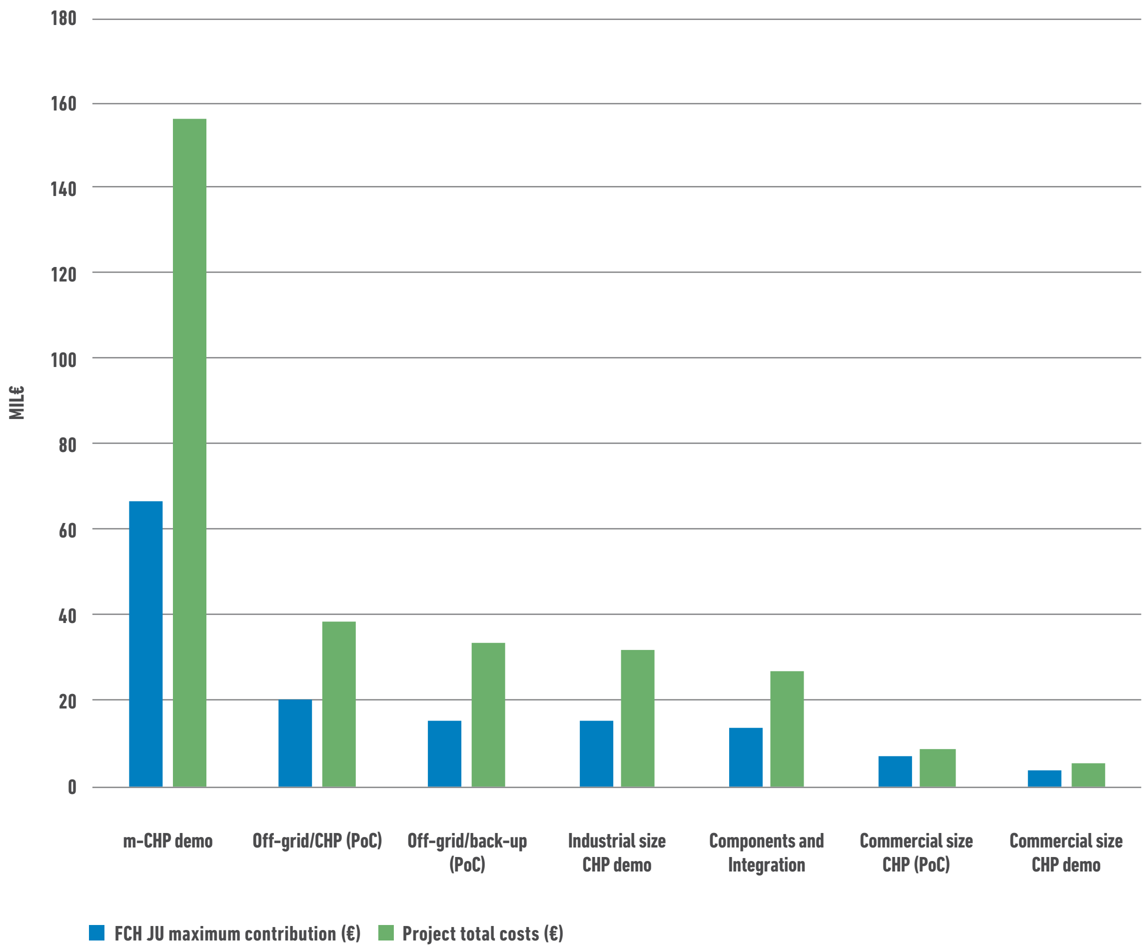
3.3.1 FOCUS AREAS AND ACHIEVEMENTS

Focus areas

The focus areas for the 2017 review are defined as follows:

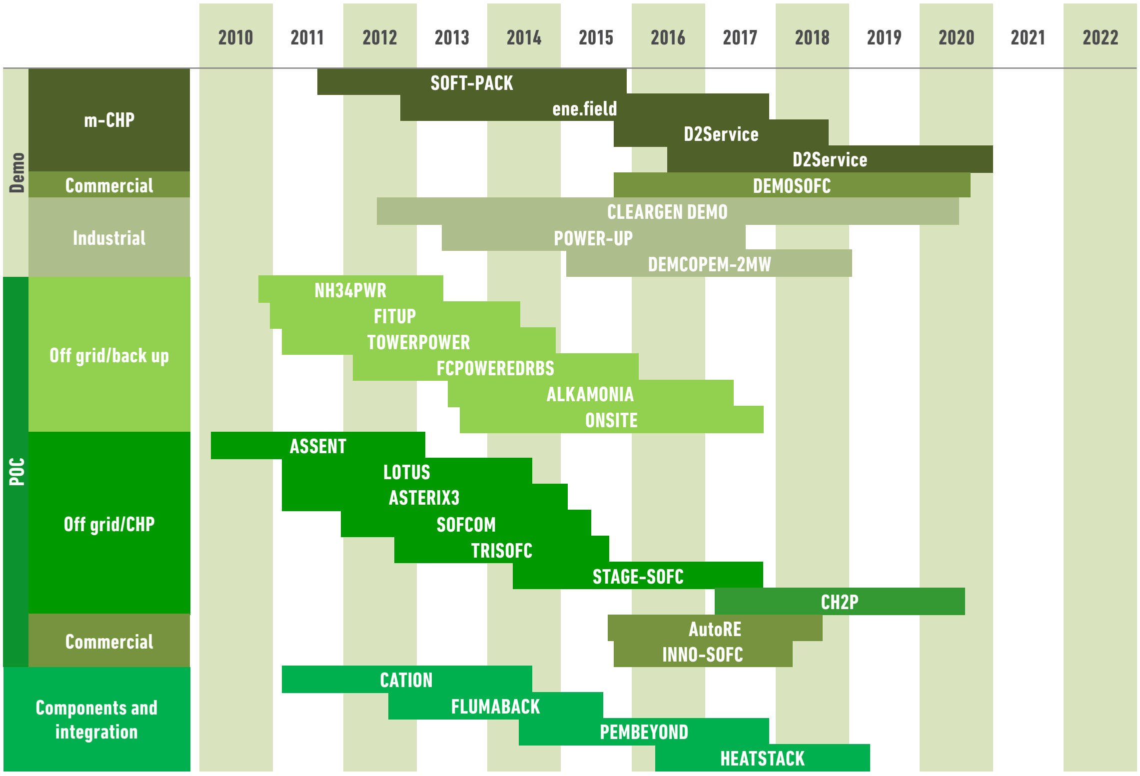
- Demonstrations involve all sizes of combined heat and power (CHP) units aimed at establishing operational performance capabilities, proving technology readiness and developing expertise for installing, operating and maintaining units. Under these demonstrations, different focus areas are included: μCHP (< 5kWe), commercial size (5-400 kWe), and industrial size (>400 kWe).
- Proof-of-Concept (PoC) projects seek to validate and test whole-system concepts, usually around technology readiness level (TRL) 4-6. Some projects aimed at improving performance, reliability, durability and cost of BoP components.
- Projects dealing with components and integration include residential μCHP generation at high electrical efficiency running on conventional heating fuels to reduce the cost of components. One project aims at integrating in a complete PEFC system the reforming of crude bioethanol and the purification of hydrogen for power generation.

Figure 8: FCH JU funding for Panel 3 (stationary fuel cell applications) from the start of the multi-annual programme up to now



The present review covers fourteen projects across five areas: ene.field, D2Service, PACE (µCHP), DEMOSOFC (Commercial size CHP), CLEARGEN DEMO, POWER-UP, DEMCOPEM-2MW (Industrial size CHP), ALKAMOMMONIA, ONSITE (Off grid / back-up), STAGE-SOFC (Off grid / CHP), AutoRE, INNO-SOFC (Commercial), PEMBEYOND, HEATSTACK (Components and integration).

Figure 9: Technology Validation projects for stationary fuel cell applications in the Energy pillar reviewed in Panel 3 (Time Frame 2010-2022)



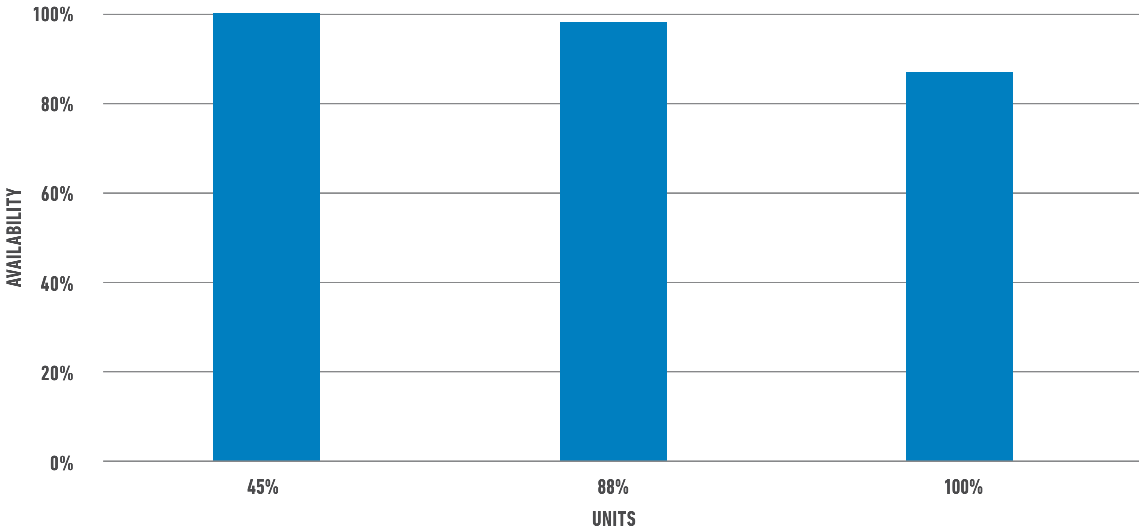
Achievements

The FCH JU-backed demonstration activities involving µCHP demo (< 5 kWe) include support for large scale demonstration through the ene.field and PACE projects. The D2Service project aims at improving the serviceability of fuel cell µCHP systems.

ene.field (603 SOFC units, 443 PEFC units) and PACE (2,500 units by 2021) are field trials for domestic and small commercial µCHP FC systems. The ene.field project has placed over 1,030 fuel cell microCHPs from ten suppliers into homes across ten European countries by July 2017. It is Europe's largest deployment of FC µCHP to date and has allowed manufacturers to start reducing costs and build markets.

Targets have been met for availability, electrical efficiency (reaching as much as 60 % for some systems) as well as total efficiencies as high as 85-95 %. Durability (12 years lifetime) performance demonstration is still ongoing. Some deployment trials claim rated durability which exceeds even targets set by FCH JU for 2023. In terms of availability, 45 % of units have reached 100 % for one year of operation and 88 % of all the systems achieved an availability equal to or above 98 % (see Figure 10).

Figure 10: General availability figures for installed μCHP systems



The target of 14,000 to 25,000 €/kW at present manufacturing volumes has been reached.

The ene.field project has generated a wealth of valuable information for FC μCHP applications, such as a full life cycle cost (LCC) and life cycle environmental assessment (LCA), identification of practical barriers to implementation and analysis of the EU supply chain. The homeowners in the field trial were able to cut energy costs by €800-1300 per year.

PACE builds upon ene.field and aims at reaching TRL 9 for FC-based micro-CHP. This project has just started and targets a field demonstration of over 2500 units. By the end of the project, unit cost is expected to drop by over 30%, and stack lifetime to exceed ten years. PACE also plans to demonstrate the benefits that can be offered to the electricity grid by coupling μCHP units (in the order of hundreds) into a virtual power plant.

The D2Service project aims at improving serviceability of residential and commercial fuel cell μCHP systems and also of fuel cells for back-up power, by optimising the design, installation and maintenance procedures of SOFC and PEMFC-based units. Analysis of operational experience from field test programs allowed identifying and prioritising changes required for increasing durability and simplifying exchangeability of components during maintenance operations.

These projects perform well in reaching their relevant targets and project impact is high, although progress versus time is not as good as one may have expected. Excellent scores are obtained for dissemination and communication, and interaction between projects is at a high level.

In the focus area **commercial size CHP demo (5-400 kWe),** one project DEMOSOFC aims at demonstrating the advantages of a commercial size SOFC-based CHP system in an industrial environment. The project targets a TRL-9 and builds upon a previous proof-of-concept project SOFCOM. The system is fuelled by biogas produced in a local wastewater treatment plant in the Turin area in Italy. The 170 kW system, once fully installed, would be the largest SOFC in Europe and likely the largest one worldwide operating on biogas.

At time of review, detailed engineering, including safety analysis and permitting procedures has been completed and the first of the three 60kWe SOFC modules is being installed, following the production of a customised biogas clean-up system.

The focus area **industrial size CHP demo** targets the demonstration of large-scale multiple megawatt fuel cell systems to identify suitable business models and replicability requirements for use in industrial chemical process applications. The 2017 review includes two PEMFC demo projects (CLEARgenDemo, DEMCOPEM) and one AFC demo (POWER-UP).

The CLEARgenDemo project targets the field demonstration of a 1 MW-scale PEMFC system. The commissioning of the two 500 kW power banks are expected for Q4 2018.

The project DEMCOPEM-2MW aims at demonstrating a CHP PEM fuel cell power plant (2 MW electrical power and 1.5 MW heat) integrated into a chlor-alkali production plant. China has been selected as the demonstration site because local cost and reliable supply of electricity constitute favourable factors for the business case. It is recommended that the lessons learned from the project are exploited in other sectors (e.g power to power, gas to power, and other applications).

In the POWER-UP project a 200 kWe alkaline fuel cell (AFC) plant was built, installed and operated in an industrial environment with electricity produced exported to the local medium-voltage grid. Automation and modern manufacturing techniques enabled the scale-up of fuel cell production whilst maintaining high quality, reproducibility and performance. The project has delivered the first large scale alkaline fuel plant in the world operating in an industrial setting. Positive learnings have been acquired on stack and BoP, supply chain management & manufacturing, and a number of patents have been generated.

These projects performed well in reaching their relevant targets and project impact is rated very high. The awareness of and alignment with the international state of the art is higher than for µCHP projects. Good scores were obtained for dissemination and communication.

The «macro focus area» **PoC (off grid/back up, off grid/CHP, commercial)** is composed of projects (ALKAMMONIA, ONSITE, STAGE-SOFC, AUTORE) with quite different scope, but they all have a PoC-focus in common.

Project ALKAMMONIA focuses on the design, manufacture and testing of a prototype integrated small-scale power system designed for remote applications. The overall objective of ONSITE is the construction and operation of a PoC SOFC/sodium-nickel-chloride-battery hybrid system generating 10 kW at high efficiency and economically competitive costs.

The aim of the STAGE-SOFC project is to develop a Proof-of-Concept (PoC) prototype of a SOFC system for small-scale CHP and off-grid applications. The first prototype achieved the targets on electrical power >5 kWAC and electrical efficiency >45% without laborious water handling under unfavourable conditions. The PoC system was designed, constructed, and commissioned and is currently being tested.

The project AUTORE targets PoC of an automotive derivative fuel cell system in the 50-100 kWe range for CHP in commercial and industrial buildings. Lab-scale testing of component for enhancing the prototype FC system, reducing its costs for electricity together with its foot-print, and increase its performance, are all underway. The H_2 reformer is undergoing final factory acceptance tests.

The main objective of INNO-SOFC is to design, assemble and demonstrate a novel 50 kW SOFC power plant. Performance and long-term testing of stacks, using interconnect plates optimised for manufacturing, has started. Most promising end-users and applications of the SOFC power plant have been identified too.

In the focus area **components and integration,** the PEMBeyond project aims at developing a bioethanol fuelled integrated PEMFC-based power system for back-up and off-grid applications. Stable catalyst for steam reforming crude bioethanol has been developed together with non-noble metal-based LT-water-gas-shift (WGS) catalyst surpassing any commercial product. A particular success is the performance of the newly developed PSA adsorbent which enables reaching hydrogen purity required for applications in automotive fuel cells.

The recently started HEATSTACK project focuses on reducing the cost of the stack and of the heat exchanger, which together represent the majority of total system CAPEX.

3.3.2 REVIEW FINDINGS

This section presents an assessment overview of projects in Panel 3.

Strengths:

For µCHP applications:
- The technology performance was demonstrated in real installations and the majority of targets set in the FCH JU Multi-Annual Work Programme have been met.
- Capital costs have decreased, and manufacturers' cost reduction curves are being met.
- European-based manufacturers of FC µCHP solutions have consolidated their activities and are now offering products off-the-shelf. This has been key to make the EU a world leader in SOFC technology for micro-cogeneration applications.

For industrial size applications:
- Deployment potential in product markets outside Europe has been demonstrated.
- Improved targeting of relevant industry sectors and specific dissemination efforts have resulted in orders for new installations, as reported by one system manufacturer.

For commercial size applications:
- Synergies in terms of R&D activities across the two markets of automotive FC and heat and power generation for stationary applications have been exploited.
- Proof of concept efforts are advancing and have paved the way for demonstration of fuel cells in stationary applications such as heat and power generation for commercial buildings.

Additional focus needed:
- Expand the duration of validation testing to better reflect the actual durability targets for CHP applications.
- Investigate factors affecting technology deployment outside EU to increase volumes and establish sustainable business cases: consider the needs of export markets significantly different from Europe in terms of unit size, fuel choice, operation modes, level of user interactions, regulatory approval, etc.) and facilitate related dissemination efforts.
- Address additional requirements to stationary FC systems arising from increased needs for their application under flexible dynamic power to power operation conditions
- Better integrate system and component development activities to further reduce CAPEX.
- Explore potential spin-offs from projects on industrial FC applications to power-to-gas solutions

Follow-up actions:
- Solicit feedback from end users and from system integrators on market needs and requirements for different applications for defining and identifying further R&I activities.
- Create stronger links with the family of projects supported by the other parts of Horizon 2020, targeting energy efficiency in the building sector.

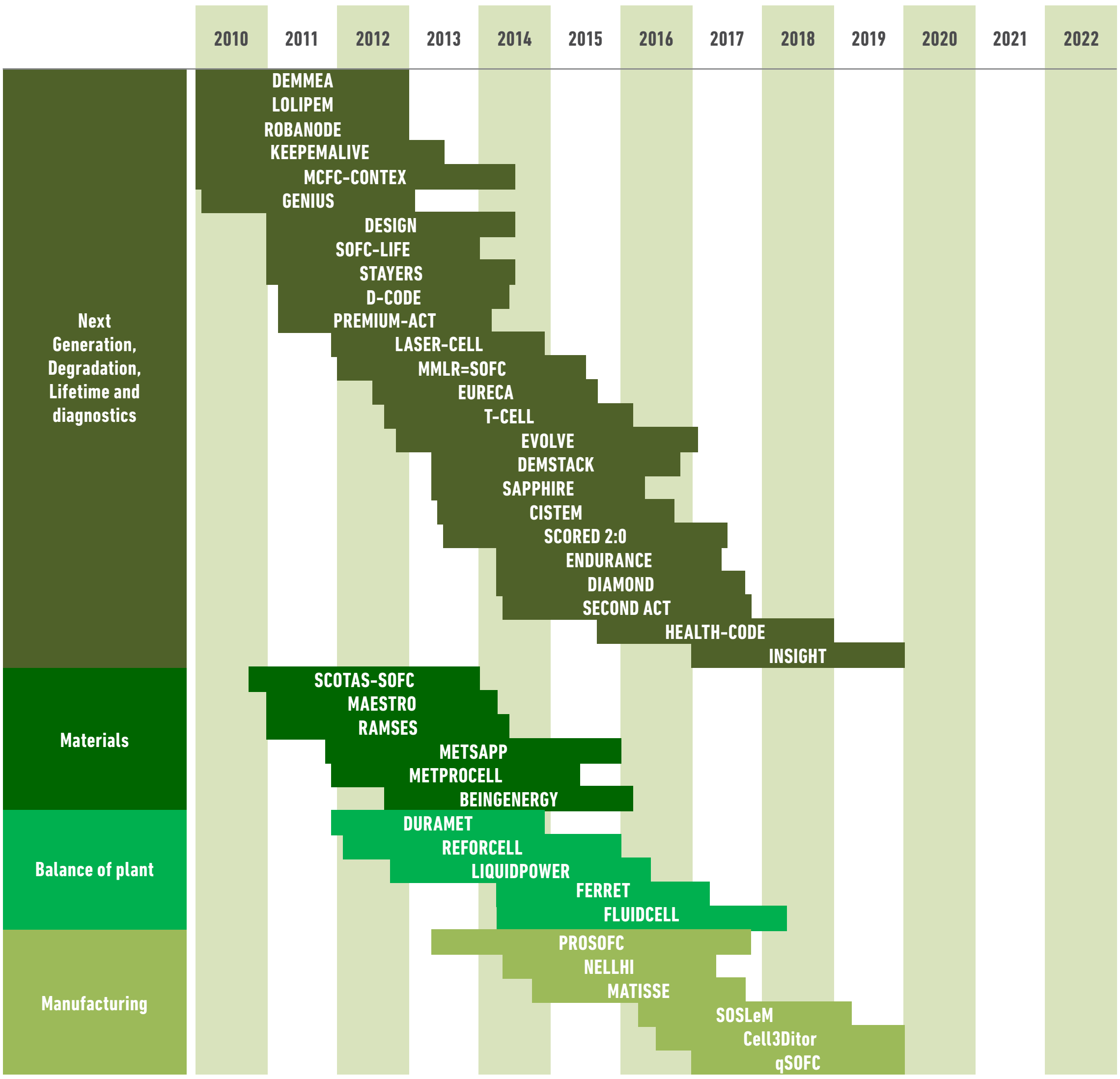
3.4 RESEARCH AND INNOVATION FOR STATIONARY FUEL CELLS

3.4.1 FOCUS AREAS AND ACHIEVEMENTS

Focus areas

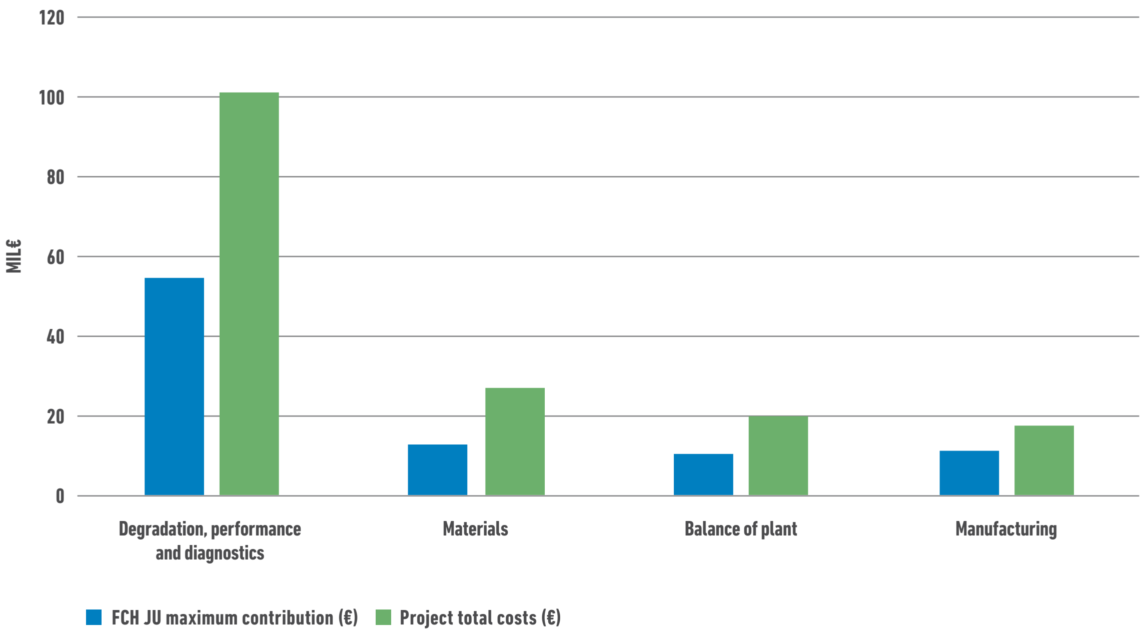
The FCH JU programme portfolio of research projects on stationary fuel cells is shown in Figure 11. The projects address a range of topics and were grouped into the focus areas of **«degradation, performance and diagnostics», «manufacturing»** and **«balance of plant».**

Figure 11: Research projects for stationary fuel cell applications in the Energy pillar reviewed in Panel 4 (Time Frame 2010-2022)



The 2017 Review covered fifteen projects with a total FCH JU contribution of €88.4 million and a total budget of €165.2 million.

Figure 12: FCH JU funding for Panel 4 (stationary fuel cell applications) from the start of the multi-annual programme up to now



Achievements

In the focus area **degradation, performance and diagnostics,** the projects reviewed are focusing on three main areas of research to improve durability and performance: application of new design solutions for HT PEM FC (DEMSTACK, CISTEM), application of new design solutions for SOFC (EVOLVE, ENDURANCE, SCORED 2.0), and diagnostics, control and monitoring (DIAMOND, SECOND ACT, HEALTHCODE).

Key achievements include an improved understanding of degradation mechanisms as well as the development of mitigation measures such as improved sealants, coatings and textured electrodes. The increased maturity of embedded monitoring tools and accelerated stress testing protocols will be highly useful for increasing the lifetime of both PEM and SOFC technologies.

The majority of the reviewed projects estimate stack lifetimes which exceed the expected target of 30,000 h. The projects on FC stacks have accumulated around 50 thousand hours of operation and the stacks have demonstrated an average availability of approaching 100 %. Long term tests were carried out for over 18300 h. A degradation rate of 3 muV/h at MEA level, corresponding to an expected 40000 h lifetime, was reported for HT PEM. For SOFC a low degradation rate of 0.2% (efficiency)/1000h for SOFC has been achieved. The added cost for the diagnostic tools is reported to be below 3 % of the total system cost.

The project DEMSTACK successfully delivered and tested a HT-PEM prototype for domestic applications, whereas CISTEM developed a modular large area pressurized HT-PEM FC for 100 kWel systems. DEMSTACK optimised a HT PEM stack design, which was obtained by using materials for electrodes and membranes developed in a predecessor project (DEMMEA). Efficiency and costs were improved and testing for several thousands of hours, using accelerated testing protocols, has been performed. The flexibility of the developed stack was tested against different gaseous fuels. The project has achieved an improvement of the HT-PEM FC technology in terms of lifetime.

EVOLVE aims at developing a new architecture for SOFC to tackle issues of carbon coking and sulphur tolerance through improved anode materials. An improved tolerance to contaminants in the fuel has been achieved. Decreased materials consumption for the electrolyte was also achieved. ENDURANCE focused on increasing SOFC stack lifetime and has increased knowledge on the underlying degradation mechanisms.

The SCORED 2.0 project addressed the issue of chromium poisoning by testing coatings for stainless steel interconnects in SOFC. Different coating methodologies were explored.

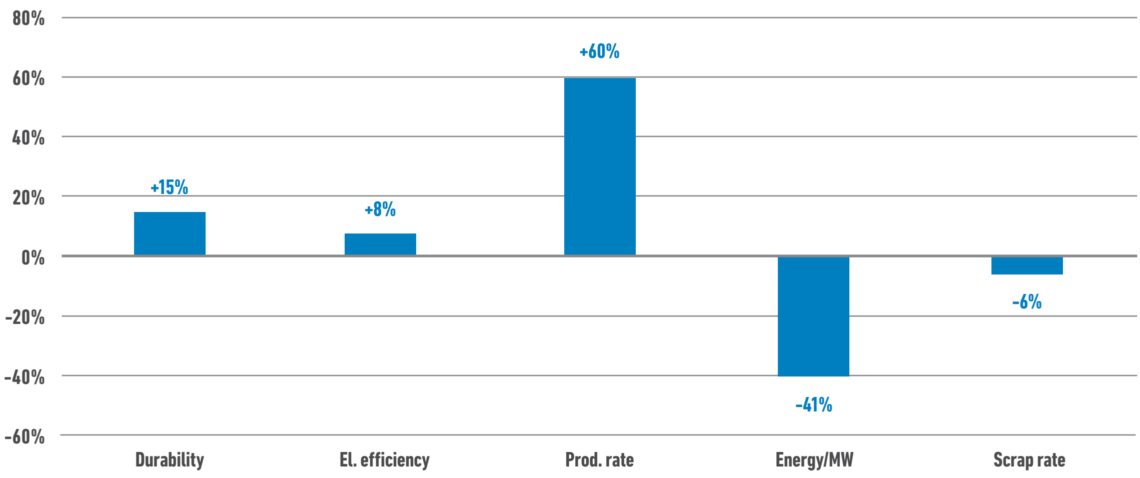
The project DIAMOND aimed at diagnosing the state-of-health for SOFC CHP systems, including predictions on remaining lifetime. The control system is able to determine the remaining useful life of the system. HEALTH-CODE (building on the project D-CODE) is focusing on producing diagnostic and monitoring tools for the status of CHP systems based on PEM-FC. Notable is the further development of electrochemical impedance spectroscopy (EIS) based diagnosis, as a tool for state-of-health assessment. In both projects, monitoring-and-control strategies and protocols have been produced and implemented. SECOND ACT worked on understanding performance degradation of stacks components used for µCHP. The project analysed the impact of three different fuel feeds: hydrogen, reformate, and methanol.

The projects in this focus area obtain moderate scores against all assessment criteria, with the exception of dissemination and communication which receives a high average rating and IP which gets a low rating. Several projects score very high on the key categories of progress towards targets, impact and state of the art (SoA). Progress in time is rated highly, and a positive attribute of this focus area is the high score for the assessment criterion dissemination and communication.

Projects in the focus area **manufacturing** (PROSOFC, NELLHI, CELL3DITOR and SOSLeM) are investigating manufacturing options for SOFC, with the exception of MATISSE, which focussed on PEM FC.

The approaches used for improving manufacturability of SOFC stacks vary. Strategies for reducing cost, use of critical raw materials and production of pollutants have all been implemented, usually without adverse effects on durability. New manufacturing techniques, new production chains with increased automation and better estimates on costs, all contributed in achieving the expected outcomes for this focus area. The newly developed SOFC production chains positively influence not only the production segment, but impact positively also the fuel cell performances in terms of efficiency and durability (see Figure 13).

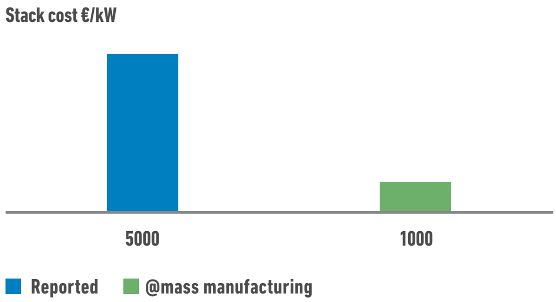
Figure 13: Based on 2016 data collection exercise. SOFC manufacturing improvements



Electrical efficiency for SOFC have reached an impressive 74 %el at stack level, which at system level is likely to meet the expected total efficiency target of 57 %. Fuel utilization rates up to 91 % were achieved with H_2. In general, cost reductions for SOFCs have been achieved through the further development of manufacturing methods, enabling projected stack costs below 1000€/kW at mass production (see). Platinum loadings in PEM-FCs have also been significantly decreased, with 40% platinum loading reduction having been reported.

The projects have made real progress in identifying and addressing durability issues related to the manufacturing process itself. Of particular significance for this focus area is the implementation of follow-up actions and commercial/IP strategies for finished projects.

Figure 14: Estimated SOFC manufacturing improvements costs associated with mass production



MATISSE worked on delivering advanced MEAs for stationary PEM stacks. Textured electrodes were manufactured and tested, and showed improved current density. The project specifically investigated three different fuel cell designs and electrode texture development for operation under H_2/O_2, H_2/Air and reformate H_2/Air. A considerable amount of work was done on stack degradation testing and manufacturing improvements. PROSOFC aims to optimise production and mechanical robustness of SOFC stacks. The project used a cost-optimal reliability-based design methodology. A high electrical efficiency has been achieved and critical failure modes have been identified. The NELLHI project developed and tested an innovative and modular 1 kW SOFC stack operating at 650°C. On the materials level, oxidation tests were conducted for different steel grades with and without coatings. Research was aimed at improving flow fields and sealings. Degradation issues due to the manufacturing process will need to be addressed as a next step to enable market introduction. The recently started CELL3DITOR project is developing 3D printing technology for the fabrication of SOFC stacks. Ceramics stacks will be manufactured in a two-step process, with the potential of substantial cost reductions. Also working on the manufacturing of SOFC stacks, SOSLEM is targeting cost reduction by adopting a lean manufacturing process. The sustainability of the production process is improved by the removal of nickel from the wastewater and avoidance of cobalt powders.

The projects' impact is rated as high, and there are excellent interactions between the projects. Dissemination activities are rated good to excellent. On the weak side, the exploitation plans and IP could be better developed.

The focus area **balance of plant** covers two projects FERRET and FLUIDCELL which aim at new solutions for CHP units by coupling them with purposely-built reformers. The fuel of choice was natural gas of different qualities for FERRET and bioethanol for FLUIDCELL. Catalytic membrane optimisation was the main outcome from both projects and the most significant results were obtained in this respect, rather than for the whole CHP system optimisation. Development of new catalysts was also achieved. As the major results in this area were linked to fuel processing, additional efforts will be needed for the improvement of other BoP components.

3.4.2 REVIEW FINDINGS

This section presents an assessment overview of projects in Panel 4.

Both the manufacturing and degradation focus areas contain at least one outstanding project.

Strengths:

- In terms of activities, the panel is well balanced between system and component design, model development, and diagnostics.
- Significant progress has been reported: advance of general SoA for SOFC, improved understanding of degradation processes, availability of effective diagnostic tools.
- Effective collaboration between industry and research institutions is evident.
- Effective participation of small and medium-sized enterprises (SMEs).
- A majority of projects have manufacturing as secondary project focus. This supports and explains the reported advancements in TRL made across the years.

Additional focus needed:

- Most of the projects focus on SOFC. The need for including also other FC technologies in the panel activities should be investigated.
- At component level, only selected system components (such as fuel processor) are targeted, additional focus is required on other BoP components.
- Despite substantial advances, the lifetime target has not been attained for all system designs.
- Harsh operating conditions have been considered, but even more work could be devoted to the development of testing protocols reflecting realistic use environments.
- There is a need for establishing reference test conditions and for standardised testing enable a better assessment of progress towards targets.
- Exploitation of project findings for their contribution to cross-cutting aspects (also going beyond the education of students which is often presented as the main cross-cutting activity).

Follow-up actions

- A focus on a smaller set of core issues with higher potential impact in terms of market size would be beneficial.
- As for the R&I projects in panel 2, more attention is needed to proper balancing between specific targets for individual performance characteristics at component level and more general performance targets at a system level.
- There is often some overlap in scope between projects focusing on degradation of SOFC. Attention should be paid to avoid a potential duplication of effort.
- Following on the progress made in catalyst and material development, higher emphasis should be placed on system design and manufacturing aspects to reach MAWP and AWP objectives.

3.5 HYDROGEN PRODUCTION, DISTRIBUTION AND STORAGE: RESEARCH AND VALIDATION

3.5.1. FOCUS AREAS AND ACHIEVEMENTS

Focus areas

The overall aim of this part of the FCH JU portfolio is to demonstrate at scale hydrogen's capacity to harness power from renewables and support its integration as an energy carrier into the energy system. This is enabled through hydrogen production from renewable sources. This group of projects cover a wide range of technologies, with different technology maturity (TRL), and potential market size.

The main effort is devoted towards the development and the demonstration of low and high-temperature electrolysis (14 of 23 projects). Progress in PEM electrolyser technology has been particularly strong and has maintained and strengthened Europe's leading position in this area.

The present review covers 23 projects across seven categories.

Figure 15: Projects for hydrogen production, distribution and storage in the Energy pillar reviewed in Panel 5 (Time Frame 2010-2022)

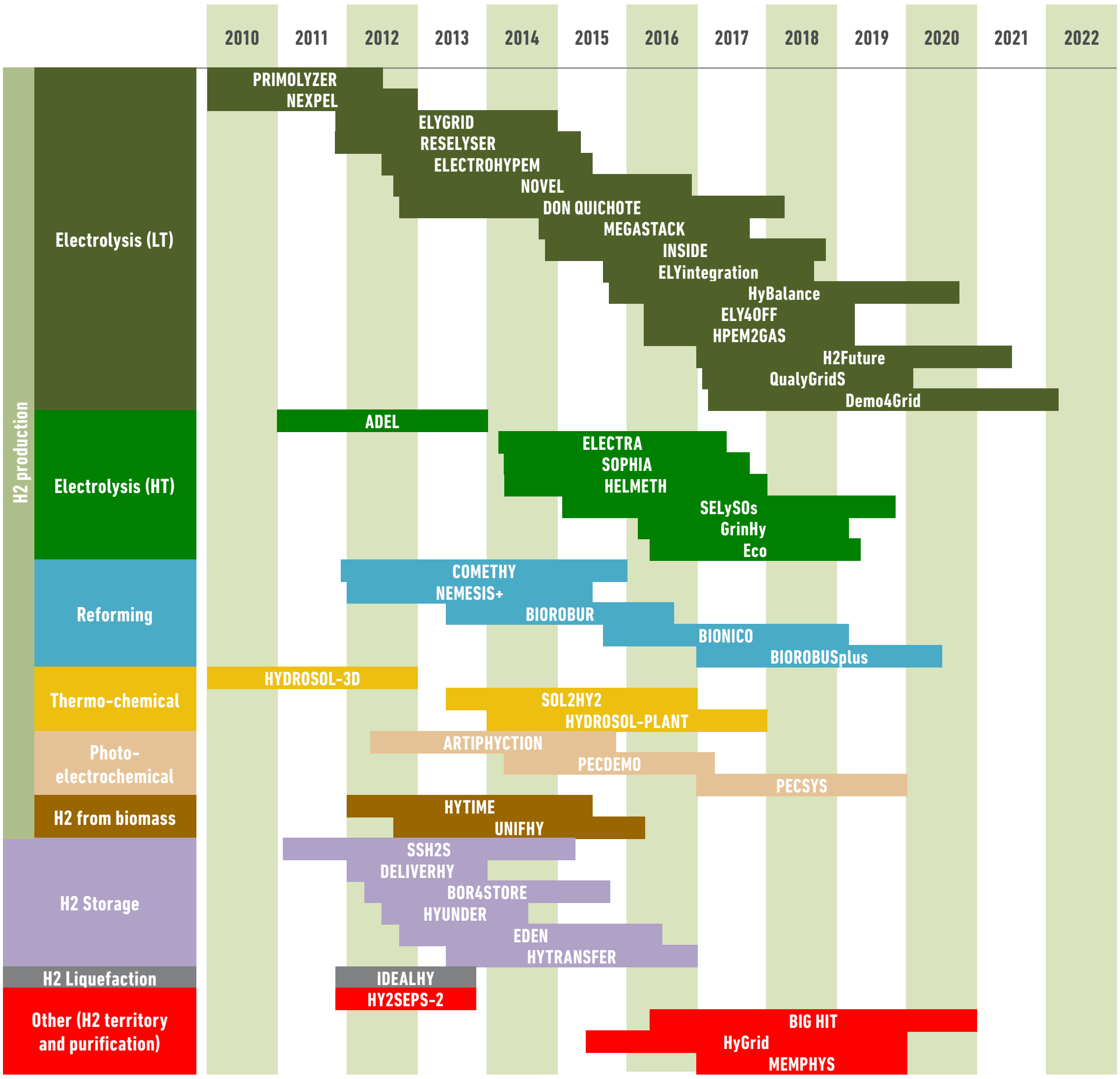
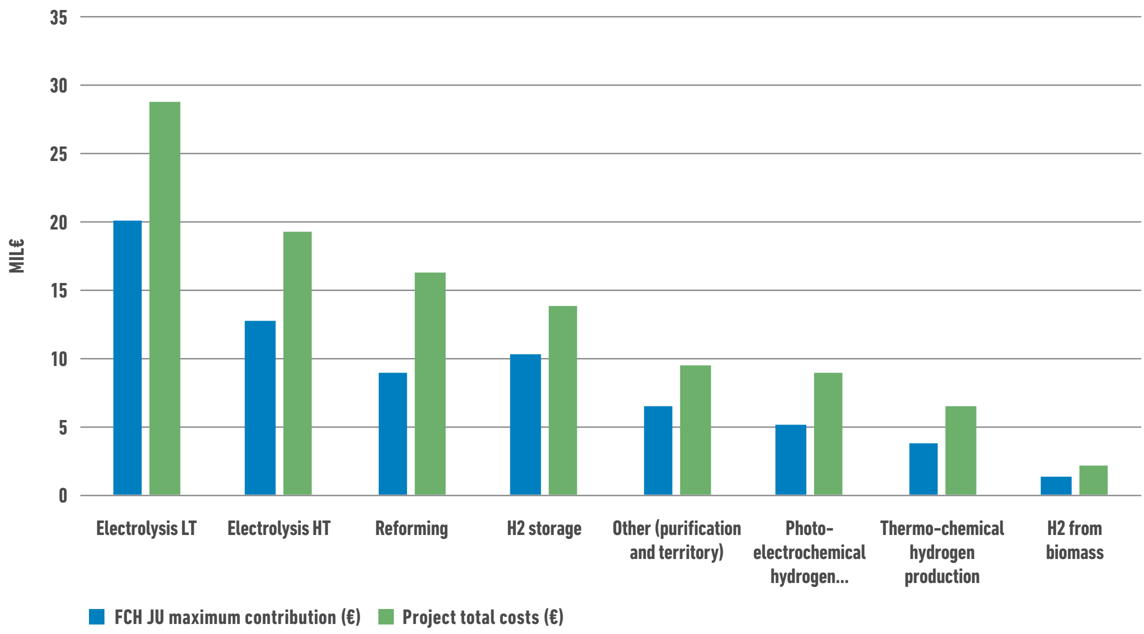


Figure 16: FCH JU funding for Panel 5 (hydrogen production, distribution and storage) from the start of the multi-annual programme up to now



Achievements

The focus area **low temperature electrolysis** includes eight projects: one projects on alkaline electrolysis, six projects on PEM electrolysis and one project on diagnostics.

For both alkaline and PEM electrolysis projects, a clear trend is visible; with projects moving from research towards demonstration. In total, 4.25 MW of alkaline electrolyser capacity is to be demonstrated through ELYntegration and Demo4Grid, and 6.23 MW of PEM electrolyser capacity through the HPEM2GAS, ELY4OFF and H2Future. A 150 kW PEM electrolyser system was demonstrated for two years in Don Quichote, and a 1.25 MW PEM electrolyser system is becoming operational as of fall 2017 as part of HyBalance.

The PEM research projects have shown that significant improvements in cost reduction and mild improvements in energy consumption can be made by using novel materials. Therefore, cost reduction strategies that are successfully adopted by (demonstration) projects are using improved but less innovative materials, larger sized stacks and systems and optimised BoP arrangements. The projects report system cost achievements between 4 M€/(t/d)(HyBalance, 500 kg/day) and 8 M€/(t/d)(Don Quichote, 65 kg/d), whereas ELY4OFF aims to achieve 6 M€/(t/d) (24 kg/d). HyBalance has also shown that for systems greater than 3 MW (> 1200 kg/d), a CAPEX of 2.3 M€/(t/d) is achievable. When looking specifically at MW-sized stacks, MEGASTACK shows that a CAPEX of 1.2 M€/(t/d) can be reached. The 2017 MAWP cost target is therefore not yet reached by the projects in this focus area, however, the best-in-class electrolyser is getting reasonably close and for multi-MW sized stacks and systems, the target costs are within reach.

The projects have a demonstrated energy consumption above 60 kWh/kg at system level. Don Quichote reports an energy consumption of 57 kWh/kg at system level, excluding hydrogen and standby losses, and 49 kWh/kg at stack level. The electrolysers in HyBalance and ELY4OFF are expected to reach an energy consumption of 54 and 50 kWh/kg respectively. HPEM2GAS aims to contribute in achieving 48 kWh/kg at system level.

HPEM2GAS and ELY4OFF address the overload capability of electrolyser systems, as they aim to reach 160 % and 150 % respectively of the nominal capacity. This is beyond the 2017 MAWP targets, although it will have to be proven in combination with a constrained degradation rate. ELY4OFF also aims to address the partial load capacity of 5 % (of the nominal capacity).

The H2Future, HyBalance and HPEM2GAS address the provision of grid services by PEM electrolysers. ELY4OFF aims for a hot start of less than three seconds, beyond the 2017 MAWP target.

The alkaline research projects have shown progress in addressing the minimum operating load capabilities through the use of innovative materials. ELYntegration aims to significantly improve the 2017 MAWP targets for CAPEX to 1.3 M€/(t/d) (currently the CAPEX is below 2.2 M€/(t/d)) and electricity consumption to 48 kWh/kg.

On average, the projects show a reasonable progress towards project targets. The project portfolio impact is reasonable as well, showing that the expected project impact is achievable, even if in some cases, it might be presently too early for a final assessment. The project portfolio shows good awareness of the SoA and provides means to go beyond it. The interaction among projects within and outside the portfolio (other panels or national projects) is reasonable, with many good examples within the project portfolio, but can still be improved. Projects significantly contribute to cross-cutting activities (e.g. RCS) and disseminate results reasonably well (including end-user markets); however, there is room for improvement.

The focus area **high temperature electrolysis** includes six projects: one project on system demonstration, two projects on proof of concept (integrated electrolyser-methanation system; solar integrated electrolyser system), one project on co-electrolysis, one project on materials (degradation) and one project on a novel electrolyser principle (proton conducting ceramics).

In total, 150 kW of solid oxide electrolyser system capacity is demonstrated in GrinHy, which would bring the technology up to TRL 5, if completed successfully.

The MAWP KPI targets for high temperature electrolyser systems for 2017 are:

- efficiency: 68 % HHV
- operational expenditure: 7.1 €/kg
- total cost of hydrogen: 8.0 €/kg
- pressure of H_2: 5 bar
- lifetime: 1 year

ELECTRA has achieved an electrical single cell efficiency of 80 % HHV at 0.2 A/cm2, whereas GrInHy targets an electrical efficiency of 95 % HHV.

The majority of the projects address degradation rates as a proxy for lifetime. A degradation rate of approximately 1 %/1000h is assumed to represent a lifetime of almost one year, assuming the system is in continuous operation and that the end of life is a degradation of 10 %. Project achievements range from 0.43%/1000h (HELMETH, steam electrolysis, short stack, 320 hour test) to 4.5 %/1000h (SOPHIA, co-electrolysis, short stack, > 1500 hour test). The GrInHy project aims at a 1 %/1000h degradation rate, which is in line with the 2017 lifetime target of one year for high temperature electrolysers. Long term testing at system level at realistic operating conditions is still required to confirm the lifetime target for 2017.

Pressurised operation is validated at short stack level (SOPHIA, 15 bar) and module level (HELMETH, 15 bar). High pressure operation is also foreseen by EcO. Another important target, is the operating current density which is confirmed between 0.8 A/cm2 (HELMETH) and 1.0 A/cm2 (SOPHIA) on stack level. In this respect, degradation rates should be observed in combination with the operating current density. Typically, milder operating current densities are selected as nominal operating current density or as current density in long-term tests.

On average, the high temperature electrolyser projects show a reasonable progress towards project targets. This is quite remarkable, considering the significant research dimension of these projects. The rating for impact shows that the expected project impacts are thought achievable. The projects are well aware of, or maybe even define, the state of the art. The interaction among projects within the focus area and outside (other focus panels or national projects) is satisfactory as well. Projects significantly contribute to cross-cutting activities (e.g. RCS) and disseminate results reasonably well.

In the focus area **reforming,** the BIONICO project aims at improving biogas reforming by reducing the number of process steps. The membrane reactor will produce about 100 kg/day of high purity hydrogen.

The BioRobur project developed and tested a biogas reformer based on autothermal reforming, with a methane conversion efficiency of >98 %. New catalyst structures were developed, improving the reliability of the autothermal reforming process. The causes of deactivation of the catalyst were studied.

The projects on biogas reforming for decentralized production are close to reaching the efficiency target of 70 % and have the potential to be able to produce hydrogen at a cost of close to €5/kg.

Both projects performed techno-economic analyses and LCA, indicating high sustainability and potential for meeting cost targets.

In the focus area **thermo-chemical hydrogen production** the SOL2HY2 and Hydrosol-Plant projects are further developing the production of hydrogen through thermo-chemical and hybrid cycles. The Hydrosol-Plant project aims at operating a 0.750 MWth scale plant for solar thermo-chemical hydrogen from water in a solar tower. The project target of 3 kg H_2/week has been achieved at laboratory level.

Focussing on the hybrid-sulfur cycle, key achievements of the finished SOL2HY2 project are the design and testing of a SO2 depolarized electrolyser, and the avoidance of both PGM catalyst and high concentrations of sulfuric acid. Overall, these projects can be considered as being at the forefront of this field of research at international level. However, meeting the cost target of 5 €/kg H_2 will be extremely challenging for all solar-to-hydrogen production routes.

In the focus area **photo-electrochemical hydrogen production** the PECDEMO project developed a hybrid photoelectrochemical-photovoltaic tandem metal oxide/silicon-based device for light-driven water splitting. The project demonstrated a device with a remarkable solar-to-H_2 efficiency of 16 %; however, it has not yet met the durability target of more than 1000 h of stable hydrogen production. Novel light management concepts based on dual photoanodes, dichroic mirrors, and rotatable photoelectrodes have been developed.

In **hydrogen storage,** the EDEN project set out to develop a new solid-state with high hydrogen storage capacity storage material, ultimately demonstrating a power-to-power system for stationary or off-grid applications. Much progress was made towards meeting the storage material cost target of < 500 €/kg. HyTransfer developed an approach for optimising means of temperature control during fast transfers of compressed hydrogen into storage vessels, typical for fuelling of on-board vehicle hydrogen storage tanks. The project aimed at meeting the specified temperature limits (gas or material) taking into account the thermal behaviour of the hydrogen storage vessel and of the rest of the system. The main goal has been to further optimise refuelling by improving process control requirements. Knowledge has been generated on thermodynamic effects and behaviour inside pressure vessels during and after fast hydrogen transfer. An innovative new hydrogen fuelling approach has been developed. Application of this fuelling protocol enables faster tank filling and drives cost reduction at the HRS and meets the MAWP target of < 3 minutes refilling time.

Regarding **hydrogen territory and purification,** BIG HIT will demonstrate the integration of hydrogen production from wind and tidal energy sources, with storage, transport and utilisation for heat, power and mobility. In the project HYGRID, developing the technology for direct separation of hydrogen from the natural gas grid, palladium- and carbon-based supported membranes have been developed, and porous tubes assessed as membrane supports. Electrochemical separation and temperature swing adsorption are also investigated, with the aim to decrease the total cost of hydrogen recovery.

3.5.2 REVIEW FINDINGS

This section presents an assessment overview of projects in Panel 5.

Strengths:

- Significant advances have been made towards reaching individual targets.
- A significant share of the projects is at TRL levels 5 and beyond. This shows the clear progress made in this area over the past years.
- Some projects have advanced the SoA in a significant manner, and EU has achieved a promising position against international SoA in solar hydrogen production and in reversible electrolysis.
- Workshops specifically dedicated to topics of common interest for different projects (e.g. degradation issues, cost reduction), have been organised.
- Some low-TRL projects have efficiently interacted with FP7-funded projects outside the FCH JU programme.
- There have been some cases of supplementary funding from national programmes, either through direct co-financing or as add-on project.

Additional focus needed:

- There is the need for establishing agreed reference test conditions and for standardised testing in order to enable a better assessment of progress towards targets.
- Project findings should be systematically exploited for contributing to cross-cutting aspects, in particular RCS and safety.
- More emphasis is needed on validation of costs for different hydrogen production routes.
- Relevant topics such as admixture of hydrogen and waste hydrogen recovery could be addressed.
- The number of workshops on issues of common interest in the electrolyser domain: e.g. dynamic behaviour of BoP components, RCS barriers, should be expanded.

Follow-up actions:

- Promote the organisation of joint workshops between projects for sharing experience and knowledge on areas of common interest, and for avoiding unnecessary duplication of activities.
- Expand outreach for disseminating electrolyser technology achievements and trigger commercial end-use interest in deploying renewable hydrogen production, including towards outside EU.

CROSS-CUTTING 04

4.1 OBJECTIVES

Cross-cutting projects constitute an essential part of the overall FCH JU project portfolio since they address challenges common to the energy and transport pillars. Cross-cutting projects are intended to support market preparation and readiness by:

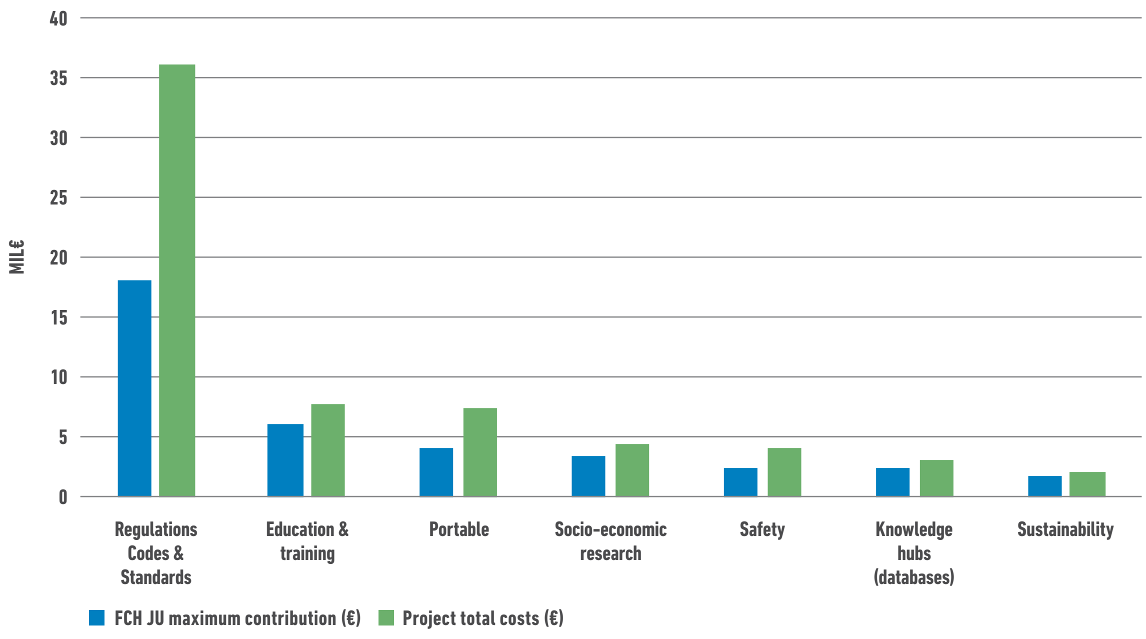
- Providing new knowledge to develop and improve regulations, codes and standards
- Generating experimental data and validating modelling approaches to address safety of FCH technologies and applications
- Preparing the European workforce
- Increasing public awareness and social acceptance
- Characterising and improving the environmental footprint of FCH technologies

Although not contributing directly to any of the above, since 2014, projects addressing portable applications, previously classified within the 'early markets' application area, have also been categorised as cross-cutting. In the present review, these projects are disregarded.

4.2 BUDGET

Since 2008, 33 projects in this area have totalled a budget of €64.9 million of which €38.2 million is from the FCH JU and €26.7 million is from partners.

Figure 17: FCH JU funding for Panel 6 (cross-cutting) from the start of the multi-annual programme up to now



4.3 FOCUS AREAS AND ACHIEVEMENTS

Focus areas

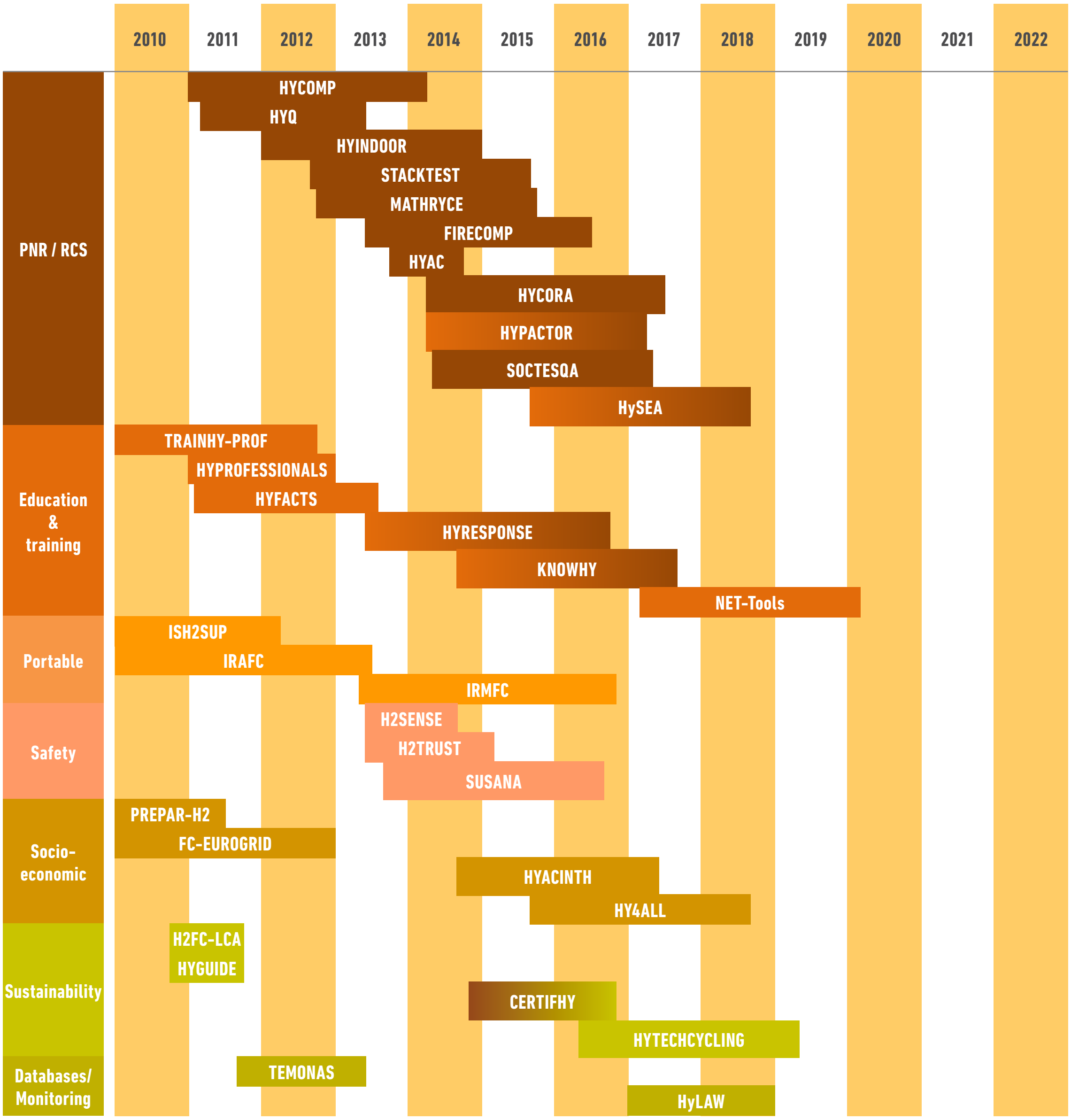
The portfolios support a number of distinct fields (with a special emphasis on the first three):

- **Pre-normative research (PNR) and input into Regulations Codes and Standards (RCS):** research into aspects of FCH technologies of interest to the industry as a whole, in view of gathering new knowledge to support the European FCH community and of transferring the knowledge generated into standards and regulations;
- **Safety aspects:** understanding safety issues associated with the deployment and adoption of FCH technologies in various applications, with an emphasis on technological and public safety;
- **Training and education:** actions to provide education and training for the FCH sector – including but not limited to scientists, engineers and technicians – and for decision-/policy-makers outside the sector, as well as the professional education sector, certification bodies and first responders;
- **Social acceptance and public awareness:** general public conferences and workshops, brochures, public 'showrooms'; addressing and informing local authorities, certification bodies and first responders, potentially interested parties and industrial stakeholders, and the general public;
- **Socio-economic research** to assess the environmental and societal impact of FCH technologies in terms of GHG emissions, primary energy use, and on competitiveness of economy;
- Supporting the development of **specific tools** for the sustainability assessment of FCH technologies, e.g. life-cycle analysis (LCA) methods, and addressing the issues related to recycling and dismantling; and
- Other activities, including establishment of databases for environmental, economic and socio-economic topics as part of the knowledge management activity, and identification and development of financial mechanisms to support market introduction.

In addition, portable/niche applications of FCH technologies not covered by the Energy and Transport pillars have in the past, also been placed in this panel.

The 2017 Review covered ten projects shown in Figure 18.

Figure 18: Cross-cutting projects reviewed in Panel 6 (Time Frame 2010-2022)



Achievements

This focus area **PNR/RCS** is composed of the projects HyCora, HyPACTOR, SOCTESQA and HySEA. In addition, other projects mainly described under other focus areas were considered here. These projects are CERTIFHY and to a lesser degree HYTECHCYCLING and SUSANA.

The project HyCora addresses a critical enabler for the whole hydrogen technology chain related to mobility, by focusing on a strategy for cost reduction of hydrogen fuel quality assurance. It has achieved considerable progress in defining credible potential cost reductions, in reviewing hydrogen impurity mapping, and in developing improved analytical methods. The project has also enabled the development of a European reference centre for the required analysis, and shows a good record of interaction with, and support to, standardisation bodies.

One of the continuous multiannual efforts in this focus area is aimed at a better understanding the lifetime degradation of high pressure on-board storage systems. In this respect, HyPACTOR focuses on understanding the degradation resulting from an external impact on storage components. This project has defined a correlation between impact and degradation, enabling progress in inspection and qualification procedures.

In a similar way, the project SOCTESQA has been able to develop, validate and submit to the relevant European and international standardisation bodies industry-wide test procedures for performance characterisation of solid oxide cell/stack assembly.

Finally, HySEA tackles one critical specific aspect related to the safe deployment of hydrogen installations in semi-confined spaces by introducing harmonized standard vent sizing requirements.

The PNR/RCS projects provide solid information to improve and develop standards at European and international level, and thereby contribute to developing an appropriate, fit-for-purpose regulatory framework for FCH technologies. The FCH JU Regulations, Codes and Standards Strategy Coordination Group (RCS SCG) has identified and prioritised items requiring further PNR.

Projects scored well in terms of targets and impact, thanks to their input into standardisation activities. They also show a satisfactory level of dissemination, because pre-normative research results can more readily be made public to a much higher extent than projects dedicated to product development.

This focus area **safety** is composed of the project SUSANA. In addition, other projects mainly described under other focus areas were considered here. These projects are HySEA, HyPACTOR, KNOWHY and HYRESPONSE and to a lesser degree SOCTESQA.

Project SUSANA is unique, having developed guidelines containing best practices for use of Computational Fluid-Dynamics modelling for safety analysis of FCH systems and infrastructures, as well as the related verification and validation procedures. Deliverables include a database which can be used by experts for verification modelling problems and model validation.

It must be noted that the projects HySea and HyPACTOR included under the PNR/RCS focus area, together with KNOWHY and HYRESPONSE included in the «education and training area», also have a strong safety dimension and have been considered as contributing also to this area . Safety-related findings from these projects feed directly into formulating safety requirements in standards and regulations presently being developed.

These projects scored well in terms of targets achievement and project impact, thanks to the sounds scientific approach and their important input into standardisation activities. The transferability of results to other areas results in a high average, because of the progress achieved in understanding fundamental safety-related phenomena which can be used in other applications, for example, SUSANA's database and verification protocols, and studies of HySea on hydrogen behaviour in semi-confined spaces.

This focus area **education and training** is composed of the projects KNOWHY and HYRESPONSE. HYRESPONSE has developed an operational hydrogen safety training platform, which has already been used several times to train first responders called to deal with incidents involving hydrogen and hydrogen technologies. It has trained 71 firefighters from fifteen countries. This platform can be exploited to train first responders outside of Europe with training materials, both in the form of a web-based course, and training sessions. KNOWHY has developed a set of training modules for technicians and other professional operators. With the successful completion of this project, the focus area education and training has produced a complete range of tools to train and educate all stakeholders and players along the technology value chain.

In the focus area **sustainability,** the project HYTECHCYCLING studies recycling, dismantling technologies, and strategies applied to the whole fuel cells and hydrogen technology chain, thus paving the way for future demonstration actions and advances in legislation. Similarly, the completed project CERTIFHY has a strong regulatory component: it has proposed a European framework for guarantees of origin for green hydrogen and developed a roadmap for its implementation in the EU.

In the focus area **socio-economic,** the project HYACINTH has performed an articulate analysis of public awareness, fears, acceptance of the FCH technologies in the energy and transport sectors in various Member States and issued a set of recommendations to increase public awareness and social acceptance.

4.4 REVIEW FINDINGS

This section presents an assessment overview of projects in Panel 6.

Strengths:

- Together with predecessor projects, the portfolio of PNR projects included in this review has generated a comprehensive understanding of individual aspects of high pressure storage systems and a solid set of recommendations to be considered for present and future standardisation activities.
- Similarly, the two education projects covered in this review completed a set of educational and training tools which has been made available to a broad range of audiences, from technician and professional operators, up to universities, regulators and public safety officials, including emergency responders. This set of educational tools will be further completed by the recently launched project NET-Tool, which is focusing on e-learning.

Additional focus needed:

- Projects should be encouraged to identify and discuss common or complementary issues in joint sessions and common workshops.
- Exploitation of cross-cutting contributions from projects in panels 1-5[9] should be encouraged from demonstration projects under panels 1, 3 and 5, in training and standardisation aspects (the latter together with the FCH JU RCS Strategy Coordination Group).
- Training modules will need regular updates to account for continuous technology progress. This applies even more for the training facilities for first responders, which moreover require substantial financing for their operation.
- Activities supporting the development of appropriate business models to enable market viability, although identified as part of the cross-cutting portfolio, have not been included so far.

9. Panel 1: Transport Technology Validation: Demonstration
Panel 2: Research and Innovation in Transport Activities
Panel 3: Technology Validation in Stationary Fuel Cell Applications
Panel 4: Research and Innovation for Stationary Fuel Cells
Panel 5: Hydrogen Production, Distribution and Storage: Research and Validation

Follow-up actions

- There is a need to guarantee up-to-date and continuous availability of educational tools and platforms developed for the initially targeted audiences, and to investigate the possibility of extending access to additional target audiences, both within and outside of the FCH community.
- Expand the success of the use of LCA to projects in all panels in order to perform quantitative evaluations of their progress (and thus also of the programme) against sustainability targets. Similarly, exploit findings and deliverables from cross-cutting projects to projects in other panels, e.g. validation of safety modelling approaches and tools, harmonised test methods for solid oxide cells and stacks.
- Investigate dissemination of cross-cutting achievements and deliverables beyond the hydrogen community still more. This has a dual purpose: ensure appropriate consideration of FCH technologies together with incumbent ones and enable correct benchmarking.
- Consider the idea of establishing, together with the standards developing organisations and with the FCH JU RCS SCG, a mechanism to monitor the effectiveness and the uptake of project inputs into European and international standardisation. This is one of the goals of the RCS Strategy Coordination Group, but it has still to be realised.

05 FCH 2 JU-FUNDED STUDIES

In between 2016 and 2017, FCH JU commissioned a number of relevant studies. These were adopted in order to support the overall objective of implementing an optimal research and innovation programme while developing a portfolio of clean and efficient solutions around Fuel Cells and Hydrogen. The studies presented under the current review span June 2016 to June 2017 and aim at addressing a number of key topics in the area of FCH.

EARLY BUSINESS CASES FOR H_2 IN ENERGY STORAGE AND MORE BROADLY POWER TO HYDROGEN APPLICATIONS - *2017*[10]

A study on the market potential of early business cases for Power to Hydrogen and Hydrogen 2 X concepts was undertaken based on high spatial resolution analysis of the electricity and hydrogen sectors, trying to identify places of electrical grid saturation and high hydrogen demand. Following the in-depth analysis of three case studies in locations of France, Denmark and Germany and the extrapolation for the whole of Europe, the study concluded that power to hydrogen (P2H) is bankable today. By 2025 an estimated cumulative electrolyser capacity of 2.8 GW could be installed in Europe with a market value of €4.2 billion. The respective figures for 2017 are 1.4 GW and €2.6 billion. In general, a total baseload electricity price of 20-50 €/MWh or lower is required to build a profitable business case. Stacking several revenue streams is an effective way of achieving profitability: most bankable business cases covered mobility and industry as primary applications of hydrogen, complemented by electricity frequency services and injection of excess hydrogen to the natural gas grid. Payback times that varied from 4 to 11 years, but these could be improved to 3 to 8 years by considering the additional revenue streams.

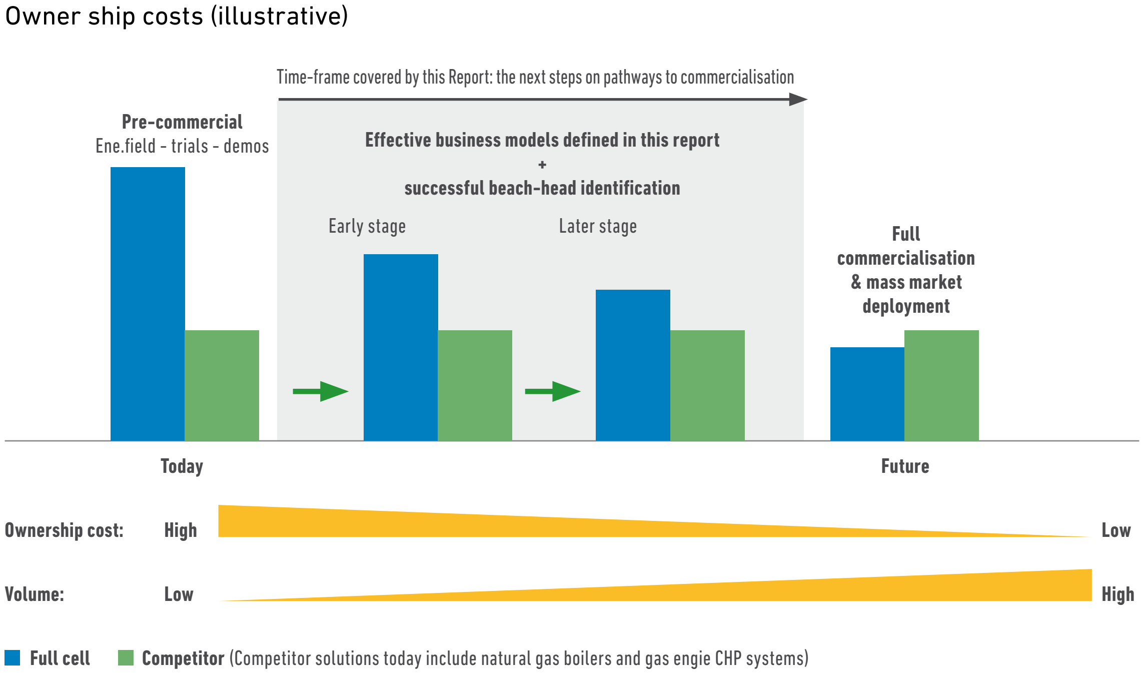
BUSINESS MODELS AND FINANCING ARRANGEMENTS FOR THE COMMERCIALISATION OF STATIONARY APPLICATIONS OF FUEL CELLS - *ONGOING*

During the period covered by this report the study supported by the FCH JU on 'Business models and financing arrangements for the commercialisation of stationary applications of fuel cells' has come to an end. This study builds on the conclusions of the FCH JU/Roland Berger study 'Stationary fuel cells in distributed generation'[11]. The Roland Berger study helped to better understand the benefits of stationary fuel cells but found that markets were still struggling to grow. Against this background the business models study was conceived with the aim of better understanding the reasons for the markets to struggle and to put forward means to overcome the barriers.

In close liaison with representatives from industry and end users the study has analysed and evaluated existing and future potential end-to-end business models and associated contractual and financing arrangements concentrating on European focus markets for fuel cells commercialization Figure 19. The study has concluded a set of recommendations for industry-wide business model innovation which include concrete actions for industry and other stakeholders to take on board. This study provides potential solutions that can take fuel cell products to the critical next stage on its pathway to commercialisation, through the use of recommended Business Models, enabling simultaneous growth in sales with reductions in costs.

10. http://www.fch.europa.eu/publications/study-early-business-cases-h2-energy-storage-and-more-broadly-power-h2-applications
11. http://www.fch.europa.eu/news/launch-study-stationary-fuel-cells-distributed-generation

Figure 19: Illustrative pathway to fuel cell commercialisation and that part of the pathway covered by this Report, based on Ownership Costs[12]



FUEL CELL BUSES COMMERCIALISATION STUDY – *ONGOING*

Supporting the development of business cases for fuel cell bus deployment, coordinating demands for these vehicles, and spreading knowledge between cities / regions were key objectives of this study. Building on the previous cluster coordination activities in the UK, Germany, Northern Europe, BENELUX and France, the study has been supporting a total of around 90 different European cities / regions in understanding the business case of fuel cell bus deployment and across these locations a potential demand for over 1,500 vehicles has been identified. Joint procurement exercises started in the UK and Germany and provisions are made for similar exercises in the other cluster areas.

A White Paper on commercialisation of hydrogen fuel cell buses produced as part of this study sets out a vision for scaling up fuel cell bus deployment to hundreds of vehicles per OEM. Two Fuel Cell Bus coalition meetings gathering PTO/PTA, FC bus OEMs, HRS operators and EU bodies (EC, FCH JU and EIB), allowing for sharing of experience and alignment of strategies, took place in the framework of the study as well.

12. The ownership cost is a financial estimate intended to help buyers / owners determine the direct and indirect costs of the fuel cell product. It can sometimes include social / environmental costs.

VALUE CHAIN AND MANUFACTURING COMPETITIVENESS ANALYSIS FOR HYDROGEN AND FUEL CELLS TECHNOLOGIES – *ONGOING*

The study on value chain and manufacturing competitiveness analysis for hydrogen and fuel cells technologies is a follow up study of an internal study finished in 2016 on the supply chain for hydrogen and fuel cells technologies. The study was contracted on 27 November 2017 for a period of eight months and with a budget of €379,225. It includes provisions for an interim report in February 2018 and a final report in June 2018.

The main objective is to perform an in-depth analysis of the European FCH value chain and manufacturing competitiveness to assess the dimension and contribution that the European FCH sector could make to the European economic recovery and sustainable growth, and to recommend specific actions and investments to public and private stakeholders.

HRS AVAILABILITY STUDY – *ONGOING*

The FCH JU has launched a study to capture in real time the availability status of Hydrogen Refuelling Stations in Europe. This will enable users to identify the nearest operational station and plan their routes while facilitating a platform of collecting relevant real-time information for HRS across Europe. To reach the final outcome, a key deliverable of the study (already completed) was to map all public HRS installed and planned in Europe while providing also data related to their technical and operational features. Following, the real time availability of each HRS will be collected in a dedicated server and the information will be made available to the public through a website. Additionally, this information will be offered freely for software or app developers to make further use of it.

In the first phase of the study, a hardware system to be installed in the HRS to track their availability status has been developed and tested. Additionally, the protocols to accept data from HRS with their own signal have been developed. In the following phase, a rollout of the system will be carried out to be able to integrate all HRS in operation and planned in Europe.

PROJECT POSTERS

06

INDEX OF POSTERS

PANEL 1
TECHNOLOGY VALIDATION IN TRANSPORT APPLICATIONS

3EMOTION
Environmentally Friendly, Efficient Electric Motion

Panel 1 — Technology validation in transport applications

Acronym:	**3EMOTION**
Project ID:	303485
Title:	Environmentally Friendly, Efficient Electric Motion
Call Topic:	SP1-JTI-FCH.2013.1.1 (2)
Project total costs (€):	€ 41,891,579
FCH JU maximum contribution (€):	€ 14,999,983
Project start/end:	01 Jan 2015 - 31 Dec 2019
Coordinator:	Van Hool, Belgium

Beneficiaries:
Acetilene & Gastecnici di Bagnoli Maria & C., Air Liquide Advanced Technol., Azienda per la Mobilita del Comune di Roma, Centro Interuniversitario Ricerca Sviluppo Sostenibile, Fit Consulting, Aalborg Kommune, Agenzia Nazionale per le Nuove Tecnologie, l'Energia e lo Sviluppo Economico Sostenibile, Rotterdamse Elektrische Tram, Services Automobiles de La Vallee de Chevreuse, Uni. Roma La Sapienza, Commissariat à l'Energie Atomique et aux Energies Alternatives CEA, Communaute Urbaine de Cherbourg, Waterstofnet, Commune de Cherbourg-en-Cotentin, Compagnia Trasporti Laziali, Dantherm Power, London Bus Services Ltd, Provincie Zuid-Holland, Regione Lazio, North Denmark Region, Vlaamse Vervoersmaatschappij de Lijn

Website: http://www.3emotion.eu/

Project and objectives

The irreversible deployment of fuel cell buses as an alternative to fossil fuel driven public transport is hampered by high costs. By achieving significant reductions on Total Cost of Ownership (TCO) for fuel cell bus operators, 3Emotion seeks to bridge the gap between current demonstration projects towards larger scale deployment as foreseen by the Bus Commercialisation study. With demonstration activities in several key EU bus markets (London, Rotterdam, Pau, Rome, Versailles and Aalborg), the project aims to demonstrate across Europe the potential value of this technology for different types of bus fleets.

Major project achievements

- 4 new buses have been put in operation during the summer of 2017: 2 in London and 2 in Rotterdam. Hence, 12 buses are operational at the moment

Future steps

- Publication of tenders for FC buses for Rome and Aalborg, foreseen for october 2018
- Start of operations in Rotterdam (PZH), foreseen for mid 2018
- Procurement of FC buses for Versailles (foreseen october 2017) and, Aalborg and Rome, foreseen mid 2018
- Integration of Pau and Connexxion as a new partner (to be completed before end 2017): demonstration of 8 articulated "tram look" FC buses
- First evaluation of ongoing demonstrations

Non-quantitative objectives and status

- Development of a transferability plan: appropriate bus business concepts will be developed for interested stakeholders to identify opportunities for FC bus operations in daily business
- Consolidation and enhancement of Hydrogen Bus Centre of Excellence: Practical information for future users is a key requirement in the deployment of fuel cell bus technology. This information will be made available

Relevant to FCH JU overarching objectives

- Reduce the production cost of fuel cell systems to be used in transport applications, while increasing their lifetime to levels which can compete with conventional technologies

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
MAIP 2008-2013	FC Bus purchase cost	EUR	1,120,000	850,000	850,000	<850,000	Delayed	Procurement of post-prototpye phase FC buses
MAIP 2008-2013	FC Bus fuel consumption	kg/100km	11	8.51			Delayed	Realisation through accurate monitoring during demonstrations
MAIP 2008-2013	FC System Lifetime	hours	15,000	15,000			Due later	Demonstrations not started, lifetime based on suppliers warranty.
MAIP 2008-2013	Vehicle availability	%	83	90			Due later	Vehicles not yet or not yet long enough in operations for evaluation.
AWP 2013	Number of bus fleets deployed	fleets	6	6	2		Due later	Buses in Rotterdam and London are operational.
AWP 2013	Number of higher capacity refuelling stations deployed	HRIs	3	3			Due later	Sites with new HRS's are Pau, Aalborg and Versailles. They will be operational at a later phase.

CHIC
Clean Hydrogen in European Cities

Panel 1 — Technology validation in transport applications

Acronym:	**CHIC**
Project ID:	256848
Title:	Clean Hydrogen in European Cities
Call Topic:	SP1-JTI-FCH.2009.1.1
Project total costs (€):	€ 81,956,227
FCH JU maximum contribution (€):	€ 25,878,334
Project start/end:	01 Apr 2010 - 31 Dec 2016
Coordinator:	Evobus, Germany
Beneficiaries: Suedtiroler Transportstrukturen, Air Products, Hysolutions, Infraserv & Co. Hochst Kg, Air Liquide Hydrogen Energy, Azienda Trasporti Milanesi, Berliner Verkehrsbetriebe, British Columbia Transit, Centro Ricerche Fiat, Ruter, Element Energy Ltd, Spilett New Technol., Euro Keys, Total Deutschland, Uni. Stuttgart, Vattenfall Europe Innovation, Hycologne - Wasserstoff Region Rheinland, Hydrogen, Fuel Cells and Electro-mobility in European Regions HYER, Linde, London Bus Services Ltd, Pe International, Planet Planungsgruppe Energie und Technik, Postauto Schweiz, Shell Downstream Services International, Wrightbus Ltd	
Website:	http://chic-project.eu/
Twitter:	@CHICproject

Project and objectives

CHIC was the crucial next step for the full commercialisation of hydrogen powered fuel cell buses. Project targets were set for fuel cell (FC) lifetime, fuel consumption, availability, running distance and hours of operation. CHIC has met and in many instances significantly exceeded expectations. It has provided further necessary evidence for the functionality of hydrogen FCl buses and the refuelling infrastructure, and the practicality of their commercialisation in the near term. The project was completed in December 2016. The public project report can be found on the CHIC website.

Major project achievements

- Greatly increased FC bus efficiency, halving the fuel consumption of previous bus generations
- Greatly increased FC lifetime exceeding targets of the project and AIP and far in excess of any previous transport FCs
- Refueller availability comparable to diesel and other conventional refuelling infrastructure

Future steps

- Project completed 2016

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
AIP 2009	HRS capacity (upgradeable)	kg		200	200		achieved	upgradable to >= 400kg/day
AIP 2009	HRS availability	%		98	98		achieved	All >94%, 3 sites >98%
AIP 2009	HRS OPEX	€/kg H_2		5	12		Not achieved	12-28 €/kg: Electricity price is dominant factor
AIP 2009	Production efficiency	%		50	54		achieved	All sites >54%
AIP 2009	Diesel replacement	million l		0.50	4.3		achieved	> 1.5 across Phase 1 sites, > 4.3 across all sites
AIP 2009	FC stack lifetime	h		4000	6000		achieved	6820h average
AIP 2009	Bus availability	%		85	69		achieved	Target likely achieved if Oslo oil leak incident is disregarded
AIP 2009	Bus fuel consumption	kg/100 km		13,0	12,1		achieved	12,1 overall 9,9 phase 1 cities
AIP 2009	Distance driven	million km		2.75	9,6		achieved	9,6 overall 4,0 phase 1 cities
AIP 2009	hours of operation	kh		160	519		achieved	519 overall project 269,4 phase 1 cities

Non-quantitative objectives and status

- Reporting of accidents during project 2010-2016
- Global Warming Potential
- 85% savings for fully green H_2 fuel in FC buses
- Individuals interviewed on buses & hydrogen powered transport
- Project Environment: 185
- Critics and Sceptics: 63
- Dissemination and Exploitation
- Local sites general: 50-80 special events in each of 6 cities; Website (>30,000 unique visitors/yr)
- Phase 2 cities identified: 5 Clusters established

Relevant to FCH JU overarching objectives

- Reduce the production cost of fuel cell systems to be used in transport applications, while increasing their lifetime to levels which can compete with conventional technologies
- Increase the energy efficiency of production of hydrogen mainly from water electrolysis and renewable sources while reducing operating and capital costs, so that the combined system of the hydrogen production and the conversion using the fuel cell system can compete with the alternatives for electricity production available on the market

EG-04-17-700-EN-P

H2ME
Hydrogen Mobility Europe

Panel 1 — Technology validation in transport applications

Acronym:	**H2ME**
Project ID:	671438
Title:	Hydrogen Mobility Europe
Call Topic:	FCH-01.7-2014
Project total costs (€):	€ 72,0 million
FCH JU maximum contribution (€):	€ 32,0 million
Project start/end:	01 Jun 2015 - 31 May 2020
Coordinator:	Element Energy Ltd, United Kingdom

Beneficiaries:
Linde Gas, H2 Mobility Deutschland, Communaute d'Agglomeration Sarreguemines Confluences, Falkenberg Energi, Hyop, Danish Hydrogen Fuel, Omv Refining & Marketing, Honda R&D Europe (Deutschland), AGA, Hyundai Motor Europe, Symbiofcell, Air Liquide Advanced Technol., Cenex - Centre of Excellence for Low Carbon and Fuel Cell Technol., Mcphy Energy, Nucellsys, BOC Ltd, Areva H2Gen, Intelligent Energy Ltd, Renault, ITM Power (Trading), Waterstofnet, Nissan Motor Manufacturing (Uk) Ltd, Air Liquide Advanced Business, H2 Logic, Icelandic New Energy Ltd, Eifer Europaisches Inst. fur Energieforschung, Linde, Bayerische Motoren Werke, Daimler

Website: http://chic-project.eu/

Project and objectives

Hydrogen Mobility Europe (H2ME) brings together Europe's four most ambitious national initiatives on hydrogen mobility (from Germany, Scandinavia, France and the UK). The project will expand their developing networks of Hydrogen Refuelling Stations (HRS) - 29 new stations will be deployed - and the fleets of FCEVs operating on Europe's roads (325 vehicles) creating both a physical and a strategic link between these four regions and three 'observer countries' (Austria, Belgium and the Netherlands), who will use the learnings produced by this project to develop their own strategies.

Major project achievements

- Fruitful first two years with 3 HRSs commissioned and 100 vehicles in operation (40 B-CLASS F-CELL Daimler cars and 60 Symbio vans)
- Technical data set delivered and analysed with emerging conclusions for project drafted
- Successful launch of follow-up project, H2ME-2, and collaboration with an extra 1100 vehicles and 20 HRS planned for the next 6 years

Future steps

- Commissioning of the rest of the HRS network
- Deployment of more vehicles, including the first next generation Daimler GLC F-CELL
- A least one major dissemination event
- Solid and growing basis of operational data from vehicles and petrol stations and further fact-based analysis on vehicles and HRS performances

Relevant to FCH JU overarching objectives

- Reduce the production cost of fuel cell systems to be used in transport applications, while increasing their lifetime to levels which can compete with conventional technologies
- Increase the energy efficiency of production of hydrogen mainly from water electrolysis and renewable sources while reducing operating and capital costs, so that the combined system of the hydrogen production and the conversion using the fuel cell system can compete with the alternatives for electricity production available on the market

Non-quantitative objectives

- Minimum of 100 FCEVs and 23 HRS
  100 vehicles and 3 HRS deployed to date - 325 FCEVs and 29 HRS planned in total by the end of the project
- Further activities for deployment of HRS and FCEVs after project
- H2ME-2 and CEF project applications submitted
- HRS to be accessible for private users and integrated in petrol courts
- All of the 700bar HRS will be accessible for private drivers. The 20 x 700bar HRS in Germany will be integrated in petrol forecourts.
- Ensure cross-fertilisation of knowledge acquired in the project
- Dedicated work package and dissemination and exploitation plan to achieve this; 3 observer countries are included in the coalition

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
AIP 2013	Min. FCEV operation during project	mths		12	12	48	achieved	All vehicles to be operated for min. 1 year or 10,000 km. Some vehicles to be operated for 3 years and >30,000km
AIP 2013	Vehicle availability	%	95	98	95	98	Due later	95-98%. measured in available operation time.
AIP 2013	Tank-to-wheel TTW) efficiency	%	40	53	52	53	Due later	40-53% - to be validated in New European Driving Cycle (NEDC) test
MAWP 2014-2020	HRS availability	%	97	97	99	98	Due later	Min. 97% (measured in usable operation)
MAWP 2014-2020	Minimum HRS operation	mths	0	24	12	24	Due later	First HRSs deployed will operate for > 3 years. Last HRS will operate for just under 2 years

FUEL CELLS AND HYDROGEN
JOINT UNDERTAKING

EG-04-17-700-EN-P

H2ME 2
Hydrogen Mobility Europe 2

Panel 1 — Technology validation in transport applications

Acronym:	**H2ME 2**
Project ID:	700350
Title:	Hydrogen Mobility Europe 2
Call Topic:	FCH-03.1-2015
Project total costs (€):	€ 102,2 million
FCH JU maximum contribution (€):	€ 35,0 million
Project start/end:	01 May 2016 - 30 Jun 2022
Coordinator:	Element Energy Ltd, United Kingdom

Beneficiaries:
Linde Gas, H2 Mobility Deutschland, Hyop, Honda R&D Europe (Deutschland), Gnvert, AGA, Air Liquide Advanced Technol., Islenska Vetnisfelagid Ehf, Communaute Urbaine du Grand Nancy, Stedin Diensten, Societe du Taxi Electrique Parisien, Partnerskab for Brint Og Braendsels Celler, Cenex - Centre of Excellence for Low Carbon and Fuel Cell Technol., Compagnie Nationale du Rhone, Hysolutions, Hydrogene de France, Nucellsys, Symbiofcell, Areva H2Gen, Renault Trucks, Societe d'Economie Mixte des Transports en Commun de L'Agglomeration Nantaise (Semitan), Ministerie van Infrastructuur en Milieu, Intelligent Energy Ltd, Manufacture Francaise des Pneumatiques Michelin, Renault, ITM Power (Trading), Kobenhavns Kommune, McPhy Energy, Nissan Motor Manufacturing (Uk) Ltd, Uni. Manchester, Air Liquide Advanced Business, H2 Logic, Icelandic New Energy Ltd, Eifer Europaisches Inst. fur Energieforschung, Bayerische Motoren Werke, Audi, Open Energi Ltd, Daimler

Website: www.h2me.eu

Project and objectives

H2ME 2 brings together actions in 8 countries in a 6-year collaboration to deploy over 1,100 fuel cell (FC) vehicles and 20 new hydrogen refuelling stations (HRS). The project will perform a large-scale market test of a large fleet of FC 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.

Major project achievements

- Fruitful first year with first HRS commissioned (Mariestad, SE) and vehicles procured (STEP Paris, City of Copenhagen)
- Technical data set delivered and analysed with emerging conclusions for project drafted
- Successful collaboration in place with H2ME project

Future steps

- > 50% of the HRS network to be commissioned
- Over 200 vehicles to be deployed including the first next generation Daimler GLC F-CELL
- A least one major dissemination event
- Further fact-based analysis on vehicles and HRS performance

Non-quantitative objectives and status

- Project target: 1,114 fuel cell vehicles and 20 HRS
- Demonstration of electrolyser integrated HRS operating in grid balance
- H2ME 2 has a dedicated work package to assess the way in which electrolytic H_2 production in the mobility sector can link to the wider energy system.
- Vehicles supplied from multiple OEMs, including cars and utility vehicle H2ME 2 will deploy cars, light duty vans and trucks from OEMs including Daimler, Honda and Symbio FCell as well procure Hyundai and Toyota cars.
- Ensure cross-fertilisation of knowledge acquired in the project
- Dedicated WP and dissemination and exploitation plan to achieve this.
- 3 observer countries are included in the coalition

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
AIP 2015	Minimum vehicle operation during project	months		36	na	36	delayed	Target 36 months or 45,000 km or 12 months and 10,000km
AIP 2015	Vehicle availability	%	95	98	na	98	delayed	no vehicle in operation
AIP 2015	Tank to wheel (TTW) efficiency	%	40	42	42	53	delayed	To be validated in New European Driving Cycle (NEDC) test.
MAWP 2014-2020	HRS availability	%	95	98	98	98	delayed	To be measured in usable operation @ end of project
MAWP 2014-2020	Hydrogen purity	%	99.99	99.99	99.99	99.99	Due later	All 700bar HRS to be comply with the SAE J2601 and SAE J2799 H_2 dispensed to have a purity >= 99.999%
MAWP 2014-2020	Minimum HRS operation (per station)	months		36	3	36	Due later	measured at end of project

HAWL

Large scale demonstration of substitution of battery electric forklifts by hydrogen fuel cell forklifts in logistics warehouses

Panel 1 — Technology validation in transport applications

Acronym:	**HAWL**
Project ID:	325381
Title:	Large scale demonstration of substitution of battery electric forklifts by hydrogen fuel cell forklifts in logistics warehouses
Call Topic:	SP1-JTI-FCH.2012.4.1
Project total costs (€):	€ 9,0 million
FCH JU maximum contribution (€):	€ 4,3 million
Project start/end:	01 Sep 2013 - 31 Aug 2017
Coordinator:	Air Liquide Advanced Business, France
Beneficiaries: Air Liquide Advanced Technol., BT Products, Cesab Carrelli Elevatori, Crown Gabelstapler, Fm France, Hypulsion, Toyota Material Handling Europe, Diagma, FM Logistic Corporate, FM Polska	
Website:	https://hawlproject.eu/en

Project and objectives

The project aims at accelerating market penetration of fuel cell technologies (i.e. fuel cell forklifts) in European warehouses.

8 different fuel cells were developed and certified for use in Europe.

Following a successful trial, 46 forklifts are now running at FM warehouse in Neuville-aux-Bois (France). Productivity is confirmed for a specific application.

The H_2 solution brings flexibility for the operations, reduces risk and is preferred by former users of the battery alternative.

A French regulation for warehouse H_2 operations was published: this will reduce time for future deployment of H_2 forklifts.

Major project achievements

- Deployment of 46 forklifts: HAWL deployment is one of the main hydrogen warehouses in Europe
- Technical maturity of the solution (station + fuel cells) confirmed: it clearly meets the logistician needs
- Publication of a French regulation for warehouse H_2 applications – reducing permitting time and bringing confidence to the logistic industry

Future steps

- Analysis of the return of experience of the 46 forklifts demonstration
- Preparation of the public conclusions
- Publication / dissemination of the public deliverables

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
MAIP 2008-2013	Cost of fuel cell systems	€/kW		3500	<3000	3000	achieved	Cost at early volume production for FC > 3kW
AIP 2012	System lifetime	hours		10000	8300	10000	Due later	Deployment too short to reach target. NB target forsees service/stack refurbishment)
AIP 2012	FC system efficiency	%		45	45	45	achieved	
AIP 2012	Refueling time	seconds		180	128	128	achieved	

Non-quantitative objectives and status

- Accelerate the market introduction of the technology
  Project allowed to create a strong reference for the European logistic industry strongly helped to convince other customers (see project Hylift-Europe)
- Develop & certify European ranges of FC products and FC-ready forklifts
  8 types of fuel cells certified.
- Solve the safety and acceptance issues
  Project was instrumental in creating French regulation: it will ease future deployments by reducing permitting time
- Assess and demonstrate the productivity given by the technology
  Productivity confirmed for a specific application

Relevant to FCH JU overarching objectives

- Reduce the production cost of fuel cell systems to be used in transport applications, while increasing their lifetime to levels which can compete with conventional technologies

EG-04-17-700-EN-P

HIGH V.LO-CITY
Cities speeding up the integration of hydrogen buses in public fleets

Panel 1 — Technology validation in transport applications

Acronym:	**HIGH V.LO-CITY**
Project ID:	278192
Title:	Cities speeding up the integration of hydrogen buses in public fleets
Call Topic:	SP1-JTI-FCH.2010.1.1
Project total costs (€):	€ 29,243,442
FCH JU maximum contribution (€):	€ 13,491,724
Project start/end:	01 Jan 2012 - 31 Dec 2018
Coordinator:	Van Hool, Belgium
Beneficiaries: Ballast Nedam International Product Management, Cng Net, Dantherm Power, Fit Consulting, Riviera Trasporti, Solvay, Uni. Genova, Waterstofnet, Aberdeen City Council*, Hydrogen, Fuel Cells and Electro-mobility in European Regions HYER, Regione Liguria, Vlaamse Vervoersmaatschappij de Lijn	
Website:	http://highvlocity.eu/ and www.fuelcellbuses.eu
Twitter:	@HighVLOCity

Project and objectives

The overall objective of High V.LO-City is to facilitate rapid deployment of FC Buses in public transport operations, by addressing the key environmental and operational concerns that transport authorities are facing today.

This is realised by demonstrating 14 FC Buses and their refuelling equipment in 4 sites throughout Europe (Antwerp, Sanremo, Aberdeen and Groningen). Currently the vehicles in Aberdeen and Antwerp are operational, while those in Groningen and Sanremo will start operations from end 2017.

Major project achievements

- High V.LO City contributes in the largest European FC Bus site in Europe in Aberdeen
- With the demonstration in the High V.LO City project, several other key projects in the deployment of FC Buses could be initiated
- One website collects and presents all required information for partners that want to be informed about FC Bus technology: www.fuelcellbuses.eu

Future steps

- Launch of FC Bus services in Sanremo. We wait for the refuelling equipment to become available
- Start of real service of FC Buses in Groningen. We wait for the refuelling equipment to become available

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
MAIP 2008-2013	Number of operational vehicles			14	9	14	Delayed	The vehicles in Antwerp and Aberdeen are operational. Those for Groningen and Sanremo will come soon.
MAIP 2008-2013	Number of operational FC bus sites			4	2	4	Delayed	The sites of Aberdeen and Antwerp are in operation. Groningen and Sanremo will come soon.
MAIP 2008-2013	Number of operational refuelling stations			4	2	4	Delayed	Refuelling stations in Aberdeen and Antwerp are operational. Groningen and Sanremo are being put in place.
MAIP 2008-2013	FC System cost	€/kW		3,500	2,500		Achieved	
AIP 2010	Set up Centres of Excellence to communicate about FC buses			4	1	1	Achieved	A virtual Centre of Excellence is set up that replaces the original foreseen physical centres. This is the FC Bus website: www.fuelcellbuses.eu

Non-quantitative objectives and status

- Evaluate the entire life cycle costs of buses: currently inputs from the buses are collected: bus performance, maintenance data, costs
- Contribute to the commercialization of H_2 Hybrid buses in Europe: with the demonstration in the High V.LO City project, several other key projects in the deployment of FC Buses could be initiated

Relevant to FCH JU overarching objectives

- Reduce the production cost of fuel cell systems to be used in transport applications, while increasing their lifetime to levels which can compete with conventional technologies

HYCARUS
Hydrogen cells for airborne usage

Panel 1 — Technology validation in transport applications

EG-04-17-700-EN-P

Acronym:	**HYCARUS**
Project ID:	325342
Title:	Hydrogen cells for airborne usage
Call Topic:	SP1-JTI-FCH.2012.1.6
Project total costs (€):	€ 12,0 million
FCH JU maximum contribution (€):	€ 5,2 million
Project start/end:	01 May 2013 - 30 Apr 2018
Coordinator:	Zodiac Aerotechnics, France
Beneficiaries:	Air Liquide Advanced Technol., Dassault Aviation, Zodiac Cabin Controls, Arttic, Commissariat à l'Energie Atomique et aux Energies Alternatives CEA, Driessen Aerospace, Inst. Nacional de Tecnica Aeroespacial, JRC -Joint Research Centre, European Commission, Zodiac ECE
Website:	http://hycarus.eu/

Project and objectives

HYCARUS develops a Generic Fuel Cell System (GFCS) in order to power non-essential aircraft applications such as a galley in a commercial aircraft or to be used as a secondary power source on-board business jets. Demonstration of GFCS performances in relevant and representative cabin environment (TRL 6) will be achieved through flight tests on-board a Dassault Falcon aircraft.

Moreover, HYCARUS will assess how to valorise the by-products (especially heat and Oxygen Depleted Air - ODA) produced by the fuel cell system to increase its global efficiency.

Major project achievements

- Completion of the verification tests of the whole GFCS
- Completion of the design and the tests of the different components and sub-systems of the GFCS
- Completion of the functional Hazard Assessment & Preliminary System Safety Assessment

Future steps

- Completion of the verification tests of the whole GFCS
- System Safety Assessment completion
- Flight Readiness Process completion
- Environmental tests of the GFCS for the flight test configuration

Non-quantitative objectives and status

- Proof of concept of H_2 storage and supply on-board an aircraft
- Gaseous 350 bars H_2 storage and supply system developed. H_2 leakage and safety management strategy approved. Demonstration planned for 2017
- Demonstrate operational capacity for such systems in aircrafts
- Fuel Cell system specification and qualification plan completed. Environmental and Flight tests planned for 2017

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
AIP 2011	Demonstrator TRL	TRL	3	6	4	6	Due later	FC sub-systems tested, Functional FC system tests ongoing for flight tests configuration
AIP 2011	Power range	kW		20.00	12.5	20.00	Due later	FC sub-systems tested, Functional fc system tests for flight tests configuration ongoing (galley configuration tests are planned late on.
AIP 2011	Durability	Hrs		2500	2000	2000	Achieved	Only FC stack durability tests performed (2000 hrs, under flight representative load profiles)
AIP 2011	FC system efficiency (LHV) @ 25% of rated power	%		55	45	45	Not achieved	based on simulation results, tests to be performed in 2018
AIP 2011	FC system power density (End of life – EoL)	kW/L		0.40	0.02	0.02	Not achieved	H_2 storage excluded. Initial target very ambitious in the timeframe of the project, for an aerospace 20kWe FC system.
AIP 2011	FC system specific power (EoL)	kW/kg		0.65	0.10	0.10	Not achieved	H_2 storage excluded. Initial target very ambitious in the timeframe of the project, for an aerospace 20kWe FC system.

FUEL CELLS AND HYDROGEN
JOINT UNDERTAKING

HYFIVE
Hydrogen for innovative vehicles

Panel 1 — Technology validation in transport applications

Acronym:	**HYFIVE**
Project ID:	621219
Title:	Hydrogen for innovative vehicles
Call Topic:	SP1-JTI-FCH.2013.1.1
Project total costs (€):	€ 39,0 million
FCH JU maximum contribution (€):	€ 18,0 million
Project start/end:	01 Apr 2014 - 30 Sep 2017
Coordinator:	Greater London Authority, United Kingdom

Beneficiaries:
Daimler, Linde, Thinkstep, Air Products, Copenhagen Hydrogen Network, Danish Hydrogen Fuel, Honda R&D Europe (Deutschland), Hyundai Motor Europe, Bayerische Motoren Werke, Element Energy Ltd, Foreningen Hydrogen Link Danmark, Omv Refining & Marketing, Istituto per Innovazioni Tecnologiche Bolzano, ITM Power (Trading), Partnerskab For Brint Og Braendsels Celler, Toyota Motor Europe

Website: http://www.hyfive.eu/

Project and objectives

HyFIVE is an ambitious European project including 15 partners for the deployment of 185 fuel cell electric vehicles (FCEVs) from the five global automotive companies who are leading in their commercialisation (BMW, Daimler, Honda, Hyundai and Toyota).

Refuelling stations configured in viable networks will be developed in three distinct clusters by deploying 6 new stations linked with 12 existing stations supplied by Air Products, Copenhagen Hydrogen Network, Linde, Danish Hydrogen Fuel, ITM Power and OMV.

Major project achievements

- Deployment of 185 vehicles supporting development of hydrogen technologies in 3 EU regions
- Deploying 6 new stations and utilising 12 existing stations to ensure utilisation and future planning
- Increasing consumer awareness as well as existing consumer support

Future steps

- Finalising data submission and data reports
- Finalising consumer attitudes reports
- Organise a final conference for the project in September 2017
- Environmental tests of the GFCS for the flight test configuration

EG-04-17-700-EN-P

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
MAIP 2008-2013	Nr vehicles deployed			185	185	185	Achieved	
MAIP 2008-2013	Nr HRSs deployed			6	6	6	Achieved	
MAIP 2008-2013	Hydrogen cost	€		10			Not achieved	We expect to achieve this in one or two of the clusters
MAIP 2008-2013	Vehicle operation	km		10,000	10,000		Achieved	Target is 12 months or 10,000 km
MAIP 2008-2013	Vehicle availability	%		95	95	95	Achieved	
MAIP 2008-2013	Station availabilty	%		98	98	98	Achieved	

Non-quantitative objectives and status

- Training and education
  Supporting FCEVs in the field and existing infrastructure: training dealers and first responders; training technicians and sales staff. Training documents
- Safety, regulations, codes and standards
  Refuelling sites are being identified according to safety considerations alongside safety risks for plans to be implemented to manage each of the risk
- Public awareness
  The project aims to raise public awareness and inform public about the technology and the benefits it brings. We do this through twitter, blogs, news

Relevant to FCH JU overarching objectives

- Reduce the production cost of fuel cell systems to be used in transport applications, while increasing their lifetime to levels which can compete with conventional technologies
- Increase the energy efficiency of production of hydrogen mainly from water electrolysis and renewable sources while reducing operating and capital costs, so that the combined system of the hydrogen production and the conversion using the fuel cell system can compete with the alternatives for electricity production available on the market

HYLIFT-EUROPE
Large scale demonstration of fuel cell powered material handling vehicles

Panel 1 — Technology validation in transport applications

EG-04-17-700-EN-P

Acronym:	**HYLIFT-EUROPE**
Project ID:	303451
Title:	Large scale demonstration of fuel cell powered material handling vehicles
Call Topic:	SP1-JTI-FCH.2011.4.1
Project total costs (€):	€ 22,0 million
FCH JU maximum contribution (€):	€ 9,3 million
Project start/end:	01 Jan 2013 - 31 Dec 2017
Coordinator:	Ludwig-Boelkow-Systemtechnik, Germany

Beneficiaries:
Air Products, Copenhagen Hydrogen Network, Dantherm Power, Fast - Federazione delle Associazioni Scientifiche e Tecniche, Air Liquide Advanced Business, Element Energy Ltd, H2 Logic, Mulag Fahrzeugwerk Heinz Wössner, Heathrow Airport Ltd, Still, JRC -Joint Research Centre, European Commission, Prelocentre

Website: http://www.hylift-europe.eu/

Project and objectives

The aim of HyLIFT-EUROPE is to demonstrate more than 200 fuel cell (FC) material handling vehicles and associated refuelling infrastructure at more than 2 sites across Europe (the initial plan foresaw 5-20 sites), making it the largest European trial of hydrogen fuel cell material handling vehicles to date. This continues efforts of the previous FCH JU supported project HyLIFT-DEMO. In the HyLIFT-EUROPE project, the partners demonstrate FC systems in material handling vehicles from the partner STILL and from non-participating OEMs.

Major project achievements

- Demonstration in real-world operation of 49 materials handling vehicles at the Prelocentre site
- Demonstration in real-world operation of an indoor hydrogen refuelling station including hydrogen supply at the Prelocente site
- Identification of a further customer to install also a fleet of FC forklifts enabling the project to achieve the 200 vehicles target

Future steps

- Extension of the project beyond current end date to demonstrate the new forklifts
- Start-up of second demonstration fleet at second site (137 FC materials handling vehicles in total)
- Large opening ceremony foreseen in second half of 2017

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1^{st} 2017	Description
MAIP 2008-2013	Nr vehicles	[-]	11	200	49	201	Due later	11 vehicles ex HyLIFT-DEMO, 49 at Prelocentre. Contracts signed for achieving target
AIP 2011	Nr FC systems	[-]	11	200	49	201	Due later	
AIP 2011	FC system efficiency	[%]	45	45-50	>45	>45	Achieved	Target already reached with past generation FC systems
AIP 2011	Refuelling time	[min]	n.a.	~3	2.5	2.5	Achieved	Application of most advanced refuelling technology
AIP 2011	HRS availability	[%]	98	>98	>99	>99	Achieved	Application of most advanced refuelling technology
Project's own	Nr HRS	[-]	0	≥ 2	2	2	Achieved	

Non-quantitative objectives and status

- Validation of Total Cost of Ownership (TCO) & path towards commercial target
  Validation of TCO and development of the path towards commercial targets are taking place
- Plan and ensure initiation of supported market deployment beyond 2018
  The project and demonstration volume in itself provide first step towards commercialisation by selling the vehicles at commercially competitive prices
- Best practice guide for hydrogen refuelling station installation
  A best practice guide documents in detail the lessons learned from obtaining safety approval for an airport HRS
- European dissemination and supporting of the European industry
  The European dissemination and supporting of the European industry is a still ongoing task to be finished only at the end of the project

Relevant to FCH JU overarching objectives

- Reduce the production cost of fuel cell systems to be used in transport applications, while increasing their lifetime to levels which can compete with conventional technologies

HYTRANSIT
European Hydrogen Transit Buses in Scotland

Panel 1 — Technology validation in transport applications

EG-04-17-700-EN-P

Acronym:	**HYTRANSIT**
Project ID:	303467
Title:	European Hydrogen Transit Buses in Scotland
Call Topic:	SP1-JTI-FCH.2011.1.1
Project total costs (€):	€ 17,8 million
FCH JU maximum contribution (€):	€ 7,0 million
Project start/end:	01 Jan 2013 - 31 Dec 2018
Coordinator:	BOC Ltd, United Kingdom

Beneficiaries:
Dantherm Power, Aberdeen City Council*, Element Energy Ltd, Hydrogen, Fuel Cells and Electro-mobility in European Regions HYER, Planet Planungsgruppe Energie und Technik, Stagecoach Bus Holdings Ltd, Van Hool

Website:	http://aberdeeninvestlivevisit.co.uk/Invest/Aberdeens-Economy/City-Projects/H2-Aberdeen/Hydrogen-Bus/Hydrogen-Bus-Project.aspx

Project and objectives

The overall project objective is to prove that the hybrid fuel cell bus is capable of meeting the operational performance of an equivalent diesel bus in long route operation whilst offering significant benefits in terms of OPEX and environmental performance.

The project will also address bus capital cost, the main commercial barrier to the technology, by deploying state- of-the-art components, to reduce the unit cost of buses below €1.1 million for the first time (excluding non-recurring engineering costs).

Major project achievements

- Europe's largest fuel cell bus fleet has been operated for over two years in Aberdeen
- UK's largest HRS (300 kg/day) installed and commissioned by BOC in March 2015, has operated with very high availability (>99%) for over two years
- HRS has dispensed over 70 tonnes of hydrogen in over 2,300 refuelling

Future steps

- Evaluate the HRS and FC bus performance with life-cycle and technical assessments
- Evaluate economic and environmental impact compared to operating regular diesel buses
- Develop a strategy for continuing FC bus and HRS operation beyond the project

Relevant to FCH JU overarching objectives

- Reduce the production cost of fuel cell systems to be used in transport applications, while increasing their lifetime to levels which can compete with conventional technologies

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
AIP 2011	FC lifetime	h	4000	6000	5184	8775	Due later	> 4,000h lifetime initially, > 6,000h as program target
AIP 2011	Bus Availability	%	85	90	75	90	Achieved	+ target of maintenance as for conventional buses
AIP 2011	Fuel Consumption	kg/100km	11-13	10	10.3	10.3	Due later	
AIP 2011	Refuelling capacity	kg/day	50	200	360	360	Achieved	Peak fuelling currently 360 kg/day. Regularly refuelling ~200kg/day
AIP 2011	Nr back-to-back refuellings	#/hour	1-2	6	6	6	Achieved	Each bus fuelling takes <10 minutes, system can manage 6 buses back to back.
AIP 2011	Potential for modular exapnsion of HRS	vehicles/d	100.00	250.00	250.00	250.00	Achieved	Mudular design exceeds the AIP targets
AIP 2011	HRS Availability	%	98	98	99.2	99.5	Due later	Excellent availability to date
AIP 2011	Hydrogen cost	€/kg	10	10			Due later	Cost of H_2 delivered to the buses + H_2 production costs basis is 6 euros/kg, assuming 200kg/day

NewBusFuel
European Hydrogen Transit Buses in Scotland

Panel 1 — Technology validation in transport applications

Acronym:	**NewBusFuel**
Project ID:	671426
Title:	New Bus ReFuelling for European Hydrogen Bus Depots
Call Topic:	FCH-01.6-2014
Project total costs (€):	€ 2,5 million
FCH JU maximum contribution (€):	€ 2,4 million
Project start/end:	01 Jun 2015 - 31 Mar 2017
Coordinator:	Element Energy, United Kingdom
Beneficiaries: Ffg Fahrzeugwerkstatten Falkenried, Linde Gas, Wsw Mobil, Mcphy Energy Deutschland, Rigas Satiksme Sia, Hydrogenics, Hyop, Ingenieurteam Bergmeister, Vip Verkehr sbetrieb Potsdam, Air Products, Vattenfall Europe Innovation, Empresa Municipal de Transportes de Madrid, Stuttgarter Strassenbahnen, Akershus Fylkeskommune, Kunnskapsbyen Lillestrom Forening, Abengoa Innovacion, Evobus, Thinkstep, ITM Power (Trading), Aberdeen City Council*, Air Products, Suedtiroler Transportstrukturen, Istituto per Innovazioni Tecnologiche Bolzano, London Bus Services Ltd, Hamburger Hochbahn, H2 Logic, Linde, Vlaamse Vervoersmaatschappij de Lijn, Birmingham City Council, Siemens	
Website:	www.newbusfuel.eu

Project and objectives

Produce 13 engineering studies to define optimal designs, H_2 supply routes, commercial arrangements and practicalities involved in refuelling high volumes of H_2 at busy bus depots across Europe.

Conclude on the cost and practical issues associated with hydrogen refuelling at a very large scale by analysing results across all studies

Prepare a range of publically accessible design guideline reports based on the analysis

Disseminate results to a wider audience to ensure the challenge of H_2 fuelling for buses is not seen as a credible reason to delay engagement with the technology.

Major project achievements

- Proved the technical feasibility of H2 bus operation at a large scale meeting local specifications and regulatory conditions
- Demonstrated the ability to provide hydrogen at high reliability for affordable prices (depending on local energy circumstances)
- Developed clear guideline documents which will allow future bus operators to easily and quickly deploy an appropriate HRS solutions for their buses

Future steps

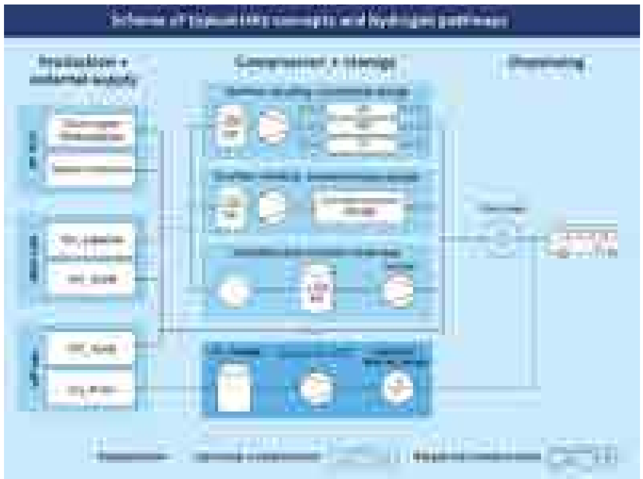
- Project finished

Non-quantitative objectives and status

- Consider fuelling station requirements for at least 75-150 buses
  All designs completed and outputs for public dissemination finalised
- Assess H_2 supply options: on-site (WE and SMR), and delivered
  NewBusFuel considered the full range of supply options and demonstrated the conditions required to acquire affordable hydrogen from each option
- Designs should focus on affordable reliable hydrogen supply
  The project has demonstrated that affordable hydrogen (cost range € 5-10/kg) can be delivered at a large bus scale with appropriate reliability
- Opportunities for standardising should be assessed
  Six cross cutting working groups were established to debate cross-industry issues. Outputs finalised in reports for each group

Relevant to FCH JU overarching objectives

- Increase the energy efficiency of production of hydrogen mainly from water electrolysis and renewable sources while reducing operating and capital costs, so that the combined system of the hydrogen production and the conversion using the fuel cell system can compete with the alternatives for electricity production available on the market
- Demonstrate on a large scale the feasibility of using hydrogen to support integration of renewable energy sources into the energy systems, including through its use as a competitive energy storage medium for electricity produced from renewable energy sources



EG-04-17-700-EN-P

PURE
Development of auxiliary power unit for recreational yachts

Panel 1 — Technology validation in transport applications

Acronym:	PURE
Project ID:	303457
Title:	Development of auxiliary power unit for recreational yachts
Call Topic:	SP1-JTI-FCH.2011.4.4
Project total costs (€):	€ 2,9 million
FCH JU maximum contribution (€):	€ 1,6 million
Project start/end:	01 Jan 2013 - 30 Jun 2016
Coordinator:	Hygear Fuel Cell Systems, The Netherlands
Beneficiaries: Danmarks Tek. Uni., Centre for Research and Technology Hellas, Scheepswerf Damen Gorinchem, JRC -Joint Research Centre, European Commission	
Website:	http://pure-project.eu/

Project and objectives

In the PURE project an auxiliary power unit (APU) for use on-board of recreational yachts has been designed, built and tested. The objectives were to test a high temperature PEM fuel cell based system running on LPG. The size and weight targets of the 500 W system were 35kg/kW and 50 liters/kW. In the project, improved Membrane-Electrode Assemblies (MEAs) have been developed and new high temperature desulfurisation and sulphur-tolerant auto-thermal reforming (ATR) catalyst materials have been tested. Two prototypes have been constructed and tested in the laboratory. The project has been finalised by a test of a prototype on board of a yacht.

Major project achievements

- Preparation of ATR catalysts for LPG which are sulphur-tolerant
- Development of a new route for MEA preparation with less waste and reduced precious metal content
- Demonstration of a LPG fuelled HT PEM fuel cell system on-board of a recreational yacht

Future steps

- Project finished

Non-quantitative objectives and status

- LPG fuelled system
  The PURE system was demonstrated on board running on LPG
- Sulfur-tolerant ATR catalyst
  catalyst developed which is tolerant to 33 ppm sulfur
- Use 3D metal printed heat exchangers
  3D metal printed heat exchangers developed and successfully tested

Relevant to FCH JU overarching objectives

- Increase the electrical efficiency and the durability of the different fuel cells used for power production to levels which can compete with conventional technologies, while reducing costs
- Increase the energy efficiency of production of hydrogen mainly from water electrolysis and renewable sources while reducing operating and capital costs, so that the combined system of the hydrogen production and the conversion using the fuel cell system can compete with the alternatives for electricity production available on the market
- Reduce the use of the EU defined 'Critical raw materials', for instance through low-platinum or platinum-free resources and through recycling or reducing or avoiding the use of rare earth elements

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
MAIP 2008-2013	Development of miniaturized BoP for specific devices 1	l/kW	380	50	180	180	Not achieved	Compact design, 3D printed metal heat exchangers, with multiple functionality
MAIP 2008-2013	Development of miniaturized BoP for specific devices 2	kg/kW	160	35	100	100	Not achieved	Compact design, 3D printed metal heat exchangers, with multiple functionality
AIP 2011	Stack power	W	500.00	500	500	500	Achieved	Use enough MEA's in the stack
AIP 2011	System electrical efficiency	%	11	30	25	25	Not achieved	High conversion in fuel processor modules
AIP 2011	System cost (mass produced)	€	50000	2500	2317	2317	Achieved	Reduce parts, mass production of stack materials

SWARM
Demonstration of Small 4-Wheel fuel cell passenger vehicle Applications in Regional and Municipal transport

Panel 1 — Technology validation in transport applications

EG-04-17-700-EN-P

Acronym:	**SWARM**
Project ID:	303485
Title:	Demonstration of Small 4-Wheel fuel cell passenger vehicle Applications in Regional and Municipal transport
Call Topic:	SP1-JTI-FCH.2011.1.1
Project total costs (€):	€ 15,7 million
FCH JU maximum contribution (€):	€ 6,8 million
Project start/end:	01 Oct 2012 - 31 Dec 2017
Coordinator:	Element Energy, United Kingdom
Beneficiaries:	Tuv Sud, Air Liquide Advanced Technol., Coventry Uni. Enterprises Ltd, Deutsches Forschungszentrum fuer Kuenstliche Intelligenz, Birmingham City Council, Ewe-Forschungszentrum für EnergieTechnol., Gespa, H2O E-Mobile, Jade Hochschule Wilhelmshaven/Oldenburg/Elsfleth, Planet Planungsgruppe Energie und Technik, Riversimple Engineering Ltd, Riversimple, Riversimple Movement Ltd, Uni. Birmingham, Service Public de Wallonie, Tuv Sud Product Service, Uni. Bremen, Uni. Liege, Uni. Libre Bruxelles
Website:	http://www.swarm-project.eu/

Project and objectives

SWARM is a demonstration project concerning a fleet of small passenger vehicles that builds on and expands existing hydrogen refuelling infrastructure in the UK, Belgium, and Germany. The vehicles are low-cost, high fuel-efficiency, hybridised, light-weight passenger cars specifically designed for city and regional transport. New hydrogen refuelling sites are to be deployed in each country to close the gaps in a continuous 'hydrogen highway' that leads from Wales and the Midlands to London, connecting to Brussels and Hamburg/Scandinavia/Berlin/ Bremen via Cologne*.

Major project achievements

- 1st full year of operation achieved for vehicles demo and further optimisation have been implemented following collaboration with universities
- 1st full year of operation achieved for HRS demo with additional sites to be rolled out
- Commercial discussions with investors with positive outcomes and preparation for post demo activities strategically for two vehicles OEMs

Future steps

- All demonstration activities at all sites to be fully started or close to
- Further vehicles optimisation and development of next generation models
- Analysis tasks to deliver first project's analysis

Non-quantitative objectives and status

- Fleet of critical mass in small vehicle segment
  Two prototypes developed for two fleets, including gen 3 prototypes ready for next step commercialisation trial
- New regional hydrogen network and increased density of EU network
  First HRS deployed in Brussels (Zaventem), densification of network in the Midlands and Wales, key node for German network linking Germany to Belgium
- Demonstrate a complementary approach to hydrogen vehicle drive trains
  Two prototypes (incl. various gen) developed with novel approach for H_2 vehicles with built-in battery dominant hybrid mode
- Strong engagement and collaboration of EU SMEs and research institutes
  Project dominated by SMEs and research partners and proposed collaboration on improvement work for vehicle development

Relevant to FCH JU overarching objectives

- Reduce the production cost of fuel cell systems to be used in transport applications, while increasing their lifetime to levels which can compete with conventional technologies

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
MAIP 2008-2013	Vehicle energy consumption	Kg/100 km	1	1	1	1	Achieved	Only 5 vehicles (2 suppliers) in operation; Both suppliers have achieved the target
AIP 2011	HRS availability	%	90	95	95	95	Achieved	>95% achieved in Zaventem (2016); 2 more HRS will be commissioned
AIP 2011	Hydrogen price dispensed at pump	€/kg	15	10	10	10	Achieved	Achieved in Zaventem (2016); 2 more HRS will be commissioned
AIP 2011	Lifetime	h	2000	3000			Due later	
AIP 2011	Driving distance	km			25900	200000	Due later	

* Subject to amendment

PANEL 2
RESEARCH ACTIVITIES FOR TRANSPORT APPLICATIONS

AUTO-STACK CORE
Automotive Fuel Cell Stack Cluster Initiative for Europe II

Panel 2 - Research activities for transport applications

Acronym:	**AUTO-STACK CORE**
Project ID:	325335
Title:	Automotive Fuel Cell Stack Cluster Initiative for Europe II
Call Topic:	SP1-JTI-FCH.2012.1.2
Project total costs (€):	€ 14,7 million
FCH JU maximum contribution (€):	€ 7,8 million
Project start/end:	01 May 2013 - 31 Jul 2017
Coordinator:	Zentrum fuer Sonnenenergie und Wasserstoff-Forschung, Baden-Wuertemberg, Germany

Beneficiaries:
Greenerity, Powercell Sweden, Reinz-Dichtungs, Solvicore, Swiss Hydrogen, Symbiofcell, Volvo Technology, Bayerische Motoren Werke, Belenos Clean Power Holding, Commissariat à l'Energie Atomique et aux Energies Alternatives CEA, Fraunhofer Gesellschaft zur Foerderung der Angewandten Forschung, Freudenberg, Freudenberg Vliesstoffe, JRC -Joint Research Centre, European Commission, Paul Scherrer Inst., Volkswagen

Website: http://autostack.zsw-bw.de/index.php?id=1&L=1

Project and objectives

AutoStack-CORE established a coalition with the objective to develop best-of-its-class automotive stack hardware with superior power density and performance while meeting commercial target cost. The project consortium combines the expertise of OEMs, component suppliers, system integrators, and research institutes. The development work has been structured in three evolutions. Two stack design evolutions were built and tested. In evolution 2, a leading peak power density of 4 kW/l was achieved. The design phase of evolution 3 is close to completion.

Major project achievements

- The stack achieved a peak power density > 4 kW/l
- Freeze-start from -20 °C to 50% nominal power could be achieved in 12 sec

Future steps

- Finalise stack assembly for testing program.
- Complete testing program
- Finalise evolution 3 concept

Non-quantitative objectives and status

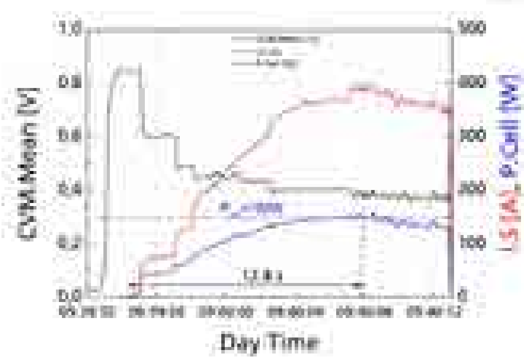
- Integrate the fragmented PEM stack research and development activities
  Consortium formed from key stakeholders from automotive OEMs (3), supply industry (4), system integrators (2)and research organisations (5)

Relevant to FCH JU overarching objectives

- Reduce the production cost of fuel cell systems to be used in transport applications, while increasing their lifetime to levels which can compete with conventional technologies

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
Project's own	Gross power at 1.5 A/cm2	kW	91	95	96.10	98	Achieved	Extrapolation from 20 cell stack using 0.35 mg/cm2 PGM loading, peak power 114.2 kW
Project's own	Minimum voltage @ peak load	V	181	200	200	200	Achieved	Voltage of 0.6 V @ peak load (1.9 A/cm2)
Project's own	Maximym Voltage	V	340	430	325	325	Achieved	Max. voltage should stay < 430 V under all conditions
AIP 2012	Specific power	kW/kg		2	2.91	2.96	Achieved	Based on nominal power @ 1.5 A/cm2 @ peak: 3.45 kW/kg
AIP 2012	Power density	kW/l		2	3.46	3.54	Achieved	Based on nominal power @ 1.5 A/cm2 @ peak: 4.12 kW/kg
AIP 2012	Voltage @ 1.5 A/cm2	mV		675	638	650	Delayed	Under AutoStack-CORE reference conditions.
Project's own	Cold start from -20 °C to 50 % power	sec		30	12.80	12.80	Achieved	
Project's own	Noble metal loading	g/kW	0.66	0.40	0.36	0.35	Achieved	Total loading, cathode + anode
Project's own	Degradation rate	µV/h	100	12	20	10	Due later	Endurance testing under FCDLC
Project's own	Specific cost	€/kW		40	36.80	36.10	Achieved	Results of a cost engineering study @ 30 000 stacks/year



COBRA
Coatings for bipolar plates

Panel 2 - Research activities for transport applications

EG-04-17-700-EN-P

Acronym:	**COBRA**
Project ID:	621193
Title:	Coatings for bipolar plates
Call Topic:	SP1-JTI-FCH.2013.1.2
Project total costs (€):	€ 3,8 million
FCH JU maximum contribution (€):	€ 2,3 million
Project start/end:	01 Apr 2014 - 31 Dec 2017
Coordinator:	Commissariat à l'Energie Atomique et aux Energies Alternatives CEA, France
Beneficiaries: Borit, Impact Coatings, Symbiofcell, Fundacion Cidetec, Inst. National Des Sciences Appliquees De Lyon	
Website:	http://www.cobra-fuelcell.eu/

Project and objectives

With a consortium integrating know-how and expertise for bipolar plate manufacturing, COBRA aims at developing the industrialisation of new metallic bipolar plates coatings, demonstrating high corrosion resistance, low electrical resistance and low cost. The project organisation emphasises the importance of field tests both in system and in vehicle for real driving conditions, coupled with post-mortem and adapted tests procedures to understand ageing mechanisms in real conditions.

Major project achievements

- Reference plates have been manufactured and tested on field in automotive and marine conditions
- Up-scaling process for innovative coating has been studied and adapted to large bipolar plate
- New plates integrating the best coating solution developed in COBRA have been manufactured are currently being tested

Future steps

- Integration of two 5kW in PEMFC system at SymbioFC and in parallel in a Hy-Kangoo vehicle for field test
- Characterisation and post-mortem analysis on stacks aged in system and on test bench
- Finalisation of the cost analysis for the coating solutions developed in COBRA
- Open workshop organised at the end of the project to share the project results

Relevant to FCH JU overarching objectives

- Reduce the production cost of fuel cell systems to be used in transport applications, while increasing their lifetime to levels which can compete with conventional technologies
- Demonstrate on a large scale the feasibility of using hydrogen to support integration of renewable energy sources into the energy systems, including through its use as a competitive energy storage medium for electricity produced from renewable energy sources

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
MAIP 2008-2013	Durability	h	2,000	5,000	1,600	2,000	Due later	Obtained in 5 kW system for reference coatings. (target based on DOE & EU values)
AIP 2013	Corrosion, anode	µA/cm²	10	10	-0.1	-0.1	Achieved	Development of alternative & low cost coatings to replace gold
AIP 2013	Corrosion, cathode	µA/cm²	10	10	1.07	1.07	Achieved	Development of alternative & low cost coatings to replace gold
AIP 2013	Area specific resistance	mohm.cm²	25	25	11	11	Achieved	Development of alternative & low cost coatings to replace gold
AIP 2013	Cost	€/kW		2.5			Due later	In progress for the COBRA low cost coating plate technology - cost analysis for reference gold-coated plates done

COMPASS
Competitive Auxiliary Power Units for vehicles based on metal supported stack technology

Acronym:	**COMPASS**
Project ID:	700200
Title:	Competitive Auxiliary Power Units for vehicles based on metal supported stack technology
Call Topic:	FCH-01.5-2015
Project total costs (€):	€ 3,920,303
FCH JU maximum contribution (€):	€ 3,920,303
Project start/end:	01 Oct 2016 - 30 Sep 2019
Coordinator:	AVL List, Austria
Beneficiaries: Nissan Motor Manufacturing (Uk) Ltd, Plansee, Forschungszentrum Julich	
Website:	www.h2020-compass.eu

Project and objectives

This project is worldwide the first (publically known) approach to integrate SOFC based APUs (Auxiliary Power Units) into electrical powertrains. With this innovative approach, the attractiveness of Battery electric vehicles can be increased due to significant improvements in vehicle range and recharging times. Within the COMPASS project an advanced APU system will be developed, to convert chemical energy stored in a high energy density fuel tank (hydrocarbon, e.g. ethanol) into electricity, to recharge the vehicle HV battery for electrical driving.

Major project achievements

- The Design Verification and Validation Documentation has been generated and supports the design and evaluation of the APU & internal components
- Button cells using COMPASS technology SOFC materials show good performance and have scope for achieving high performance even when stacked
- AVL and Nissan have agreed on boundaries between the APU & Vehicle and have a common understanding with regard to responsibility & requirements

Future steps

- MSC Stack tests under relevant operating conditions
- Detailed design of the COMPASS SOFC REX System
- Vehicle preparation
- Safety, FMEA development and implementation

Non-quantitative objectives and status

- Vehicle Integration of SOFC Systems
  Very detailed specifications for the vehicle integration of SOFC systems have been elaborated
- MSC Stack Technology
  The system integration aspects of SOFC systems with innovative MSC stacks are understood and detailed system specifications have been defined
- Safety of SOFC Systems in vehicles
  All aspects of system safety issues for SOFC systems in vehicles are understood and measures will be implemented to meet all safety requirements

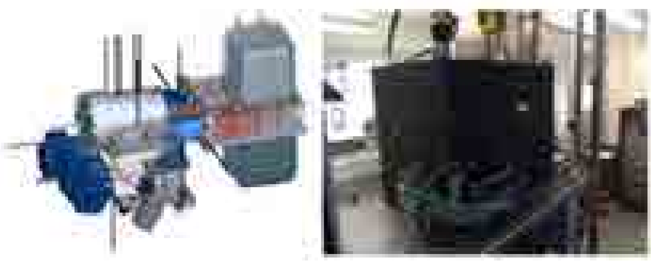
Relevant to FCH JU overarching objectives

- Reduce the production cost of fuel cell systems to be used in transport applications, while increasing their lifetime to levels which can compete with conventional technologies
- Increase the electrical efficiency and the durability of the different fuel cells used for power production to levels which can compete with conventional technologies, while reducing costs
- Reduce the use of the EU defined 'Critical raw materials', for instance through low-platinum or platinum-free resources and through recycling or reducing or avoiding the use of rare earth elements

EG-04-17-700-EN-P

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
80	1. APU system power	kW	3.00	5.00	0.00	5.00	Due later	This is a target Net power - what the vehicle expects to be avalible for charging the battery and running some electrical components on board the vehi
Select	2. Stack power	kW	0.00	6	0.00	6.00	Due later	This is the target Gross power target that the stack should supply. 1kW can be used for the BOP.
Select	3. APU Weight	kg		100.00	N/A	100.00	Due later	This is a target for the total weight of the APU system
Select	4. APU Volume	m^3		0.12	0.12	0.12	Due later	This is a target for the total volume of the APU system
Select	5. APU system durability	h	1000.00	5000.00	0.00	5000.00	Due later	This is a target for the number of operating hours that the system should be able to operate for.
Select	6. Start up time	Min	60.00	15.00	0.00	0.15	Due later	This is the time from when the start up is initiated to when full power can be supplied by the APU to the vehicle
Select	7. APU Noise	dBA	60.00	50.00	0.00	50.00	Due later	This is a target for the level of noise that the APU system can generate
Select	8. Tank-to-electricity efficiency	%	35.00	50.00	0.00	50.00	Due later	This is the target for the net electrical efficiency of on board power egeneration, which is actually supplied to the vehicle.
Select	10. Est. APU CAPEX @ mass production	€/kW	10000.00	500.00	0.00	500.00	Due later	This is the target for the capital expenditure required for the 5 kW APU system.



COPERNIC
Cost & performances improvement for CGH_2 composite tanks

Panel 2 - Research activities for transport applications

Acronym:	**COPERNIC**
Project ID:	325330
Title:	Cost & performances improvement for CGH_2 composite tanks
Call Topic:	SP1-JTI-FCH.2012.1.3
Project total costs (€):	€ 3,5 million
FCH JU maximum contribution (€):	€ 2,0 million
Project start/end:	01 Jun 2013 - 30 Nov 2016
Coordinator:	Commissariat à l'Energie Atomique et aux Energies Alternatives CEA, France
Beneficiaries: Anleg, Hochdruck Reduziertechnik, Politech. Wroclawska, Raigi, Symbiofcell, H2 Logic, Optimum Cpv	
Website:	http://www.project-copernic.com/

Project and objectives

The objectives of the COPERNIC were to improve the Compressed Gaseous Hydrogen (CGH_2) storage system cost and to increase its performances. All expected targets have been reached. For the cost reduction, the target (600 €/H_2 kg) is achieved. The gravimetric capacity reaches 4.99 % and the volumetric capacity reaches 0.0221kg/L. Productivity improvement from 120 to 70 minutes winding time is achieved. An optimised on-tank valve with pressure regulation has been successfully developed (Anleg) and passed the certification process.

Major project achievements

- Cost reduction: the target (600 €/H_2 kg) is achieved
- The improvement of performances for Copernic system are effective. The gravimetric capacity reaches 4.99 % and volumetric capacity 0.0221kg/L
- Significant breakthroughs are implemented in the Anleg on-tank valve with pressure regulation

Future steps

- Project finished

Non-quantitative objectives and status

- Develop and asses non-destructive examination method for SHM of vessel
- SHM allows identification of abnormal behaviour B4 leak, upgrade of the SAE J2601 protocol to improve safety

Relevant to FCH JU overarching objectives

- Reduce the production cost of fuel cell systems to be used in transport applications, while increasing their lifetime to levels which can compete with conventional technologies

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
MAIP 2008-2013	Design / test criteria for CGH_2 storage system	€/kg H_2	1841	600	608	608	Achieved	Reduce costs with > Composite optimisation (-13%) > vessel volume (37 to 61L: -27%) > production scale up to 8,000 unit (-30%)
MAIP 2008-2013	Gravimetric and	%	3.57	5	4.99	4.99	Achieved	Performance in real test conditions
MAIP 2008-2013	Volumetric capacity	Kg/L		0.0222	0.0221	0.0222	Achieved	Performance in real test conditions
AIP 2013	Improved pressure component	kg	6	2	1.2	1.2	Achieved	Weight reduction: 6 to 1.2 kg, Reduction of Nr of parts: 146 to 96 Power consumption < 10 W
AIP 2013	Development activities on materials	€	166	165	27	27	Achieved	Alternative materials (liner, metallic boss, matrix) selected & characterised to lower costs (no low cost carbon fibre)
AIP 2013	Lower cost production process	minutes	120	80	70	70	Achieved	With robot solution, enhanced material & Composicad development; mean winding speed achieved: 40 m/min

Giantleap

Giantleap Improves Automation of Non-polluting Transportation with Lifetime Extension of Automotive PEM fuel cells

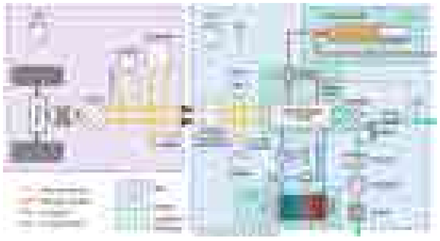
Acronym:	**Giantleap**
Project ID:	700101
Title:	Giantleap Improves Automation of Non-polluting Transportation with Lifetime Extension of Automotive PEM fuel cells
Call Topic:	FCH-01.2-2015
Project total costs (€):	€ 3,3 million
FCH JU maximum contribution (€):	€ 3,3 million
Project start/end:	01 May 2016 - 30 Apr 2019
Coordinator:	Stiftelsen Sintef, Norway
Beneficiaries: Inst. Francais Sciences et Technol. des Transports, de l'Amenagement et des Réseaux, Bosch Engineering, Uni. Franche-Comte, VDL Enabling Transport Solutions, VDL Bus Chassis, VDL Bus Roeselare, VDL Bus & Coach, Elringklinger, Ecole Nationale Superieure de Mécanique et des Microtechniques, Sveuciliste U Splitu, Fakultet Elektrotehnike, Strojarstva I Brodogradnje	
Website:	www.giantleap.eu

Project and objectives

The project deals with developing diagnostic and prognostic control systems for fuel cells and their ancillaries in buses to maximise their lifetime and reliability.

The project investigates degradation mechanisms of fuel cells, pressure reduction valves, humidifiers and compressors, in view of predicting their lifetime and controlling them to minimise total cost of ownership (TCO).

The chosen bus configuration is a battery city bus with a fuel-cell range extender that can be connected and disconnected directly by the operators, increasing flexibility and reliability.



Major project achievements

- Definition of a system architecture for the control, prognostic and diagnostic system
- Definition of interfaces between FC stack module, ancillary system and range extender
- Design of fuel-cell system w/ ancillaries

Future steps

- Realisation of the range extender and installation of the FC system
- Programming and implementation of control, prognostic and diagnostic algorithms
- Laboratory and (if possible) road tests of the bus, laboratory tests of fuel cells
- Analysis of test data

Quantitative targets and status

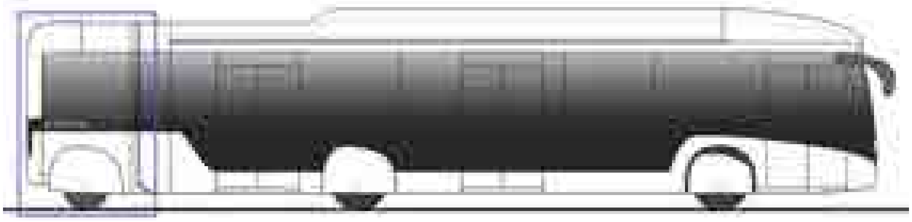
Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
AIP 2015	TRL	-	3	6	3	7	Due later	First control system incarnation in October 2017
AIP 2015	FC system cost	€/kW	4,500	500	4,500	500	Due later	First FC system blueprint completed
AIP 2015	FC system lifetime in buses	h	12,000	24,000		24,000	Due later	Testing in the last part of the project
MAWP 2014-2020	Availability	%	70	98		98	Due later	Testing in the last part of the project
MAWP 2014-2020	Fuel consumption	kg/100 km	9	8		8	Due later	Testing in the last part of the project
MAWP 2014-2020	FC bus cost	k€	1,250	650		650	Due later	Prototypes realisation & economic evaluation in the last part of the project

Non-quantitative objectives and status

- Type approval of range extenders for buses
- Range extenders and buses are difficult to type-approve since no similar bus in such a configuration has been marketed before.
- Blur difference between FC and battery buses
  With range extenders, any battery bus can be promptly converted to a long-range hydrogen bus.
- Development of standards for range extenders
  Inter-operability standards will enable competition between different bus and range-extender manufacturers
- Supporting market readiness of FC buses by 2020
  Lower TCO will help making FC buses market-ready by 2020

Relevant to FCH JU overarching objectives

- Reduce the production cost of fuel cell systems to be used in transport applications, while increasing their lifetime to levels which can compete with conventional technologies
- Increase the electrical efficiency and the durability of the different fuel cells used for power production to levels which can compete with conventional technologies, while reducing costs



H2REF
Development of a cost effective and reliable hydrogen fuel cell vehicle refuelling system

Panel 2 - Research activities for transport applications

Acronym:	**H2REF**
Project ID:	671463
Title:	Development of a cost effective and reliable hydrogen fuel cell vehicle refuelling system
Call Topic:	FCH-01.5-2014
Project total costs (€):	€ 6,5 million
FCH JU maximum contribution (€):	€ 6,0 million
Project start/end:	01 Sep 2015 - 31 Aug 2018
Coordinator:	Centre Technique des Industries Mecaniques, France

Beneficiaries:
Hexagon Raufoss, Ludwig-Boelkow-Systemtechnik, Uni. Technol. Compiegne, Haskel Europe Ltd, Haskel France, H2Nova, The CCS Global Group Ltd

Project and objectives

H2Ref addresses the compression and buffering for refuelling of 70 MPa vehicles and targets a novel cost effective, performant and reliable hydraulics-based system, from TRL 3 to 6. The new way to compress H_2 in a refuelling station is designed and a prototype compression and buffering module (CBM) is under construction. The new hydraulically-actuated compression will be tested first. Then, the full CBM including the N° of compression devices needed for the full compression and dispensing cycle will be tested in closed circuit. Later, it will be interfaced with a vehicles dispenser for demo.

Major project achievements

- High pressure bladder accumulator design for hydrogen
- Detail Design of Accumulator Test Bench and CBM prototype (full scale system): construction in progress

Future steps

- Deformation testing of accumulator critical bladder
- Finalisation of construction of Accumulator Test Bench
- Delivery of MP and HP accumulators
- Functional testing in hydrogen of bladder accumulators

Non-quantitative objectives and status

- Techno-economic analysis based on testing results
  Not initiated (testing not begun)
- Have the technology covered by the RCS (Regulations, Codes and Standards) framework
  Contact established with CEN/TC 54. Positive test results needed to begin work on standards

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
Project's own	TRL	TRL	3	6	3	6	Due later	Through extensive component & system testing
Project's own	CBM manufacturing cost @ 50 units/year	K€	750	300		300	Due later	Through novel implementation of mature technologies (hydraulics and composite pressure vessels)
Project's own	Throughput from 7 MPa @ pumping power of 75 kW	kg/d	210	720		720	Due later	30 kg/h, 24h/day
Project's own	Energy consumption	kWh/kg	3	1.5		1.5	Due later	Through conservation of source storage pressure

IMPACT
Improved lifetime of automotive application fuel cells with ultra low Pt-loading

Panel 2 - Research activities for transport applications

Acronym:	**IMPACT**
Project ID:	303452
Title:	Improved lifetime of automotive application fuel cells with ultra low Pt-loading
Call Topic:	SP1-JTI-FCH.2011.1.5 &SP1-JTI-FCH.2011.1.6
Project total costs (€):	€ 9,2 million
FCH JU maximum contribution (€):	€ 3,9 million
Project start/end:	01 Nov 2012 - 31 Oct 2016
Coordinator:	DLR, Deutsches Zentrum fuer Luft und Raumfahrt, Germany

Beneficiaries:
Commissariat à l'Energie Atomique et aux Energies Alternatives CEA, Consiglio Nazionale delle Ricerche CNR, Gwangju Inst. Science And Technology, Hochschule Esslingen, Inst. National Polytech. Toulouse, ITM Power (Trading), Solvay Specialty Polymers Italy, Tech. Uni. Berlin, Johnson Matthey Fuel Cells Ltd, JRC -Joint Research Centre, European Commission, Zentrum fuer Sonnenenergie und Wasserstoff-Forschung, Baden-Wuertemberg

Website: http://www.eu-project-impact.eu/

Project and objectives

Main project objectives are: to increase the lifetime of ultra–low Pt-loaded (< 0.2 mg/cm2) membrane-electrode assemblies (MEAs) for automotive applications to 5,000 h in dynamic operation with degradation rates <10 µVh-1 and to obtain a power density of 1 A/cm2 (performance target achieved). To achieve these targets relevant degradation mechanisms are identified and mitigation strategies are implemented though material development, structural design of cells and materials, and integration of improvements into a best MEA. The project ended in October 2016.

Major project achievements

- Demonstration of 1 W/cm2 at 0.2 mg/cm2 Pt total loading using H_2/air at 50% RH and 1.5 bar absolute pressure
- Development of new thin membranes, stable ionomers, and electrodes for low loaded MEAs
- Detailed ex-situ and in-situ analysis of the developed materials allowing a better understanding of degradation mechanism

Future steps

- Project finished

Non-quantitative objectives and status

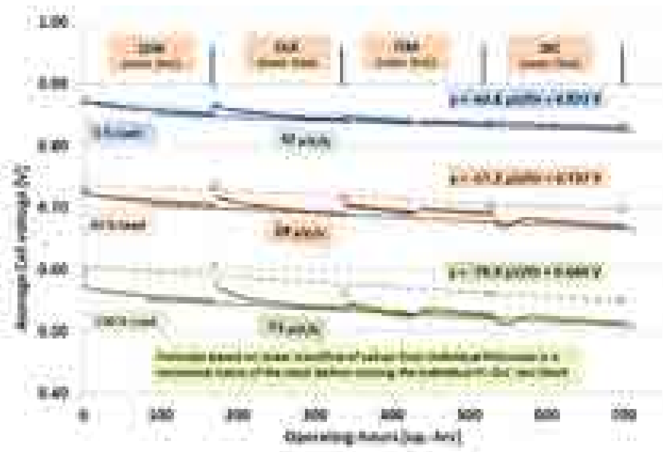
- Irreversible and reversible degradation mechanism categorisation. Detailed study on reversible and irreversible degradation rates and performance recovery procedures has been performed. The results are published

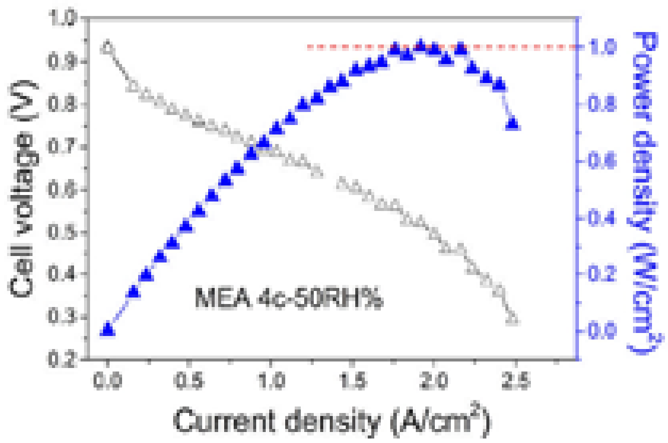
Relevant to FCH JU overarching objectives

- Reduce the production cost of fuel cell systems to be used in transport applications, while increasing their lifetime to levels which can compete with conventional technologies
- Increase the electrical efficiency and the durability of the different fuel cells used for power production to levels which can compete with conventional technologies, while reducing costs

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
MAIP 2008-2013	Stack durability	h	2,500	5,000	1,700	1,700	Not achieved	Test ended due to MEA degradation
AIP 2011	Pt loading	mg/cm2	0.6	0.2	0.2	0.2	Achieved	Performance target achieved at target loading but not durability
AIP 2011	Power density	W/cm2	0.6	1.0	1.0	1.0	Achieved	In a single cell test at 0.2 mg/cm2 total Pt loading.





INSPIRE
Integration of Novel Stack Components for Performance, Improved Durability and Lower Cost

Panel 2 - Research activities for transport applications

EG-04-17-700-EN-P

Acronym:	**INSPIRE**
Project ID:	700127
Title:	Integration of Novel Stack Components for Performance, Improved Durability and Lower Cost
Call Topic:	FCH-01.1-2015
Project total costs (€):	€ 6,9 million
FCH JU maximum contribution (€):	€ 6,9 million
Project start/end:	01 May 2016 - 30 Apr 2019
Coordinator:	Johnson Matthey, United Kingdom
Beneficiaries: VTT, Uni. Montpellier, Sgl Carbon, Albert-Ludwigs-Uni. Freiburg, Reinz-Dichtungs, Tech. Uni. Muenchen, Tech. Uni. Berlin, Johnson Matthey Fuel Cells Ltd, Pretexo, Bayerische Motoren Werke, Centre National de la Recherche Scientifique CNRS	
Website:	www.inspire-fuelcell.eu

Project and objectives

INSPIRE is an industry-led project bringing together the most advanced critical polymer electrolyte membrane fuel cell (PEMFC) stack components capable of delivering on the most challenging performance, durability and cost targets within the next generation of automotive stacks. New catalyst alloys have now met the mass activity and durability targets and will be integrated in membrane-electrode assemblies (MEAs) going forward while new gas diffusion layer (GDL) and catalyst-coated membrane (CCM) optimisation has enabled the project to achieve the 12-month performance target in screener cells. The first generation stack design has also now been designed and is earmarked to be operational by the project mid-term.

Major project achievements

- Interim target of 1.2W/cm2 power density @ 0.6V met by new MEA designed optimised for project conditions
- New alloy catalyst has achieved the stability and power density targets at high current density
- New BPP design is meeting the project specification and is being scaled up for manufacture

Future steps

- Full stack testing for GEN 1.5
- Deliver scaled up catalyst for GEN 2.0
- Delivery of thin low EW membrane for GEN 2.0
- Delivery of GEN 2.0 GDL

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
AIP 2015	Power density @ 0.6V	W/cm2	0.87	1.5	1.2	1.5	Due later	Demonstrated in screener (new GDL and MEA optimisation); to be confirmed in stack
MAWP 2014-2020	Performance loss over 6,000 hours	%		10		10	Due later	Not yet assessed
Project's own	Mass activity (MA)	A/mg	0.24	0.6	0.42	0.6	Due later	Interim target of 0.44A/mg not yet met but very close
MAWP 2014-2020	Pt loading	mg/cm2	0.45	0.125	0.30	0.12	Due later	Interim target of 0.25mg/cm2 not chosen to maximise cost/ performance benefit
MAWP 2014-2020	Cost @ 50,000 units/ year	€/kW		50		50	Due later	Not yet assessed

Non-quantitative objectives and status

- Scale-up best performing catalyst for stack MEAs
  One alloy catalyst has passed through the performance and durability stage gate and is being scaled up for MEA optimisation and testing
- Develop two new generations of bipolar plates (BPP) for automotive stacks
  First generation BPP to be implemented in GEN1.5 and GEN 2.0 stack now designed and undergoing manufacture. Stack testing now due in September 2017
- Quantify and model the changes in catalyst structure
  Model platform agreed and initial visualisation completed
- Dissemination of project results
  2 oral presentations and 4 posters already completed, as well as setting up a public website for the project, plus announcements on partner websites

Relevant to FCH JU overarching objectives

- Reduce the production cost of fuel cell systems to be used in transport applications, while increasing their lifetime to levels which can compete with conventional technologies
- Reduce the use of the EU defined 'Critical raw materials', for instance through low-platinum or platinum-free resources and through recycling or reducing or avoiding the use of rare earth elements

NANO-CAT
Development of advanced catalysts for PEMFC automotive applications

Panel 2 - Research activities for transport applications

Acronym:	**NANO-CAT**
Project ID:	325239
Title:	Development of advanced catalysts for PEMFC automotive applications
Call Topic:	SP1-JTI-FCH.2012.1.5
Project total costs (€):	€ 4,4 million
FCH JU maximum contribution (€):	€ 2,4 million
Project start/end:	01 May 2013 - 31 Jan 2017
Coordinator:	Commissariat à l'Energie Atomique et aux Energies Alternatives CEA, France
Beneficiaries: Ass. pour la Recherche et le Developpement des Methodes et Processus Industriels - Armines, C-Tech Innovation Ltd, DLR, Deutsches Zentrum fuer Luft und Raumfahrt, Nanocyl, Volvo Technology, Fundacion Tecnalia Research & Innovation, JRC -Joint Research Centre, European Commission, Centre National de la Recherche Scientifique CNRS, Basic Membranes	
Website:	http://nanocat-project.eu/

Project and objectives

The objectives of Nano-CAT were the synthesis on new catalyst concept to reduce the loading of platinum in polymer electrolyte membrane fuel cells (PEMFC) and increase durability. The consortium synthesised innovative support (high resistance carbon nanotubes and metal oxide aerogel) and did there functionalisation with platinum nanoparticles. Those new catalysts showed good performances and durability against commercial reference (Pt/C). Finally, those materials were integrated in full 25 cm2 membrane-electrode assembly (MEA) and advantages in some specific accelerated stressed tests.

Major project achievements

- Low-loaded MEA (0.25 mgPt/cm2 total) have been produced and gave 750 mW/cm2.
- 1 W/cm2 in single cell has been achieved under 1.5 bara 50%RH and 80 °C.
- Functionalisation of highly purified carbon nanotubes with homogeneous repartition of Pt nanoparticles (4 nm) and 40 % weight

Future steps

- Project finished, nevertheless, the tests in stack continue in CEA premise

Non-quantitative objectives and status

- Development and validation of testing procedures
  Participation of networking group on the harmonisation of testing procedure in single cell
- Development of catalyst deposition techniques
  Different techniques have been compared : electrodeposition, PVD, polyol, micelle in different solvents and reactants (green chemistry)

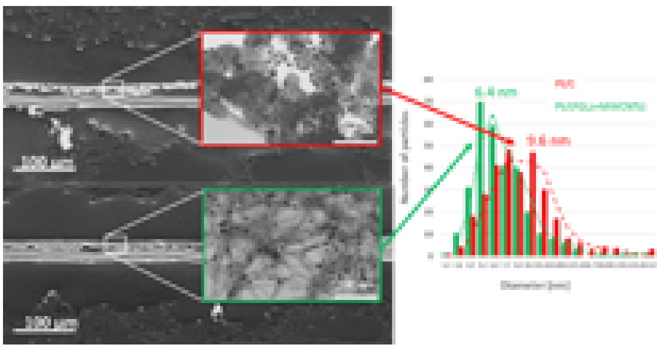
Relevant to FCH JU overarching objectives

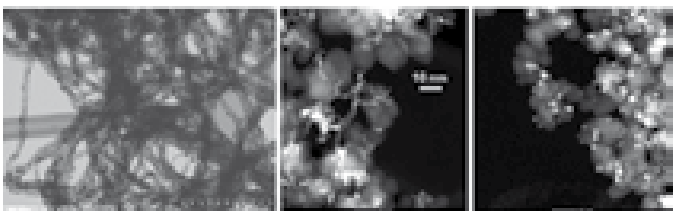
- Reduce the use of the EU defined 'Critical raw materials', for instance through low-platinum or platinum-free resources and through recycling or reducing or avoiding the use of rare earth elements

EG-04-17-700-EN-P

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
AIP 2012	MEA power density	mW/cm2	750	1000	1000	1000	Achieved	@ 2 A/cm2, achieved with 0.5 mg Pt/cm2 total
Project's own	Degradation, loss of performance	%	11	10	10	10	Achieved	For operation @ Imax (1.4 A/cm2) in ageing test
Project's own	Catalyst stability-residual electrochemical surface area (ECSA)	%	70	70	100	100	Achieved	Better degradation performance vs commercial Pt/C in RDE measurement (nanoparticles diameter 4 nm)
Project's own	Conductivity of metal oxyde aerogel	S/cm	0	0.40	0.98	0.95	Achieved	SnO2:Sb 5% aerogel (90 m2/g) has a conductivity of 0.95 S/cm
Project's own	Power density	mW/cm2	/	100	10	10	Delayed	Bioinspired catalyst for ORR performance in half cell
Project's own	Current density	mA/cm2	/	100	35	35	Delayed	Bioinspired catalyst for HOR performance in half cell
Project's own	Pt loading	g/kW	/	0.1	0.3	0.3	Delayed	MEA with 0.25 mg Pt/cm2 total give 0.3 g/kW @ P max





FUEL CELLS AND HYDROGEN
JOINT UNDERTAKING

SMARTCAT

Systematic, material-oriented approach using rational design to develop break-through catalysts for commercial automotive PEMFC stacks

Panel 2 - Research activities for transport applications

Acronym:	SMARTCAT
Project ID:	325327
Title:	Systematic, material-oriented approach using rational design to develop break-through catalysts for commercial automotive PEMFC stacks
Call Topic:	SP1-JTI-FCH.2012.1.5
Project total costs (€):	€ 4,8 million
FCH JU maximum contribution (€):	€ 2,4 million
Project start/end:	01 Jun 2013 - 31 May 2017
Coordinator:	Centre National de la Recherche Scientifique CNRS, France
Beneficiaries: Basic Membranes, Danmarks Tek. Uni., Mxpolymers, Commissariat à l'Energie Atomique et aux Energies Alternatives CEA, Stiftelsen Sintef	
Website:	http://smartcat.cnrs.fr/

Project and objectives

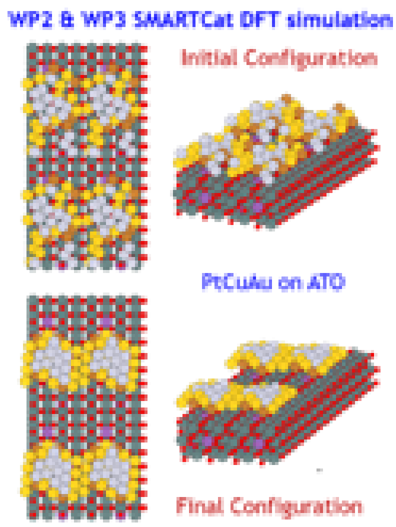
The consortium aimed to build a new concept of electrodes based on new catalyst design (ternary alloys/core shell clusters) deposited on a new high temperature operation efficient support. In order to enhance the fundamental understanding and determine the optimal composition and geometry of the clusters, advanced computational techniques were used in direct combination with electrochemical analysis of the prepared catalysts. SMARTCat will thus enable to automate the MEA production and build efficient short-stack required for competitive automotive fuel cell operation.

Major project achievements

- Development of ternary catalysts and supports with either higher activity or higher stability than Pt/C catalyst
- Stack 10 cells 220cm2 active area loaded with 0.18 mg.cm-2 Pt3NiAu 5Wcm-2 / 1.1 kW = performance of same stack loaded with 0.42 mg.cm-2 pure Pt
- Achievement of automated 70 MEA/day with membrane size = electrode size + 5%

Future steps

- Project finished



Quantitative targets and status

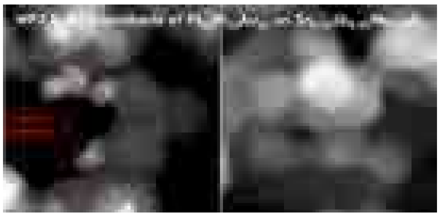
Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
AIP 2012	Catalyst loading	mg/cm2	1.4	0.01	0.05	0.05	Achieved	Low loading with significant mass activity.
Project's own	Exchange current density for 0.1mg/cm2 catalyst loading	mA/cm2	0.00025	0.001	0.001	0.001	Achieved	Best value for ternary catalyst Pt3NiAu
Project's own	Kinetic current density @0.9V for 0.1 mg/cm2 catalyst loading	mA/cm2	5.3	12.3	12.3	12.3	Achieved	Best value for ternary catalyst Pt3NiAu
Project's own	Mass activity @ 0.9 V for 0.1 mg/cm2 catalyst loading	A/g	54		176	176	Achieved	Best value for ternary catalyst Pt3NiAu
Project's own	Catalyst support conductivity	S/cm	0.01	0.1	1.45	1.45	Achieved	Through cation doping strategy + modelling the conductivity and stability of the SnO2 support is tailored by addition of Sb and Nb.
Project's own	Catalyst support surface area	m2/g	38	50	100	100	Achieved	High surface area supports (>100 m2/g) are obtained by flame spray pyrolysis. Some reduction in surface area by heat treatment
Project's own	Catalyst support pore size distribution	nm	N/A	50	50	50	Achieved	Pore size distribution in the range of 20 - 150 nm targeted. Bimodal distribution achieved by flame spray pyrolysis.
Project's own	MEA production rate	MEA/day	0	60	60	70	Achieved	Using SoA supports and membranes.
AIP 2012	Short stack power density	g kW-1	0.1	0.1	0.15	0.15	Select	For Pt3NiAu 0.18 mg/cm2 catalyst loaded 220 cm2 electrodes

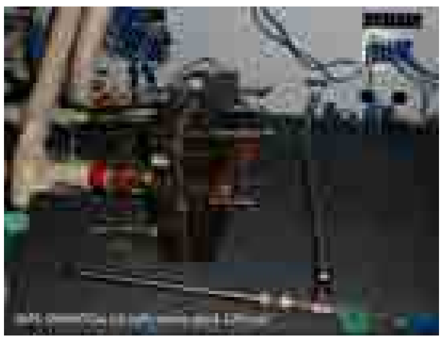
Non-quantitative objectives and status

- Stability of ternary PtMeAu/C catalysts upon potential cycling Pt3NiAu/C displays higher initial activity, whereas Pt3CuAu/C displays higher final activity
- Atomic arrangement of ternary catalysts using Molecular Dynamics MD simulations are carried out and provide atomic arrangement in line with DFT simulations and electrochemical analysis for PtMeAu (Me = Ni, Cu, Pd)
- PhD candidate training
  S. Lankiang graduated (PhD) in September 2016

Relevant to FCH JU overarching objectives

- Reduce the use of the EU defined 'Critical raw materials', for instance through low-platinum or platinum-free resources and through recycling or reducing or avoiding the use of rare earth elements





VOLUMETRIQ
Volume Manufacturing of PEM FC Stacks for Transportation and In-line Quality Assurance

Panel 2 - Research activities for transport applications

EG-04-17-700-EN-P

Acronym:	**VOLUMETRIQ**
Project ID:	671465
Title:	Volume Manufacturing of PEM FC Stacks for Transportation and In-line Quality Assurance
Call Topic:	FCH-01.2-2014
Project total costs (€):	€ 5,0 million
FCH JU maximum contribution (€):	€ 4,9 million
Project start/end:	01 Sep 2015 - 28 Feb 2019
Coordinator:	Centre National de la Recherche Scientifique CNRS, France

Beneficiaries:
Uni. Montpellier, Solvay Specialty Polymers Italy, Johnson Matthey, Intelligent Energy Ltd, Elringklinger, Johnson Matthey Fuel Cells Ltd, Pretexo, Bayerische Motoren Werke

Website: http://www.volumetriq.eu/

Project and objectives

VOLUMETRIQ is developing a EU-centric supply base for PEM fuel cell stacks and their key components with volume manufacturing capability and embedded quality control. Project electrospun membrane reinforcements have been scaled up and have passed the first level of validation for their integration into the membrane casting line. Catalyst-coated membranes (CCMs) using project ionomers deliver the 24 month target current density in project hardware under target test conditions. CCM cutting and handling processes for high volume production have been identified and are compatible with the automatic stack assembly line.

Major project achievements

- Interim power density target of 1.2 W/cm2 at 0.6 V is met using project CCMs and membranes optimised for project conditions and project cell hardware
- Electrospun reinforcement scaled-up to 20 linear m rolls. Proven possible to handle the reinforcement on high volume membrane manufacturing line.
- Successful feasibility testing of feeding JMFC-produced fully converted CCM rolls into EK automatic stack assembly line

Future steps

- Integrate scaled-up electrospun reinforcement in membrane casting line and qualify the membranes produced
- Down-select final membrane construction and catalyst layer ionomer for final CCMs
- Produce CCMs for short stack using optimised ionomers in membranes and catalyst layers
- Finalise definition of production process, quality methodology, bipolar plate production and stack assembling processes
- Manufacture and validate optimised bipolar plate

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
MAWP 2014-2020	Power density @ 0.6 V in single cell	W/cm2		1.50	1.23	1.50	Due later	Interim target of 1.2 W/cm2 at 0.6 V met through ionomer, CCM and GDL optimisation
Project's own	Power density @ 0.6 V in short stack	W/cm2		1.50		1.50	Due later	Not yet assessed
AIP 2014	Cost @ 50,000 units/ year	€/kW		100		100	Due later	Not yet assessed Expected through increased power density, reduced reject rates, supply chain manufacturing process development to TRL7
AIP 2014	Durability	h		5,000		5,000	Due later	Not yet assessed
AIP 2014	Stack TRL	None	5.00	7		7	Due later	Not yet assessed
AIP 2014	Scrap rate	%		5		5	Due later	Not yet assessed

Non-quantitative objectives and status

- Scale-up electrospun PBI reinforcements
  20 linear metres produced, roll-good, with successful manufacturing assessment for feed of the reinforcement into the coating line
- Develop ionomers with tuned properties for membrane and catalyst layer
  Optimisation and testing led to down-selection of Aquivion EW 750 g/mol for membranes. High oxygen permeability (CL) ionomers under development
- Selection of GDL
  The GDL type turned out to be a critical factor in successfully achieving the 24M power density target with project CCMs and project hardware
- Dissemination of project results
  The project has disseminated results through its website, brochure, newsletter, at 6 conferences and at 3 trade fairs

Relevant to FCH JU overarching objectives

- Reduce the production cost of fuel cell systems to be used in transport applications, while increasing their lifetime to levels which can compete with conventional technologies
- Reduce the use of the EU defined 'Critical raw materials', for instance through low-platinum or platinum-free resources and through recycling or reducing or avoiding the use of rare earth elements

PANEL 3
TECHNOLOGY VALIDATION IN STATIONARY APPLICATIONS

ALKAMMONIA
Ammonia-fuelled alkaline fuel cells for remote power applications

Acronym:	**ALKAMMONIA**
Project ID:	325343
Title:	Ammonia-fuelled alkaline fuel cells for remote power applications
Call Topic:	SP1-JTI-FCH.2012.3.5
Project total costs (€):	€ 2,9 million
FCH JU maximum contribution (€):	€ 2,0 million
Project start/end:	01 May 2013 - 30 Apr 2017
Coordinator:	AFC Energy, United Kingdom
Beneficiaries: Acta, Fast - Federazione delle Associazioni Scientifiche e Tecniche, Uni. Duisburg-Essen, UPS Systems, Zentrum Fur Brennstoffzellen-Technik, Paul Scherrer Inst.	
Website:	http://alkammonia.eu/

Project and objectives

Project ALKAMMONIA focused on the design, manufacture and testing of a prototype integrated small-scale power system designed for remote applications. The prototype integrates two main components: a fuel delivery system that passes ammonia through a cracker to produce hydrogen and an alkaline fuel cell system which utilises the hydrogen produced. A control system for the fuel cell component should be extended to manage the whole integrated system. The main development are underpinned by computational modelling and a programme of project controls running throughout the project duration.

Major project achievements

- 11.4 kWe in a 101-cell stack achieved (original target 10 kWe). Partly populated stacks in 2.5 kW range also successfully tested.
- NH3 cracker designed, built and being validated in ZBT laboratories.
- A high-level integrated system design has been produced

Future steps

- NH3 cracker HAZOP close out and validation of performance in ZBT laboratory
- BoP and cracker installation, integration and commissioning
- Operation of the integrated system for minimum 1,000 h
- Sustainability & Total System Cost Analysis plus LCA to be produced
- Dissemination and communication of project results

Non-quantitative objectives and status

- Achieve CE certification
  CE certification requirement may be reviewed, based on scenario of ownership and operation responsibility for future commercial applications
- Assessment of system impact
  Life Cycle Analysis (LCA) and Sustainability & Total System Cost Analysis pending

Relevant to FCH JU overarching objectives

- Increase the electrical efficiency and the durability of the different fuel cells used for power production to levels which can compete with conventional technologies, while reducing costs
- Reduce the use of the EU defined 'Critical raw materials', for instance through low-platinum or platinum-free resources and through recycling or reducing or avoiding the use of rare earth elements.

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
Project's own	Cracker durability	h	500	2,000			Not achieved	Validation required
Project's own	Cracker efficiency (LHV)	% (< & >)	80	80	90	90	Not achieved	Validation required
Project's own	Projected cracker costs	€	2,000	1,000	2,000		Not achieved	Pending
Project's own	Efficiency	%	50	50	55	60	Achieved	Stack operating voltage 700-800mV average cell voltage. Based on LHV of H_2 and taking the midpoint this achieves 60%LHV efficiency.
Project's own	Stack weight	kg	200	150	120	120	Achieved	Achieved using 2.5kW stack
Project's own	Stack durability	h	1,400	3,000	1,400		Not achieved	Routine testing up to 1000 h +forecasting thereafter. Coupon testing degradation rate <30 μV/h. Needs validating when cracker arrives
Project's own	Leakage losses	%	10	1			Not addressed	Subject to future design review (outside of project timeline, but future focus of company).
Project's own	High AFC BoP efficency	% (< & >)	80	90	80		Not achieved	
Project's own	Decrease BoP system costs	€	6,000	3,000	6,000		Not achieved	
select	Decrease start-up time	min(> & <)	30.00	10	30.00		Not achieved	

AutoRE
AUTomotive deRivative Energy system

Panel 3 — Technology validation in stationary applications

EG-04-17-700-EN-P

Acronym:	**AutoRE**
Project ID:	671396
Title:	AUTomotive deRivative Energy system
Call Topic:	FCH-02.5-2014
Project total costs (€):	€ 4,5 million
FCH JU maximum contribution (€):	€ 3,5 million
Project start/end:	01 Aug 2015 - 31 Jul 2018
Coordinator:	Alstom Power Ltd, United Kingdom
Beneficiaries: Nucellsys, General Electric (Switzerland), Uni. Tuscia, ELVIO Anonymi Etaireia Systimaton Paragogis Ydrogonou Kai Energeias, Sveuciliste U Splitu, Daimler, Stiftelsen Sintef	
Website:	http://www.autore-fch.com/

Project and objectives

The main objective is to create the foundations to commercialise an automotive derivative fuel cell system in the 50-100 kWe range for CHP in commercial and industrial buildings. The project is in its second year and is progressing largely to schedule. The fuel cell CHP prototype site has been prepared and the automotive derivative PEM fuel cell installed. Lab-scale testing of component enhancements to the prototype system, to reduce its cost of electricity/foot-print and increase its performance are underway. Extensive modelling of the CHP system has been carried out.

Major project achievements

- The prototype CHP site has been prepared and the fuel cell system installed, with the H_2 production system undergoing final factory acceptance tests
- Testing of selective H_2 separation membranes is underway. Relative to the baseline, cooling/dehydration of reformed natural gas feed is not required
- Modelling of the system shows that reformer thermal integration improves performance and that selective membranes should be in integrated with WGS

Future steps

- Factory acceptance test of completed H_2 production system prior to delivery to prototype test site
- Complete prototype system build and undertake 3000h duration test programme
- Complete system modelling activities including RAMS, durability and performance modelling
- Complete lab-scale testing of selective hydrogen separation membrane and compact heat exchangers
- Prepare business case for commercial system and disseminate project findings to key stakeholders

Non-quantitative objectives and status

- Support development of codes and standards for new technologies Learnings from site application to build prototype system in the UK to be made available as 'public' deliverable
- Contribute to decarbonisation of building and power generation sector Successful commercial exploitation of mid-sized auto-derivative fuel-cell based CHP systems will contribute to CO_2 reduction targets in the EU

Relevant to FCH JU overarching objectives

- Increase the electrical efficiency and the durability of the different fuel cells used for power production to levels which can compete with conventional technologies, while reducing costs

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
MAWP 2014-2020	CAPEX	€/kW	10,000	3,000		3,000	Due later	Target for grid parity on LCOE (for the 50kWe sized CHP system @ mass production)
MAWP 2014-2020	Durability	years	2	2		2	Due later	>2y life expected based on 30kh stack life; Leverage results from other EU projects (eg Giantleap/Sapphire/ Healthcode)
MAWP 2014-2020	Availability (plant)	%	97	97		9797.00	Due later	
MAWP 2014-2020	Electrical Efficiency	% LHV	40	40		40	Due later	Target for 50kWe prototype. 45-47% to be demonstrated with improved components through modelling.
MAWP 2014-2020	Thermal Efficiency	% LHV	40	45		45	Due later	Show 90% combined electrical + thermal efficiency is possible
MAWP 2014-2020	LCOE	€cent/kWh	60	20		20	Due later	i.e. move from 3*grid parity to 1*grid
	Emissions	mg/kWh	40	40		40	Due later	Low emission through low temperature catalytic combustor approach in H_2 production system

CLEARGEN DEMO
The Integration and demonstration of Large Stationary Fuel Cell Systems for Distributed Generation

Panel 3 — Technology validation in stationary applications

Acronym:	**CLEARGEN DEMO**
Project ID:	303458
Title:	The Integration and demonstration of Large Stationary Fuel Cell Systems for Distributed Generation
Call Topic:	SP1-JTI-FCH.2011.3.6
Project total costs (€):	€ 8,6 million
FCH JU maximum contribution (€):	€ 4,6 million
Project start/end:	01 May 2012 - 30 Jun 2020
Coordinator:	Dantherm Power, Denmark
Beneficiaries: Aquipac, Jema Energy, Budapesti Muszaki Es Gazdasagtudomanyi Egyetem, Centre National de la Recherche Scientifique CNRS, Hydrogene de France, Linde Gas Magyarorszag Zartkoruen Mukodo Reszvenytarsasag, Logan Energy Ltd	
Website:	www.cleargen.eu

Project and objectives

The CLEARgen Demo proposal aims to address this need for a large-scale stationary fuel cell demonstration.

The objectives of the CLEARgen Demo Project are:

1) Development and construction of a fuel cell system, purpose-built for the European market,
2) Validation of the technical and economic readiness of the fuel cell system at the megawatt scale, and
3) Field demonstration of a megawatt scale system at a European chemical production plant.

The site for the ClearGen system was found and is placed at SARA Group on Martinique, France. The preparation of the installation has started.

Major project achievements

- The final site location was established and the investors for AQUIPAC was found
- The preparation of the site and installation are progressing and the applications for the necessary permits have been sent
- The first 500 kW power bank is in commissioning and the production of the second 500 kW power bank is ready to start

Future steps

- The final location of the ClearGen system has been found and the preparation of the site was finished (September 2017)
- The two 500 kW power banks are installed, commissioned and in operation (beginning of 2018)
- The first data set from the operation is collected and analyzed (October 2018)
- The midterm conference was hold (beginning of 2018)

Non-quantitative objectives and status

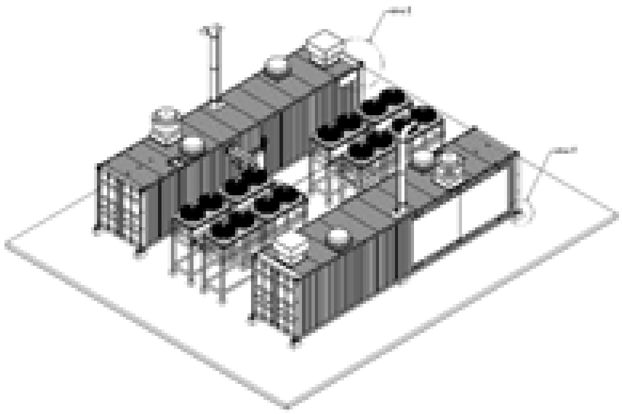
- Evaluate the entire lifecycle costs of the ClearGen installation
  To be done
- Conduct a thorough techno-economic analysis, to show transferability
  To be done
- Demonstrate the commercial viability of FC in distributed power generator
  To be done
- Facilitate EU objectives in environmental sustainability
  To be done

Relevant to FCH JU overarching objectives

- Increase the electrical efficiency and the durability of the different fuel cells used for power production to levels which can compete with conventional technologies, while reducing costs

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
AIP 2011	Demonstration size	MW	1	1	0.50	1	Due later	1st 500 kW power bank in commissioning - delivery in Sept. 2017. 2nd power bank to be delivered in Dec. 2017
MAIP 2008-2013	Stack lifetime	Hours	20,000	20,000		20,000	Due later	Expect to be exceeded after the project end
AIP 2011	Electrical Efficiency	%	50	43	48	43	Due later	Reduction of parasitic losses is important for high system efficiency
AIP 2011	System lifetime	Hours	20,000	20,000		20,000	Due later	System will be installed in the second part of 2017



D2Service
Design of 2 technologies and applications to service

Panel 3 — Technology validation in stationary applications

Acronym:	**D2Service**
Project ID:	671473
Title:	Design of 2 technologies and applications to service
Call Topic:	FCH-02.9-2014
Project total costs (€):	€ 3,6 million
FCH JU maximum contribution (€):	€ 2,9 million
Project start/end:	01 Sep 2015 - 31 Aug 2018
Coordinator:	EWE Forschungszentrum für Energietechnologie, Germany
Beneficiaries: Energy Partners, British Gas Trading Ltd, Solidpower, Zentrum fur Brennstoffzellen-Technik, Bosal Emission Control Systems, Ballard Power Systems Europe	
Website:	www.project-D2Service.eu

Project and objectives

The D2Service project aims at improving serviceability of residential and commercial fuel cell systems. Installation and maintenance procedures of SOFC and PEM fuel cell-based units are analysed and optimised to reduce service times and costs, and to avoid mistakes during installation and service. Design and the components of the units are optimised towards simplified exchangeability, increased longevity and standardisation, thus decreasing service intervals and durations. The project has reached mid-term. First laboratory tests of improved units and components have been conducted.

Major project achievements

- Improved design of SOFC and PEM μ-CHP units with respect to efficiency, serviceability, durability and cost reduction
- Suitable catalyst and adsorber materials identified for 60000h lifetime of hydrodesulphurisation component
- Identification and preparation of sites for field trial of improved units

Future steps

- Finalisation of PEM and SOFC μ-CHP unit improvements
- Installation of units on field trial sites
- Laboratory evaluation of improved μ-CHP units
- Development of guidelines for easy-to-understand graphical manuals
- Development of simplified service procedures

Quantitative targets and status

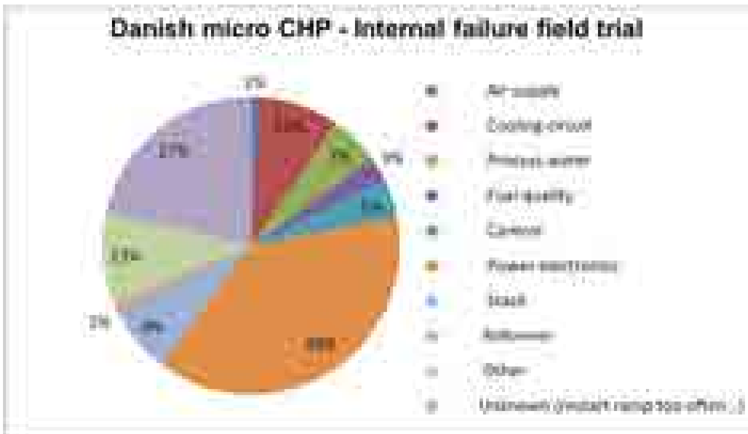
Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
AIP 2014	Presence/Service time – presence time of maintenance technician	h	8	<4	<8	<4	Due later	Redesign of system architecture +_ hot / cold components for easier maintenance / exchange
AIP 2014	Total down-time of equipment for service (PEM)	h		<48	48	24	Achieved	As above
AIP 2014	Total down-time of equipment for service (SOFC)	h	120	<48	96	0/48/72	Due later	Down-time for single service. 0 for service for components except forHotBox; 48h for periodical service; 72h for stack replacement (ca. every 3y)
AIP 2014	Increased service interval time	nr/a	4	<1	1	≤ 1	Due later	Via increased components' durability & lifetime
AIP 2014	Service cost	Euro/kW/year	11.500	<600	1.500	<600	Due later	Exact costs of redesigned components are not fixed yet

Non-quantitative objectives and status

- Elaboration of guidelines for easily understandable service manuals
  Current state-of-the-art is identified; graphical illustrations with minimal text is aimed at.
- Life-time desulphurisation (type HDS)
  Suitable catalyst and adsorber materials identified for 60000h. Necessary recirculation stream and type of recirculation device elaborated
- Water treatment optimisation
  Better material identified leading to extended service intervals

Relevant to FCH JU overarching objectives

- Increase the electrical efficiency and the durability of the different fuel cells used for power production to levels which can compete with conventional technologies, while reducing costs



DEMCOPEM-2MW

Demonstration of a combined heat and power 2 MWe PEM fuel cell generator and integration into an existing chlorine production plant

Panel 3 — Technology validation in stationary applications

Acronym:	**DEMCOPEM-2MW**
Project ID:	621256
Title:	Demonstration of a combined heat and power 2 MWe PEM fuel cell generator and integration into an existing chlorine production plant
Call Topic:	SP1-JTI-FCH.2013.3.5
Project total costs (€):	€ 10,5 million
FCH JU maximum contribution (€):	€ 5,5 million
Project start/end:	01 Jan 2015 - 31 Dec 2018
Coordinator:	Akzo Nobel Industrial Chemicals B.V., The Netherlands
Beneficiaries: Politec. Milano, Johnson Matthey Fuel Cells Ltd, Mtsa Technopower, Nedstack Fuel Cell Technology	
Website:	http://www.demcopem-2mw.eu

Project and objectives

The aim of the project is to design, construct and demonstrate an economical combined heat and power PEM fuel cell power plant and integration into a chlor-alkali production plant.

The project is currently in its third year and the PEM system has been installed in September 2016 at the chlor-alkali plant in Yingkou, China.

The initial capacity reached 1,7 MW (due to some technical limitations); from January 2017 - when technical items were solved - the installation is capable to function on full capacity of 2MW.

Major project achievements

- 2MW system operative (heat recovery available)
- Monitoring and operation possible in remote
- Reduce/minimise hydrogen waste in the chlori-alkali factory

Future steps

- Remote Monitoring of system/stacks performances
- Application and optimisation validation model developed for the project
- Optimise cost
- Supply and testing of improved stacks containing improved MEA's

Non-quantitative objectives and status

- High net conversion efficiency, i.e. > 50% electric energy on system
  Possible/achieved (even if not implemented by end-user)
- Over 2 years (16,000 hrs) for fuel cell stacks
  Data collection ongoing.
- Fully automated way of operation and remote control
  Achieved

Relevant to FCH JU overarching objectives

- Reduce the production cost of fuel cell systems to be used in transport applications, while increasing their lifetime to levels which can compete with conventional technologies
- Increase the electrical efficiency and the durability of the different fuel cells used for power production to levels which can compete with conventional technologies, while reducing costs
- Demonstrate on a large scale the feasibility of using hydrogen to support integration of renewable energy sources into the energy systems, including through its use as a competitive energy storage medium for electricity produced from renewable energy sources

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
MAIP 2008-2013	Installed capacity	MW	1	2	2	2	Achieved	+ prove potential for 20 more similar-sized PEM power plants
MAIP 2008-2013	Cost	€/kW		2500			Due later	In the remaining one and half year of the project further data will be analised for cost reduction
MAIP 2008-2013	Durability	hours		16,000			Due later	
Project's own	electrical efficiency	%		50			Achieved	
Project's own	heat+power efficiency	%		85			Not yet addressed	

DEMOSOFC
Demonstration of large SOFC system fed with biogas from WWTP

Panel 3 — Technology validation in stationary applications

Acronym:	**DEMOSOFC**
Project ID:	671470
Title:	Demonstration of large SOFC system fed with biogas from WWTP
Call Topic:	FCH-02.11-2014
Project total costs (€):	€ 5,9 million
FCH JU maximum contribution (€):	€ 4,5 million
Project start/end:	01 Sep 2015 - 31 Aug 2020
Coordinator:	Politec. Torino, Italy
Beneficiaries: Risorse Idriche, VTT, Società Metropolitana Acque Torino, Imperial College Science Technol. and Medicine, Convion	
Website:	www.demosofc.eu
Linkedin:	DEMOSOFC (Linkedin group)
Twitter:	@Steps_Polito

Project and objectives

DEMOSOFC is a 5-year project with an aim of demonstrating a medium-scale distributed CHP system (electric power of 175 kW and thermal recovery of 90 kW) based on SOFC and fed with locally available biogas produced in a waste water treatment plant.

Status at June 2017:

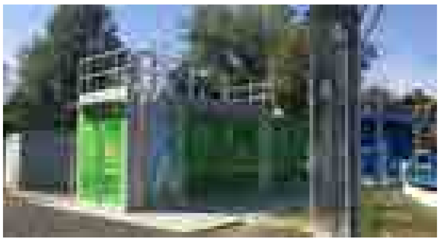
1) detailed engineering, including safety analysis and permitting procedures: completed
2) site preparation (biogas recovery and cleaning, electrical connections, thermal recovery) by mid July 2017
3) installation of the first (up to 3) SOFC module by end of July 2017
4) start up October 2017
5) business analysis (on going)

Major project achievements

- Complete experience of detailed engineering for the installation and operation of a biogas-fed SOFC CHP system at industrial scale, all included
- Complete experience of installation of a biogas-fed SOFC CHP system in an existing industrial context (waste water treatment plant)
- Design and construction of the biogas clean-up module for SOFC targets (material selection, engineering, control)

Future steps

- Complete of the DEMO installation and start-up of the operation
- Monitoring of the operation of the DEMO: Analysis of the electric
- Monitoring of the operation of the DEMO (electricity, thermal recovery, emissions)
- Analysis of the business opportunities of biogas-fed SOFC CHP systems
- Dissemination: newsletters, papers, but especially public workshops (2 in the period)



Quantitative targets and status

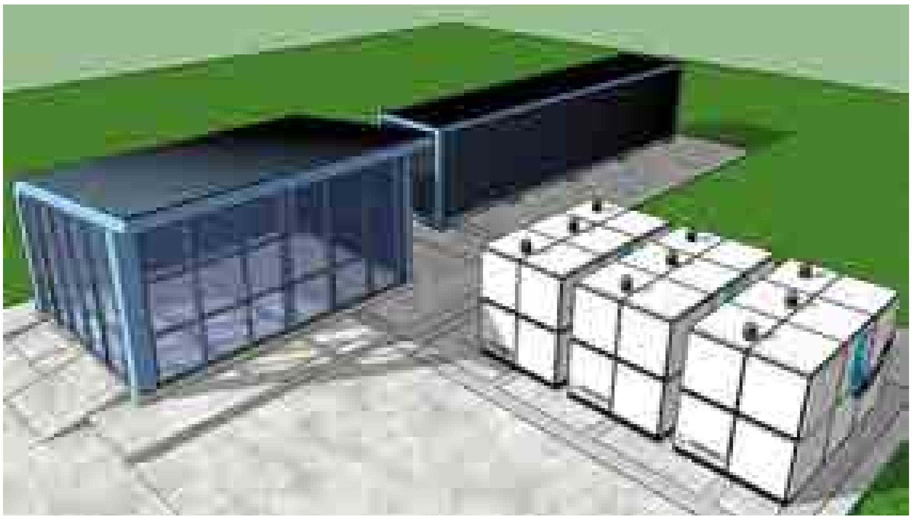
Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
AIP 2014	CAPEX of SOFC systems	€/kW	15,669	7,000		7,000	Due later	Install the third module (by Autumn 2017) with improved performances and lower unit costs
AIP 2014	Emissions of CO_2 and other contaminants	g/kWh NG	422	422	422	422	Not yet addressed	CO_2 emissions will be neutral (biogas fuel); also 27% lower vs ICE. The other contaminants (CO, PM, VOC) are absent
MAWP 2014-2020	Increase FC system electrical efficiency	%	53	58	53	58	Due later	Electrical efficiency of a complete biogas-fed SOFC system, from biogas to AC power
MAWP 2014-2020	Heat recovery	%	30	40	30	40	Due later	To organise the FC system to ensure a complete heat recovery
MAWP 2014-2020	Fuel clean-up before FC	ppm	1	0.2	0.2	0.2	Achieved	Removal of micro-contaminants in the biogas (sulphur compounds, siloxanes)

Non-quantitative objectives and status

- DEMO of a SOFC-based distributed CHP system fed by a biogenous fuel
  Installation ongoing, to be completed by July 2017 (and last SOFC module in autumn 2017). First industrial size SOFC-based system in EU so far
- Build technical knowledge, customer confidence, investor confidence
  Detailed engineering done, lessons learned for replication. Installation on-going, to be completed by July 2017 (last SOFC module in Autumn 2017)
- Demonstrate high efficiency of SOFC-based CHP systems fed by biogas
  We foresee an electrical efficiency of 53-55%, and an overall efficiency of 90%. Third SOFC module is expected to reach 58% electric efficiency
- Strong dissemination for public awareness
  Dissemination started using press release, social media (Facebook, Twitter, etc.) and website. Next actions centred on workshops after DEMO start-up

Relevant to FCH JU overarching objectives

- Increase the electrical efficiency and the durability of the different fuel cells used for power production to levels which can compete with conventional technologies, while reducing costs



ENE.FIELD
European-wide field trials for residential fuel cell micro-CHP

Panel 3 — Technology validation in stationary applications

EG-04-17-700-EN-P

Acronym:	**ENE.FIELD**
Project ID:	303462
Title:	European-wide field trials for residential fuel cell micro-CHP
Call Topic:	SP1-JTI-FCH.2011.3.7
Project total costs (€):	€ 52,5 million
FCH JU maximum contribution (€):	€ 25,9 million
Project start/end:	01 Sep 2012 - 31 Aug 2017
Coordinator:	COGEN, the European Association for the Promotion of Cogeneration, Belgium

Beneficiaries:
Hexis, Baxi Innotech, Bosch Thermotechnik, Danmarks Tek. Uni., Ballard Power Systems Europe, Dbi - Gastechnologisches Inst. G Freiberg, Dolomiti Energia, Dong Energy Oil & Gas, Dong Energy Wind Power Holding, Elcore, British Gas Trading Ltd, Ceres Power Ltd, Imperial College Science Technol. and Medicine, Eifer Europaisches Inst. fur Energieforschung, Parco Scientifico e Tecnol. Per L'Ambiente - Environment Park, Politec. Torino, Element Energy Ltd, Riesaer Brennstoffzellentechnik, Senertec Kraft-Warme Energiesysteme, Solidpower, The Energy Saving Trust Ltd by Guarantee, Vaillant, Viessmann Werke, ENGIE, Gaswarme-Inst. Essen, Hydrogen, Fuel Cells and Electro-mobility in European Regions HYER, Itho Daalderop Group, Razvojni Center Za Vodikove Tehnologije

Website: http://enefield.eu/

Project and objectives

The ene.field project has placed over 950 fuel cell µ-CHPs into homes across 12 European countries by June 2017 and has commitments to place a total of 1051 units by the end of the project on 31/08/2017. The project consortium comprises 26 partners from across research, heating industry, utility and association communities and will have received around €26 million EU funding over its duration. It is Europe's largest deployment of this modern FC µ-CHP technology to date and has allowed manufacturers to begin to reduce costs and build market.

Major project achievements

- Almost 1000 units have been installed to date out of the updated plan of 1051 units representing a 5% increase on the original plan
- Report on the non-economic barriers to large-scale market uptake of fuel cell based micro-CHP technology
- National events have been organised in several countries where installations take place to promote the technology

Future steps

- Deployment will continue until 1051 units are installed. A report will be prepared based on the inputs from manufacturers on deployment
- The report on technical performance of all µ-CHP units in the trial will be finalised
- Non-economic barriers Report, Lifecycle cost assessments, and Environmental life cycle assessments reports will be completed
- The report on macro-economic and macro-environmental impact will become available
- The final dissemination event will be held 11 October 2017 in Brussels which, at the same time, will be a launch event for PACE ("follow-up" project)

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
MAIP 2008-2013	Nr of units installed		500	1000	1046	1046	Achieved	> 1000 units by Q4 2017
MAIP 2008-2013	Nr of countries with units installed		1	11	10	10	Achieved	
MAIP 2008-2013	Nr of µ-CHP suppliers		5	9	10	10	Achieved	10 suppliers and 11 products trialled
MAIP 2008-2013	Electrical efficiency	%	30	35	35	35	Achieved	Field trials real-life data have shown electrical efficiencies in range 30 – 60%
MAIP 2008-2013	Overall efficiency >85% (LHV)	%	70	8	85	85	Achieved	Field trials real-life data have shown overall efficiencies as high as 85-95%
project's own	Availability	%	90	95	96	96	Achieved	96 to 99%

Non-quantitative objectives and status

- Increase the operational experience
  Diverse set of installations representing housing sector market throughout Europe.
  Operation in three climatic regions
- Estimate full life cycle costs and environmental sustainability asses
  A full life cycle cost (LCC) and life cycle environmental assessment (LCA) have been delivered
- Identify barriers and risks to full implementation
  Full record of issues encountered during manufacture, installation and operation, to inform practical barriers to implementation
- Disseminate to a wider audience incl. potential customers and industry
  Active dissemination was conducted throughout the project

Relevant to FCH JU overarching objectives

- Increase the electrical efficiency and the durability of the different fuel cells used for power production to levels which can compete with conventional technologies, while reducing costs

HEATSTACK
Production Ready Heat Exchangers and Fuel Cell Stacks for Fuel Cell mCHP

Panel 3 — Technology validation in stationary applications

EG-04-17-700-EN-P

Acronym:	**HEATSTACK**
Project ID:	700564
Title:	Production Ready Heat Exchangers and Fuel Cell Stacks for Fuel Cell mCHP
Call Topic:	FCH-02.6-2015
Project total costs (€):	€ 2,9 million
FCH JU maximum contribution (€):	€ 2,9 million
Project start/end:	01 Apr 2016 - 31 Mar 2019
Coordinator:	Senior UK, United Kingdom
Beneficiaries: Sunfire, Vaillant, ICI Caldaie, Uni. Birmingham, Senior Flexonics, PNO Consultants Ltd	
Website:	http://www.heatstack.eu/news-and-events/heatstack-production-ready-heat-exchangers-fuel-cell-stacks-fuel-cell-mchp/
Linkedin:	HEATSTACK Project
Twitter:	@HEATSTACK_EU

Project and objectives

HEATSTACK is an industrially focussed project aiming at cost reduction of the two most expensive components of micro-combined heat and power (µ-CHP) with a primary focus on working towards sufficient cost reductions to enable mass market adoption in domestic properties. This objective will be realised through the improved design, manufacturing process and automation of the cathode air preheater and stack, with a goal of reducing cost per unit by 50% once annual production of 10.000 units is realised by a target date of 2020.

Major project achievements

- Senior have fully developed the tooling and equipment, and process methodology, to be in a position to manufacture CAPHs reliably and efficiently
- The CAPH has been redesigned to give it higher stability and durability for extended usage
- Birmingham University's tests have provided positive and valuable data on the performance of the AluChrom 318, proving its utility in this application

Future steps

- None reported

Quantitative targets and status

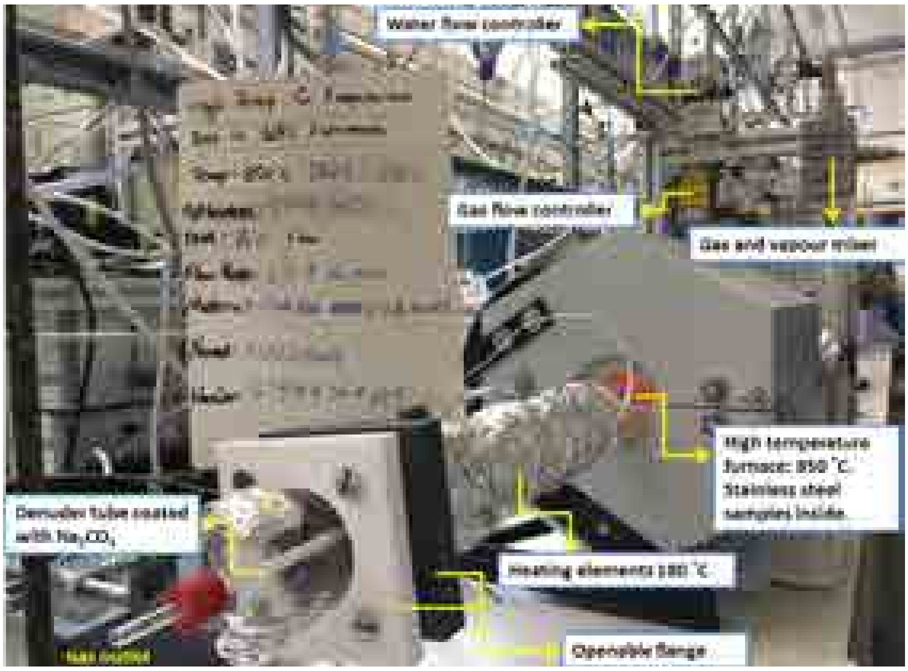
Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
Project's own	Unit cost reduction of CAPH reduced by 50%	£	600	300	500	500	Due later	Further cost reductions can only be achieved through mass manufacture and hence eocnomies of scale which was forecast for 2020
Project's own	Sealing time	min	200	100	200	100	Due later	Reduce sealing time of fuel cells by 50% - In the design phase - will be implemented in the coming year
Project's own	Nr cells per CAPH	units	28	14	14	14	Achieved	Through successful changes to CAPH design
Project's own	CAPH manufacture cycle time	h	8.83	1.35			Due later	

Non-quantitative objectives and status

- Develop novel tooling for welding process
  Successfully completed
- Establish method to repair leads to reduce scrap
  The system has been procured and has proven to be able to repair previously difficult leaks, attaining the planned objective successfully
- Material testing for understanding of corrosion & performance of AluChro
  This work is well underway and has generated positive results so far which will be used in marketing material, testing continues
- Increase production volume potential
  Vaillant's withdrawal from the fuel cell sector has made this a challenge- need applications for the CAPH and new end users are being explored

Relevant to FCH JU overarching objectives

- None reported



INNO-SOFC
Development of innovative 50 kW SOFC system and related value chain

Panel 3 — Technology validation in stationary applications

Acronym:	**INNO-SOFC**
Project ID:	671403
Title:	Development of innovative 50 kW SOFC system and related value chain
Call Topic:	FCH-02.5-2014
Project total costs (€):	€ 4,0 million
FCH JU maximum contribution (€):	€ 4,0 million
Project start/end:	01 Sep 2015 - 28 Feb 2018
Coordinator:	VTT, Finland
Beneficiaries: Forschungszentrum Julich, Energy Matters, Convion, Elcogen, Elringklinger, Agenzia Nazionale per le Nuove Tecnologie, l'Energia e lo Sviluppo Economico Sostenibile	
Website:	http://www.innosofc.eu/

Project and objectives

The INNO-SOFC project is focusing on development of an innovative 50 kW SOFC system and related value chain from interconnects and stacks to end-users and application analysis. The main objective of this project is to design, assemble and demonstrate a novel 50 kW SOFC power plant with significant cost reductions, improved efficiency and longer lifetime compared to current state of the art SOFC systems (60% electrical and 85% total efficiency). In general, the project is progressing according to the plan, except some months delay in system design and manufacturing.

Major project achievements

- Optimization of interconnect plate for manufacturing and delivery of these plates for INNO-SOFC stacks
- Identification of most promising end-users and applications.
- Stacks assembled using project's interconnect plates and characterization started (long-term and performance)

Future steps

- Application analysis with different future scenarios
- Finalising detail design of the system
- Stack delivery to Convion
- System start-up
- Continuation of stack validation

Non-quantitative objectives and status

- Identify most promising end users and customers
  Most promising end-users and application have been analysed, identified, and reported

Relevant to FCH JU overarching objectives

- Increase the electrical efficiency and the durability of the different fuel cells used for power production to levels which can compete with conventional technologies, while reducing costs

EG-04-17-700-EN-P

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
AIP 2014	Operating time	hrs		30,000		30,000	Due later	Through system design and components
AIP 2014	System cost	€/kW		4,000		4,000	Due later	
AIP 2014	Electrical efficiency	%		60		60	Due later	
AIP 2014	Total efficiency	%		85		85	Due later	
AIP 2014	Stack cost	€/kW		2,000		2,000	Due later	Elcogen stack at 5-10 MW/year production level is to be analysed to meet project target.

ONSITE
Operation of a novel SOFC-battery integrated hybrid for telecommunication energy systems

Panel 3 — Technology validation in stationary applications

Acronym:	**ONSITE**
Project ID:	325325
Title:	Operation of a novel SOFC-battery integrated hybrid for telecommunication energy systems
Call Topic:	SP1-JTI-FCH.2012.3.4 &SP1-JTI-FCH.2012.3.5
Project total costs (€):	€ 5,5 million
FCH JU maximum contribution (€):	€ 3 million
Project start/end:	01 Jul 2013 - 30 Sep 2017
Coordinator:	Consiglio Nazionale delle Ricerche CNR, Italy
Beneficiaries: Bonfiglioli Vectron, Fiamm Energy Storage Solutions, Erdle Erich Konrad, Htceramix, Ericsson Telecomunicazioni, Haute Ecole Specialisé de Suisse Occidentale, Instytut Energetyki	
Website:	http://www.onsite-project.eu/

Project and objectives

The overall objective of ONSITE is the construction and operation of a sheltered system, based on SOFC/sodium nickel chloride battery hybrid system generating 10 kW at high efficiency and economically competitive costs, i.e. a rigorous proof of concept. The demonstration of the system shall take place on a real site of an existing telecom station. Starting from SOFC previous research results, commercially available power electronics and sodium nickel chloride batteries will improve next generation SOFC systems and adapt them to the specific requirements for medium size telecom stations.

Major project achievements

- Telecom Operator engagement and arrangement of the real site for the PoC test
- Realization of a sheltered PoC able to be installed in a Telecom Operator site
- Realization of a integrated CCHP (Combined Heat Cold and Power) prototype for the ICT sector

Future steps

- Test of the sheltered 5 kW SOFC/SNC hybrid system (Telecom load at test facility)
- Installation and test of the 5 kW SOFC/SNC hybrid system at Telecom Operator site

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017
Project's own	FC system efficiency	%	30	40	40	40	Achieved
AIP 2012	Development of Proof-of-concept combining advanced components int	none					Achieved
AIP 2012	Assessment of the fuel cell system's ability to compete with existing						Due later
Project's own	Prototype ability to exchange power with the grid						Due later
Project's own	Continuos operating hours	hours		3000	600	600	Achieved
AIP 2012	Novel system architectures						Achieved
AIP 2012	The PoC system will be required to comply with all relevant CE regul.						Achieved
Project's own	Integration with an adsorption chiller in order to produce cold						Due later
Project's own	Output power	kW		10	10	10	Achieved

Non-quantitative objectives and status

- Training of young student
  The involvement of HAUTE ECOLE SPECIALISEE DE SUISSE OCCIDENTALE has allowed the training of young students

PACE
Pathway to a Competitive European FC mCHP market

Panel 3 — Technology validation in stationary applications

Acronym:	**PACE**
Project ID:	700339
Title:	Pathway to a Competitive European FC mCHP market
Call Topic:	FCH-02.9-2015
Project total costs (€):	€ 90,3 million
FCH JU maximum contribution (€):	€ 33,9 million
Project start/end:	01 Jun 2016 - 28 Feb 2021
Coordinator:	COGEN, the European Association for the Promotion of Cogeneration, Belgium
Beneficiaries: Solidpower, Viessmann Werke, Bosch Thermotechnik, Solidpower, Vaillant, Danmarks Tek. Uni., BDR Thermea Group, Ewe, Element Energy	
Website:	http://www.pace-energy.eu

Project and objectives

PACE is a major initiative aimed at ensuring the European μ-CHP sector makes the next move to mass market commercialisation. The project will deploy a total of 2,650 new fuel cell μ-CHP units with real customers and monitor them for an extended period.

This will:

- Enable fuel cell μ-CHP manufacturers to scale up production, using new series techniques, and increased automation
- Allow the deployment of new innovations in fuel cell μ-CHP products, which reduce unit cost by over 30%, increase stack lifetime to over 10 years

Major project achievements

- Deployment of units have started.
- Communications activities of the project are supported by a professional communications agency.
- Professional communications materials have been developed (website, brochure, presentation etc.)

Future steps

- The number of units deployed under PACE will significantly increase
- PACE launch event 11 October, 2017 in Brussels with units on display
- Report on the lessons learned in setting up the servicing and after sales support
- Summary results on policy scenario analysis

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
MAWP 2014-2020	Total efficiency	%	85	95	95	95	Due later	Next gen product designs with > 90% overall efficiency and/or >50% electrical efficiency
MAWP 2014-2020	Improved durability	Years	10	15	10	15	Due later	
MAWP 2014-2020	Relative CAPEX reduction-individual systems	%	100	70		70	Due later	>500 units/manufacturer, enhanced automation/scale-up
MAWP 2014-2020	CAPEX- overall average system cost	EUR	20000	10000		10000	Due later	<10,000 EUR/system - or <10,000 EUR/kWe for systems over 1kWe by end of project
MAWP 2014-2020	Stack replacement	%	100	50		50	Due later	
MAWP 2014-2020	Manufacturing capacity	Units/year	50	1000		1000	Due later	

Non-quantitative objectives and status

- Field support- cross cutting working group on training & certification
  The aim is to exchange information on training technicians and installers and to discuss options for developing more standard standardised training
- Customer feedback survey
  The aim is to collect qualitative and quantitative data on the satisfaction of customers with their units, positive and negative experiences
- Dissemination objective
  Promote Fuel Cell μ-CHP towards industry and policy-makers to facilitate the transition to mass market commercialisation
- Working with policy makers
  Identify the supportive Member State narratives and policy vehicles for introducing the favourable approaches

Relevant to FCH JU overarching objectives

- Increase the electrical efficiency and the durability of the different fuel cells used for power production to levels which can compete with conventional technologies, while reducing costs

PEMBEYOND

PEMFC system and low-grade bioethanol processor unit development for back-up and off-grid power applications

Panel 3 — Technology validation in stationary applications

EG-04-17-700-EN-P

Acronym:	**PEMBEYOND**
Project ID:	621218
Title:	PEMFC system and low-grade bioethanol processor unit development for back-up and off-grid power applications
Call Topic:	SP1-JTI-FCH.2013.4.4
Project total costs (€):	€ 4,6 million
FCH JU maximum contribution (€):	€ 2,3 million
Project start/end:	01 May 2014 - 31 Oct 2017
Coordinator:	VTT, Finland
Beneficiaries: Genport - Spin-off from Politecnico Milano, Powercell Sweden, Uni. Porto, Fraunhofer Gesellschaft zur Foerderung der Angewandten Forschung	
Website:	http://pembeyond.eu/

Project and objectives

The PEMBeyond project aims to develop a bio-ethanol fuelled integrated PEMFC based power system for back-up and off-grid applications. The work started from catalyst and adsorbent material development and continued in the design and manufacturing of subsystems. The subsystems are ready and tested, with the integrated system commissioning tests ongoing and the 1000 h field trial about to start. The goal is to eventually introduce the bio-ethanol based systems to market, allowing the direct use of easily transported and stored, locally and affordably produced low emission fuel in power generation.

Major project achievements

- A system operated on crude bioethanol designed and manufactured and the initial testing of the subsystems completed
- Development of superior PSA adsorbent able to purify syngas with 1 % of CO down to the automotive grade of 0.2 ppm in product gas
- Stable steam reforming catalyst for crude bioethanol developed, together with non-noble metal based LT-WGS catalyst surpassing any commercial products

Future steps

- The system commissioning tests will be completed and reported
- The field trial of 1000 hours will be completed and reported
- The LCA study will be completed and reported
- The roadmap to volume production and advanced concept study will be completed and reported

Non-quantitative objectives and status

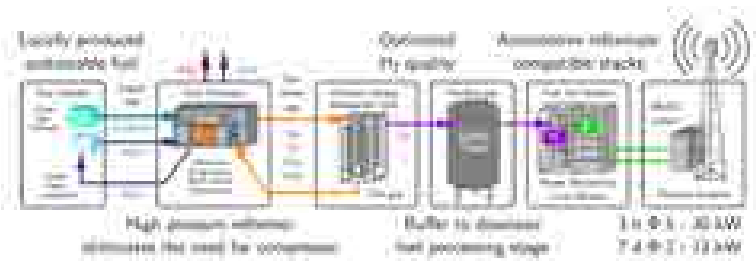
- Developing the reformed ethanol fuel cell technology for market entry
  Based on the manufactured systems, the concept is very attractive for commercialization.
  Within 2 years, a limited production could commence

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
AIP 2013	5 kW FC and H_2 system cost @ 500 units/yr	€/kW	9000	3300	3757	3500	Due later	Only small cost reductions are foreseen, but TCO is already competitive with diesel gensets.
AIP 2013	25 kW FC and H_2 system cost @ 500 units/yr	€/kW	9000	2500		2500	Due later	
AIP 2013	FC system efficiency %	%		45	48	48	Achieved	Including power electronics losses. Otherwise efficiency 53 %.
AIP 2013	System efficiency with an integrated hydrogen generator	%		30	11	20	Due later	Based on initial tests with un-optimised operation parameters. 20% may be reached with the prototype, with redesign 30 % is no problem.
AIP 2013	System life-time	h		20,000		1000	Due later	Long-term durability testing not included in project, but conclusions can be made based on the 1000-h field trial.
Project's own	Steam reforming catalyst stability with crude bioethanol	h		1000	1060	1060	Achieved	Catalyst stable with un-purified ethanol from barley feedstock.
Project's own	PSA product hydrogen CO level	ppm	100	25	20	14	Achieved	Adsorbent developed in project shows superior performance, and allows further cost reductions & higher efficiency of a 2nd generation system.
Project's own	System operating temperature	°C	0	-25	-25	-25	Achieved	700 W 10-cell reformate S2 stack successfully cold started from -25 °C without external heaters.

Relevant to FCH JU overarching objectives

- Increase the electrical efficiency and the durability of the different fuel cells used for power production to levels which can compete with conventional technologies, while reducing costs
- Increase the energy efficiency of production of hydrogen mainly from water electrolysis and renewable sources while reducing operating and capital costs, so that the combined system of the hydrogen production and the conversion using the fuel cell system can compete with the alternatives for electricity production available on the market



POWER-UP
Demonstration of 500 kWe alkaline fuel cell system with heat capture

Panel 3 — Technology validation in stationary applications

EG-04-17-700-EN-P

Acronym:	**POWER-UP**
Project ID:	325356
Title:	Demonstration of 500 kWe alkaline fuel cell system with heat capture
Call Topic:	SP1-JTI-FCH.2012.3.7
Project total costs (€):	€ 13,6 million
FCH JU maximum contribution (€):	€ 6,1 million
Project start/end:	01 Apr 2013 - 30 Jun 2017
Coordinator:	AFC Energy, United Kingdom
Beneficiaries: Air Products, Fast - Federazione delle Associazioni Scientifiche e Tecniche, G.B. Innomech Ltd, Zentrum fur Brennstoffzellen-Technik, Paul Scherrer Inst.	
Website:	http://project-power-up.eu/

Project and objectives

Project POWER-UP was established to manufacture, install and operate an industrial-scale alkaline fuel cell plant in an industrial environment. The infrastructure was designed and built to German standards, while the KORE system has been installed and operated with the produced electricity exported to the grid. The introduction of automation and modern manufacturing techniques has enabled the scale-up of fuel cell production whilst maintaining high quality. The system's technical and environmental performance, total cost of ownership, social and environmental impacts have also been determined.

Major project achievements

- Electricity fed and sold into the local grid
- Fuel cell manufacturing facility upgraded and automated, resulting in an increase in fuel cell quality, reproducibility and performance
- Alkaline fuel cell plant built, installed and operated according to local regulations

Future steps

- LCA and socioeconomic analysis

Non-quantitative objectives and status

- Clear understanding of external impacts
  Life Cycle Assessment report completed and agreed

Relevant to FCH JU overarching objectives

- Increase the electrical efficiency and the durability of the different fuel cells used for power production to levels which can compete with conventional technologies, while reducing costs
- Reduce the use of the EU defined 'Critical raw materials', for instance through low-platinum or platinum-free resources and through recycling or reducing or avoiding the use of rare earth elements

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
Project's own	Reduction in fuel cells rejected for defects	%	10	<3	15		Not achieved	Increased due to increased volume throughput. Lean tools being employed to reduce it
Project's own	Increase in cells manufactured per hour	% increase	20	20	220	220	Achieved	starting point = 16 electrodes/day
Project's own	Power output	kWe	4	500	204	240	Achieved	Qualified success in January 2016. Target revised to plant commissioning result and decision to only install 1 KORE BoP of 240kW nameplate.
Project's own	Re-use of stack components	% reused	0	70	88	80	Achieved	% by mass. The % achieved will go back down because the relative mass of the components will change as evolved technology comes online.
Project's own	Total performance loss	% (	10	3	40		Not achieved	Change of catalyst system with broader operating range
Project's own	Reduced manpower required to install fuel cell system	Person-Mth	1	0.25	1	1	Not achieved	Due to multiple site changes a system housed in a building has been used. Time quoted refers to fuel cell BoP installation only.
Project's own	Recovery of catalyst materials	%	90	97	99	99	Achieved	All waste catalyst material is recovered during manufacturing and post operation. 99% is the recovery rate from the reprocessor used.
MAIP 2008-2013	Stack electrical efficiency	%	52	58	57	57	Achieved	based on LHV

STAGE-SOFC
Innovative SOFC system layout for stationary power and CHP applications

Panel 3 — Technology validation in stationary applications

EG-04-17-700-EN-P

Acronym:	**STAGE-SOFC**
Project ID:	621213
Title:	Innovative SOFC system layout for stationary power and CHP applications
Call Topic:	SP1-JTI-FCH.2013.3.4
Project total costs (€):	€ 4,0 million
FCH JU maximum contribution (€):	€ 2,2 million
Project start/end:	01 Apr 2014 - 31 Oct 2017
Coordinator:	VTT, Finland
Beneficiaries: Lappeenrannan Teknillinen Yliopisto, Sunfire, ICI Caldaie, Zachodniopomorski Uni. Technol. W Szczecinie	
Website:	http://www.stage-sofc-project.eu/

Project and objectives

The aim of the STAGE-SOFC project is to develop a Proof-of-Concept (PoC) prototype of a new solid oxide fuel cell (SOFC) concept with a serial connection of one exothermal catalytic partial oxidation (CPOX) stage with one or a multiple of endothermic steam reforming stages. The system will combine the benefits of the simple and robust CPOX layout with the high efficiencies obtained by the steam reforming process. The first prototype achieved the set targets on electrical power >5 kW (AC) and electrical efficiency >45%. The PoC prototype has been designed, constructed, and commissioned and is currently being tested.

Major project achievements

- The PoC system has been designed, constructed and commissioned
- Extensive knowledge on hotbox design gained by experimental work and simulation
- Active dissemination of project results including conferences, exhibitions and scientific papers

Future steps

- Continue and complete the extended test runs with the PoC system
- Finalise all remaining work in WPs
- Report the work in the project

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
MAIP 2008-2013	System electrical efficiency (AC, LHV)	%		45	45		Achieved	Prototype PT1: Verified by system simulations and experimentally
MAIP 2008-2013	System total efficiency (LHV)	%		80	80		Achieved	Verified by system simulation
MAIP 2008-2013	Stack lifetime	h		40,000	20,000	40,000	Due later	Long-term stack investigations [in parallel to project] by Vaillant - in system
MAIP 2008-2013	Unit cost @ 5 kW	€/kW		4,000			Due later	Only achievable by mass-production
Project's own	Prototype running time	h		3,000		3,000	Due later	Long-term testing not started yet
Project's own	Prototype electrical power	kW		5	5.35		Achieved	Power target achieved in PT 1

Non-quantitative objectives and status

- Step change improvements over existing technology
  Design and successful evaluation of an innovative fuel cell system that achieves high electrical efficiencies without laborious water handling
- Development of PoC prototypes that form an integrated system
  Complete 5 kW prototype built and tested. The system consists of hotbox, coldbox and will be coupled to a heating system
- Novel system architectures, including new fuel processing units
  The PoC prototype will be based on an innovative hotbox for which a customised pre-reformer needs to be developed amongst other elements

Relevant to FCH JU overarching objectives

- Increase the electrical efficiency and the durability of the different fuel cells used for power production to levels which can compete with conventional technologies, while reducing costs

PANEL 4
RESEARCH ACTIVITIES FOR STATIONARY APPLICATIONS

Cell3Ditor
Cost-effective and flexible 3D printed SOFC stacks for commercial applications

Panel 4 — Research activities for stationary applications

Acronym:	**Cell3Ditor**
Project ID:	700266
Title:	Cost-effective and flexible 3D printed SOFC stacks for commercial applications
Call Topic:	FCH-02.6-2015
Project total costs (€):	€ 2,2 million
FCH JU maximum contribution (€):	€ 2,2 million
Project start/end:	01 Jul 2016 - 31 Dec 2019
Coordinator:	Fundacio Inst. De Recerca de L'Energia De Catalunya, Spain
Beneficiaries: 3Dceram, Saan Energi, Promethean Particles Ltd, Hygear Fuel Cell Systems, Francisco Albero, Uni. La Laguna, Danmarks Tek. Uni.	
Website:	www.cell3ditor.eu
Linkedin:	Cell3Ditor
Twitter:	@cell3ditor

Project and objectives

The main goal of the Cell3Ditor project is to develop a 3D printing technology for the industrial production of SOFC stacks by covering research and innovation in all the stages of the industrial value chain (inks formulation, 3D printer development, ceramics consolidation and system integration). All-ceramic joint-free SOFC stacks with embedded fluidics and current collection will be fabricated in a two-step process (single-step printing and sintering) to reduce in energy, materials and assembly costs. A novel multi-material hybrid printing technology has been developed in the first year.

Major project achievements

- Development of a hybrid 3D printer able to print multi-material ceramic devices
- Development of printable slurries of YSZ for being used with the SLA technology
- Design of a printable SOFC joint-less stack with embedded fluidics

Future steps

- Hybrid SLA inkjet printing machine ready for multi-material fabrication of 3D pieces
- Printable slurries for SLA and inkjet ready
- Multi-material 3D printing machine validated
- SOFC parts printed by inkjet or SLA
- Printable design of the SOFC stack ready

Non-quantitative objectives and status

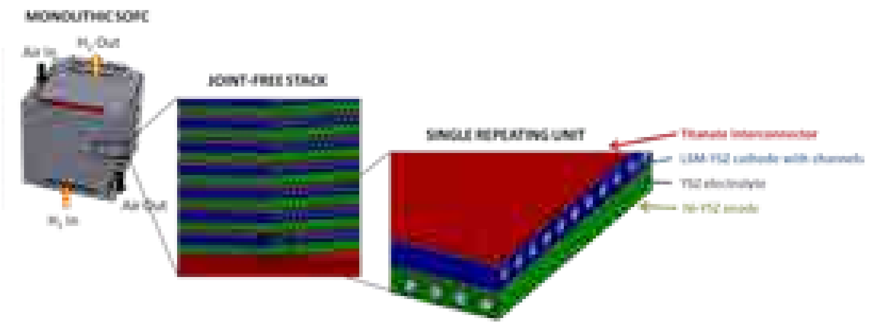
- Hybridisation of SLA and inkjet printer for fabrication of 30x30x10 cm
  To be achieved in June 2017
- Fabrication of SOFC parts by 3D printing
  To be achieved in June 2019
- Fabrication of joint-less SOFC stacks
  To be achieved in December 2019

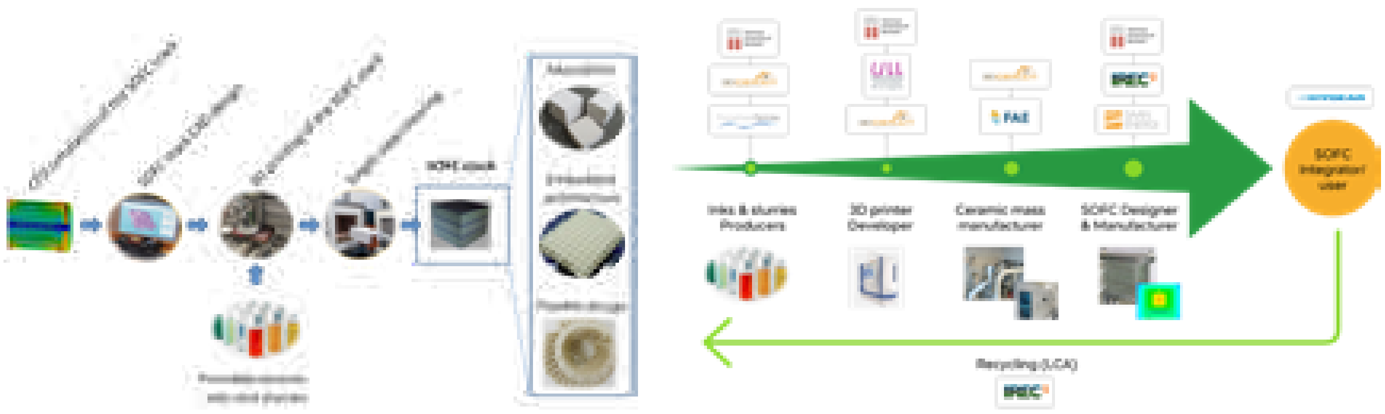
Relevant to FCH JU overarching objectives

- Increase the electrical efficiency and the durability of the different fuel cells used for power production to levels which can compete with conventional technologies, while reducing costs
- Reduce the use of the EU defined 'Critical raw materials', for instance through low-platinum or platinum-free resources and through recycling or reducing or avoiding the use of rare earth elements

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
AIP 2015	Cost	€/W	0.33	0.12		0.12	Due later	Target is cost reduction of min. 50% vs SoA
AIP 2015	Time to market	years	1	0.1		0.5	Due later	Shape customization is inherent to the technology
AIP 2015	Nr fabrication steps		60	2		2	Due later	Two steps: printing and sintering
MAWP 2014-2020	Reduce the use of "critical raw materials"	% reduction	100	80		60	Due later	Thickness reduction of interconnect and anode





CISTEM
Construction of Improved HT-PEM MEAs and Stacks for long term stable modular CHP units

Panel 4 — Research activities for stationary applications

Acronym:	**CISTEM**
Project ID:	325262
Title:	Construction of Improved HT-PEM MEAs and Stacks for long term stable modular CHP units
Call Topic:	SP1-JTI-FCH.2012.3.1 &SP1-JTI-FCH.2012.3.5
Project total costs (€):	€ 6,1 million
FCH JU maximum contribution (€):	€ 4,0 million
Project start/end:	01 Jun 2013 - 30 Sep 2016
Coordinator:	Ewe-Forschungszentrum für EnergieTechnol., Germany
Beneficiaries: Eisenhuth, Ici Caldaie, Inhouse Engineering, Owi Oel-Waerme Institut, Uni. Castilla - La Mancha, Danish Power System, Vysoka Skola Chemicko-Technologicka V Praze	
Website:	http://www.project-cistem.eu/

Project and objectives

Key issue of CISTEM is the development of HT-PEM based 4 kW stack modules (including reformer) that are suitable for larger CHP systems up to 100 kWel. The modular concept will be investigated in a Hardware-in-the-Loop (HiL) test bench with one module physically installed and the others emulated by software. The development strategy starts on the single component level and rises up to the complete CHP system. So, R&D includes the most important components like Membrane-Electrode Assemblies (MEAs), bipolar plates, reformer system and the final CHP unit design with all necessary Balance-of-Plant (BoP) components. Project is finished.

Major project achievements

- Electrical efficiency of 46% under operation with hydrogen and 0.3 A/cm²
- Degradation rate of 3 µV/h at 0.3 A/cm² und hydrogen/air operation, extended long term test with runtime over 16000 hours
- Extended long-term test with runtime over 16000 hours

Future steps

- Project finished

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
MAIP 2008-2013	Commercial application range 5-50 kW	kW	0.00	104.00	100.00		Achieved	HiL operation of complete CHP unit
MAIP 2008-2013	electrical efficiency	%	36	45	46		Achieved	
AIP 2012	degradation rate	µV/hr	6	4	3		Achieved	BoA MEAs with high durability
AIP 2012	lifetime	hr	10,000	20,000	40,000		Achieved	less than 3 µV/hr degradation rate

Relevant to FCH JU overarching objectives

- Reduce the production cost of fuel cell systems to be used in transport applications, while increasing their lifetime to levels which can compete with conventional technologies
- Increase the electrical efficiency and the durability of the different fuel cells used for power production to levels which can compete with conventional technologies, while reducing costs

DEMSTACK

Understanding the degradation mechanisms of a High Temperature PEMFCs Stack and optimization of the individual components

Panel 4 — Research activities for stationary applications

EG-04-17-700-EN-P

Acronym:	**DEMSTACK**
Project ID:	325368
Title:	Understanding the degradation mechanisms of a High Temperature PEMFCs Stack and optimization of the individual components
Call Topic:	SP1-JTI-FCH.2012.3.1 &SP1-JTI-FCH.2012.3.5
Project total costs (€):	€ 2,5 million
FCH JU maximum contribution (€):	€ 1,5 million
Project start/end:	01 May 2013 - 31 Oct 2016
Coordinator:	Foundation for Research and Technol. Hellas, Greece
Beneficiaries: Advanced Energy Technol. Ae Ereunas & Anaptyxis Ylikon & Proiontonananeosimon Pigon Energeias & Synafon Symvouleftikon Y Piresion*Adven, Prototech, Elvio Anonymi Etaireia Systimaton Paragogis Ydrogonou Kai Energeias, Fundacion Cidetec, JRC -Joint Research Centre, European Commission, Vysoka Skola Chemicko-Technologicka V Praze	
Website:	http://demstack.iceht.forth.gr/

Project and objectives

The activities of the DeMStack project were on the stack optimisation and construction based on the high temperature MEA technology of ADVENT S.A. and its long term stability testing.

The product of DeMStack is a 1kW HT PEMFC prototype stack integrated with a fuel processor. DeMStack aim was to enhance the lifetime and reduce the cost of the overall HT PEMFC technology by introducing improvements based on degradation studies and materials development that led to a reliable cost-effective product that fulfils all prerequisites for relevant field uses.

Major project achievements

- Robust MEAs with low Pt loading and excellent stability under harsh reformate feed
- Mathematical modelling assisted the efficient design of the bipolar plates and stack and can be used for the understanding of the MEA processes
- Design & manufacturing of HT PEMFC stack integrated with a fuel processor. Operation with natural gas with no degradation after >40 start-stop cycles

Future steps

- Project finished

Non-quantitative objectives and status

- Improving stack & cell designs.. components with improved performance
  Optimization of key MEA and stack components took place resulting in lower cost, ability to operate under reformate, higher performance and stability
- Construction of a fuel processor and fuel cell stack system prototype
  A unit (reformer-HT PEMFC) is constructed and operated with natural gas showing excellent stability; > 40 start-stop cycles with no degradation

Relevant to FCH JU overarching objectives

- Increase the electrical efficiency and the durability of the different fuel cells used for power production to levels which can compete with conventional technologies, while reducing costs

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
MAIP 2008-2013	Power output, small scale domestic 1 - 5 kW	kW		1	1	1	Achieved	Construction of 1 kW HT PEMFC, stacks from optimized components
Project's own	Nr units			1	1	1	Achieved	HT PEMFC operating on reformates at 180 °C
MAIP 2008-2013	Cost	€/kW		3,000	2,000	2,000	Achieved	Estimate for industrial/commercial units @ mass production
AIP 2012	Electrical efficiency	%		35-45	45	45	Achieved	Electrical efficiency at 180 degC under reformates: stack 47% LHV, system 45% LHV
AIP 2012	Operational lifetime	months		30	4	4	Achieved	Target 20000 h- 30 months; 4-5 month testing in an accelerated basis (start-stop cycles) under reformate feed

DIAMOND
Diagnosis-aided control for S systems

Panel 4 — Research activities for stationary applications

Acronym:	**DIAMOND**
Project ID:	621208
Title:	Diagnosis-aided control for SOFC power systems
Call Topic:	SP1-JTI-FCH.2013.3.3
Project total costs (€):	€ 3,6 million
FCH JU maximum contribution (€):	€ 2,1 million
Project start/end:	01 Apr 2014 - 30 Sep 2017
Coordinator:	Hygear, The Netherlands
Beneficiaries: Htceramix, VTT, VTT, Uni. Salerno, Commissariat à l'Energie Atomique et aux Energies Alternatives CEA, Inea Informatizacija Energetika Avtomatizacija Doo, Inst. Jozef Stefan	
Website:	www.diamond-sofc-project.eu/about/

Project and objectives

The objective of the project is to contribute to SOFC systems reliability and durability through design and implementation of a hierarchical control system supported by fault diagnostic system on two different SOFC CHP systems, one conventional (DIAMOND C) and the other advanced (DIAMOND A). A thorough inventory of faults and failures, which might occur in SOFC CHP systems, has been made. Fault detection and isolation algorithms and advanced and supervisory control algorithms have been developed and implemented on both systems for validation.

Major project achievements

- Development and validation of soft sensors to determine the minimum and maximum stack temperature in the DIAMOND C system
- Development and validation of models for the DIAMOND A and DIAMOND C system
- Operation of the DIAMOND A system for over 2000 hours using standard control

Future steps

- Testing DIAMOND C system with advanced control
- Test DIAMOND A system using the advanced control, supervisory control and FDI algorithms

Non-quantitative objectives and status

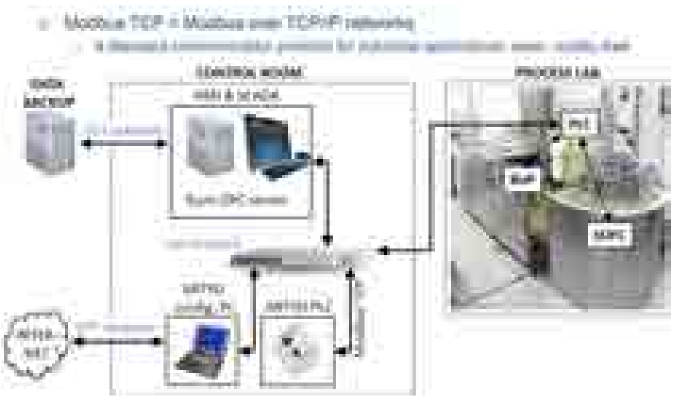
- Advanced diagnostics
  Dynamic system models have been developed in combination with the Fault Tree Analysis a FDI algorithms have been developed, and implemented
- Advanced diagnostics
  Soft sensors were developed and validated. THDA (Total Harmonic Distortion Analysis) has been validated for use with SOFC stacks
- Innovative control strategies
  Low-level feedforward-feedback control was designed and verified, and is implemented for system control;
- Supervisory control was designed and verified

Relevant to FCH JU overarching objectives

- Increase the electrical efficiency and the durability of the different fuel cells used for power production to levels which can compete with conventional technologies, while reducing costs

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
MAIP 2008-2013	lifetime	hrs		85,000		-	Due later	The advanced control is able to determine the system remaining useful life (RUL)
MAIP 2008-2013	Electrical efficiency	%		50		50	Due later	Efficiency not yet determined, will be determined using the Optimizer control



ENDURANCE
Enhanced durability materials for advanced stacks of new solid oxide fuel cells

Panel 4 — Research activities for stationary applications

Acronym:	**ENDURANCE**
Project ID:	621207
Title:	Enhanced durability materials for advanced stacks of new solid oxide fuel cells
Call Topic:	SP1-JTI-FCH.2013.3.1
Project total costs (€):	€ 4,4 million
FCH JU maximum contribution (€):	€ 2,5 million
Project start/end:	01 Apr 2014 - 31 May 2017
Coordinator:	Uni. Genova, Italy
Beneficiaries: Schott, Htceramix, Marion Technol., Solidpower, Uni. Di Pisa, Centre National de la Recherche Scientifique CNRS, Commissariat à l'Energie Atomique et aux Energies Alternatives CEA, Helmholtz-Zentrum Berlin fur Materialien und Energie, Ecole Polytechnique Federale de Lausanne, Fundacio Inst. De Recerca de L'Energia De Catalunya, Inst. of Electrochemistry and Energy Systems	
Website:	http://www.durablepower.eu/index.php

Project and objectives

The focus of the project was to contribute to SOFC breakthrough marketing process by increasing the stack longevity without losing efficiency. To start from the state-of-art achievements with the purpose of reinvest the knowledge for the sake of technology, the consortium has a strong industrial core balanced by the scientific partners with the common goal to solve the most urgent issues and then to increase the life span of the SOFC stacks. The main strategy:

1) to improve the knowledge on degradation mechanisms

2) to refine the predictive models

3) to introduce interactive counteractions

Major project achievements

- Improved descriptive and predictive models: electrochemical behaviour, mechanical behaviour, degradation rate according to specific failures
- Positive effect of improved diffusion barrier in cells; introduction of improved glass-ceramic sealant in real stacks
- Realisation of the Serious Game "The Lost Colony: an Energy game" as a dissemination tool for schools about hydrogen and renewable energy

Future steps

- Project finished

Non-quantitative objectives and status

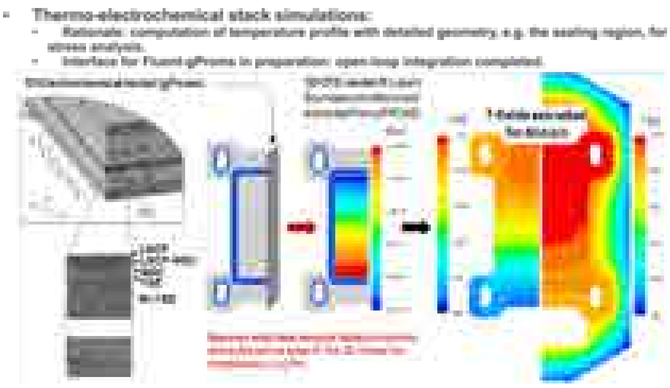
- Improved glass-ceramic as sealing material
  Completed. Two new formulations were selected out of 20 and applied to final short stacks for statistical validation
- Knowledge on electrodes and electrolytes evolution in operating cells
  Advances in the study of evolution of single elements and of interfaces between elements of a cell
- Introduction of advanced virtual research communication tools (VRIMS)
  Development and use of VRIMS products: Book of Samples; Knowledge Pool and Handbook of Experiments
- Advanced Testing Method: Intensive Active Tests and Analyses (IATA)
  Development and Application of IATA - successfully approbated on cells, stacks, modelling data; demonstrates increased sensibility towards degradation

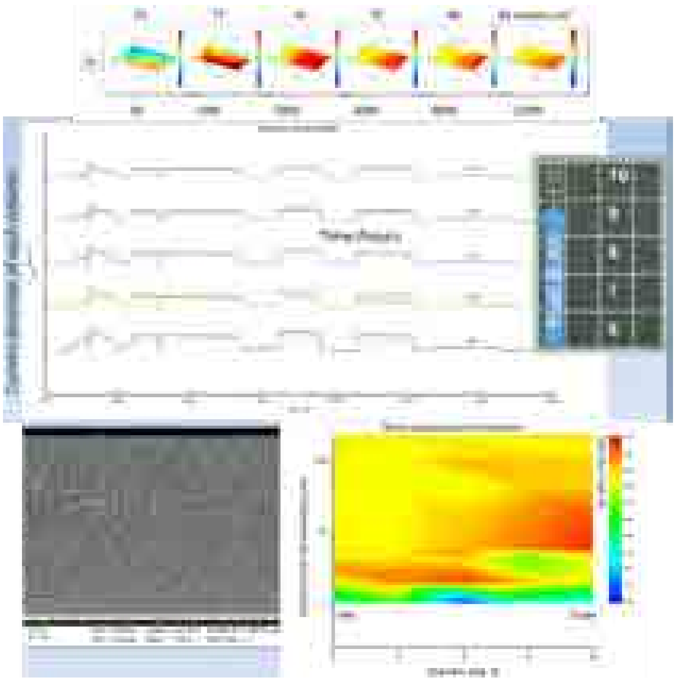
Relevant to FCH JU overarching objectives

- Increase the electrical efficiency and the durability of the different fuel cells used for power production to levels which can compete with conventional technologies, while reducing costs
- Demonstrate on a large scale the feasibility of using hydrogen to support integration of renewable energy sources into the energy systems, including through its use as a competitive energy storage medium for electricity produced from renewable energy sources

Quantitative targets and status

Target Source	Parameter	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
AIP 2013	Failure Mode and Effects Analysis				Achieved	The FMEA was turned into Degradation Rate & Mode and Effects analysis. Literature and research data collected to reach an higher degree of awareness
AIP 2013	Nr thermal cycles	50	50	50	Achieved	Complete short stacks tested from room to operating temperature
AIP 2013	Nr of idle to load cycles	100	100	100	Achieved	Complete short stacks at operating temperature





EG-04-17-700-EN-P

EVOLVE
Evolved materials and innovative design for high-performance, durable and reliable SOFC cell and stack

Panel 4 — Research activities for stationary applications

Acronym:	EVOLVE
Project ID:	303429
Title:	Evolved materials and innovative design for high-performance, durable and reliable SOFC cell and stack
Call Topic:	SP1-JTI-FCH.2011.3.1
Project total costs (€):	€ 5,7 million
FCH JU maximum contribution (€):	€ 3,1 million
Project start/end:	01 Nov 2012 - 31 Jan 2017
Coordinator:	DLR, Deutsches Zentrum fuer Luft und Raumfahrt, Germany
Beneficiaries: Alantum Europe, Ceraco Ceramic Coating, Ceramic Powder Technology, Saan Energi, Ass. pour la Recherche et le Developpement des Methodes et Processus Industriels - Armines, Consiglio Nazionale delle Ricerche CNR, Inst. Polytechn. Grenoble	
Website:	http://www.evolve-fcell.eu/

Project and objectives

Beyond the state of the art, the EVOLVE cell concept aims at combining the beneficial characteristics of the previous cell generations, the so called ASC and MSC (anode-supported or metal-supported cells) while tackling key challenges like sulphur poisoning and redox stability. The innovation of the EVOLVE cell concept remains in its anode compartment avoiding the use of pure nickel as structural component. The substrate, providing mechanical strength to the fuel cell, is based on a robust metal alloy 3D porous backbone enhancing stability during re-oxidation cycles and an electronic conducting material based on perovskite oxides

Major project achievements

- Cell Architecture with processing route demonstrating significant power density demonstrated at Stack level
- Superior redox tolerance against state of the art anode supported cells demonstrated
- Technology at competitive cost compared to other High Temperature Fuel Cell technologies

Future steps

- Project finished

Non-quantitative objectives and status

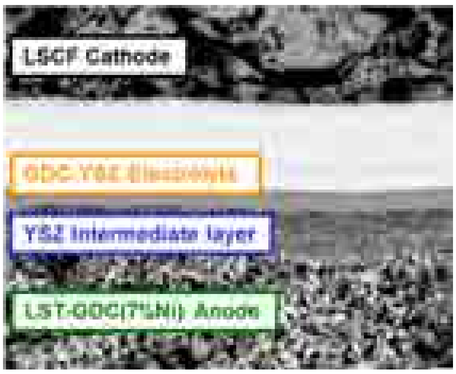
- Next generation cell and stack
  Achieved: Novel architecture with breakthrough manufacturing route demonstrated

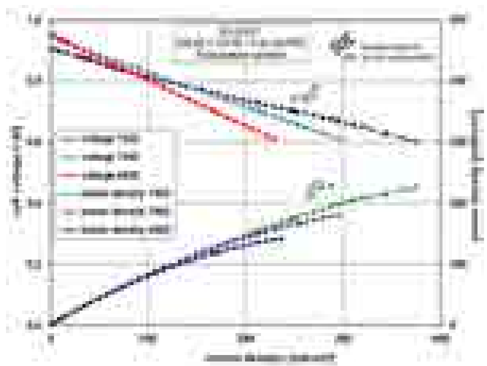
Relevant to FCH JU overarching objectives

- Increase the electrical efficiency and the durability of the different fuel cells used for power production to levels which can compete with conventional technologies, while reducing costs

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
Project's own	Lifetime in terms of red-ox cycles	cycles	1	50	54	54	Achieved	Isothermal redox cycles (750°C) Cell voltage variation < 2%. Power Density at 0,7 V varied by 30% max.
AIP 2011	Materials consumption for the electrolyte	mg/cm^2	20	5	3	3	Achieved	$1.2 mg/cm^2$ of yttria stabilised zirconia + $1.5 mg/cm^2$ of gadolina doped ceria
MAIP 2008-2013	Degradation rate of cell voltage s	% / 1000 h	1	0.25	30	30	Not achieved	Need to mature the architecture and understand the degradation processes. Not achievable in the frame of the project





EG-04-17-700-EN-P

FERRET
A flexible natural gas membrane reformer for m-CHP applications

Panel 4 — Research activities for stationary applications

Acronym:	**FERRET**
Project ID:	621181
Title:	A flexible natural gas membrane reformer for m-CHP applications
Call Topic:	SP1-JTI-FCH.2013.3.3
Project total costs (€):	€ 3,2 million
FCH JU maximum contribution (€):	€ 1,7 million
Project start/end:	01 Apr 2014 - 31 Mar 2017
Coordinator:	Tech. Uni. Eindhoven, The Netherlands
Beneficiaries: Hygear, ICI Caldaie, Johnson Matthey., Politec. Milano, Fundacion Tecnalia Research & Innovation	
Website:	http://www.ferret-h2.eu/
Linkedin:	Membrane Reactors

Project and objectives

The FERRET project aimed at improving the technology based on membrane reactors and test a fully functional reactor for use in a µ-CHP unit suitable for different qualities of natural gas found across Europe.

FERRET objectives

- Design a flexible reformer in terms of catalyst, membranes and control for different natural gas compositions
- Use hydrogen membranes to produce pure hydrogen and help with shifting all the possible H_2 production reactions towards the desired products.
- Scale up the new H_2 selective membranes and catalyst production
- Introduce ways to improve the recyclability of the membrane

Major project achievements

- Novel catalyst produced for fluidised beds
- A new type of membrane has been produced and patented
- The fluidized bed membrane reactor system has been proven at TRL 5

Future steps

- Project finished

EG-04-17-700-EN-P

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
MAIP 2008-2013	Lower emissions and use of multiple fuels	%			100		Achieved	System flexible for different NG qualities
MAIP 2008-2013	Overall efficiency CHP units	%	80	90	80	80	Not achieved	Only reformer was functional
MAWP 2014-2020	Cost per system (1kWe + household heat).	€	20,000	5,000	5,500	5,500	Achieved	Cost could be achieved for mass production or slightly higher µ-CHP system sizes. With ceramic-supported membranes the cost is < the target
AIP 2013	Proof-of-Concept of CHP applications within laboratory.	TRL	3	5	5	5	Achieved	Prototype built and tested
AIP 2013	Durability	h	0	1000	300	300	Not achieved	
select	Length	cm	15	20	20	20	Achieved	

Non-quantitative objectives and status

- Novel catalyst for NG reforming in fluidized beds
- New types of membranes
  We have developed a new kind of membrane that is more resistant than the standard one. We have patented the new double skin membrane

Relevant to FCH JU overarching objectives

- Increase the electrical efficiency and the durability of the different fuel cells used for power production to levels which can compete with conventional technologies, while reducing costs

FLUIDCELL
Advanced m-CHP fuel cell system based on a novel bio-ethanol fluidized bed membrane reformer

Acronym:	**FLUIDCELL**
Project ID:	621196
Title:	Advanced m-CHP fuel cell system based on a novel bio-ethanol fluidized bed membrane reformer
Call Topic:	SP1-JTI-FCH.2013.3.4 &SP1-JTI-FCH.2013.3.3
Project total costs (€):	€ 4,2 million
FCH JU maximum contribution (€):	€ 2,5 million
Project start/end:	01 Apr 2014 - 30 Apr 2017
Coordinator:	Fundacion Tecnalia Research & Innovation, Spain
Beneficiaries: Hygear, ICI Caldaie, Politec. Milano, Tech. Uni. Eindhoven, Uni. Porto, Uni. Salerno, Commissariat à l'Energie Atomique et aux Energies Alternatives CEA, Quantis Sàrl	
Website:	http://www.fluidcell.eu/

Project and objectives

The FluidCELL project aims at developing an advanced µ-CHP fuel cell system for decentralized off-grid applications. The new µ-CHP will be based on a novel bio-ethanol fluidised bed catalytic membrane reformer working at low temperature (≤ 500ºC) and the most advance technology at the fuel cell level.

Main progresses up to date:

- Catalyst & membranes for bio-ethanol reforming prototype developed
- Bioethanol steam reforming in a CMR under fluidisation validated at lab-scale and model validated
- Pilot scale reformer built (membranes should be integrated)
- Fuel cell stack prototype manufactured

Major project achievements

- Fluidised Bed Membrane Reactor concept validated at lab-scale (TRL 4). Phenomenological model validated.
- Prototype membrane reactor system built (membranes should be integrated in). Catalyst and membranes for prototype manufactured.
- Fuel cell stack manufactured

Future steps

- Prototype reactor final assembling, testing and validation
- Manufacturing the FC stack
- Proof of Concept of the novel µ-CHP system, integrating the new reactor prototype and FC stack with optimised BoP (at least 1000 h testing)
- Technical economic assessment and optimization of both reactors and complete system
- Life Cycle Analysis and safety analysis

Quantitative targets and status

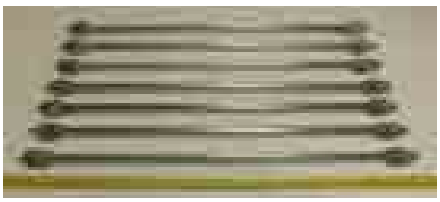
Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
MAIP 2008-2013	Overall efficiency mCHP unit	%	80	90	NA	90	Due later	To be confirmed end of the project; simulations show it is possible to achieve this
MAIP 2008-2013	Cost per system (1kWe + household heat)	€	20,000	5,000			Due later	Cost could be achieved for mass production or slightly higher µ-CHP system sizes
AIP 2013	Durability in continuous operating	h	0	1000	0	1000	Due later	70,000 h operation on other µ-CHP. None of them have a CMR as reformer

Non-quantitative objectives and status

- Lower emissions and use of multiple fuels
  Bio-ethanol as fuel (instead of LPG or Diesel). Production of H_2 validated at lab-scale
- Novel catalyst for bio-ethanol reforming
  Catalyst for the prototype developed. Novel catalyst for bio-ethanol reforming under moderate conditions (<500ºC) and fluidisation has been developed
- Development of long (>15 cm) and mechanically stronger H_2-selective membrane
  Pd-based membranes developed onto 50 cm long thicker ceramic porous supports
- Membrane scale-up, processing issues
  40 membranes around 40 cm long 10/4 mm Out and Inner diameter have been manufactured
- Membrane reactor
  FBMR concept validated at lab-scale (TRL 4). Phenomenological model validated

Relevant to FCH JU overarching objectives

- Increase the electrical efficiency and the durability of the different fuel cells used for power production to levels which can compete with conventional technologies, while reducing costs
- Increase the energy efficiency of production of hydrogen mainly from water electrolysis and renewable sources while reducing operating and capital costs, so that the combined system of the hydrogen production and the conversion using the fuel cell system can compete with the alternatives for electricity production available on the market



HEALTH-CODE
Real operation PEM fuel cells HEALTH-state monitoring and diagnosis based on dc-dc COnverter embeddeD Eis

Panel 4 — Research activities for stationary applications

Acronym:	**HEALTH-CODE**
Project ID:	671486
Title:	Real operation PEM fuel cells HEALTH-state monitoring and diagnosis based on dc-dc COnverter embeddeD Eis
Call Topic:	FCH-02.3-2014
Project total costs (€):	€ 2,3 million
FCH JU maximum contribution (€):	€ 2,3 million
Project start/end:	01 Sep 2015 - 31 Dec 2018
Coordinator:	Uni. Salerno, Italy
Beneficiaries: Bitron, Ballard Power Systems Europe, Electro Power Systems Manufacturing, Uni. Technol. Belfort Montbeliard, Uni. Franche-Comte, Aalborg Uni., Torino E-District Consorzio, Eifer Europaisches Inst. fur Energieforschung, Absiskey	
Website:	http://pemfc.health-code.eu/

Project and objectives

HEALTH-CODE aims at improving and validating in emulated real operations an advanced monitoring and diagnostic tool capable of evaluating the state-of-health and extrapolating lifetime of Polymer Electrolyte Membrane Fuel Cell systems (PEMFCs). The focus of the project is related to μ-Combined Heat and Power and backup applications. The tool is based on the use of suitable data derived from Electrochemical Impedance Spectroscopy (EIS) measurements performed during systems operation. HEALTH-CODE also aims at reducing experimental campaign time and costs by means of innovative scaling-up methodology.

Major project achievements

- Completion of the first experimental campaign on both stack technologies with the measurements of about 1200 EIS spectra in normal and faulty states
- Design and preliminary testing of the Second Generation of the EIS board and the Low Voltage DC/DC converter
- Design and preliminary testing on project data of the different algorithms accounted for the Monitoring and Diagnostic Tool

Future steps

- Completion of the Second Experimental Campaign on both stack technologies and with respect to the remaining faults to be tested
- Delivery of High Voltage DC/DC converter and testing its functionalities as well as communication and performance with EIS board
- Improvement of diagnostic algorithms on new data from the project and thorough assessment of performances
- Testing of Scaling-up algorithm on whole project data for final performance assessment and validation
- Integration of designed power electronics, EIS board and diagnostic algorithm on systems and validation tests

Non-quantitative objectives and status

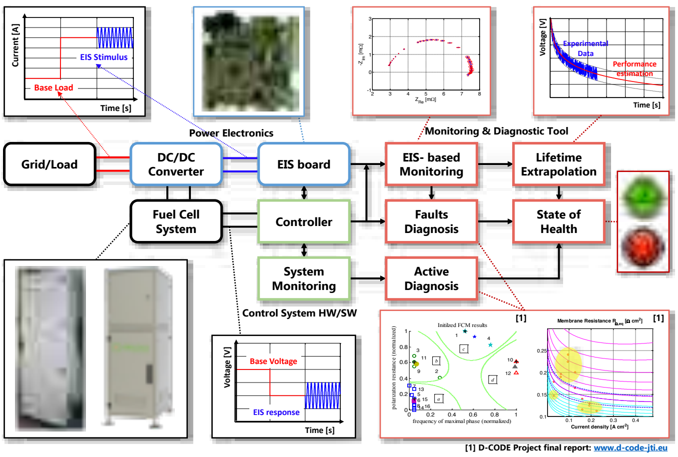
- Enhanced Monitoring and Diagnostic Tool for PEMFC systems
  Activities on time; first results achieved on data acquired in the project; further tests are ongoing upon availability of new data from the project
- EIS board cost <3% of the overall system manufacturing cost
  The final design of the EIS board fulfilled the requirement of cost being under the 3% of the overall cost of both residential and backup systems
- Backup system designed to be coupled with electrolyser
  The tests on O_2-fed backup system has been performed with respect to all the faults accounted in the project
- EIS to estimate features at cell level to monitor their time evolution
  Methodologies for State-of-Health and lifetime assessment have been designed and preliminary tested upon available project data

Relevant to FCH JU overarching objectives

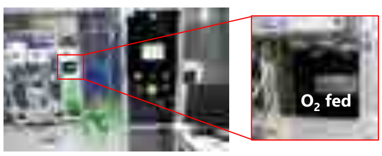
- Increase the electrical efficiency and the durability of the different fuel cells used for power production to levels which can compete with conventional technologies, while reducing costs

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
MAWP 2014-2020	Efficiency	%	32	36	32	36	Due later	Proper fault diagnosis will reduce voltage decay over the working time.
MAWP 2014-2020	Durability	years	1.71	2.28	1.71	2.28	Due later	Proper fault diagnosis will reduce voltage decay over the working time.
MAWP 2014-2020	Availability	%	98	99	98	99	Due later	Increase in the mean time between failures

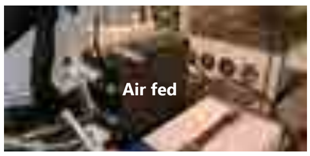


EPS short stack @ UFC



EIS spectra acquired so far: Around **1200** of which **25% in nominal conditions** and **75% in faulty operations**

BPSE stack @ AAU



BPSE stack @ EIFER

MATISSE
Manufacturing improved stack with textured surface electrodes for stationary and CHP applications

Acronym:	**MATISSE**
Project ID:	621195
Title:	Manufacturing improved stack with textured surface electrodes for stationary and CHP applications
Call Topic:	SP1-JTI-FCH.2013.3.2
Project total costs (€):	€ 3,2 million
FCH JU maximum contribution (€):	€ 1,7 million
Project start/end:	01 Oct 2014 - 30 Sep 2017
Coordinator:	Commissariat à l'Energie Atomique et aux Energies Alternatives CEA, France
Beneficiaries: Areva Stockage D'Energie, Inhouse Engineering, Nedstack Fuel Cell Technology, Zentrum fuer Sonnenenergie und Wasserstoff-Forschung, Baden-Wuertemberg	
Website:	http://matisse.zsw-bw.de/general-information.html

Project and objectives

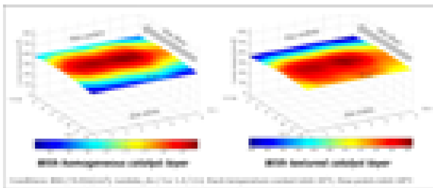
MATISSE is targeting the delivery of PEMFC advanced cells and stacks for stationary applications. Three fuel cell designs are addressed for specific operation i.e. H_2/O_2, H_2/Air and reformate H_2/Air. The methodology is based on the assessment of stacks with improved MEAs, including new compositions and processes developed to validate automated manufacturing. Performance, durability and heterogeneities of reference MEAs with homogeneous electrodes have been analysed before implementing MEAs with textured electrodes, allowing to modify the local operation of the cells and stacks behaviour.

Major project achievements

- Analysis of current distribution and improvement of cells performance by texturing the catalyst layers for 3 conditions (H_2 or Reformate/Air, H_2/O_2)
- Validated transfer to a fully automated process (screen-printing pilot line) for manufacturing large size electrodes of 3 different PEMFC designs
- Successful implementation of reference and textured MEAs showing targeted performance in all cases and expected durability under Reformate or H_2/Air

Future steps

- Complete performance and durability tests in short stacks with textured electrodes
- Validation of automated manufacturing of textured electrodes to be implemented in short or full stacks
- Validation of automated assembling with the MEAs for the full stacks and final tests
- Cost assessment for the different stacks with last selected type of electrodes and MEAs
- Description of automated stacking machine with analysis and feasibility of adaptation to different design



Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
MAIP 2008-2013	Electrical efficiencies for power unit (µ-CHP reformate H_2/Air)	%	34	43			Not yet addressed	Improved performance at short stack level with reference MEAs and textured electrodes
MAIP 2008-2013	Electrical efficiencies for power unit (power plant H_2/air)	%	45	50			Not yet addressed	Improved performance at short stack level with reference MEAs and textured electrodes
MAIP 2008-2013	Electrical efficiencies for power unit (smart grid H_2/O_2)	%	45	47			Not yet addressed	Improved performance at short stack level with reference MEAs and textured electrodes
MAIP 2008-2013	lifetime for cells and stack (mCHP reformate/air)	hrs		40,000	10,000		Due later	Lower degradation rate in reformate /air case. Achieved: ≤10.000 h (based on decay rate of 15microV/h and power loss of 20%)
MAIP 2008-2013	lifetime for cells and stack (power plant H_2/air)	hrs		20,000			Due later	Lower degradation rate with improved electrodes under specific AST cycles H_2/Air ~ 350hrs and ~90µV/h
MAIP 2008-2013	lifetime for cells and stack (smart grid H_2/O_2)	hrs		40,000			Due later	durability of new MEAs to be tested
AIP 2013	Reduced stack components costs						Due later	Cost assessment to be done for final MEAs developed with textured electrodes and automated processes

Non-quantitative objectives and status

- Validate automated manufacturing of MEAs for cost reduction
  Electrodes by screen-printing pilot line successfully implemented in 3 stack designs for industrial applications (reformate or pure H_2/Air and H_2/O_2)
- Analysis of local operation for understanding and cells improvement
  In-situ analysis of current density distribution using segmented plates in specific performance and ageing conditions for 3 PEMFC technologies
- Develop textured electrodes to improve MEA performance and robustness
  Modified current distribution and improved cells behaviour demonstrated with non-homogeneous active layers in 3 types of short stacks
- Validation of new electrodes under specific ageing conditions
  MEAs tested on the long term (>4000hrs) under Reformate/Air or with AST cycles under H_2/Air reached expected degradation rates (15 or 90µV/h)

Relevant to FCH JU overarching objectives

- Increase the electrical efficiency and the durability of the different fuel cells used for power production to levels which can compete with conventional technologies, while reducing costs

EG-04-17-700-EN-P

NELLHI
New all-European high-performance stack: design for mass production

Panel 4 — Research activities for stationary applications

Acronym:	**NELLHI**
Project ID:	621227
Title:	New all-European high-performance stack: design for mass production
Call Topic:	SP1-JTI-FCH.2013.3.2
Project total costs (€):	€ 2,8 million
FCH JU maximum contribution (€):	€ 1,6 million
Project start/end:	01 May 2014 - 30 Apr 2017
Coordinator:	ENEA, Agenzia Nazionale per le Nuove Tecnologie, l'Energia e lo Sviluppo Economico Sostenibile, Italy
Beneficiaries: Borit, Clausthaler Umwelttechnik Inst., Aktsiaselts Elcogen, Sandvik Materials Technology, VTT, VTT, Elcogen, Flexitallic Ltd	
Website:	http://www.nellhi.eu/

Project and objectives

NELLHI combines European know-how in single cells, coatings, sealing, and stack design to produce a novel modular 1 kW SOFC stack at reduced temperature, of unprecedented performance. The stack has been developed over 3 successive generations according to system integrators' requirements guided by an industrial advisory group. The target application of the development is stationary and residential combined heat and power production based on natural gas, and will form the basis for Elcogen Oy's commercial SOFC stack technology as well as enforce market penetration for component manufacturers.

Major project achievements

- Highest efficiencies achieved for SOFC operated below 700°C
- Cost reductions achieved by designing for mass manufacture and low-cost materials
- Advanced knowledge gained on cell processes, sealing materials and interconnect oxidation behaviour

Future steps

- Project finished

Non-quantitative objectives and status

- Improve capacity and maturity of all-European SOFC stack supply chain Industrial partners specializing in specific stack components have increased reliability, capacity and know-how

Relevant to FCH JU overarching objectives

- Increase the electrical efficiency and the durability of the different fuel cells used for power production to levels which can compete with conventional technologies, while reducing costs

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
MAIP 2008-2013	Electrical efficiency	%	50	60	74	74	Achieved	Measured with natural gas for Elcogen 1 kW stack; Achieved thanks to: innovative stack design, high manufacturing quality and optimized operation
MAIP 2008-2013	Stack cost	€/kW	10000	1000	1000	1000	Achieved	At >50MW/year stack production volume
Project's own	Durability	h	2000	10000	10000	30000	Not achieved	projected through current measurement with natural gas for Elcogen 1 kW stack
Project's own	Leak rate	%	1.00	0.50	0.30	0.30	Achieved	After 10 thermal cycles
Project's own	fuel utilization capability	%	70	85	91	91	Achieved	Measured with H_2 Achieved thanks to innovative stack design
Project's own	manufacturing yield	%	90	95	97	97	Achieved	For stacks. Achieved thanks to innovative design allowing component imperfections
Project's own	voltage loss	%	1	0.50	0.60	0.60	Not achieved	After 10 thermal cycles.
Project's own	Cell cost	€/kW		300	280	280	Achieved	For cells these results were obtained after a series of experiments optimising all manufacturing process steps.
Project's own	interconnect cost	€/kW		200	290	290	Not achieved	At 100k pieces per year.
Project's own	manufacturing yield	%	90	95	95	96	Achieved	Achieved thanks to simplified design, optimized material, volume

PROSOFC
Production and reliability oriented SOFC cell and stack design

Panel 4 — Research activities for stationary applications

Acronym:	**PROSOFC**
Project ID:	621216
Title:	Production and reliability oriented SOFC cell and stack design
Call Topic:	SP1-JTI-FCH.2012.3.2
Project total costs (€):	€ 7,3 million
FCH JU maximum contribution (€):	€ 3,0 million
Project start/end:	01 May 2013 - 31 Oct 2017
Coordinator:	AVL List, Austria
Beneficiaries: Danmarks Tek. Uni., Dynardo Austria, Forschungszentrum Julich, Htceramix, Imperial College Science Technol. and Medicine, Ecole Polytechnique Federale de Lausanne, Karlsruher Inst. Technol., JRC -Joint Research Centre, European Commission, Topsoe Fuel Cell	
Website:	http://prosofc-project.eu/

Project and objectives

PROSOFC directly contributes to the FCH JU objectives "Improved cell and stack design and manufacturability for application specific requirements", with the following targets for stationary SOFC systems:

- lifetime > 40.000h
- electrical efficiency 55%+, total efficiency 85%+
- commercial cost target of 4000 EUR/kW

The aim of the project is to significantly improve the stack robustness and decrease costs.

Major project achievements

- Identification of most critical failure modes for the considered baseline SOFC stack design
- Evaluation and implementation of design enhancement to improve reliability and durability
- Creation of a methodological and tooling framework to be used in future projects

Future steps

- Long term stack testing
- Demonstration of the methodology by applying the sensitivity analysis (based on optSlang) on the stack models (e.g. of EPFL or AVL)
- Finalization of reliability calculation
- Material and cell tests

Non-quantitative objectives and status

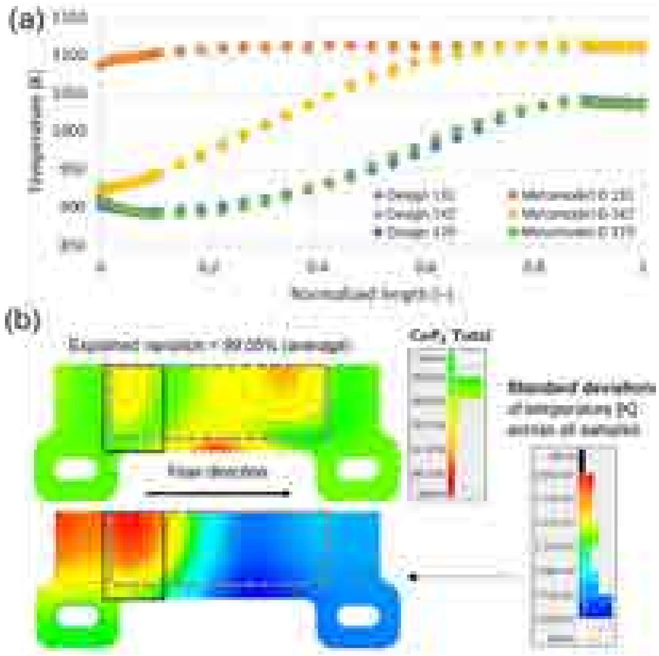
- Better robustness, better lifetime, improved manufacturing methods Major failure modes and sources identified (glass seal breakage/ delamination, loss of contact). Design alternatives proposed and implemented

Relevant to FCH JU overarching objectives

- Increase the electrical efficiency and the durability of the different fuel cells used for power production to levels which can compete with conventional technologies, while reducing costs

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
MAIP 2008-2013	Electrical efficiency (SOFC system)	%	45	55	55	56	Achieved	Objective attained on the system, achieving 55% electrical efficiency net AC at 1.5kW
MAIP 2008-2013	Lifetime/Durability (SOFC System)	h	0	40,000	13,000	17,500	Due later	Durability mostly impacted by external factors (infrastructure and system). Robustness clearly improved thanks current project.
MAIP 2008-2013	Cost vs starting value (SOFC system)	%	100	50	50	40	Achieved	Cost reduction @ stack and system level.
MAIP 2008-2013	Improved manufacturing methods / Stack scrap rate: 5% by 2017	%	NA	95	88	92	Due later	Increasing quality requirements limit yield. Cost reduction efforts limit yield additionally on certain components (e.g. cells)
MAIP 2008-2013	Higher power density	W/cm²	0.32	0.30	0.32	0.32	Achieved	



SCORED 2:0
Steel coatings for reducing degradation in SOFC

Panel 4 — Research activities for stationary applications

EG-04-17-700-EN-P

Acronym:	**SCORED 2:0**
Project ID:	325331
Title:	Steel coatings for reducing degradation in SOFC
Call Topic:	SP1-JTI-FCH.2012.3.4
Project total costs (€):	€ 3,8 million
FCH JU maximum contribution (€):	€ 2,2 million
Project start/end:	01 Jul 2013 - 30 Jun 2017
Coordinator:	Uni. Birmingham, United Kingdom
Beneficiaries: ENEA, Agenzia Nazionale per le Nuove Tecnologie, l'Energia e lo Sviluppo Economico Sostenibile, Solidpower, Ecole Polytechnique Federale de Lausanne, VTT, VTT, Turbocoating, Teer Coatings Ltd	
Website:	http://www.birmingham.ac.uk/research/activity/scored/index.aspx

Project and objectives

High temperature corrosion is a crucial problem in operating solid oxide fuel cell (SOFC) systems. In particular, the chromium poisoning of the air electrode (cathode) is recognised as one of more serious contributions to the performance degradation of SOFC devices. The project aimed at testing different coating materials and processes to apply protective coatings to stainless steel SOFC interconnects to reduce chromium release on cathode side interconnect surfaces. A succession of 5 generations of different coating materials were tested. The project ends in June 2017.

Major project achievements

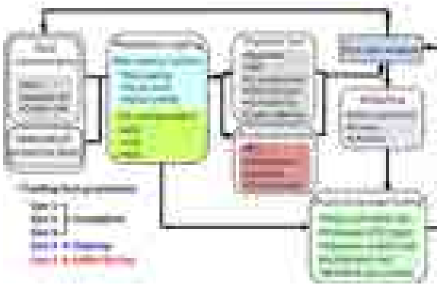
- Proof-of-concept stacks have been operated, one >11,000 hours, the second still ongoing to prove the effectiveness of coating and coating processes
- Degradation of G3 and G5 coatings lead to degradation rates <0.3%/kh
- Proof that several coating techniques will lead to satisfactory solutions

Future steps

- Project finished

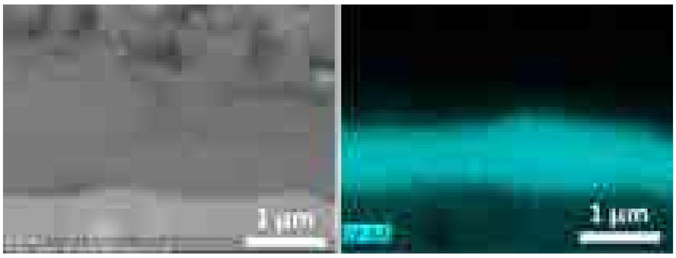
Relevant to FCH JU overarching objectives

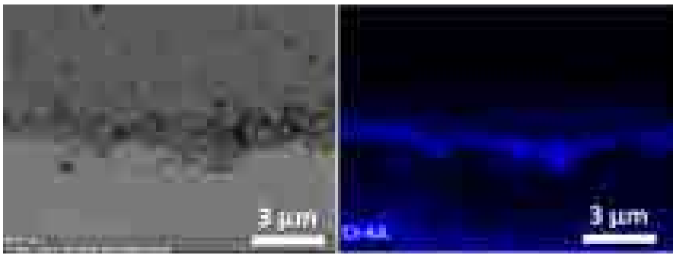
- Reduce the production cost of fuel cell systems to be used in transport applications, while increasing their lifetime to levels which can compete with conventional technologies
- Increase the electrical efficiency and the durability of the different fuel cells used for power production to levels which can compete with conventional technologies, while reducing costs

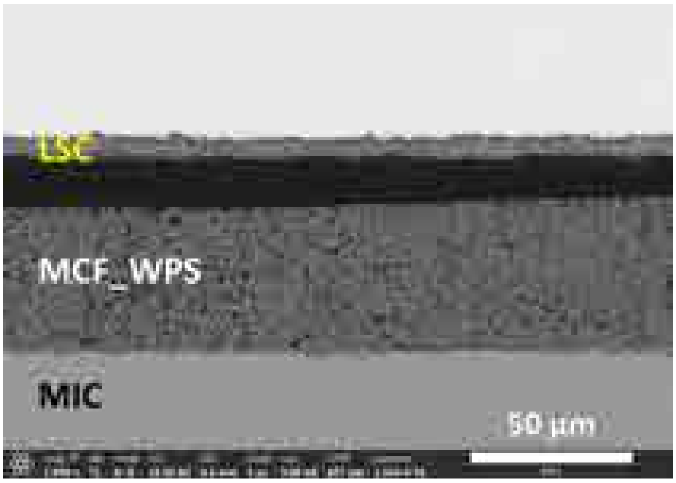


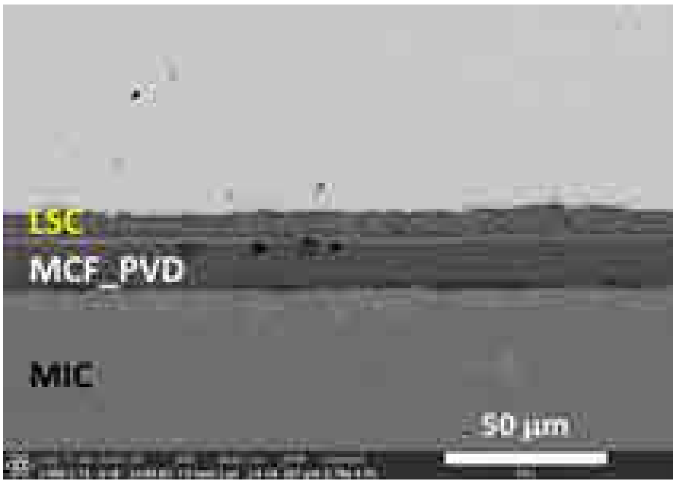
Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
Project's own	testing duration	hours	3,000	10,000	11,000	>11,000	Achieved	testing proof-of-concept stack
Project's own	ASR of protective layer	mΩ cm²	40	40	40	40	Achieved	ASR better than pre-coated Sandvik steel









SECOND ACT

Simulation, statistics and experiments coupled to develop optimized and durable µCHP systems using accelerated tests

Acronym:	**SECOND ACT**
Project ID:	325331
Title:	Simulation, statistics and experiments coupled to develop optimized and durable µCHP systems using accelerated tests
Call Topic:	SP1-JTI-FCH.2013.3.1
Project total costs (€):	€ 4,6 million
FCH JU maximum contribution (€):	€ 2,5 million
Project start/end:	01 May 2014 - 31 Oct 2017
Coordinator:	Commissariat à l'Energie Atomique et aux Energies Alternatives CEA, France
Beneficiaries: DLR, Deutsches Zentrum fuer Luft und Raumfahrt, Ici Caldaie, EWII Fuel Cells, Nedstack Fuel Cell Technology, Politec. Milano, JRC -Joint Research Centre, European Commission, Tech. Uni. Graz, Stiftelsen Sintef	
Website:	http://second-act.eu/

Project and objectives

Second Act is focused on degradation understanding and proposal of modified stack components for improved durability of PEM fuel cell systems operating under Hydrogen, Reformate, or Direct Methanol. Modelling and experimental characterisations during or post-ageing allowed to identify mechanisms and causes for reversible or non-reversible losses mainly related to the catalysts. New cathode catalyst and catalyst layers made with various local compositions along the cells surface were implemented in cells or stacks and showed improved stability during long term or accelerated ageing tests.

Major project achievements

- Integration of a new cathode catalyst leading to reduced degradation rates for cells and stacks aged in the different conditions of the project
- Local data analyses and modelling allowed to define non-homogeneous active layers mitigating localized degradations & improving performance stability
- Successful modelling of non-reversible or reversible mechanisms allowing to simulate local operation within catalyst layers during ageing

Future steps

- Complete ageing tests on the long term with modified electrodes implemented in H_2 and reformate PEMFC stacks
- Finalize demonstration of improved stability for gradient DMFC MEAs at larger scale in real size cell
- Complete analyses of long term ageing data
- Complete validation of degradation models and related simulation of performance losses
- Complete post-ageing analyses on modified electrodes for further interpretation

Relevant to FCH JU overarching objectives

- Increase the electrical efficiency and the durability of the different fuel cells used for power production to levels which can compete with conventional technologies, while reducing costs
- Demonstrate on a large scale the feasibility of using hydrogen to support integration of renewable energy sources into the energy systems, including through its use as a competitive energy storage medium for electricity produced from renewable energy sources

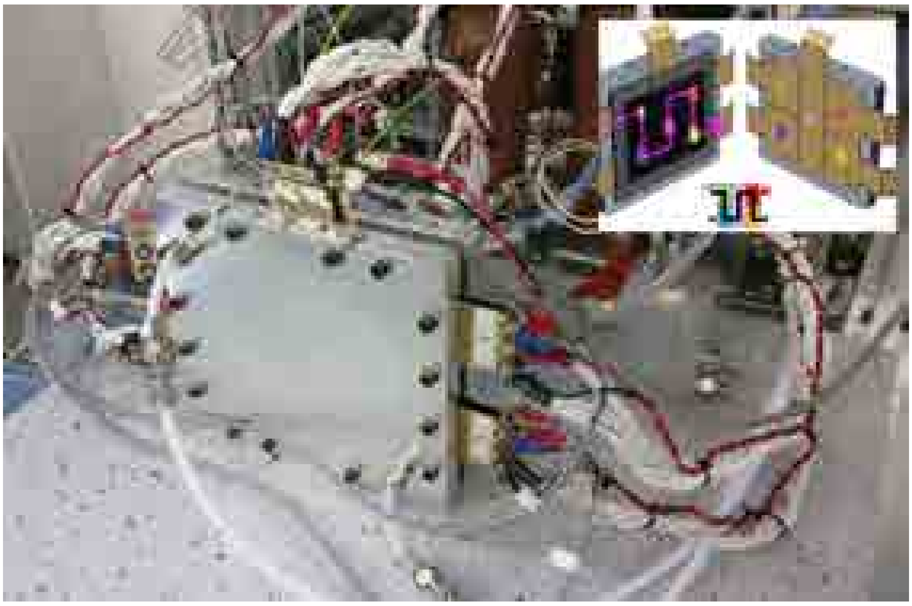
EG-04-17-700-EN-P

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
MAIP 2008-2013	~ 100 MW installed electric capacity	kW					Not yet addressed	outcomes are related to the operation and data exploitation of different stacks (more than 80kW total) + installation of one new system of 2-3kW
MAIP 2008-2013	Cost for micro CHP	€/kW		4000-5000			Not yet addressed	Cost reduction considered through improved durability with better stability and robustness of the fuel cells
MAIP 2008-2013	Cost for industrial / commercial units	€/kW		1500-2500			Not yet addressed	Cost reduction considered through improved durability with better stability and robustness of the fuel cells
AIP 2013	Long-term degradation observations	hrs	20,000	20,000	12,300	15,000	Due later	Focus was on the investigation of ref and modified MEAs aged on the long term, with specific or accelerated tests and comparing the degradation rates

Non-quantitative objectives and status

- Understanding of cell/stack degradation for H_2 & Reformate PEMFC; DMFC
  In-situ and post-ageing analyses on reference and modified components. Integration of mechanisms in cell models and validation of their impact
- Demonstrating improvements thanks to core components modifications
  Demonstration of less performance losses with new cathode catalyst and modified catalyst layers with non-homogeneous compositions along the surface
- Collection, production and analysis of ageing data (3 FC types)
  Ageing tests performed on several cells and stacks including continuous data collection and analysis of reversible and permanent losses vs conditions
- Quantification of mechanisms (experimental and models) & verification of improvement
  Application of selected accelerated or specific tests and mitigation strategies, for the assessment of mechanisms' impact and of modified electrodes



SOSLeM
Solid Oxide Stack Lean Manufacturing

Panel 4 — Research activities for stationary applications

Acronym:	**SOSLeM**
Project ID:	700667
Title:	Solid Oxide Stack Lean Manufacturing
Call Topic:	FCH-02.6-2015
Project total costs (€):	€ 2,9 million
FCH JU maximum contribution (€):	€ 2 million
Project start/end:	01 Apr 2016 - 31 Mar 2019
Coordinator:	Solidpower, Italy
Beneficiaries: Greenlight Innovation, Htceramix, AVL List, Athena, Ecole Polytechnique Federale de Lausanne	
Website:	www.soslem.eu

Project and objectives

SOSLeM aims at reducing manufacturing costs for SOFC stacks by about 70%, while at the same time making production more resource efficient and realising environmental benefits by:

- Optimising the production of SOFC cassettes by lean manufacturing processes, improved sealing adhesion and using automated anode contact layer laser welding
- Improving stack preparation by advanced glass curing, stack conditioning and improved gas stations
- Enabling environmental benefits by on-site nickel removal from wastewater
- Implementing a large furnace arrangement and a multi-stack production station

Major project achievements

- Reduction of manufacturing costs for stack production
- Enable of environmental benefits through removal of Co-based powder from the stack manufacturing process

Future steps

- Implementation of cassettes produced with new welding process
- SOFC stack conditioning with new stack qualification test station in SOLIDpower's production line

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
MAWP 2014-2020	Manufacturing costs for stack production	€/kW	4,500	981	3,108	1,500	Due later	This parameter summarises most of the activities of the SOSLeM project

Non-quantitative objectives and status

- Enable environmental benefits:
  - Replacement of Co-based powder
  - Evaluation of On-site Nickel removal from wastewater

Relevant to FCH JU overarching objectives

- Increase the electrical efficiency and the durability of the different fuel cells used for power production to levels which can compete with conventional technologies, while reducing costs

PANEL 5
HYDROGEN PRODUCTION, DISTRIBUTION AND STORAGE: RESEARCH AND VALIDATION

BIG HIT
Building Innovative Green Hydrogen systems in an Isolated Territory: a pilot for Europe

Panel 5 — Hydrogen production, distribution and storage: research and validation

EG-04-17-700-EN-P

Acronym:	**BIG HIT**
Project ID:	700092
Title:	Building Innovative Green Hydrogen systems in an Isolated Territory: a pilot for Europe
Call Topic:	FCH-03.2-2015
Project total costs (€):	€ 7,2 million
FCH JU maximum contribution (€):	€ 5,0 million
Project start/end:	01 May 2016 - 30 Apr 2021
Coordinator:	Fundacion para Desarrollo de las Nuevas Tecnologias del Hidrogeno en Aragon, Spain

Beneficiaries:
Calvera Maquinaria E Instalaciones, The Scottish Hydrogen And Fuel Cell Association Ltd, Danmarks Tek. Uni., Shapinsay Development Trust, Community Energy Scotland Ltd, Ministry for Transport and Infrastructure, Malta, Orkney Islands Council, Giacomini, Symbiofcell, ITM Power (Trading), The European Marine Energy Centre Ltd

Website:	https://www.bighit.eu/
Linkedin:	BIG HIT
Twitter:	@H2BIGHIT

Project and objectives

BIG HIT will create a replicable hydrogen territory in Orkney (Scotland) by implementing a fully integrated model of hydrogen production, storage, transportation and utilisation for heat, power and mobility. It will absorb curtailed energy from two wind turbines and tidal turbines and use 1.5MW of PEM electrolysis to convert it into ~50 t/year of hydrogen. This will be used to heat two local schools, and transported by sea to Kirkwall in hydrogen trailers where it will be used to fuel a 75kW fuel cell and a refuelling station.

Major project achievements

- None reported

Future steps

- None reported

Relevant to FCH JU overarching objectives

- Increase the electrical efficiency and the durability of the different fuel cells used for power production to levels which can compete with conventional technologies, while reducing costs
- Increase the energy efficiency of production of hydrogen mainly from water electrolysis and renewable sources while reducing operating and capital costs, so that the combined system of the hydrogen production and the conversion using the fuel cell system can compete with the alternatives for electricity production available on the market
- Demonstrate on a large scale the feasibility of using hydrogen to support integration of renewable energy sources into the energy systems, including through its use as a competitive energy storage medium for electricity produced from renewable energy sources

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
AIP 2015	Develop a Hydrogen Territory in at least one EU isolated territory	1	0	1	0.2	1	Due later	New possibility to Orkney in order to increase RES penetration by H_2
AIP 2015	Co-involve at least 1 follower territory	1	0	1	0	1	Due later	Malta
AIP 2015	Electrolysis power	MW	0	1.5	0.50	1.5	Due later	One electrolyser built (0.5MW). 1MW PEMWE delayed in the groundworks for commissioning
AIP 2015	HRS in operation	1	0	1	0	1	Due later	The HRS is built but is delayed in the groundworks for commissioning
Project's own	2 x 30 kW catalytic H_2 boilers for heating 2 Orkney schools	kW	0	60	0	60	Due later	First boiler built and tested, to be sent when groundworks at the Shapinsay school are finished
Project's own	Nr electric vans with FC range extender		0	10	5	10	Due later	First five H_2 vans are in Orkney
Project's own	75kW FC in operation in Orkney harbour	kW	0	75	75	75	Achieved	Built, waiting for H_2 production to start operation
Project's own	2 Multi Element Gas Containers - H_2 storage		0	2	2	2	Achieved	Built (200 bar & 270 kg), waiting for H_2 production to start
Project's own	Reduction of curtailed energy	GWh/yr	0	-2.7	0	-2.7	Due later	Through conversion of wind & tidal generation
Project's own	Reduction of GHG emissions by 330 t/year	t/yr	0	-330	0	-330	Due later	Through reduction of diesel

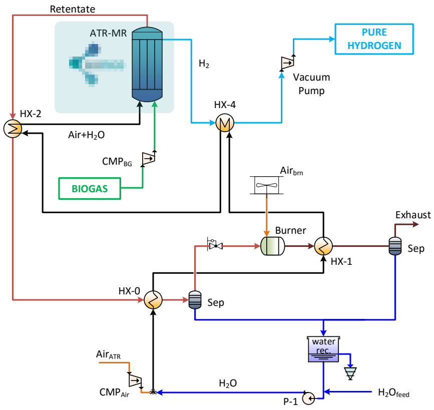
BIONICO
BIOgas membrane reformer for deceNtralIzed hydrogen produCtiOn

Panel 5 — Hydrogen production, distribution and storage: research and validation

Acronym:	**BIONICO**
Project ID:	671459
Title:	BIOgas membrane reformer for deceNtralIzed hydrogen produCtiOn
Call Topic:	FCH-02.2-2014
Project total costs (€):	€ 3,4 million
FCH JU maximum contribution (€):	€ 3,1 million
Project start/end:	01 Sep 2015 - 28 Feb 2019
Coordinator:	Politec. Milano, Italy
Beneficiaries: Rauschert Kloster Veilsdorf, Abengoa Hidrogeno, ICI Caldaie, Fundacion Tecnalia Research & Innovation, Johnson Matthey, Tech. Uni. Eindhoven, ENC Energy, ENC Power Lda, Abengoa Research, Quantis	
Website:	http://www.bionicoproject.eu/
Linkedin:	Membrane Reactors

Project and objectives

BIONICO will develop, build and demonstrate at a biogas plant a novel catalytic membrane reactor integrating H_2 production (100 kg/day) and separation in a single vessel. A significant increase of the overall efficiency (up to 72%) and decrease of volumes and auxiliary heat management units is expected. Currently, new highly active PGM doped alumina reforming catalysts to produce H_2 from diverse biogas mixtures has been developed, together with new ceramic-supported tubular membranes stable at high temperature (550-600 °C). The membrane reactor is in the preliminary design phase.

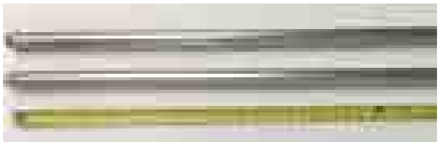


Major project achievements

- Development of highly active, durable and stable reforming catalysts to produce hydrogen from diverse biogas mixture coupled with steam (and air)
- Development of Palladium-based tubular supported membranes, for application in biogas reforming catalytic membrane reactors
- Identification of the state-of-the-art performance of conventional system for hydrogen production from biogas

Future steps

- Catalyst production for the pilot plant
- Membrane production for the pilot plant
- Design of the pilot plant and definition of the operating conditions
- Assembly of the reactor at the manufacturer site



Quantitative targets and status

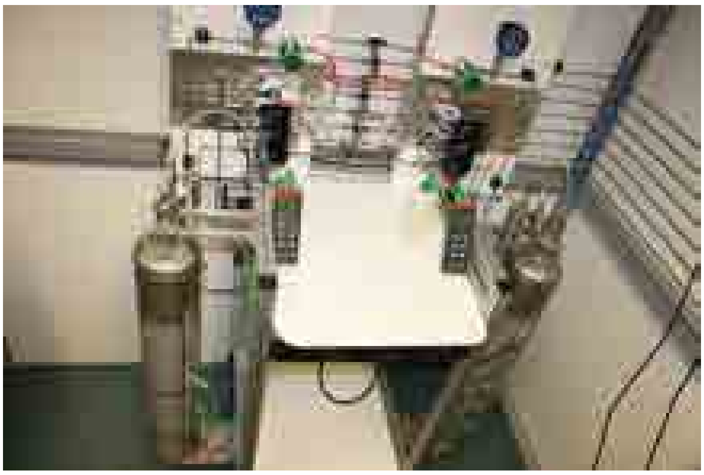
Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
MAWP 2014-2020	H_2 production efficiency	%	59.2	72		70.8	To be addressed	Preliminary simulation results
AIP 2014	H_2 production in a single step	step	4	1	1	1	Achieved	Demonstrated at lab scale
AIP 2014	Demonstrate BIONICO concept at a landfill plant delivering 100 kg/day	kg/day	0	100		100	To be addressed	
Project's own	Development, test, manufacturing and scale up of novel Membranes						Due later	Manufacturing and scale up is ongoing
Project's own	Develop, test, manufacturing and scale up of novel catalyst						Due later	Manufacturing and scale up is ongoing

Non-quantitative objectives and status

- Strengthen collaboration between partners
  Master student exchange between Politecnico di Milano and TUE

Relevant to FCH JU overarching objectives

- Increase the energy efficiency of production of hydrogen mainly from water electrolysis and renewable sources while reducing operating and capital costs, so that the combined system of the hydrogen production and the conversion using the fuel cell system can compete with the alternatives for electricity production available on the market



BIOROBUR
Biogas robust processing with combined catalytic reformer and trap

Panel 5 — Hydrogen production, distribution and storage: research and validation

Acronym:	**BIOROBUR**
Project ID:	325383
Title:	Biogas robust processing with combined catalytic reformer and trap
Call Topic:	SP1-JTI-FCH.2012.2.3
Project total costs (€):	€ 3,8 million
FCH JU maximum contribution (€):	€ 2,4 million
Project start/end:	01 May 2013 - 31 Aug 2016
Coordinator:	Politec. Torino, Italy
Beneficiaries: Erbicol, Pirelli & C. Eco Technology Ro, Scuola Universitaria Professionale Svizzera It., Tech. Uni. Bergakademie Freiberg, Centre for Research and Technology Hellas, Centre National de la Recherche Scientifique CNRS, Hysytech, Uab Modernios E-Technologijos	
Website:	http://www.biorobur.org/

Project and objectives

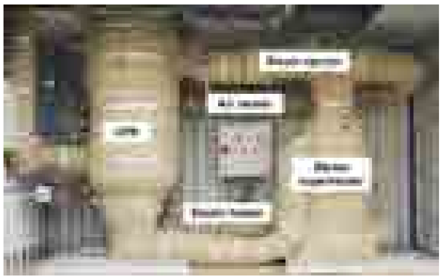
The BioRobur project developed and tested a robust and efficient biogas reformer for hydrogen (H_2) production, with a nominal production rate of 50 Nm3/h (107 kg/h) and an energy efficiency of 65%. The fuel processor employs a catalytic autothermal reforming (ATR) process using a structured catalyst to convert biogas (with no preliminary CO_2 separation) into H_2, with the adoption of a catalytic wall-flow filter located downstream from the ATR processor to effectively filter and gasify in-situ the carbon emissions eventually generated.

Major project achievements

- Development and testing of a robust and efficient decentralised processor based on the ATR of biogas with a nominal production rate of 50Nm3/h of H_2
- System energy efficiency of biogas conversion into green hydrogen of 65%
- Excellent material supports and catalysts with excellent performances were proposed and tested

Future steps

- Project finished



Quantitative targets and status

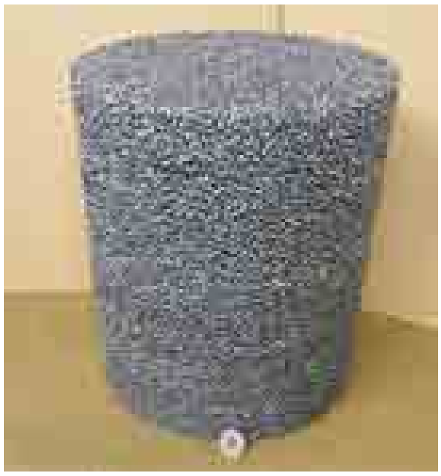
Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
MAIP 2008-2013	Scalability: lab scale to H_2 production level	Nm3/h		50	50	50	Achieved	High thermal conductivity of cellular materials and internal heat generation in the process allowed perfect scale-up
AIP 2012	Nominal production rate pure hydrogen (50-250 kg/day)	kg/day		50-250	107	107	Achieved	Using noble metal - based coated monolith.
AIP 2012	Biogas to hydrogen conversion efficiency	%		65	65	65	Achieved	Target reached in the BioRobur testing campaign
AIP 2012	Materials costs for 50 Nm3/h hydrogen production rate	€		25,000	200,000		Achieved	Reused test rig for pilot scale reformers of up to 250 Nm3/h developed within FP6 EU project
AIP 2012	CO concentration at the reformer exit	% vol	10	9.9	9.9	9.9	Achieved	Target reached with the BioRobur technology.

Non-quantitative objectives and status

- Scale-up: high performance materials supports and catalysts
  Cellular materials adopted and synthesised catalysts for the ATR support and soot trap allowed to a perfect scale-up of the unit
- Manufacture of new supports for biogas ATR
  Innovative supports were designed and tested
- Development and testing a pre-commercial plant for 50Nm3/h of hydrogen
  Developed and tested a pre-commercial plant for H_2 production from the biogas ATR. Plant flexibility demonstrated
- High degree of reactor compactness & design simplification
  Good functionality and proper interaction of the main components demonstrated

Relevant to FCH JU overarching objectives

- Increase the energy efficiency of production of hydrogen mainly from water electrolysis and renewable sources while reducing operating and capital costs, so that the combined system of the hydrogen production and the conversion using the fuel cell system can compete with the alternatives for electricity production available on the market
- Demonstrate on a large scale the feasibility of using hydrogen to support integration of renewable energy sources into the energy systems, including through its use as a competitive energy storage medium for electricity produced from renewable energy sources
- Reduce the use of the EU defined 'Critical raw materials', for instance through low-platinum or platinum-free resources and through recycling or reducing or avoiding the use of rare earth elements



FUEL CELLS AND HYDROGEN JOINT UNDERTAKING

DON QUICHOTE
Demonstration of new qualitative concept of hydrogen out of wind turbine electricity

Acronym:	**DON QUICHOTE**
Project ID:	303411
Title:	Demonstration of new qualitative concept of hydrogen out of wind turbine electricity
Call Topic:	SP1-JTI-FCH.2011.2.1
Project total costs (€):	€ 4,8 million
FCH JU maximum contribution (€):	€ 2,9 million
Project start/end:	01 Oct 2012 - 31 Mar 2018
Coordinator:	Hydrogenics Europe, Belgium
Beneficiaries: Thinkstep, Etablissementen Franz Colruyt, Fast - Federazione delle Associazioni Scientifiche e Tecniche, Hydrogen Efficiency Technol. (Hyet), Tuv Rheinland Industrie Service, Waterstofnet, Icelandic New Energy Ltd, JRC -Joint Research Centre, European Commission	
Website:	http://www.don-quichote.eu/

Project and objectives

Don Quichote demonstrates the technical and economic viability of an integrated hydrogen storage system for renewables linked to H_2 refuelling and re-electrification assets. The commercial opportunity connecting intermittent renewable electricity to transport applications is assessed by Total Cost of Ownership analysis (TCO). By demonstrating the impact on efficiency and costs of the operations of a logistics centre, the project demonstrates the market readiness of the H_2-components needed for storing renewable energy. The innovative components are a 150kW PEM electrolyser and a 120kW PEM fuel cell.

Major project achievements

- Development, construction, delivery and site operation of a PEM electrolyser (30 Nm³/h, 10 bar)
- Development, construction and operation of a Fuel Cell outdoor system (120kW)
- LCA analysis performed

Future steps

- Continuous monitoring of extension including PEM electrolyser and fuel cell stack
- Construction and on-site installation of a new compressor
- Performance monitoring of the system with a new compressor (final Phase)
- Complete outstanding deliverables
- Closing event

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
AIP 2011	Well to tank efficiency	%		55	58	60	Achieved	Electrolyser system: 70% (full production); compressor: 85% in steady state
AIP 2011	Cost of hydrogen delivered	€/kg		15	13	11	Achieved	Intermittent operation & low H_2 demand → > energy/cost overhead vs optimal case.
AIP 2011	ISO/DIS 14786-2 compliant	Y/N		no	no	yes	Achieved	H_2 quality compliant to fuelling standard
AIP 2011	Availability	%		95	94	97	Due later	Up-time not yet achieved in all (monthly) periods due to corrective maintenance measures/inactivity
Select	Operational hours	hr	0	25,000	16,000	22,000	Due later	Mission time (ready for production) not sufficient
AIP 2011	durability	yrs		10	3	4	Not yet addressed	Post-project lifetime assured

Non-quantitative objectives and status

- Develop a portfolio of sustainable hydrogen production
  Power based (energy supply side) steering of both PEM and alkaline water electrolysis
- R&D in innovative hydrogen production and supply chains
  PEM and FC units constructed and in operation
- Storage processes meeting increasing H_2-demand
  High pressure (450 bar) carbon fibre storage solution implemented
- Distribution processes for end-use
  80-100 refuelling every month since start of operation

Relevant to FCH JU overarching objectives

- Increase the energy efficiency of production of hydrogen mainly from water electrolysis and renewable sources while reducing operating and capital costs, so that the combined system of the hydrogen production and the conversion using the fuel cell system can compete with the alternatives for electricity production available on the market
- Demonstrate on a large scale the feasibility of using hydrogen to support integration of renewable energy sources into the energy systems, including through its use as a competitive energy storage medium for electricity produced from renewable energy sources

ECo
Efficient Co-Electrolyser for Efficient Renewable Energy Storage

Panel 5 — Hydrogen production, distribution and storage: research and validation

EG-04-17-700-EN-P

Acronym:	**ECo**
Project ID:	699892
Title:	Efficient Co-Electrolyser for Efficient Renewable Energy Storage
Call Topic:	FCH-02.3-2015
Project total costs (€):	€ 3,2 million
FCH JU maximum contribution (€):	€ 2,5 million
Project start/end:	01 May 2016 - 30 Apr 2019
Coordinator:	Danmarks Tek. Uni., Denmark
Beneficiaries: Vdz G, Htceramix, Belgisch Laboratorium van de Elektriciteitsindustrie, Enagas, Fundacio Inst. De Recerca de L'Energia De Catalunya, Eifer Europaisches Inst. fur Energieforschung, ENGIE, Ecole Polytechnique Federale de Lausanne, Commissariat à l'Energie Atomique et aux Energies Alternatives CEA	
Website:	http://www.eco-soec-project.eu/
Twitter:	@ECo_SOEC

Project and objectives

The ECo Project aims at utilising electricity from renewable sources for production of storage media via electrolysis of steam & CO_2 through solid oxide electrolysis.

Objectives/Status:

- Cell improvement/First candidates through design of structures developed
- Durability under realistic co-electrolysis operating conditions/ Benchmark tests performed in different operation modes
- Integration of the SOEC with input electricity & CO_2 and catalytic hydrocarbon production & economic evaluation/Model established
- LCA: Ongoing
- Test of a co-electrolysis system under realistic conditions/Under development

Major project achievements

- Solid oxide cells were developed based on electrode structure design
- Benchmark co-electrolysis durability tests were carried out at different operation modes
- System layout of power-to-methane system including realistic CO_2 sources and capture technologies was established

Future steps

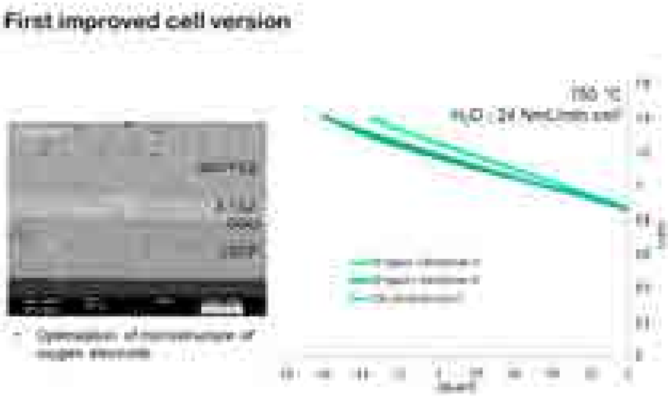
- Verification of improved cells
- Durability mapping under relevant conditions
- High pressure performance and durability testing
- Analysis and optimization of most promising specific system designs

Relevant to FCH JU overarching objectives

- Increase the energy efficiency of production of hydrogen mainly from water electrolysis and renewable sources while reducing operating and capital costs, so that the combined system of the hydrogen production and the conversion using the fuel cell system can compete with the alternatives for electricity production available on the market
- Demonstrate on a large scale the feasibility of using hydrogen to support integration of renewable energy sources into the energy systems, including through its use as a competitive energy storage medium for electricity produced from renewable energy sources

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
Project's own	Area specific resistance at 750 °C	Ohm cm²	0.60	0.20	0.34	0.2	Due later	Materials development and structural optimisation
Project's own	Durability	%/1000 h	3	1	2	1	Due later	Development of more stable cells and mapping of critical (for degradation) operation parameters
Project's own	Co-electrolysis temperature for -1.3 A/cm² at 10 bar	°C	800	750		750	Due later	No results published (only in house reports), project will deliver first results
Project's own	High pressure co-electrolysis durability	% realised	0	100	10	100	Due later	No durability results published, project will deliver first results
Project's own	System test	% realised	0	100	0	100	Not yet addressed	No durability results published, project will deliver first results
Project's own	Potential practical system-design case studies	% realised	0	100	20	100	Due later	Development of process concepts for specific cases - power to gas (or liquid) incl. all sources & final hydrocarbon production
Project's own	Economic analysis	% realised	0	100	0	100	Due later	Case and competition analysis for the proposed plant
Project's own	LCA	% realised	0	100	10	100	Due later	Consideration of various CO_2 and electricity sources of fossil or renewable origin



EDEN
High energy density Mg-based metal hydrides storage system

Panel 5 — Hydrogen production, distribution and storage: research and validation

Acronym:	**EDEN**
Project ID:	303472
Title:	High energy density Mg-based metal hydrides storage system
Call Topic:	SP1-JTI-FCH.2011.2.4
Project total costs (€):	€ 2,6 million
FCH JU maximum contribution (€):	€ 1,5 million
Project start/end:	01 Oct 2012 - 30 Jun 2016
Coordinator:	Fondazione Bruno Kessler, Italy
Beneficiaries: Mbn Nanomaterialia, Panco - Physikalische Technik Anlagenentwicklung & Consulting, Uni. La Laguna, Cidete Ingenieros, JRC -Joint Research Centre, European Commission, Matres	
Website:	http://www.h2eden.eu/

Project and objectives

The EDen project aimed to develop a POWER-to-POWER system consisting of:

(1) a new storage material with high hydrogen storage capacity, for distributed level applications, included on

(2) a specifically designed storage tank, integrated with

(3) an energy provision system able to match local energy sources with energy demand in form of reversible solid oxide cell.

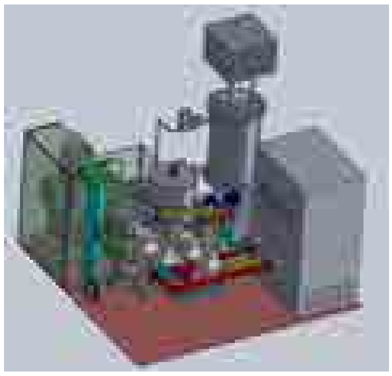
The technology was demonstrated in Barcelona, installed in a facility of the Energy Agency of the City. The final net cycle efficiency of the system was 25%

Major project achievements

- Mg-based powder produced by High Energy Ball Milling, with 7.1 wt.% H_2/MH storage capacity and desorption rate > 1 gH2/min/kg at 320 °C and 1.2 bar
- Intermediate and full storage tanks realized, integrated of thermal and hydrogen management able to release more than 1,5 litres per minute
- Full scale POWER TO POWER system, using HT electrolyser / fuel cell and solid state integrated storage, with integrated fuel and thermal management

Future steps

- Project finished



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Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
Project's own	Cost of hydrogen storage considering 100 cycles	€/kg	800	500	500	300	Achieved	Nr of performed cycles to increase in last demo period
AIP 2011	Material storage capacity	wt. %	5.50	6.00	7.10	7.10	Achieved	Target material also with H_2 sorption density > 80 kgH2/m², desorption rate > 3g/min
AIP 2011	Material cost	€/kg		30	42	28	Achieved	Demonstrated it could be achieved through hydride mass production (several tons/year)
AIP 2011	H_2 desorption rate	g/min		3	1.50	1.70	Achieved	Important to feed the FC and maintain the power output
AIP 2011	Absorption heat recovery	%		25	26.50	26.50	Achieved	Heat recovered during the electrolysis mode
AIP 2011	Total hydrogen stored	kg		0.60	0.82	0.82	Achieved	Hydrogen stored in the tank at maximum capacity
AIP 2011	Hydrogen volumetric density, material	kg/l		0.08	0.13	0.13	Achieved	Volumetric density of Mg hydride at max. performance
AIP 2011	Hydrogen volumetric density, tank	kg/l		0.04	0.04	0.04	Achieved	H_2 volumetric density including tank structures

Non-quantitative objectives and status

- Training and education of professionals
  PhD Student trained in the electrochemical characterization of SOFC units. He performed physicochemical SOFC studies for EDEN.
- Safety, Regulations, codes and standards
  FCH JU Joint Workshop on Hydrogen Storage, 02/10/13
- Assessment of safety regulations, networking with institutes as PTB, firefighters of Barcelona
- Public awareness
  Five events, including ES and IT press release, interview at RAI and ADA Channel. Special issue "Tutto Scienze" in La Stampa, EU press release on Build up

Relevant to FCH JU overarching objectives

- Reduce the production cost of fuel cell systems to be used in transport applications, while increasing their lifetime to levels which can compete with conventional technologies
- Increase the energy efficiency of production of hydrogen mainly from water electrolysis and renewable sources while reducing operating and capital costs, so that the combined system of the hydrogen production and the conversion using the fuel cell system can compete with the alternatives for electricity production available on the market
- Demonstrate on a large scale the feasibility of using hydrogen to support integration of renewable energy sources into the energy systems, including through its use as a competitive energy storage medium for electricity produced from renewable energy sources

ELECTRA

High temperature electrolyser with novel proton ceramic tubular modules of superior efficiency, robustness, and lifetime economy

Acronym:	**ELECTRA**
Project ID:	621244
Title:	High temperature electrolyser with novel proton ceramic tubular modules of superior efficiency, robustness, and lifetime economy
Call Topic:	SP1-JTI-FCH.2013.2.4
Project total costs (€):	€ 4,0 million
FCH JU maximum contribution (€):	€ 2,2 million
Project start/end:	03 Mar 2014 - 02 Jun 2017
Coordinator:	Uni. et I Oslo, Norway
Beneficiaries: Abengoa Hidrogeno, Agencia Estatal Consejo Superior de Investigaciones Cientificas, Coorstek Membrane Sciences, Marion Technol., CRI EHF, Stiftelsen Sintef	
Website:	http://www.mn.uio.no/smn/english/research/projects/chemistry/electra/index.html

Project and objectives

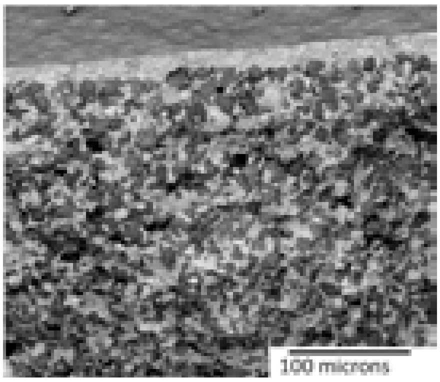
The main objective of the ELECTRA project is to develop robust tubular proton ceramic electrolysers (PCEs) that can produce dry pressurised hydrogen directly from steam, alleviating downstream separation and compression. A scalable and cost-efficient process for producing large quantities of tubular Ni-BZCY/BZCY half-cells has been developed. These have been used to produce fully assembled tubular PCEs with the highest hydrogen production rate reported thus far, implementing a novel steam anode. A techno-economic study of integration with renewable energy sources has been completed.

Major project achievements

- A robust, scalable and cost-efficient processing route for tubular PCE half-cells has been developed to produce high quality tubular segments
- A steam anode material with state-of-the-art performance has been successfully developed and demonstrated with ASR < 0.2 Ohm cm^2 at 700°C
- Step-change improvement in both scale and electrical efficiency of PCE technology using tubular geometry and high steam pressure

Future steps

- Project finishes early June 2017. Mainly final test of co-electrolysis and test of kW-size multi-tubular module remains



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Quantitative targets and status

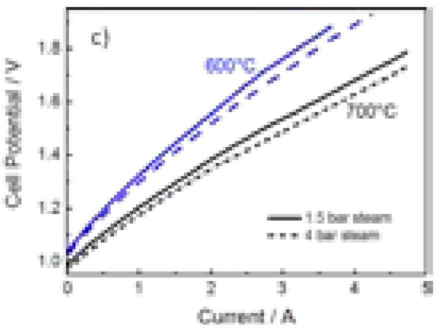
Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
MAIP 2008-2013	Module capacity	L/h	0	250	0	125	Due later	Module designed & commissioned, construction imminent
MAIP 2008-2013	Electrical efficiency	%	30	80	80	80	Achieved	Electrical efficiency for single cell at 0.2 Acm^-2
AIP 2013	Area Specific Resistance (ASR) of cell	Ohm cm^2	10	1	2	2	Delayed	Total ASR over 10 cm^2 tubular cell at 700C
Project's own	Anode ASR	Ohm cm^2	3	0.20	0.20	0.20	Achieved	Polarisation resistance of steam anode at 700°C
Project's own	Conductivity	S cm-1	1	300	1000	1000	Achieved	Conductivity of current collection material
Project's own	Module power	kW	0	1	1	0.50	Due later	Limited by production of tubes

Non-quantitative objectives and status

- Robust and scalable production of tubular PCE half-cells
  Fully optimised production process of extrusion and spray-coating in a cost-efficient process with high yield of defect-free half-cells
- Techno-economic evaluation of PCE integration with renewable energy
  Techno-economic analysis completed
- Proof-of-concept of co-ionic co-electrolysis of CO_2 and H_2O
  Under testing
- Design, commissioning and construction of multi-tube module
  Finalised design in terms of thermal zones and gas flow optimisation, fully commissioned and construction almost completed

Relevant to FCH JU overarching objectives

- Increase the energy efficiency of production of hydrogen mainly from water electrolysis and renewable sources while reducing operating and capital costs, so that the combined system of the hydrogen production and the conversion using the fuel cell system can compete with the alternatives for electricity production available on the market
- Reduce the use of the EU defined 'Critical raw materials', for instance through low-platinum or platinum-free resources and through recycling or reducing or avoiding the use of rare earth elements



ELY4OFF
PEM ElectroLYsers FOR operation with OFFgrid renewable installations

Panel 5 — Hydrogen production, distribution and storage: research and validation

Acronym:	**ELY4OFF**
Project ID:	700359
Title:	PEM ElectroLYsers FOR operation with OFFgrid renewable installations
Call Topic:	FCH-02.1-2015
Project total costs (€):	€ 2,3 million
FCH JU maximum contribution (€):	€ 2,3 million
Project start/end:	01 Apr 2016 - 31 Mar 2019
Coordinator:	Fundacion para Desarrollo de las Nuevas Tecnologias del Hidrogeno en Aragon, Spain
Beneficiaries: Instrumentacion y Componentes, EPIC Power Converters, ITM Power (Trading), Commissariat à l'Energie Atomique et aux Energies Alternatives CEA	
Website:	www.ely4off.eu

Project and objectives

The main goal of the ELY4OFF is the development and demonstration of an autonomous off-grid electrolysis system (PEMWE, 50 kW) linked to renewable energy sources (solar PV), including the essential overarching communication and control system for optimising the overall efficiency when integrated in a real installation. Demonstration in Huesca (Spain) will last 8 months. The progress of the project (13 months of development as of May 1st, 2017) follows the schedule foreseen.

Major project achievements

- Thin membranes have been successfully tested at ITM facilities
- The definitive topology for the DC/DC converter to directly link the PV field with the PEMWE has been identified
- A computer model has been elaborated with Odyssey tool and allows predicting behaviour of the system in different conditions

Future steps

- Completion of PEMWE fabrication
- Completion of DC/DC converter
- Commissioning of all the components of the system at demo site
- Execution of demonstrative period
- Development of the exploitation strategy and business plan

Non-quantitative objectives and status

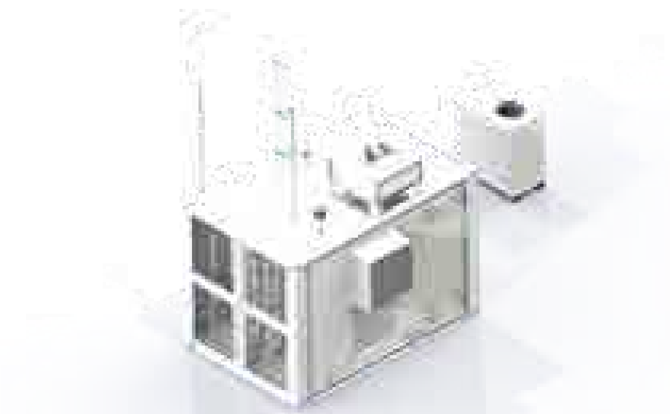
- Development of an overarching control system
  The main specifications were established and more details are in progress
- Identification of eventual RCS barriers
  RCS at demo site were identified, and at EU and international level are expected in the last stage of the project
- To explore potential uses of H_2
  The H_2 produced will be linked to another project were electrical mini buses with H_2 range extender are expected to be deployed in Huesca
- New business model
  Replicable to EU and international environments. To be started during 2017

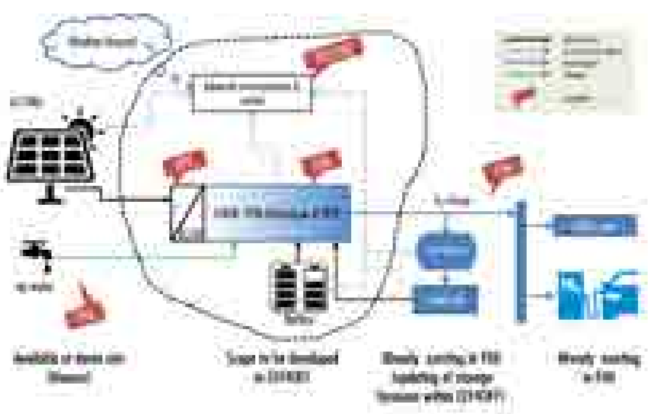
Relevant to FCH JU overarching objectives

- Increase the energy efficiency of production of hydrogen mainly from water electrolysis and renewable sources while reducing operating and capital costs, so that the combined system of the hydrogen production and the conversion using the fuel cell system can compete with the alternatives for electricity production available on the market

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Best est. of final project result	Target: status on May 1st 2017
MAWP 2014-2020	Efficiency at system level	kWh/kg	55	50	50	Not yet addressed
MAWP 2014-2020	Efficiency degradation	%/8000h	2	2	2	Not yet addressed
MAWP 2014-2020	CAPEX	M€/(t/d)	3.7	6	6	Not yet addressed
MAWP 2014-2020	H_2 production flexibility (degradation <2%)	%	5-150	5-150	5-150	Not yet addressed
MAWP 2014-2020	Hot start (min to max power)	seconds	10	2	<3	Not yet addressed
MAWP 2014-2020	Cold start (min to max power)	seconds	<120	<300	<300	Not yet addressed
Project's own	Stack lifetime	h	40000	60000	60000	Not yet addressed
Project's own	Stack capacity	Nm3/h	14	>13	14.2	Not yet addressed
Project's own	Output pressure	bar	20	20	20	Not yet addressed
Project's own	Ramp up (min to full load)	%/s		50	100	Not yet addressed





ELYntegration
Grid Integrated Multi Megawatt High Pressure Alkaline Electrolysers for Energy Applications

EG-04-17-700-EN-P

Acronym:	**ELYntegration**
Project ID:	671458
Title:	Grid Integrated Multi Megawatt High Pressure Alkaline Electrolysers for Energy Applications
Call Topic:	FCH-02.8-2014
Project total costs (€):	€ 3,3 million
FCH JU maximum contribution (€):	€ 1,8 million
Project start/end:	01 Sep 2015 - 31 Aug 2018
Coordinator:	Fundacion para Desarrollo de las Nuevas Tecnologias del Hidrogeno en Aragon, Spain
Beneficiaries: Instrumentacion y Componentes, Iht Industrie Haute Technol., Rheinisch-Westfaelische Tech. Hochschule Aachen, Vlaamse Instelling voor Technol. Onderzoek, Fraunhofer Gesellschaft zur Foerderung der Angewandten Forschung	
Website:	http://www.elyntegration.eu

Project and objectives

ELYntegration is focused in the design and engineering of a robust, flexible and cost-competitive MW-scale alkaline water electrolyser, capable of producing with a single stack up to 4.5 ton /day hydrogen under highly dynamic power supply when high renewable energies shares are considered. The most attractive business models and the assessment on market potential have been implemented. Advanced materials have been developed and tested at micro pilot level. Degradation tests at pilot scale level and demonstration of the industrial prototype in real conditions are planned.

Major project achievements

- Implementation of test bench for testing at pilot scale and design of AST protocols for degradation assessment
- Novel advanced materials for AWE developed (eight structures as separators and two set of electrodes), tested at micropilot scale
- Communication protocols for grid services defined and new potential business models identified

Future steps

- C&CS validated at industrial scale
- Commissioning of advanced stacks: 3 for pilot scale and at least 2 for industrial scale tests
- Accelerated stress tests at pilot scale
- Demonstration of technology at industrial scale and under dynamic profiles coupled to a RE system
- Design of multi MW high pressure alkaline water electrolysis

Non-quantitative objectives and status

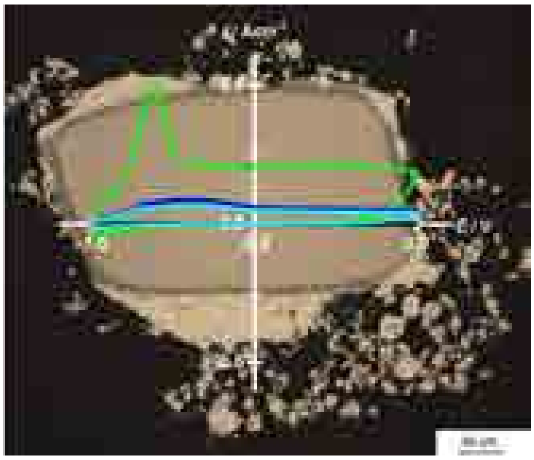
- Communication and control capabilities (C&CS)
  An assessment of the requirements to provide grid and balancing services has been carried out. C&CS will be validated in summer 2017 within WP5
- Regulatory framework and end-user requirements
  The regulatory framework and end user requirements for an electrolyser providing grid services have been carried out
- Business models
  The most attractive business scenarios based on the utilization of the MW HP AWE for grid and energy storage devices have been identified
- Dissemination of the results
  The communication is being made through different channels and taking into account several target audiences in order to maximize the impact

Relevant to FCH JU overarching objectives

- Increase the energy efficiency of production of hydrogen mainly from water electrolysis and renewable sources while reducing operating and capital costs, so that the combined system of the hydrogen production and the conversion using the fuel cell system can compete with the alternatives for electricity production available on the market
- Demonstrate on a large scale the feasibility of using hydrogen to support integration of renewable energy sources into the energy systems, including through its use as a competitive energy storage medium for electricity produced from renewable energy sources

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
MAWP 2014-2020	Efficiency degradation	%/year	2	1.5		1.5	Not yet addressed	Accelerated stress protocols (AS) defined. Test bench implemented
MAWP 2014-2020	Reduction of CAPEX	M€/(t/d)	2.18	1.30	<2.18	<1.30	Due later	Through improvements on stack design, BOP optimisation and manufacturing processes
Project's own	Increase of stack size	kW	3500	9700	0	9700	Not yet addressed	Once validated and demonstrated at prototype level, all advanced constructive features will be integrated in the design of a MW HP AWE system
Project's own	Increase of stack capacity	t/d H_2	1.62	4.50	0	4.50	Not yet addressed	Development of final design according to incremental results from various project tasks
Project's own	Increase of out-put pressure	bar	33	35-60	33	35 (60)	Not yet addressed	60 bar to be tested at pilot scale first. Materials development crucial



FUEL CELLS AND HYDROGEN JOINT UNDERTAKING

GrInHy
Green Industrial Hydrogen via Reversible High-Temperature Electrolysis

Panel 5 — Hydrogen production, distribution and storage: research and validation

EG-04-17-700-EN-P

Acronym:	**GrInHy**
Project ID:	700300
Title:	Green Industrial Hydrogen via Reversible High-Temperature Electrolysis
Call Topic:	FCH-02.4-2015
Project total costs (€):	€ 4,5 million
FCH JU maximum contribution (€):	€ 4,5 million
Project start/end:	01 Mar 2016 - 28 Feb 2019
Coordinator:	Salzgitter Mannesmann Forschung, Germany
Beneficiaries: VTT, Sunfire, Salzgitter Flachstahl, Politec. Torino, Ustav Fyziky Materialu, Akademie Ved Ceske Republiky, Eifer Europaisches Inst. fur Energieforschung, Boeing Research & Technology Europe	
Website:	http://www.green-industrial-hydrogen.com/home/

Project and objectives

Central to the GrInHy project is the manufacturing, integration and operation of the worldwide most powerful reversible high-temperature steam-electrolyzer (HTE) at an integrated iron-and-steel works.

The project objectives comprise the targeted electrical system efficiency of > 80 %_LHV, the upscaling of the HTE towards a power input of 150 kW_AC, the field operation of at least 7,000 h and degradation tests at stack level of > 10,000 h with a degradation rate of < 1 %/1,000 h.

The on-site installation of the GrInHy system started in June. Test operation is planned for July 2017.

Major project achievements

- Separate lab commissioning of both the RSOC and HPU container
- Start of 10,000 h stack testing
- First test results at cell and stack level regarding glass sealing and thermo-mechanical strength; fuel reforming/cleaning test results

Future steps

- Finishing of on-site installation and commissioning of the GrInHy system - both RSOC and Hydrogen Processing Unit container - by end of June 2017
- Starting of test operation in July 2017
- Finishing the 7,000 h test operation in June 2018
- Finishing the 10,000h stack testing in the end of 2018
- Report on techno-economic evaluation of GrInHy concept on cost targeting and evaluation in March 2018

Non-quantitative objectives and status

- Elaboration of an exploitation roadmap for cost reducing measures
  A draft exploitation roadmap has been prepared. It will be updated during the second half of the project
- Development of dependable system cost data
  The first prototype has been set up. Its costs will be analysed in detail to compile a reliable database for future cost estimations
- Integration of a reversible operation mode (fuel cell mode)
  The prototype is designed with the ability to operate in reverse mode as power generator with H2 or NG. This will be proofed during onsite tests

Relevant to FCH JU overarching objectives

- Increase the energy efficiency of production of hydrogen mainly from water electrolysis and renewable sources while reducing operating and capital costs, so that the combined system of the hydrogen production and the conversion using the fuel cell system can compete with the alternatives for electricity production available on the market
- Demonstrate on a large scale the feasibility of using hydrogen to support integration of renewable energy sources into the energy systems, including through its use as a competitive energy storage medium for electricity produced from renewable energy sources

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
MAWP 2014-2020	Overall electrical efficiency	%HHV	68	95		95	Due later	The use of HTE and steam from waste heat will enable the system to achieve highest efficiencies
MAWP 2014-2020	System capacity	kW	75	150		150	Due later	The prototype will comprise a newly designed larger RSOC module
MAWP 2014-2020	Lifetime	h	2000	7000		15000	Due later	The prototype uses a robust design and enhanced cell and stack technology to enable a longer lifetime
Project's own	Degradation	%/kh	1	1		1	Due later	The prototype uses an enhanced cell and stack technology to enable low degradation

HELMETH
Integrated High-Temperature electrolysis and methanation for effective power to gas conversion

Panel 5 — Hydrogen production, distribution and storage: research and validation

EG-04-17-700-EN-P

Acronym:	**HELMETH**
Project ID:	621210
Title:	Integrated High-Temperature electrolysis and methanation for effective power to gas conversion
Call Topic:	SP1-JTI-FCH.2013.2.4
Project total costs (€):	€ 3,8 million
FCH JU maximum contribution (€):	€ 2,5 million
Project start/end:	01 Apr 2014 - 31 Dec 2017
Coordinator:	Karlsruher Inst. Technol., Germany
Beneficiaries: Ethosenergy Italia, European Research Inst. of Catalysis, Nat. Tech. Uni. Athens, Politec. Torino, Sunfire, DVGW Deutscher Verein des Gas- und Wasserfaches - Technisch-Wissenschaftlicher Verein	
Website:	http://www.helmeth.eu/

Project and objectives

The objective of the HELMETH project is the proof of concept of a highly efficient Power-to-Gas technology with methane as chemical storage and by thermally integrating high temperature electrolysis (SOEC technology) with CO2 methanation. The aim is to prove and demonstrate that high temperature electrolysis and methanation can be coupled and thermally integrated towards conversion efficiencies > 85 % from renewable electricity to methane. So far, promising results have been obtained. Pressurized SOEC module has been successfully operated. Methanation module is in commissioning phase.

Major project achievements

- SOEC short stacks tests have been performed at 800°C and pressurised conditions. Degradation rates < 0.5 %/ 1000 h and feasibility of co-electrolysis
- Efficiencies > 85% for large-scale plants based on realistic assumptions and lab tests. SNG quality is met with reactor concept based on lab experiments
- The world's first pressurized SOEC module has been successfully operated. Methanation module is in commissioning phase

Future steps

- Completion of studies related to scale-up and technical harmonization & regulation
- Characterisation of methanation module
- Coupling of methanation and SOEC module. Operation of coupled prototype in the last quarter of 2017

Non-quantitative objectives and status

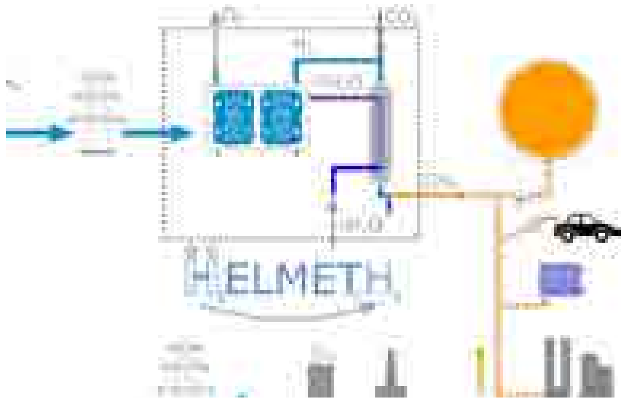
- Manufacture of dedicated HTE cell and stacks for use in large systems
  The developed HTE cells and stack within HELMETH are the suitable basis for upscaling to large systems
- Develop concepts of HTE for use with renewable energy production
  This is the major target of HELMETH. So far promising results have been obtained as described
- Develop concepts for pressurised electrolysis for more economical system
  Pressurized SOEC module has been successfully operated.
- Test & evaluation of cells, stacks and systems under realistic conditions

Relevant to FCH JU overarching objectives

- Increase the energy efficiency of production of hydrogen mainly from water electrolysis and renewable sources while reducing operating and capital costs, so that the combined system of the hydrogen production and the conversion using the fuel cell system can compete with the alternatives for electricity production available on the market
- Demonstrate on a large scale the feasibility of using hydrogen to support integration of renewable energy sources into the energy systems, including through its use as a competitive energy storage medium for electricity produced from renewable energy sources

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
AIP 2013	Current density @ 800-1000°C & pressurised cond.	A/cm²		1	1	1	Achieved	1 A/cm² achieved on cell tests, 0.8 A/cm² at stack level
AIP 2013	Degradation rates for short stacks	%/ 1000 h		0.5	0.43	0.43	Achieved	Degradation rates < 0.5%/1000 h indirectly proven by linear extrapolation based on 320 h of tests + plausibility due to previous long-term tests
AIP 2013	Conversion efficiency from electricity to methane	%		85	86	86	Due later	Detailed simulations including BoP predict a total conversion efficiency of 86% (large scale plant). Operation of final prototype at end of 2017



HPEM2GAS
High Performance PEM Electrolyzer for Cost-effective Grid Balancing Applications

Panel 5 — Hydrogen production, distribution and storage: research and validation

Acronym:	**HPEM2GAS**
Project ID:	700008
Title:	High Performance PEM Electrolyzer for Cost-effective Grid Balancing Applications
Call Topic:	FCH-02.2-2015
Project total costs (€):	€ 3,8 million
FCH JU maximum contribution (€):	€ 2,5 million
Project start/end:	01 Apr 2016 - 31 Mar 2019
Coordinator:	Consiglio Nazionale delle Ricerche CNR, Italy
Beneficiaries: EStadtwerke Emden, Solvay Specialty Polymers Italy, ITM Power (Trading), Hochschule Emden/Leer, Ewii Fuel Cells, Uniresearch, JRC -Joint Research Centre, European Commission	
Website:	www.hpem2gas.eu

Project and objectives

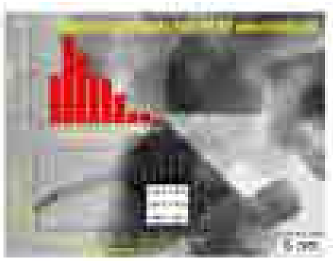
The HPEM2GAS project is developing a high performance PEM electrolysis technology optimised for grid management service (power-to-gas) through both stack and balance of plant innovations, culminating in a six-month field test of an advanced 180 kW (nominal) PEM electrolyser. The project will also contribute significantly to reducing the electrolyser CAPEX and OPEX costs. HPEM2GAS develops key technologies to bring innovative solutions from TRL 4 to 6 and will deliver a techno-economic analysis and an exploitation plan to bring the innovations to market.

Major project achievements

- Achievement of operating current density for PEM electrolysis of 3 A cm-2 at about 80% efficiency
- Reduction of total noble metal catalyst loading per MEA to less than 0.5 mg cm-2
- Development of advanced stack components and design (e.g. Aquivion membranes, stable nanostructured catalysts, advanced stack design)

Future steps

- Validation of the conventional PEM electrolysis system (298 kW) used as baseline to assess the progress achieved in this project
- Large area MEA manufacturing for final PEM electrolysis stack
- Assembling and testing of the final PEM electrolysis stack
- Completion of the BoP for the new system
- Test-site completed



EG-04-17-700-EN-P

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
Project's own	Membrane conductivity for large area membranes	S cm-1	0.15	0.20	0.20	0.25	Achieved	Solvay Aquivion E98-09S membrane of 90 µm. Proton conductivity is >200 mS/cm-1 at T >80°C in presence of liquid water
Project's own	Anode overpotential vs. thermoneutral potential	mV	300	200	200	150	Achieved	IrRuOx solid solutions showed OER overpotential of 153 mV, IR-free, at <80 °C and 3 A/cm2 with noble metal loading <0.4 mg/cm² anode
Project's own	Cathode overpotential vs. RHE at 3 A cm-2 less than:	mV	100	50	50	50	Achieved	2 nm Pt/C catalysts showed HER overpotential of 65 mV at 80 °C and 3 A/cm² with noble metal loading <0.1 mg/cm²
Project's own	Performance of 3 A cm-2 at Ucell<1.8 V under nominal operation	A/cm2	2	3	3	3	Achieved	3 A/cm² @1.81-1.79 V at 80-90 °C, with total noble metal loading per MEA < 0.5 mg/cm²
Project's own	Performance of 4.5 A cm-2 at Ucell<2 V under transient operation	A/cm2	3	4.5	4.5	4.5	Achieved	4.5 A/cm2 @1.92-1.96 V at 80-90 °C, with total noble metal loading per MEA < 0.5 mg/cm²
Project's own	Degradation lower than 5 µV/h/cell in a 1000 h test	µV/h/cell	10	5	5	3	Achieved	Degradation < 5 µV/h/cell in 1000 h test in single cell at 1 A/cm²
Project's own	Electrolysis system with hydrogen capacity > 80 kg H_2/day	kg H2/day		80	80	80	Due later	New HPEM2GAS system under development. Conventional system, 134.4 kg H_2/day operating at a current density about 1 A/cm² reported (TRUST)
AIP 2015	Efficiency better than 82% HHV H_2	%	74	82	82	82	Due later	Target achieved at present only in terms of cell voltage efficiency at 3 A/cm². Complete system testing foreseen later
AIP 2015	Energy consumption lower than 48 kWh/kg H_2.	kWh/kg H2	51.10	48	48	48	Due later	Target achieved at present only in terms of cell voltage efficiency at 3 A/cm². Complete system testing foreseen later
Project's own	Gas cross over <0.5 vol % H_2 in the O_2 stream (faradaic effciency)	%	1	0.5	0.5	0.5	Achieved	Achieved at nominal (not yet at very low) current density. Mitigation strategy addressed for the low current range (recombination cat.)

Non-quantitative objectives and status

- Readiness of setup field testing site
  Detailed engineering and approval by local authorities achieved; analysis of different test scenarios carried out and reported
- Successful demonstration of the electrolysis system in grid balancing
  Planning of the field-test site is progressing well, as well as system and components development
- Final event/demonstration at the field test site
  Organisation of the final event planned in terms of period, location and stakeholders to invite is ongoing

Relevant to FCH JU overarching objectives

- Increase the energy efficiency of production of hydrogen mainly from water electrolysis and renewable sources while reducing operating and capital costs, so that the combined system of the hydrogen production and the conversion using the fuel cell system can compete with the alternatives for electricity production available on the market
- Demonstrate on a large scale the feasibility of using hydrogen to support integration of renewable energy sources into the energy systems, including through its use as a competitive energy storage medium for electricity produced from renewable energy sources
- Reduce the use of the EU defined 'Critical raw materials', for instance through low-platinum or platinum-free resources and through recycling or reducing or avoiding the use of rare earth elements

HyBalance

Panel 5 — Hydrogen production, distribution and storage: research and validation

EG-04-17-700-EN-P

Acronym:	**HyBalance**
Project ID:	671384
Title:	HyBalance
Call Topic:	FCH-02.10-2014
Project total costs (€):	€ 15,6 million
FCH JU maximum contribution (€):	€ 8 million
Project start/end:	01 Oct 2015 - 30 Sep 2020
Coordinator:	Air Liquide Advanced Business, France
Beneficiaries: Neas Energy, Copenhagen Hydrogen Network, Hydrogenics Europe, Ludwig-Boelkow-Systemtechnik, Air Liquide Global E&C Solutions France, Cemtec Fonden	
Website:	www.hybalance.eu
Linkedin:	HyBalance

Project and objectives

HyBalance will demonstrate the link between energy storage in the form of hydrogen and the deployment of hydrogen mobility solutions. It will not only validate the highly dynamic PEM electrolysis technology and innovative hydrogen delivery processes involved but also demonstrate these in a real industrial environment by applying high pressure hydrogen production and delivery equipment. The plant is under construction. The electrolyser has been delivered.

Major project achievements

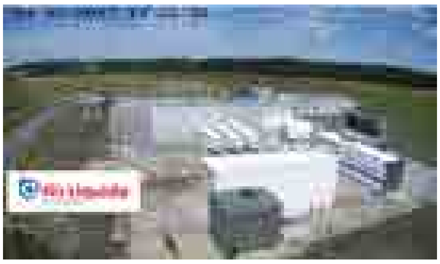
- Factory Acceptance Test validated
- Electrolyser delivered onsite

Future steps

- Site Acceptance Test of the electrolyser
- Site Acceptance Test of the entire plant
- Opening Event

Relevant to FCH JU overarching objectives

- Demonstrate on a large scale the feasibility of using hydrogen to support integration of renewable energy sources into the energy systems, including through its use as a competitive energy storage medium for electricity produced from renewable energy sources



Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
MAWP 2014-2020	Cost goal	€/kW	0	2570	1810	1000	Achieved	Target achieved for installation from 2.5 MW onwards
AIP 2014	Efficiency	kWhel/kgH2		57.5	54	54	Achieved	Unit is designed for >20 khrs performance within this target
AIP 2014	System lifetime	hours		20,000		20,000	Due later	Unit designed for 20 000 hrs with 10% degradation

FCH | FUEL CELLS AND HYDROGEN JOINT UNDERTAKING

HYDROSOL-PLANT
Thermochemical hydrogen production in a solar monolithic reactor: construction and operation of a 750 kWth plant

Panel 5 — Hydrogen production, distribution and storage: research and validation

EG-04-17-700-EN-P

Acronym:	**HYDROSOL-PLANT**
Project ID:	325361
Title:	Thermochemical hydrogen production in a solar monolithic reactor: construction and operation of a 750 kWth plant
Call Topic:	SP1-JTI-FCH.2012.2.5
Project total costs (€):	€ 3,5 million
FCH JU maximum contribution (€):	€ 2,2 million
Project start/end:	01 Jan 2014 - 31 Dec 2017
Coordinator:	Centre for Research and Technology Hellas, Greece
Beneficiaries: Hygear, Centro de Investigaciones Energeticas, Medioambientales y Tecnologicas-Ciemat, Helmholtz-Zentrum Berlin fur Materialien und Energie, Ellinika Petrelaia	
Website:	http://www.hydrosol-plant.certh.gr/

Project and objectives

Within the HYDROSOL PLANT project the development and operation of a plant for solar thermo chemical hydrogen production from water is pursued. The main objectives of HYDROSOL-PLANT are to achieve a material lifetime exceeding 1000 operational hours and to construct a solar hydrogen production demonstration plant in the 750 kWth range to verify the developed technology for solar thermochemical water splitting and demonstrate hydrogen production and storage on site at levels above 3kg/week.

Major project achievements

- Manufacturing of novel redox structures
- Durability testing of structured redox material for over 1000 h of consecutive water splitting and thermal reduction
- Scale-up of reactors. The largest solar redox reactors to date

Future steps

- Completion of solar reactors and peripherals installation, solar plant operation and evaluation of results
- LCA and identification of points for minimal environmental impact of further commercialisation
- Workshop organization

Non-quantitative objectives and status

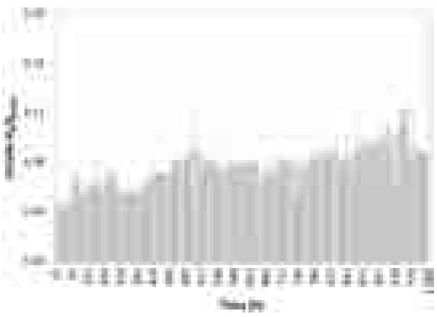
- Modelling and simulation of the plant and of key components
  Objective completed: covers reactants and products conditioning, heat recovery, use of excess/waste heat, monitoring and control
- Field tests of prototype plant
  Installation of the reactors and all peripherals in progress. Thermal and H_2 production experiments will be implemented until the end of the project

Relevant to FCH JU overarching objectives

- Increase the energy efficiency of production of hydrogen mainly from water electrolysis and renewable sources while reducing operating and capital costs, so that the combined system of the hydrogen production and the conversion using the fuel cell system can compete with the alternatives for electricity production available on the market

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
AIP 2012	Material lifetime	h	20	1000	1002		Achieved	Structured monolithic bodies entirely of the redox material
AIP 2012	Solar hydrogen generator scale	MW	0.10	0.75	0.10	0.75	Due later	Lab-scale evaluation corresponding to >6months on-sun operation
AIP 2012	Demonstration of hydrogen production and storage on site	Kg/week	0.1	3.00	3.30	3.00	Due later	Largest solar thermochemical H_2 production facility to date



HyGrid
Flexible Hybrid separation system for H_2 recovery from NG Grids

Panel 5 — Hydrogen production, distribution and storage: research and validation

Acronym:	**HyGrid**
Project ID:	700355
Title:	Flexible Hybrid separation system for H_2 recovery from NG Grids
Call Topic:	FCH-02.5-2015
Project total costs (€):	€ 2,8 million
FCH JU maximum contribution (€):	€ 2,5 million
Project start/end:	01 May 2016 - 30 Apr 2019
Coordinator:	Tech. Uni. Eindhoven, The Netherlands
Beneficiaries: Hygear Technology and Services, Hydrogen Efficiency Technol. (Hyet), Hygear Fuel Cell Systems, Hygear, Saes Getters, Naturgas Energia Distribucion, Quantis, Fundacion Tecnalia Research & Innovation	
Website:	http://www.green-industrial-hydrogen.com/home/

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 will be on the hydrogen separation through a combination of membranes, electrochemical separation and temperature swing adsorption to be able to decrease the total cost of hydrogen recovery. The project targets a pure hydrogen separation system with power and cost of < 5 kWh/kgH2 and < 1.5 €/kgH2. A pilot designed for >25 kg/day of hydrogen.

Major project achievements

- New type of sealing produced and patented
- New membranes produced and tested
- Models have been validated

Non-quantitative objectives and status

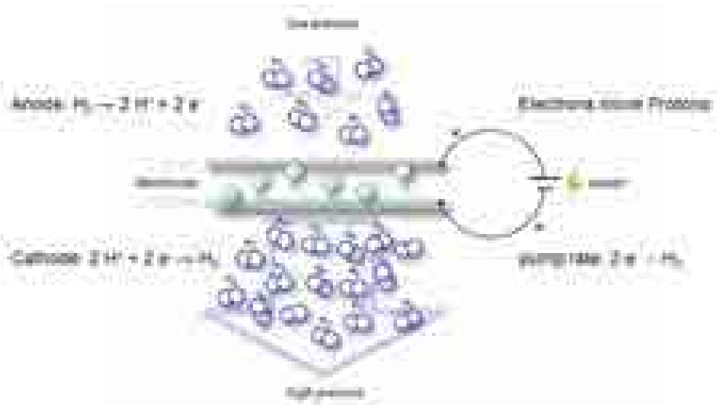
- New types of membrane sealings
  We have developed a new kind of sealing that is more resistant than the standard one. We have patented the new sealing

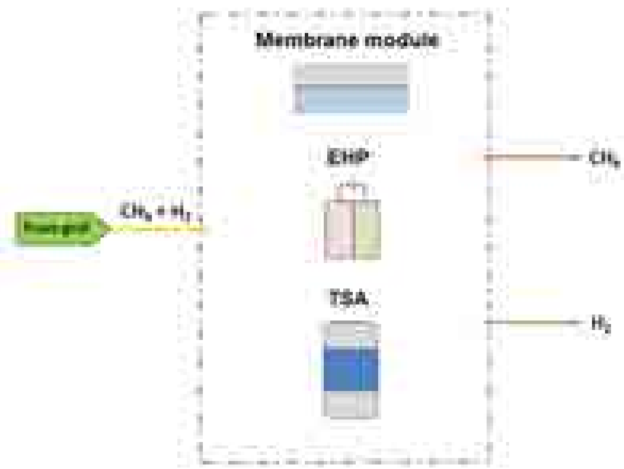
Relevant to FCH JU overarching objectives

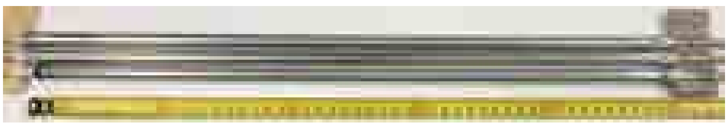
- Increase the electrical efficiency and the durability of the different fuel cells used for power production to levels which can compete with conventional technologies, while reducing costs
- Demonstrate on a large scale the feasibility of using hydrogen to support integration of renewable energy sources into the energy systems, including through its use as a competitive energy storage medium for electricity produced from renewable energy sources

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017
AIP 2015	Pure hydrogen separation system with low power	kWh/kgH2	-	5			Due later
AIP 2015	pure hydrogen separation system with low cost	€/kgH2	-	1.5			Due later
AIP 2015	Pure hydrogen production	kg/day	0	25			Due later
AIP 2012	P rototype unit	TRL	3	5	3	5	Due later







HYTRANSFER
Pre-normative research for thermodynamic optimization of fast hydrogen transfer

EG-04-17-700-EN-P

Acronym:	**HYTRANSFER**
Project ID:	325277
Title:	Pre-normative research for thermodynamic optimization of fast hydrogen transfer
Call Topic:	SP1-JTI-FCH.2012.2.6
Project total costs (€):	€ 3,1 million
FCH JU maximum contribution (€):	€ 1,6 million
Project start/end:	01 Jun 2013 - 31 Dec 2016
Coordinator:	Ludwig-Boelkow-Systemtechnik, Germany
Beneficiaries: Honda R&D Europe (Deutschland), Centre National de la Recherche Scientifique CNRS, Raufoss Fuel Systems, Testnet Engineering, JRC -Joint Research Centre, European Commission, L'Air Liquide, The CCS Global Group Ltd	
Website:	http://www.hytransfer.eu/

Project and objectives

HyTransfer developed and experimentally validated an innovative approach for optimised fast filling of compressed hydrogen, meeting the material temperature limits of the tanks taking into account the container and system's thermal behaviour. The new approach enables faster filling in combination with reduced pre-cooling requirements. Relevant cost savings were identified. The project was concluded in December 2016.

Major project achievements

- Knowledge on thermodynamic effects and behaviour inside pressure vessels during and after fast hydrogen transfer was created
- An innovative new hydrogen refuelling approach was developed. This approach enables faster refuelling by also enabling reduced costs at the HRS

Future steps

- Project finished

Quantitative targets and status

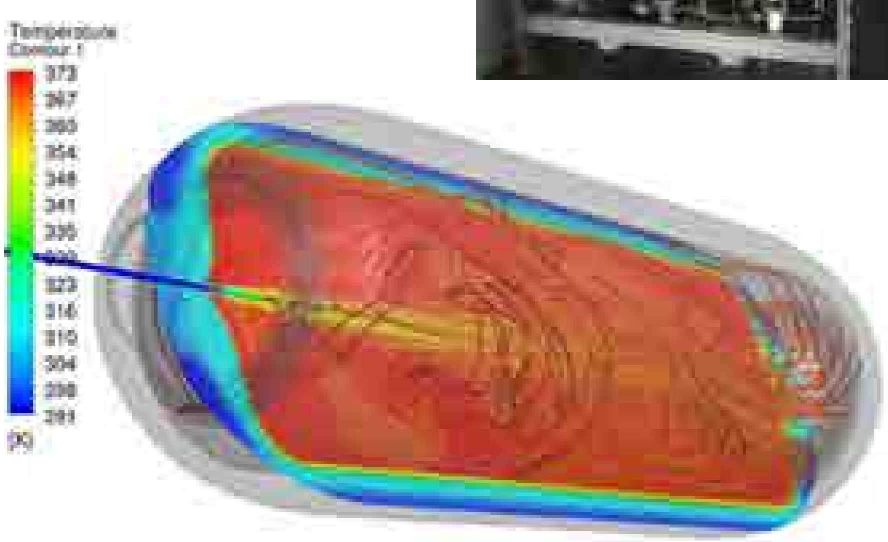
Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
Project's own	typical refuelling duration	minutes	5	3	3	3	Achieved	3 minutes or below for all relevant refuelling conditions

Non-quantitative objectives and status

- Improve thermodynamic knowledge on fast hydrogen refuelling
  Objective achieved. Large-scale experimental campaigns were performed. Different tank sizes and refuelling conditions were considered
- Develop model to predict thermodynamic conditions during refuelling
  Objective achieved. Software model was validated using extensive data from the experimental campaigns
- Develop innovative approach for fast hydrogen refuelling
  Objective achieved. New approach was developed and confirmed by software modelling
- Quantify improvements of new refuelling approach
  Objective achieved. Refuelling time can be reduced while also reducing pre-cooling requirements. Relevant cost savings were identified

Relevant to FCH JU overarching objectives

- Reduce the production cost of fuel cell systems to be used in transport applications, while increasing their lifetime to levels which can compete with conventional technologies
- Increase the energy efficiency of production of hydrogen mainly from water electrolysis and renewable sources while reducing operating and capital costs, so that the combined system of the hydrogen production and the conversion using the fuel cell system can compete with the alternatives for electricity production available on the market



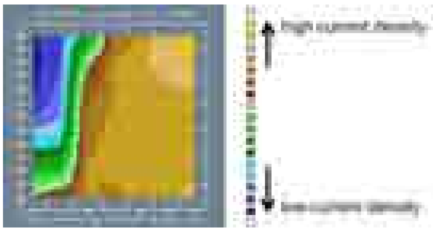
INSIDE
In-situ Diagnostics in Water Electrolyzers

Panel 5 — Hydrogen production, distribution and storage: research and validation

Acronym:	**INSIDE**
Project ID:	621237
Title:	In-situ Diagnostics in Water Electrolyzers
Call Topic:	SP1-JTI-FCH.2013.2.2
Project total costs (€):	€ 3,6 million
FCH JU maximum contribution (€):	€ 2,1 million
Project start/end:	01 Nov 2014 - 31 Oct 2018
Coordinator:	DLR, Deutsches Zentrum fuer Luft und Raumfahrt, Germany
Beneficiaries: Acta, Heliocentris Italy, Centre National de la Recherche Scientifique CNRS, New Nel Hydrogen, Hochschule Esslingen	
Website:	www.inside-project.eu

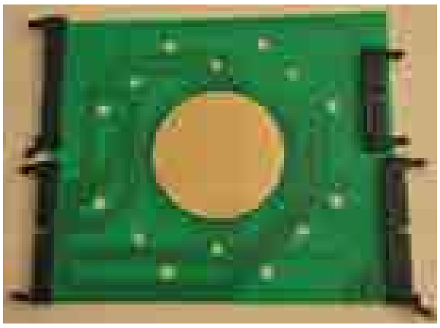
Project and objectives

The development of diagnostics tools for three independent water electrolysis technologies with individual properties is pursued: polymer-electrolyte membrane (PEM WE), alkaline (AWE) and anion exchange membrane (AEM WE) water electrolysis. The tool provides in-operando data from inside the electrolyser systems. It is based on an existing technology, which has been successfully used in the research on polymer electrolyte fuel cells. The aim is to use these diagnostics tools for online monitoring with the possibility for online adaptation of operational parameters, and for the prevention of hazardous operation modes while optimising the overall performance.



Major project achievements

- Applicability for in-operando current densities were evaluated in PEMWE test cell operation for various scenarios
- Prototype diagnostics hardware for AEMWE designed, manufactured and integrated. Evaluation pending



Future steps

- Evaluation of 1st prototype for AEM WE (July 2017)
- Manufacturing and integration of 1st prototype for PEMWE until Sept 2017
- Manufacturing and integration of 1st prototype for AWE until Sept 2017
- Design for 2nd generation prototypes until Nov 2017; for 3rd generation prototypes until Mar 2018
- Public workshop on results and recommendations in Sept 2018

Quantitative targets and status

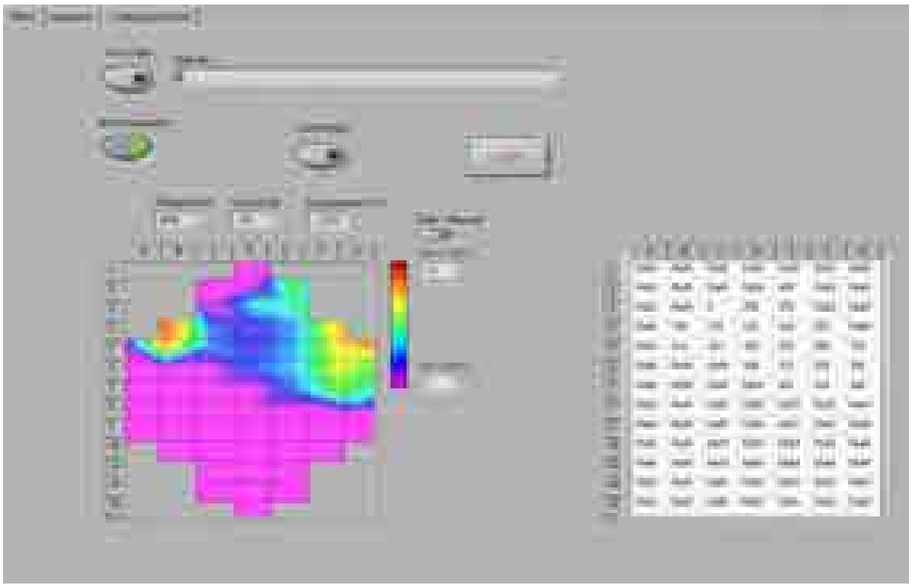
Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
MAIP 2008-2013	PEM WE Diagnosis/monitoring tool availability						Delayed	
MAIP 2008-2013	AWE Diagnosis/monitoring tool availability						Delayed	
MAIP 2008-2013	AEM WE Diagnosis/monitoring tool availability						Achieved	

Non-quantitative objectives and status

- Evaluation and verification of normal and accelerated test protocols
  Due later. Main objectives enable evaluation of test protocols. Test protocols to start with have been designed
- Recommendation for improvements of water electrolysers
  Due later. Public summary on the lessons learned for electrolyser design/development, which were learned during the use of the diagnostics prototypes

Relevant to FCH JU overarching objectives

- Increase the energy efficiency of production of hydrogen mainly from water electrolysis and renewable sources while reducing operating and capital costs, so that the combined system of the hydrogen production and the conversion using the fuel cell system can compete with the alternatives for electricity production available on the market



EG-04-17-700-EN-P

MEGASTACK
Stack design for a Megawatt scale PEM electrolyser

Panel 5 — Hydrogen production, distribution and storage: research and validation

Acronym:	**MEGASTACK**
Project ID:	621233
Title:	Stack design for a Megawatt scale PEM electrolyser
Call Topic:	SP1-JTI-FCH.2013.2.3
Project total costs (€):	€ 3,9 million
FCH JU maximum contribution (€):	€ 2,1 million
Project start/end:	01 Oct 2014 - 30 Sep 2017
Coordinator:	Stiftelsen Sintef, Norway
Beneficiaries: Commissariat à l'Energie Atomique et aux Energies Alternatives CEA, Fraunhofer Gesellschaft zur Foerderung der Angewandten Forschung, ITM Power (Trading)	
Website:	www.megastack.eu

Project and objectives

The project aim to take advantage of the existing PEM electrolyser stack designs of ITM Power as well as novel solutions in the low-cost stack design concepts developed in FCH JU projects NEXPEL and NOVEL. To up-scale the design concept from a 10-50 kW to a MW-sized stack, we will perform integrated two-phase flow and structural mechanics modelling together with optimisation of stack components such as MEAs, current collectors and sealings. The stack design will have ease of manufacture and stack assembly as a major goal, with necessary quality control processes and robust supply chains.

Major project achievements

- MW stack design successfully completed and prototype manufactured
- Multiphysics models developed for simulation of flow distribution and stack performance
- Improved understanding of two-phase flow and wetting properties in porous transport layers, including several new measurement methods developed

Future steps

- Prototype demonstration
- Dissemination of project results

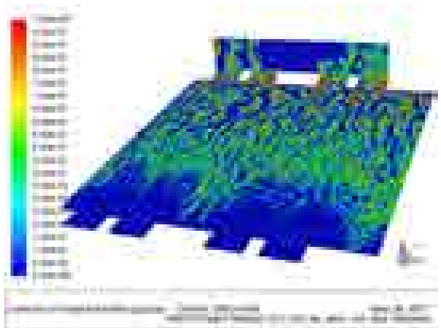
Relevant to FCH JU overarching objectives

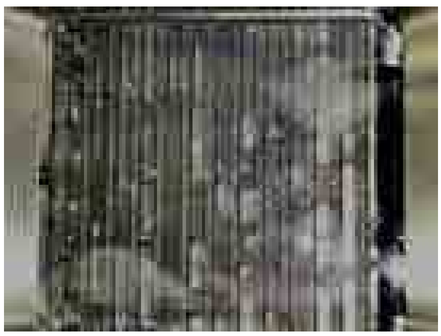
- Increase the energy efficiency of production of hydrogen mainly from water electrolysis and renewable sources while reducing operating and capital costs, so that the combined system of the hydrogen production and the conversion using the fuel cell system can compete with the alternatives for electricity production available on the market

EG-04-17-700-EN-P

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
MAIP 2008-2013	Stack cost	€/(Nm3/h)	4000	2500	2500	2500	Achieved	Upscale and design improvements
MAIP 2008-2013	Current density	A/cm²	1	1.2	1.5	1.5	Achieved	MEA and PTL improvement
AIP 2013	Hydrogen production capacity	Nm3/h	20	60	60	60	Achieved	
AIP 2013	Stack availability	%	99	99		99	Not yet addressed	
AIP 2013	Lifetime	h	40,000	40,000	200	40,000	Not yet addressed	Lifetime will not be measured in this project. Extrapolation of 3- month test will be used





NOVEL
Novel materials and system designs for low cost, efficient and durable PEM electrolysers

Panel 5 — Hydrogen production, distribution and storage: research and validation

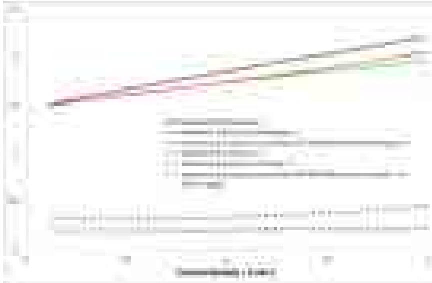
Acronym:	**NOVEL**
Project ID:	303484
Title:	Novel materials and system designs for low cost, efficient and durable PEM electrolysers
Call Topic:	SP1-JTI-FCH.2011.2.7
Project total costs (€):	€ 5,9 million
FCH JU maximum contribution (€):	€ 2,6 million
Project start/end:	01 Sep 2012 - 30 Nov 2016
Coordinator:	Stiftelsen Sintef, Norway
Beneficiaries: Areva Stockage d'Energie, Areva H2Gen, Beneq, Commissariat à l'Energie Atomique et aux Energies Alternatives CEA, Fraunhofer Gesellschaft zur Foerderung der Angewandten Forschung, Johnson Matthey Fuel Cells Ltd, Paul Scherrer Inst., Teer Coatings Ltd	
Website:	www.novelhydrogen.eu

Project and objectives

The main objective of NOVEL was to develop and demonstrate an efficient and durable PEM water electrolyser utilising the new, beyond the state of the art materials developed within the project. The electrolyser would demonstrate the capability to produce hydrogen with an efficiency of at least 75% (LHV) at rated capacity with a stack cost below €2,500/(Nm3/h and a target lifetime in excess of 40,000 hours (< 15 µVh-1 voltage increase at constant load).

Major project achievements

- Identified degradation mechanisms in PEM electrolysers
- Membranes and MEAs with lower H_2 crossover and lower costs
- Oxygen electrocatalysts with higher activity



Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
MAIP 2008-2013	stack CAPEX	€/(Nm3/h)		2000	1500	1500	Achieved	
AIP 2011	Lifetime	h		40,000			Not yet addressed	Lifetime target not met: No time in project to verify + some material solutions do not have the lifetime needed
AIP 2011	Efficiency	% (LHV)		75	68	68		Efficiency target will not be reached, but not needed to reach the related programme objectives
MAIP 2008-2013	Cost of hydrogen	€/kg		5	3.55	3.55	Achieved	Cost calculations - for an electricity price of 0.057€/kWh

Non-quantitative objectives and status

- Alternative materials for bipolar plates and current collectors
  Development of coatings. The goal is to reduce the contact resistance of Titanium decreasing the passivation of titanium to increase the electrolyser lifetime
- Polymer membranes with improved conductivity
  Thinner, more conductive and reinforced PFSA membranes.
- More efficient catalysts for the oxygen evolution reaction
  Catalysts with 300% mass activity vs. state of the art demonstrated ex situ

Relevant to FCH JU overarching objectives

- Increase the energy efficiency of production of hydrogen mainly from water electrolysis and renewable sources while reducing operating and capital costs, so that the combined system of the hydrogen production and the conversion using the fuel cell system can compete with the alternatives for electricity production available on the market
- Demonstrate on a large scale the feasibility of using hydrogen to support integration of renewable energy sources into the energy systems, including through its use as a competitive energy storage medium for electricity produced from renewable energy sources
- Reduce the use of the EU defined 'Critical raw materials', for instance through low-platinum or platinum-free resources and through recycling or reducing or avoiding the use of rare earth elements

PECDEMO
Photoelectrochemical demonstrator device for solar hydrogen generation

Panel 5 — Hydrogen production, distribution and storage: research and validation

EG-04-17-700-EN-P

Acronym:	**PECDEMO**
Project ID:	621252
Title:	Photoelectrochemical demonstrator device for solar hydrogen generation
Call Topic:	SP1-JTI-FCH.2013.2.5
Project total costs (€):	€ 3,4 million
FCH JU maximum contribution (€):	€ 1,8 million
Project start/end:	01 Apr 2014 - 31 Mar 2017
Coordinator:	Helmholtz-Zentrum Berlin fur Materialien und Energie, Germany
Beneficiaries: Evonik Industries, DLR, Deutsches Zentrum fuer Luft und Raumfahrt, Solaronix, Ecole Polytechnique Federale de Lausanne, Uni. Porto, Technion Israel Inst. Technol	
Website:	www.pecdemo.eu

Project and objectives

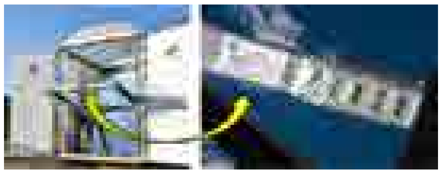
PECDEMO's aim is to develop a hybrid photo-electrochemical-photovoltaic tandem device for light-driven water splitting based on wide-bandgap metal oxide absorbers and thin film photovoltaic cells. Innovative cell designs are used to address critical scale-up issues, such as mass transport limitations and resistive losses. A >50 cm2 cell design is used to construct a water splitting module that has been tested in the field. In parallel, extensive techno-economic and lifecycle analyses based on actual performance characteristics have been carried out.

Major project achievements

- Highest efficiencies (up to 16.2% HHV) ever reported for metal oxide/silicon based PEC/PV tandem devices
- Largest PEC/PV demonstrator (4 x 50 cm2) tested outside under concentrated sunlight
- Innovative novel device concepts demonstrated and published in high impact journals

Future steps

- Project finished



Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
Project's own	Stability	hours		1000	1000		Achieved	Measured in lab for Fe2O3 photo-anodes
Project's own	Photoelectrode area	cm^2	1	50	50		Achieved	Largest BiVO4 area ever reported, achieved with optimised spray recipe in combination with novel electro-deposition recipe for Ni grid on FTO
Project's own	Solar-to-hydrogen efficiency	% (HHV)	7.30	10	16.20		Achieved	Achieved with novel Ga2O3/ Cu2O nanowire electrode coupled to silicon PV cell with dichroic mirror for photon management

Non-quantitative objectives and status

- Demonstration of prototype water splitting devices
  Hybrid photo-electrochemical / photovoltaic module for water splitting with total area of 200 cm2 has been demonstrated
- Estimate feasibility to meet EU target cost of 5 €/kg H_2
  Cost estimates made for three different production scenarios, value of 9 €/kg was estimated for single home application based on 8% efficient devices
- Design innovative device architectures for efficient light harvesting
  Novel light management concepts based on dual photo-anodes, dichroic mirrors, and rotatable photo-electrodes have been demonstrated
- Develop diagnostic methods to identify energy losses and degradation
  Opto-electrical studies revealed critical loss mechanisms in semiconductor/catalyst interfaces, active power management used to enhance efficiencies

Relevant to FCH JU overarching objectives

- Increase the energy efficiency of production of hydrogen mainly from water electrolysis and renewable sources while reducing operating and capital costs, so that the combined system of the hydrogen production and the conversion using the fuel cell system can compete with the alternatives for electricity production available on the market
- Demonstrate on a large scale the feasibility of using hydrogen to support integration of renewable energy sources into the energy systems, including through its use as a competitive energy storage medium for electricity produced from renewable energy sources
- Reduce the use of the EU defined 'Critical raw materials', for instance through low-platinum or platinum-free resources and through recycling or reducing or avoiding the use of rare earth elements

SElySOs

Development of new electrode materials and understanding of degradation mechanisms on Solid Oxide High Temperature Electrolysis Cells

Panel 5 — Hydrogen production, distribution and storage: research and validation

Acronym:	**SElySOs**
Project ID:	671481
Title:	Development of new electrode materials and understanding of degradation mechanisms on Solid Oxide High Temperature Electrolysis Cells
Call Topic:	FCH-02.1-2014
Project total costs (€):	€ 2,9 million
FCH JU maximum contribution (€):	€ 2,9 million
Project start/end:	02 Nov 2015 - 01 Nov 2019
Coordinator:	Foundation for Research and Technol. Hellas, Greece
Beneficiaries: Prototech, Pyrogenesis, Forschungszentrum Julich, Ethniko Kentro Erevnas Kai Technologikis Anaptyxis, Vysoka Skola Chemicko-Technologicka V Praze, Centre National de la Recherche Scientifique CNRS	
Website:	http://selysos.iceht.forth.gr/
Linkedin:	SElySOs Project

Project and objectives

SElySOs focuses on understanding of the degradation & lifetime fundamentals on both of the SOEC electrodes, for minimisation of their degradation & improvement of their performance and stability mainly under water electrolysis and to a certain extent under water/CO_2 co-electrolysis conditions. The main efforts comprise investigation of:

(i) Modified SoA Ni-based cathode cermets

(ii) Alternative perovskite-type cathode materials

(iii) Thorough investigation on the O_2 electrode and

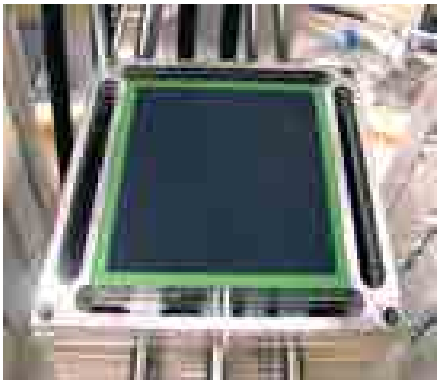
(iv) Development of a theoretical model for description of the performance & degradation of the SOEC H_2 electrode

Major project achievements

- The first results with modified Ni-based & Ni-free cathodes and studies on conventional O_2 cermets in H_2O electrolysis conditions are quite promising
- Very interesting remarks have been derived via operando observations of nickel/ceria electrode surfaces during HT electrolysis measurements
- A 0-D kinetic model of the solid oxide steam electrolysis on the cathode electrode has been developed

Future steps

- Optimized cathodes (H_2O electrodes) for H_2O electrolysis SOECs
- Optimized cathodes (H_2O electrodes) for H_2O/CO_2 co-electrolysis SOECs
- Optimized anodes (O_2 electrodes) for H_2O electrolysis SOECs
- Stack connection for 100 mbar pressure fluctuations and > 1 Mohm electrical insulation successfully verified



Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
MAWP 2014-2020	Long term electrical system efficiency (HHV)	%	74	>90			Not yet addressed	Conclusions for the specific objective are not available yet
MAWP 2014-2020	Improvement on the efficiency degradation rate	%/year	2-5	<1			Not yet addressed	Conclusions for the specific objective are not available yet
MAWP 2014-2020	Increase of TRL		3	5	3	5	Due later	Conclusions for the specific objective are not available yet

Non-quantitative objectives and status

- New materials and component design less prone to degradation During the 1st year of operation a series of Ni-based and Ni-free electrodes started to be investigated under various SOEC H_2O electrolysis conditions
- Understanding of degradation mechanisms under dynamic operation During the 1st year of operation a mathematical model has been developed particularly for the SOEC H_2O electrolysis reaction.
- Reduction of electricity consumption for H_2 production by 10% by 2025 SElySOs is on its first year of operation and conclusions for the specific objective are not available yet
- Development of improved & robust SOEC systems (cells/stack/s) SElySOs is on its first year of operation and conclusions for the specific objective are not available yet

Relevant to FCH JU overarching objectives

- Increase the electrical efficiency and the durability of the different fuel cells used for power production to levels which can compete with conventional technologies, while reducing costs
- Increase the energy efficiency of production of hydrogen mainly from water electrolysis and renewable sources while reducing operating and capital costs, so that the combined system of the hydrogen production and the conversion using the fuel cell system can compete with the alternatives for electricity production available on the market
- Reduce the use of the EU defined 'Critical raw materials', for instance through low-platinum or platinum-free resources and through recycling or reducing or avoiding the use of rare earth elements

SOL2HY2
Solar to hydrogen hybrid cycles

Panel 5 — Hydrogen production, distribution and storage: research and validation

EG-04-17-700-EN-P

Acronym:	**SOL2HY2**
Project ID:	325320
Title:	Solar to hydrogen hybrid cycles
Call Topic:	SP1-JTI-FCH.2012.2.5
Project total costs (€):	€ 3,7 million
FCH JU maximum contribution (€):	€ 2,0 million
Project start/end:	01 Jun 2013 - 30 Nov 2016
Coordinator:	Enginsoft, Italy
Beneficiaries: Aalto-Korkeakoulusaatio, ENEA, Agenzia Nazionale per le Nuove Tecnologie, l'Energia e lo Sviluppo Economico Sostenibile, Erbicol, DLR, Deutsches Zentrum fuer Luft und Raumfahrt, Oy Woikoski, Outotec (Finland)	
Website:	sol2hy2.eucoord.com

Project and objectives

Solar-powered thermo-chemical cycles are capable to directly transfer concentrated sunlight into chemical energy by a series of chemical and electro-chemical reactions, and of these cycles, the hybrid-sulphur (HyS) cycle was identified as the most promising one. The project focus was on bottlenecks solving materials R&D and demonstration of the key components of the solar-powered, CO_2-free hybrid water splitting cycles, complemented by their advanced modelling and process simulation, with conditions and site-specific technical-economical assessment optimization, quantification and benchmarking.

Major project achievements

- The final flowsheets and software for SOL2HY2 plant were developed and analyzed with the flowsheets including solar power input for key units
- New SO_2 depolarized electrolyser was designed, built and tested
- For high temperature solar operations the stability tests at 1000°C for the tailored higher-temperature catalysts were carried out

Future steps

- Project finished

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
MAIP 2008-2013	Cost of H_2 delivered at refuelling station	€/kg		5			Not addressed	Not directly addressed
AIP 2012	Catalysts with better activities +30%	%	30	50	30	30	Achieved	Electro-catalysts with 50% better efficiency vs. Pt/Pd. will be not used in final design
AIP 2012	Redox materials with doubled conversion rate	times	2.00				Achieved	Redox materials are not used

Non-quantitative objectives and status

- Integration of HyS cycle features to semi-centralised H_2 production
  Design and development of the components for electrolyser stack, cracker and plant for test facility at Solar Tower Julich (capacity ~1 MW)
- New materials solutions
  Development and optimization of SDE catalysts, ceramics solar components, protective corrosion-resistant coatings
- New software for virtual plants
  For the first time, MODAO+FEM+CFD was integrated with and the plant predictions were made

Relevant to FCH JU overarching objectives

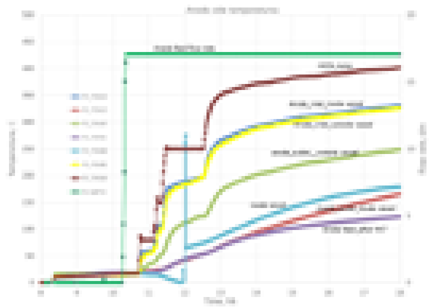
- Increase the energy efficiency of production of hydrogen mainly from water electrolysis and renewable sources while reducing operating and capital costs, so that the combined system of the hydrogen production and the conversion using the fuel cell system can compete with the alternatives for electricity production available on the market
- Reduce the use of the EU defined 'Critical raw materials', for instance through low-platinum or platinum-free resources and through recycling or reducing or avoiding the use of rare earth elements

SOPHIA
Solar integrated pressurized high temperature electrolysis

Acronym:	**SOPHIA**
Project ID:	621173
Title:	Solar integrated pressurized high temperature electrolysis
Call Topic:	SP1-JTI-FCH.2013.2.4
Project total costs (€):	€ 6,0 million
FCH JU maximum contribution (€):	€ 3,3 million
Project start/end:	01 Apr 2014 - 30 Sep 2017
Coordinator:	Hygear, The Netherlands
Beneficiaries: Commissariat à l'Energie Atomique et aux Energies Alternatives CEA, DLR, Deutsches Zentrum fuer Luft und Raumfahrt, Ecole Polytechnique Federale de Lausanne, Htceramix, Solidpower, VTT, VTT, ENGIE	
Website:	http://www.sophia-project.eu/

Project and objectives

The aim of the SOPHIA project was to develop a solar-powered High Temperature Electrolysis (HTE) system, and develop technology for co-electrolysis. The technology is prototyped on a 3 kW-scale, and designed for operation at 15 bar. The complete system, comprising of the HTE stack-subsystem and solar receiver has been tested at the Solar Simulator at DLR (Deutsches Zentrum fuer Luft und Raumfahrt). Testing at HyGear will follow. A market analysis shows that for systems producing hydrocarbons the availability of CO_2 is not limiting, but the solar power is. Various cell, Single Repeat Units (SRU), and stack tests have been done in (co-)electrolysis mode.



Major project achievements

- High pressure operation of short stacks up to 15 bar
- Co-electrolysis operation proven, producing H_2 and CO plus some CH_4 depending on conditions
- Development of a system for pressurised operation

Future steps

- Final testing of complete system at a pressure of 15 bar

Quantitative targets and status

Target Source	Parameter	Unit	Starting point	Target for project	Achieved to date in project	Best est. of final project result	Target: status on May 1st 2017	Description
MAIP 2008-2013	Degradation	%/1000hr	2	0.50	4.50	1.00	Due later	Operation mode and microstructure improvement
MAIP 2008-2013	Current density	A/cm²	0.70	1	1	1	Achieved	Operation mode and microstructure improvement

Non-quantitative objectives and status

- PoP of a HT SOE system at kW size under realistic conditions
  System has been tested in combination with a simulated solar heat source
- Develop cells and up-scaling the production of such cells
  Cells have been developed and applied; cell production has been upscaled
- Develop concepts for high pressure electrolysis for more economical systems
  Fuel production via co-electrolysis SOEC and syngas upgrading has been studied by a techno-economic analysis

Relevant to FCH JU overarching objectives

- Increase the energy efficiency of production of hydrogen mainly from water electrolysis and renewable sources while reducing operating and capital costs, so that the combined system of the hydrogen production and the conversion using the fuel cell system can compete with the alternatives for electricity production available on the market

PANEL 6
CROSS-CUTTING

CERTIFHY
Developing a European Framework for the generation of guarantees of origin for green hydrogen

Panel 6 — Cross-cutting

Acronym:	**CERTIFHY**
Project ID:	633107
Title:	Developing a European Framework for the generation of guarantees of origin for green hydrogen
Call Topic:	SP1-JTI-FCH.2013.5.5 (2)
Project total costs (€):	€ 551,6 million
FCH JU maximum contribution (€):	€ 432,5 million
Project start/end:	01 Nov 2014 - 31 Oct 2016
Coordinator:	Hinicio, Belgium
Beneficiaries: Ludwig-Boelkow-Systemtechnik, Tuv Sud Industrie Service, Stichting Energieonderzoek Centrum Nederland	
Website:	http://www.certifhy.eu/

Project and objectives

CertifHy aimed to:

1) Define a widely acceptable definition of green hydrogen

2) Determine how a robust GoO scheme for green hydrogen should be designed and implemented throughout the EU

3) Agree on a roadmap for implementation.

A core element of the project was a step-by-step consultation process with industry, policy makers, NGOs and other stakeholders to reach a wide consensus.

Major project achievements

- Achieved consensus of definition of green hydrogen, endorsed by a wide variety of stakeholders
- Industrial commitment ensured to produce green hydrogen GOs
- Common understanding and buy in on the roadmap for the implementation phase

Future steps

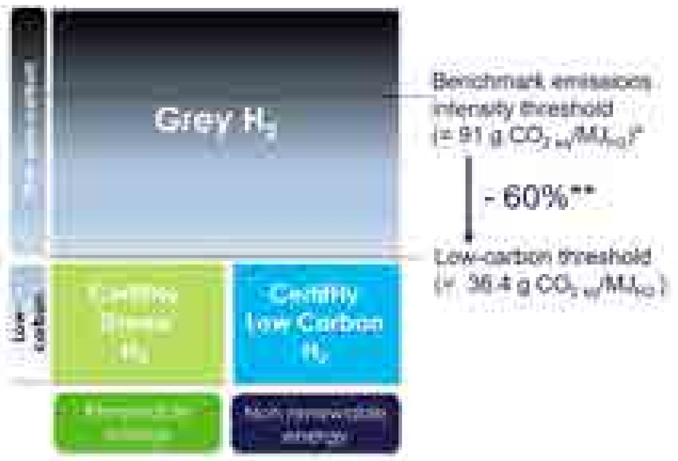
- Eleborate procedures for plant certification and batch auditing
- Development of GO registry
- Selection of pilot plants and testing of the procedures

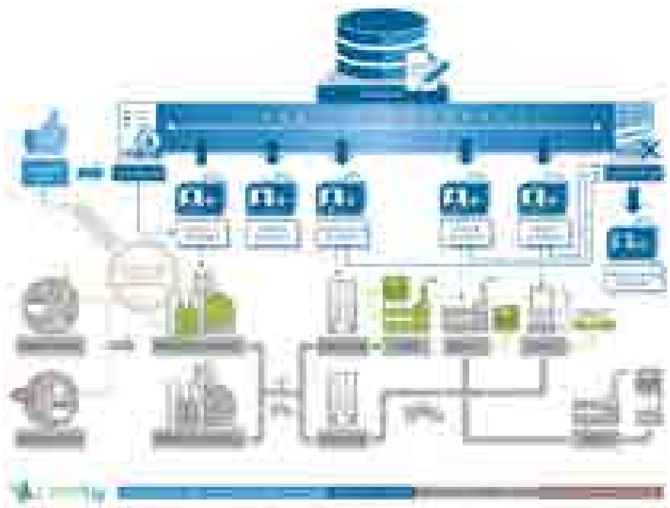
Non-quantitative objectives and status

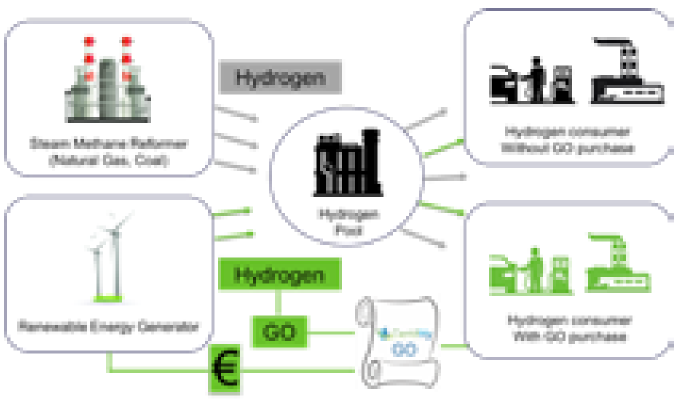
- Achieve consensus amongst stakeholders
  Endorsement from a wide variety of stakeholders have been achieved at the end of the project
- Roadmap for the implementation
  Stakeholders are prepared and engaged for a piloting phase

Relevant to FCH JU overarching objectives

- Demonstrate on a large scale the feasibility of using hydrogen to support integration of renewable energy sources into the energy systems, including through its use as a competitive energy storage medium for electricity produced from renewable energy sources







EG-04-17-700-EN-P

HYACINTH
Hydrogen acceptance in the transition phase

Panel 6 — Cross-cutting

Acronym:	**HYACINTH**
Project ID:	621228
Title:	Hydrogen acceptance in the transition phase
Call Topic:	SP1-JTI-FCH.2013.5.3
Project total costs (€):	€ 999,3 million
FCH JU maximum contribution (€):	€ 661,5 million
Project start/end:	01 Sep 2014 - 31 May 2017
Coordinator:	Centro Nacional de Experimentacion de Tecnologias de Hidrogeno y Pilasde Combustible Consorcio, Spain
Beneficiaries: Aberdeen City Council*, I Plus F France, Norstat Deustchland, Centro de Investigaciones Energeticas, Medioambientales y Tecnologicas-Ciemat, Uni. Leeds, Uni. Sunderland, Consultoria de Innovacion y Financiacion Sl, Fraunhofer Gesellschaft zur Foerderung der Angewandten Forschung, Fundacion Cidaut, Razvojni Center Za Vodikove Tehnologije	
Website:	http://hyacinthproject.eu/
Twitter:	@HYACINTHPROJECT

Project and objectives

The objective of HYACINTH project is to achieve a greater understanding of the social acceptance of fuel cells and hydrogen (FCH) technologies and applications at European level through two studies: (1) Public awareness and acceptance and (2) Stakeholder acceptance of FCH technologies across Europe. In addition, with the obtained results, a tool to facilitate the product development and market introduction has been developed, being better aimed to the target audience, giving better response to the expectations and reducing the risks or barriers to FCH technologies' acceptance.

Major project achievements

- Report on results of the stakeholders survey
- Report on general finding on public acceptance
- Develop a Social Acceptance Management Toolbox (SAMT) to help promoters and decision makers integrate issues related to social acceptance

Future steps

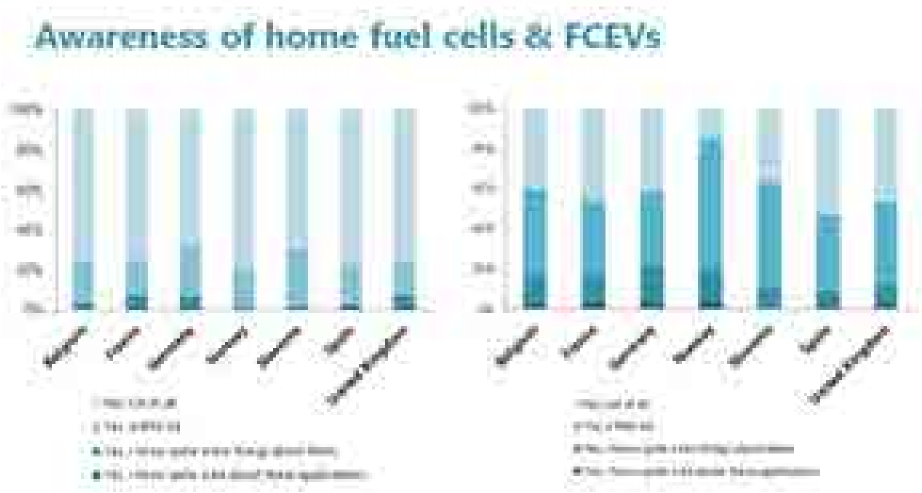
- Review the Report of the stakeholder survey and the Integrated report on general findings on public acceptance
- Write up the Periodic Report and Final Report for HYACINTH project
- To attend to conferences for a mayor dissemination of results

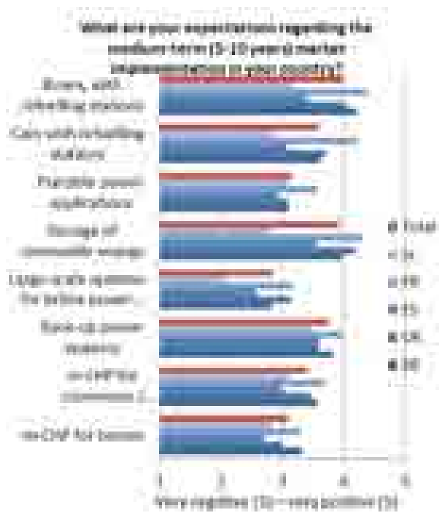
Relevant to FCH JU overarching objectives

- Reduce the production cost of fuel cell systems to be used in transport applications, while increasing their lifetime to levels which can compete with conventional technologies
- Increase the electrical efficiency and the durability of the different fuel cells used for power production to levels which can compete with conventional technologies, while reducing costs
- Increase the energy efficiency of production of hydrogen mainly from water electrolysis and renewable sources while reducing operating and capital costs, so that the combined system of the hydrogen production and the conversion using the fuel cell system can compete with the alternatives for electricity production available on the market
- Demonstrate on a large scale the feasibility of using hydrogen to support integration of renewable energy sources into the energy systems, including through its use as a competitive energy storage medium for electricity produced from renewable energy sources

Non-quantitative objectives and status

- Public awareness (Achieved)
- European public acceptance: analysis (Achieved)
- Public familiarity with hydrogen technologies, namely in stationary and mobile applications (µ-CHP and vehicles, which are closer to the market. (Achieved)
- Identification of fears associated with FCH technologies - general public survey on costs and benefits of both applications and the evaluation of consequences (see next target) (Achieved)
- How is hydrogen safety perceived by the general public? The majority of issues raised by respondents are related to the price and safety (Achieved)
- Identify and understand acceptance of stakeholders - to examine public awareness, familiarity, perception of benefits and costs, global attitude and acceptance of FCH technologies (Recommendations) (Achieved)
- Social Acceptance research Management Toolbox (SAMT) The project has developed a Social Acceptance Information Tool Box (SAMT). Tool Box Handbook. https://hyacinth.sunderland.ac.uk/
- Impact of first use of hydrogen in the mobility sector in stakeholder HYACINTH project has asked attendees to the WHEC 2016 Conference who participated in a FC vehicle test drive about their opinion after the test drive.
- Stakeholders opinion on HYACINTH results The opinion of attendees to workshops is positive - results are very interesting for sector and the toolbox has a great utility





HYCORA
Hydrogen contaminant risk assessment

Panel 6 — Cross-cutting

Acronym:	**HYCORA**
Project ID:	621223
Title:	Hydrogen contaminant risk assessment
Call Topic:	SP1-JTI-FCH.2013.1.5
Project total costs (€):	€ 3,9 million
FCH JU maximum contribution (€):	€ 2,1 million
Project start/end:	01 Apr 2014 - 30 Jun 2017
Coordinator:	VTT, Finland
Beneficiaries: Powercell Sweden, Commissariat à l'Energie Atomique et aux Energies Alternatives CEA, JRC -Joint Research Centre, European Commission, Protea Ltd, Stiftelsen Sintef	
Website:	http://hycora.eu/

Project and objectives

The main objective of the HyCoRA project is to provide information to reduce the cost of hydrogen fuel quality assurance (QA). It will also provide recommendations for revision of the existing ISO 14687-2:2012 standard for hydrogen fuel in automotive applications.

For developing the strategy for hydrogen fuel QA cost reduction, a hydrogen quality risk assessment is used to define the needs for hydrogen impurity gas analysis, system level PEMFC contaminant research and purification in hydrogen production, especially by steam methane reforming (SMR) with pressure swing adsorption (PSA).

Major project achievements

- Cheaper and more reliable quality assurance procedures and instrumentation for HRSs
- The real susceptibility for various poisonous species (HCHO, HCOOH, CO, H2S) has been studied successfully
- Three sampling campaigns from the HRSs have been completed, technical data collected and results disseminated

Future steps

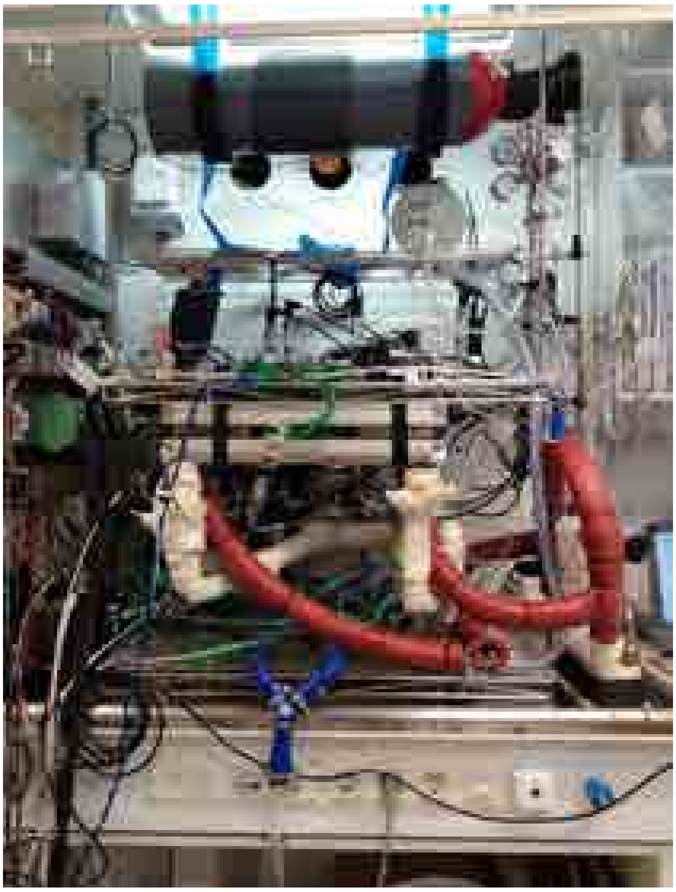
- Finalising some of the FC measurements
- Completing the remaining 10 technical deliverables
- Writing of publications

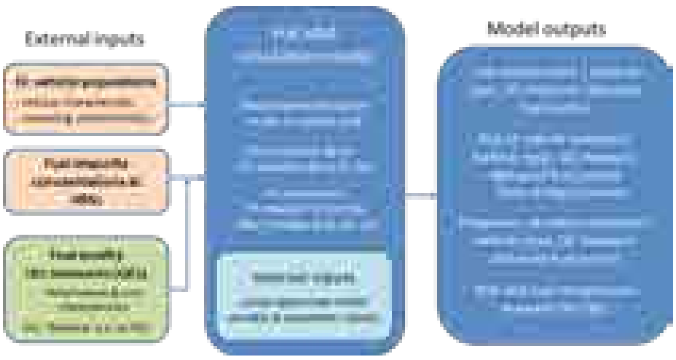
Relevant to FCH JU overarching objectives

- Demonstrate on a large scale the feasibility of using hydrogen to support integration of renewable energy sources into the energy systems, including through its use as a competitive energy storage medium for electricity produced from renewable energy sources

Non-quantitative objectives and status

- Identifying the impurity limits of PEMFCs under automotive operation
  A more complete overview of the real susceptibility of various contaminant in automotive operation achieved
- Technical data on fuel composition and impurity concentration at HRS
  Three sampling campaigns have been completed, fuel composition and impurity concentrations analysed. Particulate sampling conducted in 2nd and 3rd
- Simplified and diversified set of requirements for H_2 fuel quality
  Constructing a probabilistic risk assessment model for determining QA needs
- Design and verification of gas sampling instrumentation to HRS
  Verification of instrumentation for gas and particulate sampling is completed. Has been successfully utilised to complete 3 sampling campaigns





EG-04-17-700-EN-P

HYPACTOR
Pre-normative research on resistance to mechanical impact of composite overwrapped pressure vessels

Panel 6 — Cross-cutting

Acronym:	**HYPACTOR**
Project ID:	621194
Title:	Pre-normative research on resistance to mechanical impact of composite overwrapped pressure vessels
Call Topic:	SP1-JTI-FCH.2013.5.6
Project total costs (€):	€ 4,0 million
FCH JU maximum contribution (€):	€ 2,1 million
Project start/end:	01 Apr 2014 - 30 Jun 2017
Coordinator:	Commissariat à l'Energie Atomique et aux Energies Alternatives CEA, France
Beneficiaries: Alma Consulting Group, Hexagon Raufoss, Institut de Soudure Association, Norges Tek-Naturvitenskapelige Uni., Politech. Wroclawska, L'Air Liquide	
Website:	www.hypactor.eu

Project and objectives

The main objective of HYPACTOR is to provide recommendations for Regulations, Codes and Standards (RCS) regarding the qualification of new designs of Composite Overwrapped Pressure Vessels (COPV) and the procedures for periodic inspection in service of COPV subjected to mechanical impacts.

Relevant to FCH JU overarching objectives

- Demonstrate on a large scale the feasibility of using hydrogen to support integration of renewable energy sources into the energy systems, including through its use as a competitive energy storage medium for electricity produced from renewable energy sources

Major project achievements

- Recommendations for RCS regarding qualification of COPVs with respect to impact, inspection of impacted COPVs
- Understand & characterise the relationship between the impact, the damage and the loss of performance of COPV at short term
- Definition of a test configuration and inspection procedures for impacted COPVs

Future steps

- Final workshop and webinar to present pre-normative recommendations 19/06/17
- Final consortium meeting 20-21/06/17

Non-quantitative objectives and status

- Identify the different types of alterations that may be produced by mechanical impacts and develop an understanding of their consequences (not yet achieved - due later)
- Establish a relation between severity of impact, level of damage, and effect on structural integrity (achieved)
- Apply the results of the above to assess the reliability of composite pressure vessels in the foreseen applications and potential needs of protection (achieved)
- Evaluate non-destructive examination methods, such as analysis of acoustic emissions, and associated pass/fail criteria (achieved)
- Description and quantification of the effect of mechanical impacts on composite pressure vessel structure (achieved)
- Assessment of the structural reliability of composite pressure vessels in the foreseen service conditions and opportunities of improvement (achieved)
- Recommendations to industry and for international standards development (not yet achieved - due later)
- Improved methods and criteria for inspection of pressure vessels in service (not yet achieved - due later)
- Extensive experimental database database including impact & damage characteristics, NDT results & integrity (achieved)
- Numerical model for the prediction of residual bust pressure (achieved)
- Critical damage description (achieved)
- Testing configuration, NDT protocols, pass/fail criteria defined (achieved)

FUEL CELLS AND HYDROGEN JOINT UNDERTAKING

HYRESPONSE
European hydrogen emergency response training programme for first responders

Panel 6 — Cross-cutting

Acronym:	**HYRESPONSE**
Project ID:	325348
Title:	European hydrogen emergency response training programme for first responders
Call Topic:	SP1-JTI-FCH.2012.5.3
Project total costs (€):	€ 2,6 million
FCH JU maximum contribution (€):	€ 1,8 million
Project start/end:	01 Jun 2013 - 30 Sep 2016
Coordinator:	Ecole Nationale Superieure des Officiers de Sapeurs-Pompiers, France
Beneficiaries: Areva Stockage D'Energie, Crisis Simulation Engineering, Fast - Federazione delle Associazioni Scientifiche e Tecniche, Uni. Ulster, Air Liquide Hydrogen Energy, The CCS Global Group Ltd	
Website:	http://www.hyresponse.eu/

Project and objectives

The HyResponse project targets to create a European Hydrogen Safety Training Platform, which develops a toolbox for European First Responders to help them assessing status and decision making on the emergency response level in case of incident/accident on site. The training is threefold:

- Educational training including hydrogen hazard and risks from hydrogen applications
- Operational-level training on mock-up real scale transport and hydrogen stationary installations
- Innovative virtual training exercises reproducing entire accident scenarios

The project finished in September 2016.

Major project achievements

- Creation of the operational training platforms
- Realisation of the three experimental training sessions
- Edition of the European emergency response guide

Future steps

- Project finished

Relevant to FCH JU overarching objectives

- Demonstrate on a large scale the feasibility of using hydrogen to support integration of renewable energy sources into the energy systems, including through its use as a competitive energy storage medium for electricity produced from renewable energy sources

Non-quantitative objectives and status

- Developing training programmes at all levels: 3 training levels developed
- Dissemination of the programme results through public awareness events and initiatives
- Install a European Hydrogen Training Platform on which full scale exercises will be realised: Construction of a physical platform and also a virtual reality platform

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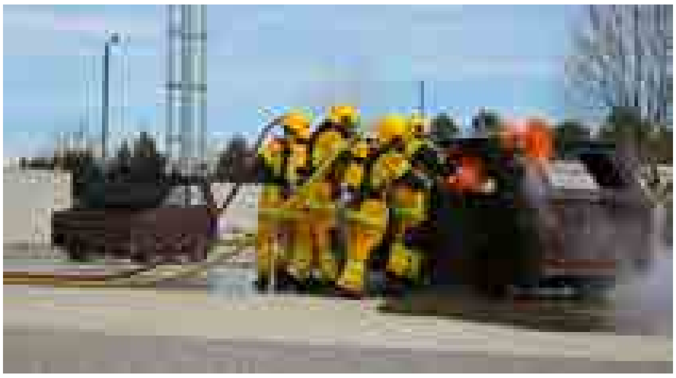

HySEA

Improving Hydrogen Safety for Energy Applications (HySEA) through pre-normative research on vented deflagrations

Panel 6 — Cross-cutting

EG-04-17-700-EN-P

Acronym:	**HySEA**
Project ID:	671461
Title:	Improving Hydrogen Safety for Energy Applications (HySEA) through pre-normative research on vented deflagrations
Call Topic:	FCH-04.3-2014
Project total costs (€):	€ 1,5 million
FCH JU maximum contribution (€):	€ 1,5 million
Project start/end:	01 Sep 2015 - 31 Aug 2018
Coordinator:	Gexcon, Norway
Beneficiaries: Hefei Uni. Tech., Impetus Advanced Finite Element Analyses, Uni. Science & Tech. China, Uni. Di Pisa, Uni. Warwick, Fike Europeba	
Website:	www.hysea.eu

Project and objectives

The overall goal of the HySEA project is to conduct pre-normative research on vented hydrogen deflagrations with an aim to provide recommendations for European and international standards on hydrogen explosion venting mitigation systems, and to develop and validate engineering models (EMs), computational fluid dynamics (CFD) and finite element (FE) methods that can be verified and validated against data from experiments performed in containers and smaller enclosures with industry-representative obstacles.

Major project achievements

- Completed two experimental campaigns with vented hydrogen deflagrations for homogeneous mixtures
- Completed blind-prediction study for vented hydrogen deflagrations in 20-foot ISO container
- Improved computational fluid dynamics (CFD) models for vented hydrogen deflagration

Future steps

- Organize second HySEA blind-prediction study with vented hydrogen deflagrations in 20-foot ISO containers with obstacles and inhomogeneous mixtures
- Complete second experimental campaign with vented hydrogen deflagrations in 20-foot ISO containers with obstacles and inhomogeneous mixtures
- Complete second experimental campaign with vented hydrogen deflagrations in small-scale enclosure with obstacles and inhomogeneous mixtures
- Release improved computational fluid dynamics (CFD) tools for vented hydrogen deflagrations
- Evaluate and possibly improve engineering models for vented hydrogen deflagrations and present these to members of relevant standardizing committees

Relevant to FCH JU overarching objectives

- Demonstrate on a large scale the feasibility of using hydrogen to support integration of renewable energy sources into the energy systems, including through its use as a competitive energy storage medium for electricity produced from renewable energy sources

Non-quantitative objectives and status

- To perform experiments in real-life enclosures with obstacles
  This work progresses according to schedule, but with some delays in reporting due to more demanding analysis of data than expected.
- To organize blind-prediction validation studies
  On schedule (one completed, one scheduled for autumn 2017).
- To develop, verify and validate EMs and CFD-based tools
  On schedule
- To formulate recommendations to the standardizing committees
  Somewhat behind schedule due to delayed recruitment of personnel

HYTECHCYCLING

New technologies and strategies for fuel cells and hydrogen technologies in the phase of recycling and dismantling

Panel 6 — Cross-cutting

Acronym:	**HYTECHCYCLING**
Project ID:	700190
Title:	New technologies and strategies for fuel cells and hydrogen technologies in the phase of recycling and dismantling
Call Topic:	FCH-04.1-2015
Project total costs (€):	€ 497,6 million
FCH JU maximum contribution (€):	€ 497,6 million
Project start/end:	01 May 2016 - 30 Apr 2019
Coordinator:	Fundacion para Desarrollo de las Nuevas Tecnologias del Hidrogeno en Aragon, Spain
Beneficiaries:	Parco Scientifico e Tecnol. Per l'Ambiente - Environment Park, Uni. V Ljubljani, Industrias Lopez Soriano, Fundacion Imdea Energia
Website:	www.hytechcycling.eu

Project and objectives

HYTECHCYCLING's main aim is to deliver reference documentation and studies about existing and new recycling and dismantling technologies and strategies applied to Fuel Cells and Hydrogen technologies, paving the way for future demonstration actions and advances in legislation. To date the project has studied the critical materials present in these technologies and the available recycling techniques and strategies. The regulatory framework has also been reviewed. A Life-cycle assessment (LCA), new recycling strategies and a business model are other project objectives.

Major project achievements

- Identification and classification of critical materials in fuel cells (PEMFC and SOFC) and water electrolysers (alkaline and PEM) linked to the existing recycling and dismantling technologies
- First approach of the LCA and the impact of the recycling and dismantling in FCH technologies
- Actual regulatory framework and barriers identified

Future steps

- Update the dissemination and awareness plan
- Initial workshop to have a first outlook of needs from FCH actors
- Final workshop for FCH actors to know and validate the final new strategies and technologies in the phase of recycling and dismantling
- LCA inventory of hazardous materials in FCH technologies and set-up of reference case studies with new strategies in dismantling and recycling stage
- New recycling and dismantling technologies and strategies for FCH technologies defined

Relevant to FCH JU overarching objectives

- Reduce the use of the EU defined 'Critical raw materials', for instance through low-platinum or platinum-free resources and through recycling or reducing or avoiding the use of rare earth elements

Non-quantitative objectives and status

- Identification of critical materials and roadmap for their reduction
  The identification has been done linked with strategies for recycling and dismantling. Next step: development of new strategies and roadmap.
- Reference LCA cases will be developed for implementation of recycling
  The first approach for LCA is finished. This will lead with the objective of "process data about recycling that can be used for life cycle analysis"
- Business model looking for wide implementation
  Not started yet
- Development of reference documentation, guidelines and recommendations
  Continuous progress

FUEL CELLS AND HYDROGEN JOINT UNDERTAKING

IRMFC
Development of a portable internal reforming methanol High Temperature PEM fuel cell system

Panel 6 — Cross-cutting

Acronym:	**IRMFC**
Project ID:	325358
Title:	Development of a portable internal reforming methanol High Temperature PEM fuel cell system
Call Topic:	SP1-JTI-FCH.2012.4.2 SP1-JTI-FCH.2012.4.4
Project total costs (€):	€ 3,4 million
FCH JU maximum contribution (€):	€ 1,5 million
Project start/end:	01 May 2013 - 31 Oct 2016
Coordinator:	Foundation for Research and Technol. Hellas, Greece
Beneficiaries: Advanced Energy Technol. Ae Ereunas & Anaptyxis Ylikon & Proiontonananeosimon Pigon Energeias & Synafon Symvouleftikon Y Piresion*AdvenT, Arpedon Metritikes Diataxeis Kai Organa Michanimata Ypresies EPE, Enerfuel Inc., Institut Fuer Mikrotechnik Mainz, Uni. Patras, Fraunhofer Gesellschaft zur Foerderung der Angewandten Forschung, Zentrum Fur Brennstoffzellen-Technik, JRC -Joint Research Centre, European Commission, Uniwersytet Marii Curie-Sklodowskiej	
Website:	http://irmfc.iceht.forth.gr/

Project and objectives

Taking advantage of the innovative outcomes of previous FCH JU project IRAFC, the functionality of internal reforming methanol fuel cell (IRMFC) modules of 100 W was demonstrated. The IRMFC partnership brought together specialists in catalysis, high-temperature polymer electrolytes, high-temperature PEMFC stacks and RSC for portable applications. The observed stability of the IRMFC module and key components was satisfactory in the timeframe of the performed tests. Specific targets for efficiency improvement were identified, including the reformer activity and thermal stability of the membrane under on/off cycles.

Major project achievements

- New-type methanol reformer (ultrathin and lightweight) and bipolar plates (operation at 200-230°C) delivered and tested for >1000 h
- IRMFC stacks (up to 100 W) and BoP components tested and delivered
- Poor cycling stability of the membrane-electrode assembly (MEA) limited operation for long periods; currently confronted with new generation of polymer electrolytes under development

Future steps

- Project finished

Relevant to FCH JU overarching objectives

- Increase the electrical efficiency and the durability of the different fuel cells used for power production to levels which can compete with conventional technologies, while reducing costs

Non-quantitative objectives and status

- Operation of 100 W Internal Reforming Methanol Fuel Cell
  Two 100 W modules were tested and delivered. Low stability of membrane against on/off cycling conditions limited operation for long periods
- Cost reduction to < 5000€/kW
  The final cost is much higher because of the delivery of a single integrated system. A rough estimation for the equivalent at mass production is below this target
- Electrical efficiency > 30% at 210-220°C (methanol/water fuel)
  Not measured for the final system. Balance-of-plant (BoP) completed but not integrated with the stack

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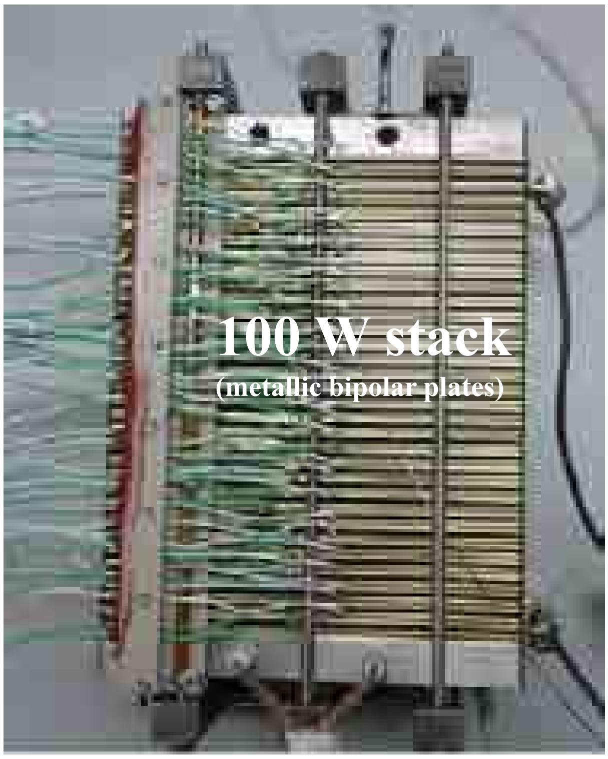


KNOWHY
Improving the knowledge in hydrogen and fuel cell technology for technicians and workers

Panel 6 — Cross-cutting

Acronym:	**KNOWHY**
Project ID:	621222
Title:	Improving the knowledge in hydrogen and fuel cell technology for technicians and workers
Call Topic:	SP1-JTI-FCH.2013.5.2
Project total costs (€):	€ 1,4 million
FCH JU maximum contribution (€):	€ 1,0 million
Project start/end:	01 Sep 2014 - 31 Aug 2017
Coordinator:	Tech. Uni. Delft, The Netherlands
Beneficiaries: Campus Automobile Spa-Francorchamps, Fast - Federazione delle Associazioni Scientifiche e Tecniche, Fundacion San Valero, Kiwa Training, Mcphy Energy, Parco Scientifico e Tecnol. Per l'Ambiente - Environment Park, PNO Consultants, Tech. Uni. Muenchen, Uni. Birmingham, Vertigo Games, Fundacion para Desarrollo de las Nuevas Tecnologias del Hidrogeno en Aragon, Inst. Superior Tecnico	
Website:	http://knowhy.eu/
Linkedin:	KnowHy

Project and objectives

KnowHy aims to provide the fuel cells and hydrogen (FC & H2) sector with a training offer for technicians and workers featuring quality in contents, accessibility in format and language, practicality for the targeted audience, ease of scalability and update, and at competitive costs to make the training offer economically sustainable after project completion.

The main project actions are:

- Developing an online tool for accessing to the training contents via the web
- Developing specific courses adapted to the different applications
- Carrying out practical seminars in existing facilities

Major project achievements

- Development of a core module with 5 specialisation modules including serious games and practical sessions - all have been translated into 6 European languages
- So far 668 trainees have been registered on the KnowHy platform of which 21% have finished e-learning and practical session
- Results of satisfaction survey:
  - Overall satisfaction: 9/10
  - Companies satisfaction: 8.5/10
  - Practical session: 9/10
  - Serious Games: 8.6/10

Future steps

- Improve the quality of course contents
- Finalise the structure of the KnowHy a Special Purpose Vehicle
- Attempt a new round of training during September and October 2017 in some partner countries
- Contact the trainees who did not finish the courses and encourage them to complete them
- Offer courses in other countries such as US, Norway and Slovenia

Non-quantitative objectives and status

- Develop 6 modules including serious games and practical sessions
  Achieved, translated into 6 European languages
- Teach 1000 trainees
  668 trainees registered on the KnowHy platform by May 1st, 2017
- Identification of target group, topics and modules definition
  Done, providing the technicians with the required training in the field of FC & H2 with foremost importance on the safety & maintenance aspects
- Effective teaching methodology defined & the course platform set
  Done, developing an effective teaching methodology based on e-learning (including video lectures), serious game, practical session
- Establish a self-financing KnowHy legal entity
  Will be completed - need to set up a Special Purpose Vehicle (SPV) plan and discussions are ongoing
- Dissemination of results to industry, stakeholders, etc
  Will be completed - collect the feedback from students, analyse and identify improvement potential based on lessons learned

SOCTESQA
Solid oxide cell and stack testing, safety and quality assurance

Panel 6 — Cross-cutting

Acronym:	**SOCTESQA**
Project ID:	621245
Title:	Solid oxide cell and stack testing, safety and quality assurance
Call Topic:	SP1-JTI-FCH.2013.5.4
Project total costs (€):	€ 3,2 million
FCH JU maximum contribution (€):	€ 1,6 million
Project start/end:	01 May 2014 - 30 Apr 2017
Coordinator:	DLR, Deutsches Zentrum fuer Luft und Raumfahrt, Germany
Beneficiaries: ENEA, Agenzia Nazionale per le Nuove Tecnologie, l'Energia e lo Sviluppo Economico Sostenibile, Danmarks Tek. Uni., Commissariat à l'Energie Atomique et aux Energies Alternatives CEA, Eifer Europaisches Inst. fur Energieforschung, JRC -Joint Research Centre, European Commission	
Website:	http://www.soctesqa.eu/

Project and objectives

The aim of the project is to develop uniform and industry-wide test modules and programs for solid oxide cell and stack (SOC) assembly units. New application fields are addressed, based on the operation of the SOC cell/stack assembly in the fuel cell (SOFC), in the electrolysis (SOEC) and in the combined SOFC/SOEC mode. This covers the wide field of power generation systems, e.g. stationary SOFC, μ-CHP, mobile SOFC APU, SOEC power-to-gas and combined SOFC/SOEC power-to-gas-to-power systems. The results of the project are being successfully implemented into international standards.

Major project achievements

- Altogether 11 generic test modules for SOFC, SOEC and combined SOFC/SOEC have been developed which cover stationary and mobile applications
- The test procedures contain all important guideline information in order to achieve high quality, reproducible and repeatable test results
- The project outcome is already being transferred to standards developing organisations (e.g. IEC, CEN/CENELEC, ISO, VDMA)

Future steps

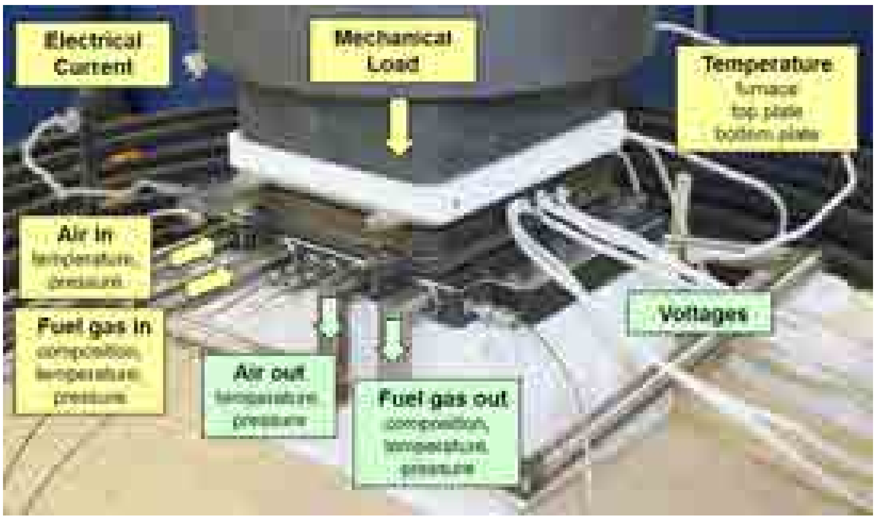
- Project finished

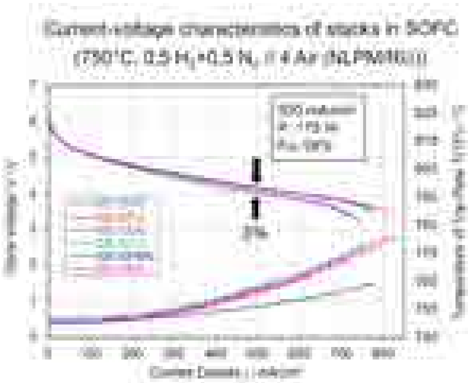
Relevant to FCH JU overarching objectives

- Reduce the production cost of fuel cell systems to be used in transport applications, while increasing their lifetime to levels which can compete with conventional technologies
- Increase the electrical efficiency and the durability of the different fuel cells used for power production to levels which can compete with conventional technologies, while reducing costs
- Increase the energy efficiency of production of hydrogen mainly from water electrolysis and renewable sources while reducing operating and capital costs, so that the combined system of the hydrogen production and the conversion using the fuel cell system can compete with the alternatives for electricity production available on the market

Non-quantitative objectives and status

- Development and validation of testing procedures for SOFC/SOEC
  Altogether 11 generic test modules for SOFC/SOEC applications have been developed, validated and optimised within 4 different testing campaigns
- Identification of testing procedures for solid oxide technology
  All specifications, nomenclature, test modules and test programmes were identified and defined
- Establishment of methodologies for testing data
  A general test module (TM00) was developed, which describes methodologies, collection, formulary, analysis and presentation of test data
- Interaction with standards developing organisations (SDOs)
  Results are being transferred to main bodies currently working on regulations for hydrogen and fuel cell technology (e.g. IEC, CEN/CENELEC, ISO, VDMA)





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SUSANA
Support to safety analysis of hydrogen and fuel cell technologies

Panel 6 — Cross-cutting

Acronym:	**SUSANA**
Project ID:	325386
Title:	Support to safety analysis of hydrogen and fuel cell technologies
Call Topic:	SP1-JTI-FCH.2012.5.2
Project total costs (€):	€ 2,1 million
FCH JU maximum contribution (€):	€ 1,1 million
Project start/end:	01 Sep 2013 - 31 Aug 2016
Coordinator:	Karlsruher Inst. Technol., Germany
Beneficiaries: Areva Stockage d'Energie, Health and Safety Executive, Element Energy, JRC -Joint Research Centre, European Commission, Uni. Ulster, National Center For Scientific Research "Demokritos"	
Website:	http://www.support-cfd.eu

Project and objectives

SUSANA critically reviewed the state-of-the-art in physical and mathematical modelling of phenomena and scenarios relevant to hydrogen safety, i.e. releases and dispersion, ignitions and fires, deflagrations and detonations, etc. A major objective was to develop and compile a guide of best practices in use of Computational Fluid Dynamics (CFD) for safety analysis of FCH systems and infrastructures, to update verification and validation procedures and to generate a database of verification problems and model validation. Dissemination activities, workshops and seminars executed concluded the work at end of project.

Major project achievements

- Support of the Computational fluid Dynamics (CFD) user community through the creation of a database of the simulations performed identifying the reliability of the applied analysis
- Development of a verification and validation database to support the CFD community
- Model evaluation protocol and guidelines to best practice in safety-related numerical simulations

Future steps

- Project finished

Non-quantitative objectives and status

- Database for verification and validation problems in CFD analysis (Achieved)
  A database was developed to incorporate related experimental data concerning modelling and simulation of safety analysis by CFD (database available)
- Model evaluation protocol (Achieved)
  A model evaluation protocol was developed to guide CFD users to achieve best results in safety related simulations
- Critical analysis and requirements to physical and mathematical models (Achieved)
  Critical analysis was executed by reviewing the state-of-the-art of safety-related documents and publications at international level
- Best practices in numerical simulations (Achieved)
  Guidelines were developed in relation to best practice in numerical simulation

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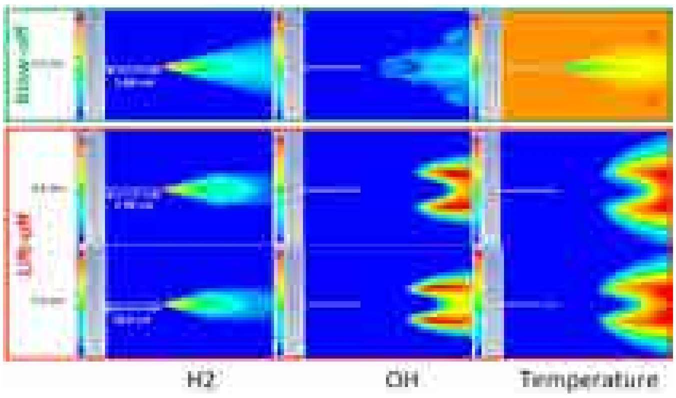

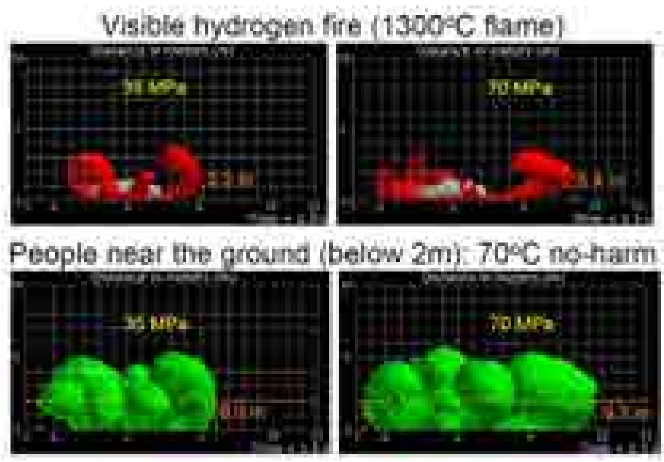

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