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Fuel Cells and Hydrogen

Joint Undertaking

Programme Review 2011

Final Report

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New Energy World JU
fuel cells & hydrogen for sustainability

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Fuel cells and hydrogen Joint Undertaking
Email: fch-ju@fch.europa.eu
www.fch-ju.eu

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List of acronyms

AA	Application Area
AIP	Annual Implementation Plan
APU	Auxiliary Power Unit
CHP	Combined Heat and Power (generation)
CCS	Carbon Capture and Storage
DoE US	Department of Energy, US
EIB	European Investment Bank
FP7	7th Research and Development Framework Programme of the EU (2007-2013)
GHG	Greenhouse Gases
IG	Industry Grouping
IPHE	International Partnership for Hydrogen in the Economy
ISO	International Organization for Standardization
JU	Joint Undertaking
LCA	Life Cycle Assessment
MAIP	Multi-Annual Implementation Plan
MCFC	Molten Carbonate Fuel Cells
OEM	Original Equipment Manufacturer
PEMFC	Proton Exchange Membrane Fuel Cells
PNR	Pre-Normative Research
RCS	Regulations, Codes and Standards
RG	Research Grouping
SET-Plan	Strategic Energy Technology Plan
SME	Small and Medium Enterprises
SOFC	Solid Oxide Fuel Cells
SRA	Strategic Research Agenda
TRL	Technology Readiness Levels
UPS	Uninterruptible Power Supply

Executive summary

The Fuel Cells and Hydrogen Joint Undertaking (FCH JU) has the ambitious objective to place Europe at the forefront of the development, commercialization and deployment of fuel cells and hydrogen technologies, as of 2015. About €470 million, over a six year period, have been granted by the European Union to achieve this, and private funds are being attracted to support the same ambition, as part of the global European effort embedded in the multi-annual implementation plan MAIP (2008-2013).

A periodic evaluation of such a strategic program is relevant to address the question of whether the public-private partnership is on the path of reaching its objectives and to enable adjustments to its course if and where needed.

This first Programme Review from the FCH JU has the objective of assessing the portfolio of projects; 44 projects from the call 2008 and 2009 as well as some 14 projects supported by the European Commission under the 7th framework programme, which are linked to the Joint Undertaking portfolio and have been either the forerunners or the complement of a number of FCH JU projects. These projects cover a mix of basic and applied research, and demonstration activities.

The review process is intended to take place on an annual basis and to contribute as far as possible to a pro-active and continuous management of the entire portfolio, future calls as well as to the next phase of the programme.

This year's review highlights that the programme has made substantial progress. The portfolio of projects is focused on the aspirations of, and structured to address the challenges identified in the MAIP; any gaps in the portfolio of projects arising from the annual implementation plans of 2008 and 2009 are likely to have been rectified in subsequent annual plans. Progress is being made towards a range of objectives established in the MAIP, e.g. cost reduction, component and system durability and performance, and this is occurring across all Application Areas. Even if some achievements fall short of quantitative targets, it has to be nuanced by the fact that the MAIP targets go beyond the programme's actual scope and budget.

Progress is real and industry involvement definitely makes a difference. In many cases, industry plays a significant role in the leadership and shaping of activities; SMEs are particularly well represented in many of the projects, accounting for 50% of industrial participation.

The FCH JU is definitely having a positive impact on the fuel cell and hydrogen technology programmes of activities at the Member State level, in the areas of both RTD and demonstrations. There is also evidence of active participation by projects at the international level. Some projects notably may serve as best practices examples since they can trace their development back to previous European and/or Member State supported projects and have clear plans to utilise the results and developments in the future. The portfolio also includes projects with very real prospects of advancing through the entire RTD cycle from basic research through applied research to demonstrations, and then, if successful, to commercialisation. Such virtuous cycles towards innovation confirm the mission of the FCH JU.

The FCH JU is one of only five innovative European public-private partnerships, all without precedence, and it should not be surprising that there are some learning points arising from the review.

The MAIP targets may be worth revisiting to ensure that they are better tailored to the activities of the FCH JU, the FCH JU being only part of European efforts to commercialise fuel cell and hydrogen technologies; longer term headline volume and cost targets could be supplemented by more relevant interim targets.

Interaction and collaboration within and between the FCH JU programme and projects and those of the member states, as well as at international level, can be enhanced and improved to the benefit of all parties. Closer cooperation with other fuel cell and hydrogen research programmes at regional, European and international level, notably with US, Japan, Canada and Korea is further encouraged.

In the area of *transportation and refuelling infrastructure*, dominated so far by large demonstration projects, a stronger emphasis on the building of an infrastructure in collaboration with Member States, which eventually must be Europe-wide is recommended. There are also calls for improved coordination with national efforts and regional initiatives.

Hydrogen production and distribution is regarded as a crucial area for the long-term success of the fuel cell technology. So far under-emphasized – notably from a budgetary point of view, this application area would benefit from looking more at short term challenges (industrialization, optimization, mass production of conventional hydrogen production technologies), whilst maintaining work on longer term solutions (new sustainable and efficient pathways).

Stationary and CHP projects focused primarily on the RTD pathway – understanding degradation and lifetime fundamentals, through applied research related to component improvement, control and diagnostics to advance the area to a position of being successfully demonstrated. Coordination and active industry involvement is required as developments are likely to be needed across the complete system, cell and stack, balance of plant, power electronics, controls etc for successful commercialisation.

Regarding early markets, reinforcing the link with industry is suggested for this application area, especially in harmonizing regulations, codes and standards and also to align targets related to number of installations of UPS and back-up power in 2015 as well as performance and costs targets. Ensuring close involvement of end-user businesses in the development of projects is particularly relevant to align expectations about timing and costs.

The relevance of sustaining *cross cutting activities* over the lifetime of the FCH JU and beyond is highlighted as well as the need to develop a strategic approach to use and optimise project results.

Codes and standards, especially on safety issues, are considered increasingly important, and need to be emphasized, in particular with more involvement from industry. Standardisation has to be considered internationally, in coordination with other continents (US, Japan). Effort in the area should be industry driven, in a transparent and inclusive approach to avoid predominance of special interests, preferably through advisory groups. Projects in other application areas, nearing commercialization, would need to address specifically cross cutting issues such as RCS. Opportunities to strengthen links between PNR and LCA projects and other FCH JU projects should be developed in order to ensure use of results for all projects as well as use of real world data from projects by PNR and LCA ones.

Acknowledging the longer term development effort is essential, especially for basic research as well as training, education and awareness projects which span the lifetime of the FCH JU.

The FCH JU has a limited lifespan with funds available to 2013, although project administration runs through to 2017. A successor initiative to or continuation of the current FCH JU in the Horizon 2020 programme provides the opportunity to consider substantive changes that could improve its effectiveness. There might also be an opportunity to reshape the programme structure away from four parallel AAs each addressing basic and applied research and demonstrations to a 'funnel shaped' structure which recognises that many basic research activities are relevant to all applications, and therefore can be undertaken in common activities, but also sets out demonstration activities for each AA.

Following on the foregoing, an opportunity to institute deployment/ demonstration programmes over the lifetime of the FCH JU would be worth exploring; these would follow a common strategy, have common objectives and be additive over time as more businesses and regions decide to join the effort.

Introduction

Our modern society is based on primary energy consumption. A direct link exists between energy consumption per inhabitant and the welfare of the populations in the different countries of the world. It is then of critical importance for any economy to understand its energy mix, (between fossil –coal, natural gas, oil…–, nuclear and renewable energy sources), its future strategic options and evolution pathways, together with the principle energy challenges it faces.

The European Union's energy strategy, the EU 2020 strategy, aims to address energy security, resource efficiency and climate change challenges. The Union's objectives by 2020 are:

- to reduce the greenhouse gas emissions levels by 20%
- to increase the share of renewable energies to 20%
- to increase the energy efficiency by 20%

The portfolio of energy technologies able to achieve these objectives is identified in "The European Strategic Energy Technology Plan - Towards a low carbon future", also known as the "SET Plan". This plan, published in 2009, has identified fuel cell and hydrogen technologies as a key technology for Europe, which has a significant potential to contribute to a number of Europe's key policy goals, including the reduction of CO_2 emissions of the energy system, particularly transport, improving energy security and the increased use of renewables in Europe's energy mix, whilst also promoting innovation-driven growth and employment.

Fuel cells and hydrogen are medium and long term energy options, whose contribution to meeting the 2020 EU targets on greenhouse gases emissions, renewable energy and energy efficiency, are recognised as minor. They are however expected to play a significant role in achieving the EU vision for a low carbon economy by 2050. By 2050 it is expected that cost competitive carbon free hydrogen produced through renewable, nuclear or CCS methods will be widely available, fuelling a European fleet of fuel cell powered vehicles. It is also expected that distributed generation utilising virtual power plants including CHP and power with only fuel cells will provide the power and heat required by Europe's communities alongside more traditional power and heat generation methods.

In order to realise these public benefits, the Fuel Cells and Hydrogen Joint Undertaking brings public and private interests together in an innovative, industry-led implementation structure with the objective of accelerating the commercialisation of hydrogen and fuel cell technologies. Bringing public and private interests together ensures that the jointly defined research programme better matches industry's needs and expectations.

FCH JU is a Joint Technology Initiative (JTI) within the Seventh Framework Programme 2007 – 2013 (FP7), implemented as a Joint Undertaking with three members: European Commission representing the European Union, European Industry Grouping for Fuel Cells and Hydrogen, (NEW-IG) and Research Grouping for Fuel Cells and Hydrogen (N-ERGHY). The partnership was set up by the Council Regulation N° 521/2008 of 30 May 2008 for a period up to 31 December 2017. The FCH JU began operating in 2008, and became autonomous in November 2010.

The FCH JU has the objective of supporting RTD projects that will accelerate the commercialisation of fuel cell and hydrogen technologies in Europe, helping achieve the market breakthrough necessary to allow market forces to drive substantial public benefits, and for Europe to become a global leader. It operates an integrated RTD programme carried out by and in co-operation with its stakeholders: industry including SMEs, and research centres and universities, together with the Member States and Europe's regions and municipalities.

It supports RTD developments and demonstrations through a series of projects that cover the entire RTD range of activities from basic and breakthrough research through applied research (RTD) to demonstrations of fuel cell and hydrogen technologies. These are complemented and supported by cross-cutting activities e.g. Regulations, Codes and Standards, Pre-Normative Research, socio-economic analysis, life cycle analysis, market support, public awareness, education and training. The projects are funded by both private and public sectors, the FCH JU contribution being awarded as grants through open, annual and competitive calls for proposals.

The research agenda outlining the research and demonstration activities to be supported by the FCH JU is set out in the Multi-Annual Implementation Plan (MAIP) of the FCH JU, adopted by the Governing Board on 15 May 2009.[1]

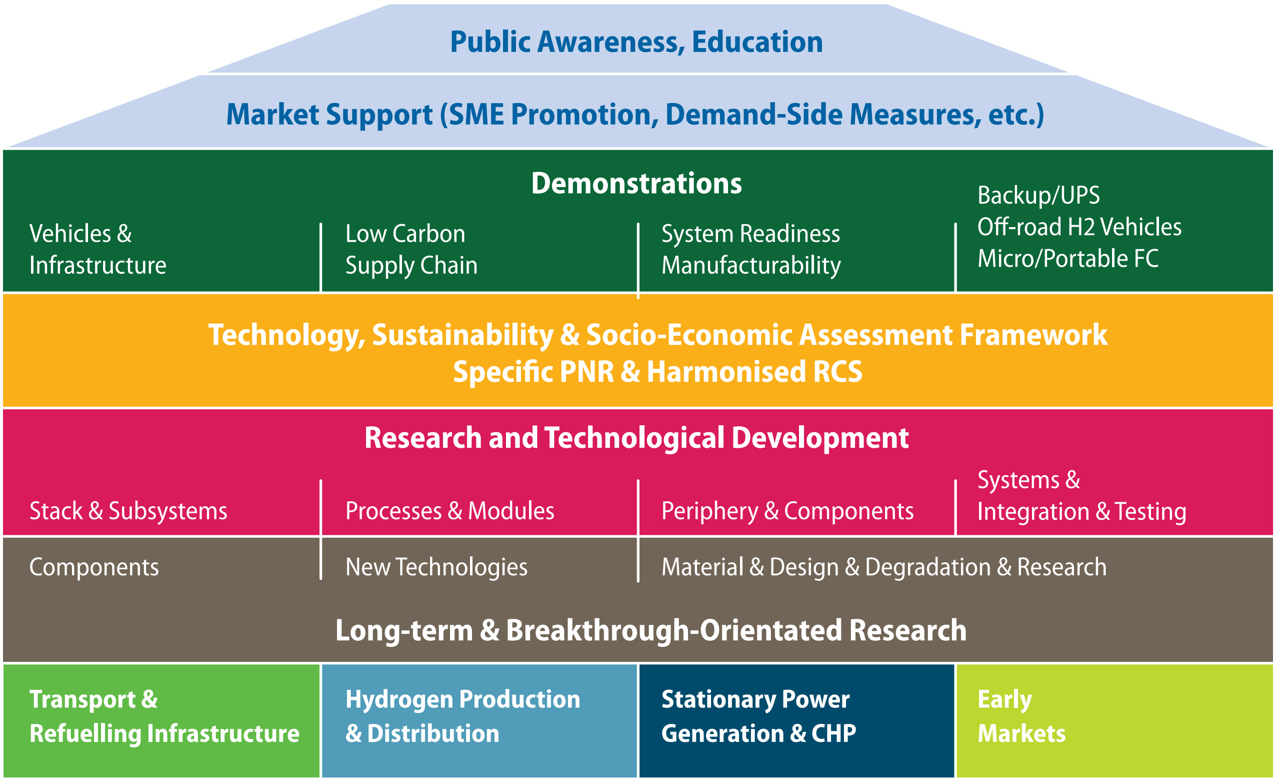


Figure 1: Graph of the Multi-annual implementation plan

The MAIP defines strategic orientations as well as tentative budget breakdown for the full period 2008-2013 by application area (see Figure 2) and by action category (see Figure 3).

Figure 2 : Budget breakdown by application area

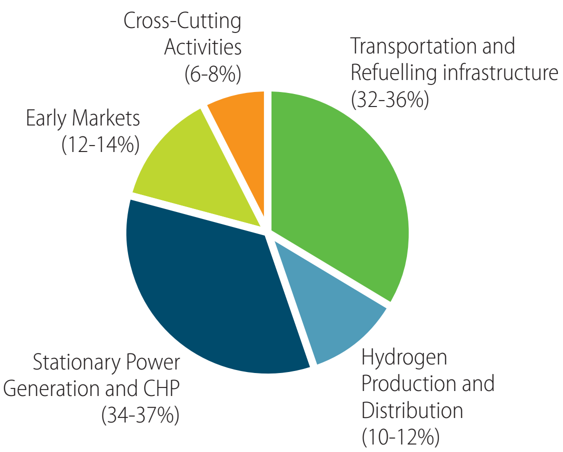
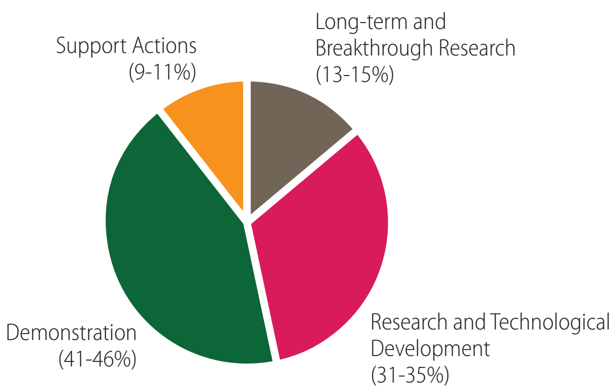


Figure 3: Budget breakdown by activity type



[1] http://www.fch-ju.eu/sites/default/files/EvalFuelCellHydroReport2011_ALLBROCHURE_WEB.pdf

The MAIP also covers additional activities that would benefit the FCH JU portfolio as a whole. The inclusion of Europe's SMEs in projects is a particular goal recognising the competitiveness and innovativeness of these entities. Interactions and collaboration are also sought with JRC, Members States and regions.

- Joint Research Centre – the European JRC provides an opportunity for the FCH JU to access leading capability and know-how in Europe, and it is envisaged that the JRC may provide in-kind contributions to activities or be part of projects;
- Member States (MS) – the Member States invariably operate fuel cell and hydrogen research and development programmes, and these provide a source of additional capability and know-how, plus potential funds, to enhance the activities of the fuel cell and hydrogen industry to the benefit of Europe as a whole;
- Regions – Europe's regions provide opportunities for collaboration especially with regard to demonstration activities, the FCH JU is working with the HYER organisation of European regions and municipalities to realise the benefits of collaboration;

Benefits will also arise from co-operation with international bodies/agencies e.g. International Partnership for Hydrogen in the Economy (IPHE) and other global economies such as the USA, Japan, Korea.

The strategy and objectives set out in the MAIP are translated into annual programmes of activities in the Annual Implementation Plans (AIP), which set out the topics for the Call for Proposals for which project proposals are required by each application area. Consortia are invited to submit proposals to a competitive process which assesses each proposal on a range of criteria, with the highest scoring examples being selected for FCH JU support.

To date five AIPs have been written and published: 2008, 2009, 2010, 2011 and 2012. An updated version of the MAIP has in the meantime been adopted by the Joint Undertaking.[2]

As part of its activities and in accordance with the Interim Evaluation published on 20 July 2011[3], the FCH JU launched in 2011 a regular review process of the portfolio of RTD projects. This process began with the Programme Review Day held on the 22nd November 2011. It is the first time that such a review has been undertaken by the FCH JU, although similar exercises have been held by the European Commission prior to the establishment of the FCH JU.

The objective of the Programme Review Day was to consider the progress that the portfolio of projects has made, the alignment or otherwise with the FCH JU RTD strategy (the Multi-annual implementation plan) of accelerating commercialisation, and to identify weaknesses and propose improvements for the future. The emphasis was not on assessing individual projects, but rather on the portfolio as a whole.

58 projects in total participated in the Review: 44 FCH JU supported from the calls 2008 and 2009, as projects from Call 2010 were still under negotiation, as well as 14 projects supported directly by the European Commission under the 7th Framework programme. The inclusion of the European Commission supported projects, which are primarily breakthrough rather than commercially orientated projects, reflects the broad alignment of these with the FCH JU's objectives and their direct relationship with FCH JU supported projects.

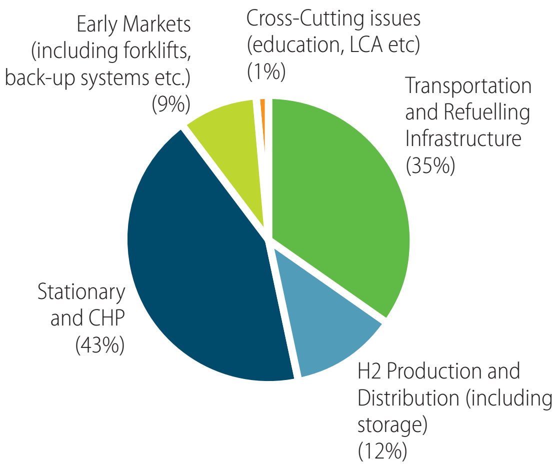
The projects reviewed covered the range of RTD activities supported by the FCH JU: from Basic/Breakthrough research, Applied research and development (RTD) to Demonstration activities. The FCH JU's four Application Areas (AAs) were covered: Transportation, Hydrogen Production, Storage and Distribution, Stationary Power and CHP, and Early Markets, together with the Cross-Cutting activities.

The projects had generally been running for less than two years, some less than a year, as they had been successfully submitted to the Annual Implementation Plans of 2008 and 2009.

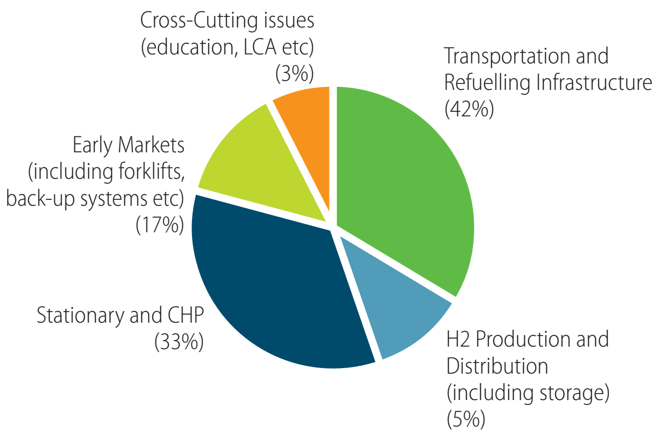
2 http://www.fch-ju.eu/page/documents

3 http://www.fch-ju.eu/sites/default/files/EvalFuelCellHydroReport2011_ALLBROCHURE_WEB.pdf

Figure 4: Budget breakdown by application area for the 2008 and 2009 selected projects



Call 2008:
Budget: 27.2 M€
16 projects granted in December 2009



Call 2009:
Budget: 72.5 M€
28 projects granted in December 2010

The geographical distribution of the beneficiaries is presented in Figures 5 and 6 for respectively the 2008 and 2009 grants.

Figure 5: Geographical distribution of the beneficiaries of the 2008 grants

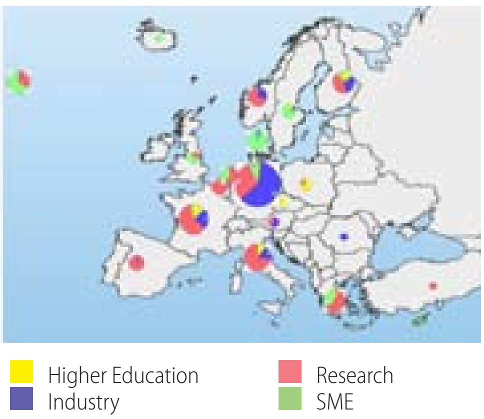
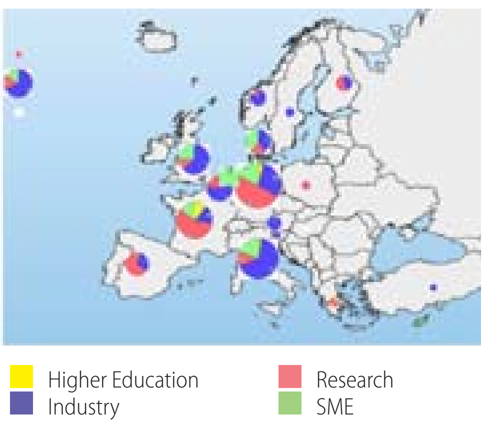


Figure 6: Geographical distribution of the beneficiaries of the 2009 grants



A team of 17 independent reviewers[4] appointed by the FCH JU undertook remote assessment based on harmonised project presentations and attended the Programme Review day structured in 16 different sessions, four running in parallel at any one time.

Each session was attended by two or more independent reviewers from within Europe, and also from Japan and the USA. Each reviewer prepared and submitted a report on their assessment and views on the projects and the portfolio as a whole. These individual reports were analysed and assimilated to provide the basis of this report.

4 Cf. list of reviewers, p.35

FCH JU project portfolio analysis

Transport and refuelling infrastructure
Hydrogen production and storage
Stationary applications
Early markets
Cross-cutting issues

Transportation and refuelling infrastructure

Priorities of the Multi-annual Implementation Plan

The main objective of the transportation application area strategy is the testing and development of competitive hydrogen-fuelled road vehicles and corresponding refuelling infrastructure, together with full supporting elements for market deployment and increased industrial capacity. The emphasis of the MAIP is on large scale fleet demonstrations, including cars and buses, plus a number of refuelling stations Europe wide. Such demonstrations are to test for durability, robustness, reliability, efficiency and sustainability of vehicles and infrastructures for everyday use. The original global market objectives were for thousands of vehicles by 2015 and mass production from 2020. The AA has also sought to support activities focused on developing a credible European leadership in stack research and development, working with OEMs, the supply industry and research institutes; undertake research and technology development to improve PEMFC for transport use, for example stable and long life membranes, stable and low cost catalysts, corrosion resistance and low weight, cost and volume bipolar plates; and finally to support heavy duty transport applications with the common goal of reducing CO_2 emissions and local pollution and increasing the efficiency of on-board power generation. It sees opportunities to co-ordinate activities with the other AAs.

The Transportation AA Calls for 2008 and 2009 were in line with the MAIP's strategy for this application area. These Calls included the core requirements for large scale demonstration of road vehicles and refuelling infrastructure, (a consistent theme in all AIPs to date) together with supporting activities, including feasibility studies for developing a cluster for large scale vehicle demonstrations and for a European fuel cell stack cluster, plus the development of PEMFC components and PNR work on fuel quality and composite storage.

The successful projects from these two AIPs cover the range of activities: CHIC and H2Moves Scandinavia projects are focused on vehicle demonstrations, together accounting for a large proportion of funds; feasibility studies have been undertaken by Autostack and NextHyLights projects; HyQ and HyCOMP are respectively addressing the PNR requirements for hydrogen fuel quality and composite storage; and PEMICAN is to reduce catalyst loadings for automotive PEMFC.

The review recognised the alignment of the projects with the MAIP. Given the comparatively early nature of these projects, there is no need for any re-focusing, although progress within the next year will allow this view to be updated. There were considered to be no gaps in the portfolio with regard to demonstrations and PNR activities, but there was concern that PEMFC development activities were too small and limited at present, and more effort was required. This latter point appears to have been addressed in succeeding AIPs.

The primary concern of the reviewers was the extent to which the MAIP 2015 volume and cost targets for vehicle demonstrations would be achieved; for example the pathway to 500 buses in demonstration by 2015 wasn't clear. As such revisions to target numbers may be required. Other cost and performance targets in the MAIP may also require revision in the future. There is a need to ensure that projects deliver on cost reductions, e.g. PEMFC components; as such it was felt that the involvement of suppliers would improve the cost awareness of the projects.

Reviewers highlighted the opportunity, and need, for the FCH JU to work with Member States on vehicle demonstrations, including hydrogen infrastructure, given the scale of actual and potential activities in Germany, Scandinavia notably. It is noteworthy that the FCH JU is part of German, Norwegian and UK H2 mobility discussions. Such co-operation could assist the achievement of the MAIP targets. The FCH JU should also support activities to harmonize RCS for the transportation sector.

Special attention is deemed necessary for the build-up of a hydrogen infrastructure in Europe for all vehicle types, especially if the 2015 targets are to be met. A project to support this in co-operation with the Member States would be valuable for the FCH JU, according to some reviewers.

Further development of the European supply base was recommended for the system elements of cell and stack, balance of plant, as well as hydrogen storage technologies. This would be complemented by more R&D for these items.

Harmonized Regulations, Codes and Standards would enable faster implementation of demonstration activities, whilst also setting the scene for market deployment; the FCH JU might consider supporting this in the application area itself.

Feasibility studies were considered to provide valuable backing for the transport application area, which is also well served by a range of studies including the report on a portfolio of power trains, a fact-based study[5].

[5] http://www.fch-ju.eu/sites/default/files/documents/Power_trains_for_Europe.pdf

Project name	Type	Description	Coordinator	EC Funding (M€)
H2 Moves Scandinavia	Demonstration car fleet and station	European project H2moves Scandinavia sets out to gain customer acceptance for electric vehicles with fuel cells in Scandinavia	Ludwig-Bölkow-Systemtechnik GmbH, Germany	7.8
CHIC	Demonstration bus fleet	The CHIC project will forge partnerships between cities which have previously gained experience with hydrogen powered buses and 14 new cities and regions in Europe which are considering moving into the field. These partnerships will facilitate the effective and smooth introduction and expansion of the new systems now and into the future	Daimler, Germany	25.8
Autostack	Feasibility study	While the supply base for materials and components in Europe is well advanced and competitive, stack integration is lagging behind due to massive investment requirements and risks associated with commercialization. The project aims to develop approaches to address the critical barriers for substantial improvement of collaboration between major stakeholders and establishing a solid business model for an independent European stack integrator for automotive applications. The key objective of the work proposed is to develop a solid business case and propose actions to facilitate the market start of a European automotive fuel cell stack industry	Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW), Germany	1.2
NextHyLights	Feasibility study	NextHyLights is assisting the FCH JU to prepare the next consequent step, the planning and preparation of further large-scale demonstration projects for next-generation hydrogen vehicle fleets at additional demo sites across Europe	Ludwig-Bölkow-Systemtechnik GmbH, Germany	0.5
PEMICAN	New material of automotive PEMFC	The objective of PEMICAN is to develop and manufacture MEA (membrane Electrode Assembly) with reduced Platinum cost	Commissariat à l'énergie atomique (CEA), France	1.8
HyQ	PNR for fuel quality	The project consists of pre-normative studies to provide a strong support to Regulation Codes and Standards organizations in order to normalize an acceptable fuel quality for PEMFC	CEA, France	3.7
HyCOMP	PNR for fuel quality	HyCOMP conducts pre-normative research on high-pressure type III and type IV composite cylinders for hydrogen storage and transport for automotive, stationary and transportable applications	Air Liquide, France	2

Hydrogen Production, Storage and Distribution

Priorities of the Multi-annual Implementation Plan

The area aims to develop a portfolio of cost-competitive, energy efficient and sustainable hydrogen production, storage and distribution processes and to test these under real market conditions. A mid-term objective has been to supply carbon lean or carbon free hydrogen by 2015, complemented with preparatory work to enable the wide spread introduction of hydrogen infrastructure beyond 2020-2030. Given the range of processes with differing degrees of maturity, production capacity and sustainability the AA has emphasized the need for R&D for mature production and storage technologies, whilst also supporting longer term, fully sustainable production and supply pathways. Mature technologies include: i) reforming bio-fuels plus conventional fuels; ii) cost-efficient low-temperature electrolysers adapted for large scale use of carbon free electricity; iii) biomass to hydrogen using thermal conversion. Longer term technologies include water splitting plus thermo-chemical processes based on solar, nuclear or waste heat plus development of low temperature, low cost biological hydrogen and photo-electrochemical processes for direct hydrogen production. Production methods are allied to storage options to include high volumes e.g. underground and liquefaction, plus long term breakthrough solid and liquid materials storage.

The 2008 and 2009 AIPs have focused on the range of topics in the Hydrogen Production, Storage and Distribution AA. Proposals for electrolysers have been a particularly strong theme, supplemented by thermo-chemical processes with solar heat sources, development of fuel processing catalysts, and gas purification technologies plus storage. However, not all of these topics were fulfilled by successful project proposals.

The portfolio assessed during the review day included projects supported by the FP7 Energy Calls and the FCH JU Calls. The portfolio covered the electrolyser topic well, both PEM and Solid Oxide based, e.g. NEXPEL, ADEL and Primolyser, sustainable hydrogen production with a mix of longer term basic breakthrough research and nearer application projects, e.g. HyCycles, WELTEMP, SOLHYDROMICS, NanoPEC Hydrosol–3D, and several solid state storage projects, two basic research, NanoHy and FlyHy, and one more applied project, SSH2S.

Absence of coverage of certain topics from the 2008 and 2009 calls is noted, as well as a lack of nearer market projects such as proof-of-concept and demonstrations, and no liquid or compressed storage projects, plus limited PNR and RCS activity; only one PNR project for compressed storage which is a Transport Call project has been started. Follow-on AIP Calls for 2010 and 2011, together with the current 2012 Call have partially addressed these gaps with one project on liquid storage from 2010 Call and two projects on solid storage from Call 2011 under negotiation. Several projects from the 2010 and 2011 Calls are now targeting proof-of-concepts and a demonstration project from the 2011 Call is currently under negotiation.

Regarding **sustainable hydrogen production**, all projects reviewed can potentially contribute considerably to the goals of the MAIP, covering a range of different longer term potential hydrogen production technologies highlighted in the MAIP. This group is currently at a low level on the technology readiness level scale (TRL), but should continue to receive support given their longer term potential.

Consideration should also be given to ensuring that future projects for the range of technologies such as biological, photo-electrochemical and thermo-chemical processes, include scaling up of their hydrogen production capacity are supported. At present only two FCH JU supported projects (Hydrosol-3D from Call 2008 covered by this review and one from Call 2010) cover these low-carbon production routes. Reviewers recommended that all alternative technologies should be treated equally.

It would be valuable to consider additional longer term hydrogen production technologies such as photolysis, which potentially could attain the same level of importance as photo-biolysis in the future, and co-gasification of biomass. Indeed the gasification of biomass with coal in tandem with CCS could significantly extend the use of biomass in the production of sustainable hydrogen in the nearer term, although this is clearly dependent upon the progress of CCS technologies.

Progress towards affordable hydrogen from non-traditional sources was claimed by the projects, with €7/kg estimated for photo-chemical and biological processes against a target of €5/kg, but these were on a timescale of ten years and not 2015. Future MAIPs should contain specific quantifiable objectives in terms of hydrogen production and cost targets for different production supply chains. These should be clearly set within the framework of the SET plan, the 20-20-20 strategy and the 2050 targets

Concerning storage activities, the three projects were aligned with the objectives of this area, with two FP7 projects focused on basic research and development, materials development and characterisation, whereas the FCH JU project was more industry needs focused.

The reviewers raised the issue of whether and how the MAIP targets for this area would be met, certainly with regard to the 2015 targets. The 9% weight solid state storage of hydrogen target was felt to be some way off, although progress was being made; the FCH JU might consider it relevant to set alternative targets for different applications of individual storage technologies, as different technologies have different performance requirements.

Programme Reviewers recognised that there needs to be a shift from materials research towards 'functioning machines' similar to SSH2S. Storage projects were making progress, but needed to undertake more product development rather than materials research, using the best available materials and engineering solutions for proof-of-concept and validation projects which can show real progress of the technology. Optimisation of the best available materials, low costs, mass production and viable engineering solutions are the main future longer term research topics in this field.

In general, no project investigated or mentioned the potential of adsorption or concepts such as cryo-compressed hydrogen storage. The portfolio is thus more limited than might be desired. A specific topic on low temperature hydrogen storage should be considered within the AIP Calls for example solid state storage using high porosity, materials or hybrids.

Regarding new electrolysers, reviewers positively noted the continuity between the projects from FP7 and those supported by FCH JU. With five projects in the portfolio, the field is well represented in the total MAIP portfolio. Two solid oxide electrolyser projects were complemented by three PEM projects focused on improved PEM electrolyser units with various objectives, including utilising renewable energy sources, and integration with domestic fuel cell CHP units.

No refocusing is believed to be necessary, but the efforts in the field should be sustained by the FCH JU. The principle lines of improvement for electrolysers will continue to be efficiency, cost reduction and integration with renewable energy sources and fuel cells. A valuable addition to the portfolio would be a topic on the development and demonstration of power electronics for operation and control of electrolysers.

Reviewers underlined also that the MAIP cost target for hydrogen (<€5,000/Nm^3) does not apply uniquely to this technology because it depends on the cost of electricity (CoE). Given the importance of electricity costs to the total cost of hydrogen produced, special focus on electricity prices is recommended. A further comment regarding cost was that electrolyser projects did not appear to take into account the potentially high cost of renewable electricity. The 2015 targets will need to be revisited as and when more results are available from the current portfolio.

Also noted, future MAIP text should contain specific quantifiable objectives in terms of volume of hydrogen production and cost targets for different production supply chains. These should be framed by the SET plan, 20-20-20 strategy and 2050 targets.

In terms of future projects the reviewers emphasized the need to maintain a balance between nearer market developments, which were necessary to demonstrate progress and meet 2020 targets, and longer term breakthrough research required to meet the 2050 targets.

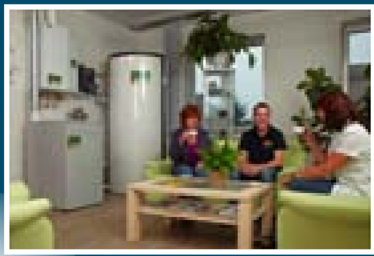
More generally, reviewers mentioned the opportunity to review the budget distribution for this area which tends to be lower than the Transportation and Stationary areas, as well as develop a better and stronger co-ordination at the Member State level.

Project name	Type	Description	Coordinator	EC Funding (M€)
HYDROSOL-3D	Sustainable H_2 production	The project aims at the preparation of a demonstration of a CO_2-free hydrogen production and provision process and related technology, using two-step thermochemical water splitting cycles harnessing concentrated solar radiation	Center for Research and Technology, Greece	1.78
SSH2S	H_2 storage	The main objective of SSH2S is to develop a full tank-FC integrated system I and to demonstrate its application on a real system. The final aim is to clearly demonstrate the applicability of the proposed integrated system in real applications	University of Turin, Italy	1.6
NEXPEL	New electrolysers	Demonstration of an efficient PEM electrolyser integrated with Renewable Energy Sources	Sintef, Norway	1.3
ADEL	New electrolysers	The project proposes to develop a new steam electrolyser concept aiming at optimizing the electrolyser life time by decreasing its operating temperature while maintaining satisfactory performance level and high energy efficiency	Htceramix, Switzerland	2
Primolizer	New electrolysers	The project is to develop, construct, and test a cost-minimised highly efficient and durable PEM-Electrolyzer stack aimed for integration with domestic µCHPs	IRD, Denmark	1.2
Projects managed by the European Commission				
NanoPEC	Sustainable H_2 production	The key objective of NanoPEC is to develop advanced, nanostructured composite photoelectrodes that can significantly enhance hydrogen production by way of photo-electrochemical (PEC) water splitting	Ecole Polytechnique Fédérale de Lausanne, Switzerland	2.6
SOLHYDROMICS	Sustainable H_2 production	Development of efficient chemical or biological systems converting solar energy into chemical energy for water splitting. Low temperature hydrogen production shall also be demonstrated in small scale reactors	University of Turin, Italy	2.7
HYCYCLES	Sustainable H_2 production	The objective of Hycycles was to provide detailed solutions for the design of specific key components, and in particular on the materials needed for sulphur based thermochemical cycles for hydrogen production	DLR, Germany	3.7
NANOHY	H_2 storage	It is the overall goal of the project to produce nanocompositic materials for hydrogen storage which have altered properties with respect to working temperature and pressure, an enhanced reversibility, and controlled interaction between the hydride and the environment, leading to improved safety properties	Karlsruhe Institute of Technology, Germany	2.3
FLYHY	H_2 storage	At present no solid state hydrogen storage material fulfils all requirements for mobile applications at the same time, i.e. high storage density, operational temperatures and heating compatible with PEM fuel cells, fast hydrogen loading and low production costs. FlyHy focused on the first three points	Helmholtz-Zentrum Geesthacht, Germany	2.0
RELHY	New electrolysers	The RelHy project targeted the development of novel or improved, low cost materials (and the associated manufacturing process) for their integration in efficient and durable components for the next generation of electrolysers based on Solid Oxide Electrolysis Cells (SOEC)	CEA-Liten, France	2.9
WELTEMP	New electrolysers	The strategic development of the WELTEMP project was an elevated operating temperature of the PEM electrolyser. This is expected to significantly improve the energy efficiency because of the decreased thermodynamic energy requirement, enhanced electrode kinetics, and the possible integration of the heat recovery	Technical University, Denmark	2.3

Stationary power production and CHP

Priorities of the Multi-annual Implementation Plan

The strategy for the Stationary Power Generation and CHP area in the MAIP is to improve the technology for fuel cell stacks and balance of plant components to the level required to enable products to bridge the gap between laboratory and pre-commercial systems for power or power and heat. This AA has sought to provide a pathway supporting necessary basic and breakthrough research at one end of the research spectrum, through applied research including proof-of-concept, to technology validation and field demonstrations at the other end. As such the AA calls for the further development of the main fuel cell technologies (SOFC, MCFC and PEMFC) in order to improve performance, durability, reliability, robustness and costs. The FCH JU has focused therefore on the one side on a better understanding of degradation and lifetime fundamentals, development of novel cell and stack architectures, reliable control and diagnostic tools and balance of plant, and on the other side of demonstrating proof-of-concept, validation and demonstration activities, the latter to include full integration into existing fuel and grid infrastructures. It recognises also the opportunity to co-ordinate R&D with other AAs.



The initial AIPs of the FCH JU in 2008 and 2009 followed the broad strategic objective of providing support for projects along the RTD pathway of basic/breakthrough research, for example understanding degradation and lifetime fundamentals, and applied research e.g. component improvement and control and diagnostics, with less emphasis on the demonstration activities at the beginning of the programme. The objective was to advance stationary power generation and CHP systems to a position where they can be successfully demonstrated later on.

The Stationary project portfolio at the 2011 review was arrayed across a number of sessions, from basic/breakthrough research for new materials and stack for fuel cell applications e.g. SCOTAS-SOFC, SOFC-Life, Smallinone and Maestro, and fuel cell degradation aspects e.g. Decode, Stayers and PremiumAct, through to more applied research for operation diagnostics tools e.g. Genius and Design, and stationary application proof-of-concepts and system components development e.g. Cation, Lotus and Asterix III. The portfolio included both FP7 and FCH JU supported projects.

In general, the broad thrust of the MAIP has been achieved and confirms the approach of initially focusing on more research oriented projects and later going on to call for demonstration of technology projects (as is likely to be confirmed again with the new projects to be signed under calls 2010 and 2011).

The gaps identified in the portfolio covered manufacturability of materials and components, the small number of PEM focused projects in new materials and cell and stack design topics, and similarly the small number of SOFC focused projects in the degradation topics. However, it was considered there is no need to refocus efforts, but rather to sustain the topics going forward and to ensure improved coverage as all AA could benefit from these activities.

The issue of ensuring that basic research meets the needs of industry was raised (especially for the FP7 projects), for example understanding the current challenges required to meet commercial objectives, rather than more 'blue sky' research. A fair balance of longer term projects and projects of pre-commercial relevance is recommended, as well as strengthening of the industrial relevance of all projects. Targets need to be aligned with commercial objectives, for example the impact on cost and durability.

Reviewers believe that it is appropriate to assess the impact of even basic and applied research projects on competitiveness of end products; all projects should therefore be continually evaluated for their potential to deliver commercially relevant results. In addition, all projects should be required to determine key performance indicators, how they are progressing towards these; quantitative metrics to determine success or failure need to be established at the beginning of projects with off-ramps and alternative paths established early on.

Targets in the MAIP need to be continuously updated and clarified in terms of durability, reliability, cost and operational performance e.g durability targets based on performance parameters, duty cycles or minimum number of on/off cycles depending on application.

The reviewers recommended highlighting the longer term objectives of the MAIP beyond 2020 to be able to secure a longer term vision for the required research and development activities; there should be more additional detailed quantitative targets for each technology, notably with industry input to ensure that relevant research with a good prospects of commercial implementation is undertaken; pre-competitive targets can be set by industry, end users and the public sector in workshops and partnerships e.g. of best practise in the USA, the USDRIVE partnership between US DOE and US council for automotive research.

The need for benchmarks and cost and performance targets were raised, and in anticipation of these comments, the FCH JU has already commissioned the project FCH-EuroGrid to look at and advise on these future targets.

In addition, general comments made by the reviewers included the view that FCH JU projects were better aligned, than the FP7 projects, with more commercial focus and industrial participation, as well as better views on progressing the results and findings.

Fuel Cell Degradation portfolio of projects are focused on one of the MAIP's principle basic research goals of longer term research to better understand degradation/failure mechanisms and lifetime requirements of technology mature fuel cell stack types. Given the fundamental importance of this topic to all types of fuel cell technologies in all applications, since longer lasting and better performing stacks will result in more competitive end products, sustained and continued efforts are needed over the lifetime of the FCH JU. Possible improvements include better links with other projects in the stationary portfolio, e.g. stack and system durability, operating diagnostics, but also enhanced co-operation between FCH JU projects and projects of Member States and those elsewhere in the world.

Different technologies are covered by all degradation projects, but there is still an imbalance between the main technologies PEMFC, SOFC and MCFC. The reviewers believe that SOFC is particularly under-represented given its significance to the stationary application area. One explanation of this significant gap in SOFC degradation work could be due to project focus on anode degradation, notably sulphur and carbon deposition, as well as efforts on new materials. These SOFC projects are also very much fundamental research orientated. However, work on major degradation modes e.g. interconnect, sealing, cathode degradation is required, whilst in addition more work on developing accelerated aging tests is essential e.g. extrapolations from 1,000 and 5,000 hours. Similar comments also apply to the MCFC technology although whether there is enough European industrial interest and support in this technology is an issue.

On the other hand, PEMFC technologies, both high and low temperature are well covered by the existing portfolio of projects and appropriate targets exist. The work includes single component, materials and stack investigations, development of lifetime prediction models, and of accelerated test procedures and protocols. Both laboratory and real world data and results are being utilised.

More specific comments include that test conditions, especially accelerated stress tests, should be harmonized in terms of definition of the conditions such as amplitude and frequency of cycles, temperature and humidity. There is a significant opportunity of aligning as far as it is possible with similar work in the USA, Japan, Canada and Korea. As noted above development of accelerated stress tests for SOFC technologies should be a common objective and would benefit from collaboration.

Common open workshops to encourage more interchange of ideas and/or results between the degradation focused projects, and between these and other FCH JU projects would benefit the programme as a whole. A greater use of demonstration sourced data and results should also be encouraged, rather than relying on laboratory tests only.

In conclusion, the FCH JU might need to consider how the needs of all application areas on degradation issues are addressed rather than focusing them only in the Stationary AA Calls.

For new materials and stacks issues, the portfolio included a number of projects managed by the European Commission under the FP7 Energy programme, and a number of FCH JU supported projects. The reviewers believed that the FCH JU projects had clear performance goals, e.g. cost reduction, by reducing precious metal content in PEM systems, or durability improvements. However better indication of progress towards these goals or probability that they would be achieved, would have been welcome. Possible gaps identified are in the area of manufacturing and cell-stack design, for example there appear to be no significant efforts on powder production for ceramic components, whilst some of the higher risk SOFC concepts rely on production of electrodes by infiltration for which industrial capability is not proven enough.

A primary issue for this topic area that was raised by the reviewers was whether there were enough PEM focused projects, where the needs are as equally as important as SOFC. The imbalance between PEM and SOFC in the portfolio may simply reflect the lower number of PEM proposals received in response to the 2008 and 2009 AIPs. The existing PEMFC work would have been more valuable if it had better considered both materials properties and interaction with other components, sub-systems and systems e.g. entire membrane assemblies rather than just parts thereof.

The reviewers noted that the basic/fundamental research nature of these projects means that they had relevance to all AA, even though the FCH JU projects were primarily called for and supported by the Stationary AA: thus of the eleven projects, six were considered of better relevance to the Transportation area, eight to the Stationary and two to Early Markets, some being relevant to two or more AAs.

The topic of **diagnostics tools** is widely recognised as fundamental for safe, effective and efficient operation of fuel cells to improve reliability and durability. The three projects currently funded by the FCH JU provide substantial coverage of the topic and its challenges. If successful, these projects provide critical input to control strategies to ensure sound system operation, avoidance of adverse operating states and recovery where necessary, as well as feedback for cell and stack materials and sub-system components developments. These could be very beneficial for and should help prolong fuel cell lifetimes.

The reviewers recommended stronger linkages between this diagnostic topic and the Fuel Cell degradation topic, with potential for cross learning and knowledge development. However, this may be difficult because the degradation projects are primarily PEM orientated, whilst the Diagnostic topic has two SOFC and one PEM focused project. As such the reviewers recommended that the FCH addresses this imbalance in the future so that the linkages can be strengthened.

Moreover the reviewers noted that whilst generic tools are the most profitable outcome of these topics, their development will be extremely challenging as degradation mechanisms, for example, may vary between materials, cell and stack designs and individual systems. Greater and deeper analysis may be required to understand the correlations between degradation and operating conditions to develop valuable diagnostic tools.

Further it is not clear that individual developers are targeting the same fault modes, and as such whether generic versus dedicated tools will eventually be required. It is possible that existing tools could be developed further rather than attempting to develop tools from scratch in the next phase of the programme.

Finally, the costs and affordability of diagnostic systems for fuel cell systems need to be better understood. This can only be achieved with greater industry involvement, both end users and supply chain businesses.

It is noteworthy that the previous 2007 Review undertaken by the European Commission, identified the need for more **components and sub-system development, as well as proof of concept** projects in Europe's RTD activities. The FCH JU portfolio addresses this comment with four projects, albeit these are focused on SOFC technology. This outcome is due to the fact that no successful proposals were received from other technologies. It should also be noted that the FCH JU Calls in 2008 and 2009 were technology neutral calling for proposals for any technology. Nonetheless achieving a better balance between different technologies is an issue still worthwhile considering.

As a general comment, reviewers considered that the portfolio of projects in the stationary application area requires further co-ordination as developments are likely to be required across the complete system development e.g. cell and stack, power electronics and controls etc for successful commercialisation. Furthermore, the MAIP objectives in terms of volumes of units and costs for 2015 should be revised and focus on achieving 2020 goals.

Project name	Type	Description	Coordinator	EC funding (M€)
RAMSES	New materials & stacks	The project aims at developing an innovative high performance, robust, durable and cost-effective Solid Oxide Fuel Cell based on the Metal Supported Cell concept	CEA, France	4.7
MAESTRO	New materials & stacks	The objective of MAESTRO is to improve the mechanical properties of low equivalent weight state of the art perfluorosulfonic acid membranes using chemical and thermal processing and filler reinforcement methodologies	CNRS, France	2.26
SCOTAS-SOFC	New materials & stacks	The project will demonstrate a new full ceramic SOFC cell with superior robustness regarding sulphur tolerance, carbon deposition (coking) and re-oxidation (redox resistance). Such a cell mitigates three major failure mechanisms which today have to be addressed at the system level	Technical university, Denmark	4.4
SOFC-Life	New materials & stacks	This project is concerned with understanding the details of the major SOFC continuous degradation effects and developing models that will predict single degradation phenomena and their combined effect on SOFC cells and single repeating units	Forschungszentrum Jülich, Germany	2.4
D-CODE	Degradation issues	The D-CODE project aims to develop and implement on-line electrochemical impedance spectroscopy (EIS) to have direct and meaningful information on the system status. The D-CODE project's outcomes are expected to improve management and operational capabilities of both low and high temperature PEM fuel cells, to enhance monitoring capabilities, increase maintenance intervals with higher MTBF and reduce degradation rate, while optimizing system performance	University of Salerne, Italy	1.1
MCFC-CONTEX	Degradation issues	MCFC-CONTEX aims to tackle the degradation of components by investigating poisoning mechanisms caused by alternative fuels and applications and determining precisely MCFC tolerance limits for long-term endurance and by optimizing fuel and gas cleaning to achieve tailored degrees of purification according to MCFC operating conditions and tolerance	ENEA, Italy	1.8

ROBANODE	Degradation issues	The ROBANODE project proposes an integrated strategy for understanding the mechanism of processes which cause anode degradation in hydrogen and natural gas fuelled SOFCs by combining robust theoretical modelling with experiments over an extended range of operating conditions, using a large number of modified state-of-the-art Ni-based anodes	Foundation for Research and Technology, Greece	1.5
KEEPEMALIVE	Degradation issues	KEEPEMALIVE aims to establish improved understanding of degradation and failure mechanisms, accelerated stress test protocols, sensitivity matrix and lifetime prediction models for Low Temperature PEMFC to enable a lifetime of 40 000h at realistic operation conditions for stationary systems, in compliance with performance and costs targets	Stichting Energieonderzoek Centrum, The Netherlands	1.2
DEMMEA	Degradation issues	The objective of the present proposal is to understand the functional operation and degradation mechanisms of high temperature H_3PO_4 imbibed PEM and its electrochemical interface	Advanced Energy Technologies, Greece	1.6
PREMIUM ACT	Degradation issues	Project on the durability of PEFC (Polymer Electrolyte Fuel Cells), targeting one of the main hurdles still to overcome before successful market development of stationary fuel cell systems	CEA-Liten, France	2.5
LoLiPEM	Degradation issues	The main objective is to give a clear demonstration that long-life stationary power generation, CHP systems based on PEMFCHs operating above 100°C can now be developed on the basis of recent knowledge on the degradation mechanisms of ionomeric membranes and on innovative synthetic approaches recently disclosed by some participants of this project	National council for Research, Italy	1.4
STAYERS	Degradation issues	Project STAYERS is dedicated to the goal of obtaining 40,000 hours of PEM fuel cell lifetime employing the best technological and scientific means	NEDSTACK, Netherlands	1.9
GENIUS	Operation diagnostics	The GENIUS project aims to develop a 'GENERIC' tool that would only use process values (normal measurements and system control input parameters) to evaluate the state of health of any SOFC system	European Institute for Energy Research, Germany	2.07
DESIGN	Operation diagnostics	The project proposes to study the influence of slowly-damaging conditions on measures performed on the stack sub-components: the Cells and the Single Repeating Units (SRU) and on small stacks	CEA, France	1.7
LOTUS	Proof-of-concept and system component development	The LOTUS project is to build and test a Low Temperature SOFC system prototype based on new SOFC technology combined with low cost, mass-produced, proven components. The use of a modular concept and design practices from the heating appliances industry will reduce maintenance and repair downtime and costs of the system	Hygear, The Netherlands	1.6
ASTERIX3	Proof-of-concept and system component development	The objective of the collaboration was to evaluate HTceramix's SOFC technology in perspective of development of a residential micro-CHP application with a strong and well defined market focus	Dantherm, Denmark	1.3
ASSENT	Proof-of-concept and system component development	This project is focused on the development of fuel and water management for SOFC systems. The fuel management, and especially recirculation, is a key question in achieving high electric efficiency and rejecting external water supply	VTT, Finland	2.0
CATION	Proof-of-concept and system component development	This project is focused on the development of SOFC system's air side fluid and thermal management and mechanical solutions, i.e. cathode subsystem and individual components	Technical Research Centre, Finland	2.6

Projects managed by the European Commission				
DECODE	Degradation issues	The main objective of the planned project DECODE was to increase the life-time of fuel cells for automotive applications. It is well-known that liquid water plays a crucial role in the degradation processes of fuel cells. The DECODE project aimed at identifying characteristic behaviour regarding degradation and malfunctions with special emphasis on liquid water interactions	DLR, Germany	3.6
SMALLINONE	New materials & stacks	The project aims to realise fuel cells via vacuum techniques, develop an innovative architecture (incorporation of the catalytic functions in the ionic membrane) as well as incorporate smart functionalities in the membrane (electronic conductivity, hydrophilic functions)	CEA-Liten, France	1.8
EFFIPRO	New materials & stacks	EFFIPRO shall establish the first set of chemically and mechanically robust PCFC electrolyte and electrodes that demonstrates acceptable single cell performance, and in this manner lead towards a future superior fuel cell technology for power production from reformed fossil as well as hydrogen-based renewable energy.	University of Oslo, Norway	2.5
IDEAL-Cell	New materials & stacks	The IDEAL-Cell project aims at developing an innovative high temperature fuel cell concept based on a dual membrane (conducting both O^{-2} and H^{+}) and operating at intermediate temperature, ideally 600 °C. This new system combines the benefits of state-of-the-art PCFCs and SOFCs while evading their disadvantages (associated to the presence of water at the electrodes)	Armines, Paris	3.3
ZEOCELL	New materials & stacks	ZEOCELL puts forward an innovative concept to overcome the current limitations of commercial available PEMFCs based on the use of multifunctional nanostructured materials, capable to withstand temperatures in the range 130º-200º C	University of Zaragoza, Spain	1.9
METSOFC	New materials & stacks	The projects aims to develop novel metal supported cell and stack SOFC tech nology based on product definitions and test protocols defined by APU end users, as well as develop and optimize novel materials, design and manufacturing processes for metal based SOFC stack prototypes governed by crucial product requirements	Topsoe fuel cells, Denmark	3.9
QUASIDRY	New materials & stacks	The objective of QuasiDry is to develop the fuel cell electrolyte membranes of the next generation of fuel cells. The increase of proton conductivity with temperature, including at low RH, will allow continuous increase in fuel cell performance with temperature	CNRS, France	1.7

Early Markets

Priorities of the Multi-annual Implementation Plan

The strategy for the Early Markets Application Area has been to develop and deploy a range of fuel cell based products with near term market potential, which will build-up and sustain a manufacturing and supply base, and provide real world operational experience to feed back into the RTD process. This would be supported by development of balance of plant components and fuel cell technologies. The MAIP therefore calls for short term demonstrations of a range of i) portable and micro-fuel cells, ii) portable generators, back-up power and UPS systems, iii) speciality vehicles, including hydrogen related infrastructure, together with technology development projects with commonality with the Transportation and Stationary AAs. These would assist address issues of cost competitiveness, lifetime, reliability and sustainability.

The application area mainly covers **material handling vehicles** such as forklifts and **back-up and UPS power systems**, where the focus was on demonstrations in the 2008 and 2009 AIPs, in line with MAIP strategy.

These were supported by several more basic and applied research orientated topics such as balance of plant components for miniature fuel cell systems, and PNR and RCS for indoor use of hydrogen and fuel cells. The Early Market application area has also sought to promote investigation of degradation issues in concert with the Stationary application area.

The portfolio of Early Market orientated projects was split over several of the sessions during the review day. Early market mobility demonstrations were well covered with the SHEL, MobyPost and HyLift Demo projects, supplemented by portable and back-up applications projects such as FITUP and NH34PWR. Projects addressing other topics in the Early Market Calls were rather more limited with ISH2SUP, in-situ hydrogen supply for micro-fuel cells and IRAFC, internal reforming of alcohol for high temperature PEMFC.

In assessing the portfolio the reviewers noted the good coverage of demonstration projects in general, but that there was no demonstration of micro-fuel cell systems, the active projects being basic and applied research focused. Furthermore the demonstration projects that were being conducted seemed to be a mix of demonstration and some applied research. As such there was a concern that there was not enough basic and applied research to support the Early Market area. They did note, however, that several of the projects in the new materials and stacks for fuel cell applications and degradation aspects topics sessions were relevant to Early Market Applications.

These projects also aim to demonstrate the use of hydrogen from different sources as well. However, it was noted that use of hydrogen from waste processing route, in the MobyPost project, is theoretical, and it was not clear why solar decentralised solution was chosen as a source of hydrogen. Nor was there an assessment of the adequacy or otherwise of on-board storage of hydrogen, or whether more research and development would be required.

Furthermore there were queries over the extent to which the projects were making progress towards the other Early Market targets such as hydrogen cost and system efficiencies. The reviewers believed that it was critical that the projects paid close attention to cost reduction activities to determine the future competitiveness of the technology. RCS activity was also seen as an area for improvement. As with the other AAs subsequent Early Market AIPs have called for more R&D projects, and PNR and RCS topics. The need for European wide Regulations, Codes and Standards is underlined, in order to ensure that demonstrations and eventually market introduction can be undertaken across all Member States; it was clear that there were substantial differences between the demonstration activities in terms of permissions from the relevant authorities which affected ease or otherwise of implementation; the FCH JU has a very important role in this area.

Portable and back-up applications were covered with a mix of projects with some more R&D focused and others undertaking technology demonstrations. As a rule the projects followed the basic requirements of the MAIP/AIP, for example the demonstration of UPS/Back-up systems, but it is clear that gaps exist in the portfolio. In portable, there are no demonstration activities in the micro-fuel cell field. As such there is a feeling that the activities are insufficiently focused on the MAIP requirements.

Even given the number of demonstration projects it was not clear how the 2015 MAIP targets would be met; ie it was doubtful that 1,000 UPS/Back-Up units, nor 12,000 portable/micro-units, would be in service in 2015, at least not from FCH JU supported activities. Given this, reviewers wondered specifically whether the micro-sector markets had potential and simply required more research and development, whether the market opportunity was large enough, given advances in batteries, or would already be supplied by existing European and non-European fuel cell products.

Overall given the early stage of these projects it is too early to recommend any refocusing of the MAIP, but it may be necessary to consider the revision of performance and cost targets in the future. Additionally, since the MAIP encompasses objectives beyond the scope and capability of the FCH JU, it might be relevant to consider specific targets with more substantial demonstrations focusing on the most promising technology in the Early Market field. Ensuring that end-user businesses taking part in demonstrations were closely involved with the development of projects in order to sell the idea and align expectations about timing and costs is considered important.

Project name	Type	Description	Coordinator	EC funding (M€)
Mobypost	Demonstration of FC vehicles	Mobypost will implement low pressure storage solutions for hydrogen over two fleets of five vehicles on two different sites for postal mail delivery. Development of the vehicles and the associated refueling stations will be realized considering all the certification processes required and taking into account public acceptance toward solutions that will be implemented	Institut Pierre Vernier, France	4.2
SHEL	Demonstration of forklifts	The project will demonstrate 10 units of 1.5-2.5 ton FCH FLTs and associated hydrogen refuelling infrastructure across 3 sites in Europe: UK, Spain and Turkey. The project examines the production of the forklift and benchmarking FCH and FLT system components. A key objective is also to develop unified rapid product certification and infrastructure build approval procedures across the EU	Cidetec, Spain	2.44
HyLIF-DEMO	Demonstration of forklifts	The HyLIFT-DEMO project objectives are: to conduct 2 year demonstration of 30 units of 2.5-3.5 tons forklifts with a fully integrated 3rd generation fuel cell system, to conduct 2 year demonstration of hydrogen refuelling infrastructure at 3 end-user sites throughout Europe	LBST, Germany	2.88
ISH2SUP	H_2 supply for micro-fuel cells	The ISH2SUP-project concentrates to research and development of the cartridge technology and the electrical system	Aalto University, Finland	1.0
IRAFC	Development of PEM fuel cell stack	The main objective of the proposal is the development of an internal reforming alcohol high temperature PEM fuel cell	Advanced Energy Technologies, Greece	1.4
FITUP	Demonstration of back-up power systems	A total of 19 market-ready fuel cell systems from 2 suppliers will be installed as UPS/ backup power sources in selected sites across the EU. Real-world customers from the telecommunications and hotel industry will utilize these fuel cell-based systems, with power levels in the 1-10kW range, in their sites	Electro power systems	2.47
NH34PWR	Demonstration of power units	The project aims to demonstrate that a fully-integrated, turn-key power system (PowerCube TM) is technologically viable and can be readily manufactured to meet the cell phone operators' targets of reliability, longevity and low-maintenance. A further key project objective is to deploy several power systems (PowerCubes TM) as customer acceptance trial units in multiple sites across several climate zones and principally in sub-Sahara Africa. This will follow the development and field evaluation of a refueling, maintenance and repair infrastructure	Diverse Energy, UK	3.06

Cross-Cutting activities

Priorities of the Multi-annual Implementation Plan

The objective of the Cross-Cutting AA has been to support and enable other AAs at the programme level. It has sought to undertake a range of projects including those focused on socio-economic, environmental and energy impact of the FCH technologies, the development of processes to monitor the RTD programme, and support the European fuel cell and hydrogen sector to commercialise its products. In particular Regulation Codes and Standards (RCS) are identified as a critical activity requiring support of the FCH JU to address barriers associated with varying standards across Europe; socio-economic research is seen as playing a role in providing data and information to educate and inform policy and decision makers, investors and end users; Life Cycle Assessments enhance the understanding of the environmental and sustainability benefits and challenges of FCH products; and training and general public education and awareness are necessary to advance the general understanding of FCH technologies.

The MAIP sets out the objective of Cross-Cutting projects to support and enable the other AAs to prepare for commercialisation. The AIPs in 2008 and 2009 reflect this objective with topics including Technology Monitoring and Assessment and Life Cycle Assessment projects, training and education programmes as well as socio-economic planning. Further cross-cutting projects have been supported in the Calls of the Transportation and Stationary AAs e.g. hydrogen fuel quality and hydrogen composite storage as well as benchmarks for stationary applications.

The portfolio of Cross-Cutting projects was reviewed primarily in the three sessions of: socio-economic projects, training and education and PNR and LCA projects. In all there is a good coverage of projects for the Cross-Cutting objectives, with the exception of RCS, financing instruments and public awareness. PNR projects include HyQ and HyCOMP, LCA is covered by FC-HyGuide, whilst Prepar-H2 and NextHyLights support the socio-economic activities, FC-EuroGrid is assessing benchmarks for Stationary applications, and HyFacts, Train-Hy and HyProfessionals focus on training and education.

Although there is a wide spread of projects under the Cross-Cutting theme which are relevant to the MAIP, two concerns arise: first whether there are sufficient RCS projects to support the AAs, for example safety of hydrogen and fuel cells, and secondly that some of the Cross-Cutting projects were called for and supported not by the Cross-Cutting AA, but by the Transportation and Stationary AAs.

The lack of RCS must be resolved and this should require a greater involvement by industry. If necessary such projects could be called through the relevant AAs, rather than through the Cross-Cutting AA in order to ensure that project objectives align with needs, that industry is part of these at least through advisory groups, and that they are aware of, have access to and can use the results.

Pre-normative Research and Lifecycle Assessment Activities are considered of specific relevance to the needs of the fuel cell and hydrogen sector, as their results and findings will benefit the longer term commercialization of these technologies.

Specific comments include that in order to achieve maximum alignment with the needs of end users, the creation of advisory groups is considered paramount; similarly these groups provide a means for disseminating the results and findings, and of achieving real added value. To achieve the latter workshops are also recommended.

Interactions and collaborations are viewed as an integral part of cross-cutting projects such as PNR and LCA; the FCH JU should seek to ensure that projects meet their proposed activities, and if necessary enforce these; future AIP calls should be specific on this point.

There is an opportunity to strengthen links between pre-normative projects and other FCH JU projects to ensure that information flows to the projects, and also that experimental and real world data and information pass from these back to PNR and LCA projects to improve outputs.

Socio-Economic and Benchmarking projects clearly seem to play a significant role filling gaps in information and understanding to allow the FCH JU programme as a whole to be more successful. Such data and information will allow for the preparation of future FCH JU projects. Together the three projects therefore provide valuable backing for the transportation and stationary application areas. Being more specific on the goals of these projects in the MAIP might be necessary, notably about the data and information required.

However, it was felt that although the projects were good on facts and data, there was nonetheless a lack of strategic vision for the relevant sectors. As such it was recommended that more specific goals be developed for the socio-economic projects supported by the FCH JU.

Providing critical information and learning is important. Equally important is how results will feed into the programme and be used by the end-users. Apart from making the results/findings available on-line, a more pro-active approach is recommended to ensure that end-users are aware of, have access to and can use the results/findings.

Socio-economic studies of this nature are valuable contributions to understanding the opportunities and issues that the FCH JU and projects face as well as involving the wider community in the work of the FCH JU; for example with regard to the use of LCAs and public views on hydrogen in different Member States.

Training and Regulatory Aspects are addressed and meet the strategic training and education objectives of the MAIP through three complementary projects addressing differing needs: training for graduates and post-graduates, technical professional training, and provision of information and training for safety institutions and professionals.

More specific goals in terms of outcomes e.g. training years provided, organisations contacted would be welcome. Reviewers invited the FCH JU to review this area by introducing specific assessment criteria such as dissemination efforts, teaching modules provided and trail target groups successfully engaged.

In association with the above reviewers suggested that the FCH JU should provide a 'one stop shop' for training and education needs within Europe so that entities, public and private could contact a single point for their fuel cell and hydrogen education and training needs.

The greatest concern of the reviewers regarding training initiatives is that fact that these activities need to be sustained over a long term and that two or three year programmes are not sufficient in this respect. Continuity of effort is required to meet a constant and evolving need for training and education for industry and research institutes. As the industry evolves it is to be expected that demand will grow, yet there is no longer term plan evident to meet this demand.

Reviewers also noted the need for projects to expand their interactions and collaborations into the regions and Member States for training purposes, but also to the international level to work alongside other countries.

Regulations, Codes and Standards

The extent to which the FCH JU portfolio is addressing the regulatory aspects of the sector is much less obvious. Indeed the initial impression is that the area is less than ideal in terms of project activity and coverage of the subject matter. This is to be addressed given the importance of this activity to the development of the demonstration activities and early deployment. Standards for fuel cell and hydrogen technologies are essential to ensure that Europe's market opportunities are maximised and not weakened by fragmentation. In addition Europe must actively engage with the international standards groups and this should be a remit of the FCH JU.

On a general note, the MAIP itself was felt to be vague about specific data and information required, and the goals that need to be met; best summed up as there is a recognition of the need, but not a full understanding of the role of Cross-Cutting. This will require a refocus on the Cross-Cutting theme by the FCH JU.

The other primary concern of the reviewers was that Cross-Cutting activities need to be sustained over the lifetime of the FCH JU and beyond. Training and education projects for example may run for two/three years, but the need will be constant over the life of the FCH JU and should grow as fuel cell and hydrogen technologies move towards commercialisation. Resolving this issue requires FCH JU intervention; a framework training approach in collaboration with Member States involving FCH JU projects in professional training might be one option.

Project name	Type	Description	Coordinator	EC funding (M€)
FC-Eurogrid	Benchmark	The main objective of the project is to establish technical and economic targets and benchmarks that allow the assessment of fuel cells in stationary power generation. The fuel savings and CO_2 emission reductions will be a function of the electricity grid structure and the fuels employed. Using these results it will be possible to determine, whether a fuel cell installation effectively improves fuel use and improves the CO_2 footprint, amongst other criteria.	Forschungszentrum Jülich GmbH, Germany, Dr Robert Steinberger-Wilckens, University of Birmingham, UK	0.5
TRAINHY	Training	The project contributes to tackling this training deficit by devising a system of vocational education and training (VET) for post-graduate engineers and scientists, either at a Masters or PhD studies level of education or already employed by a company	Forschungszentrum Jülich, Germany	0.26
HyPROFESSIONALS	Training	Development of training initiatives for technical professionals will be started aiming to secure the required mid- and long-term availability of human resources for hydrogen technologies	Foundation for Hydrogen in Aragon	0.37
HY-FACTS	Safety	HyFacts aims to develop and initiate dissemination of training material for Regulators and Public Safety Officials, which are responsible persons and work for entities, having to position themselves in the increasing number of upcoming installation of hydrogen-related technologies in public areas, companies, universities, research centers, fairgrounds, harbor sites and other places where fuel cell and hydrogen (FCH) installations and mobile applications shall be installed and operated in the near future	TÜV SÜD Akademie	2.0
HyCOMP	PNR	Currently, the most mature technology for storing hydrogen is in compressed form in high-pressure cylinders. To improve volumetric and gravimetric performances, carbon fibre composite cylinders are currently being developed. However, current standards do not allow cylinder design to be optimized. The objective of HyCOMP is to produce improved type approval and batch testing protocols. The main outcome of the project will be a documentation of the real performance of composite cylinders to support Authorities and Industry in making enhanced RCS	Air Liquide	1.3
FC-HyGUIDE	LCA	The project FC-HyGuide aims to develop a guidance manual for LCA of Fuel Cell and Hydrogen based systems and related training materials and courses	PE International, Gemany	0.6

Conclusion and recommendations

List of reviewers

Conclusion and recommendations

This 2011 Programme Review emphasized the **substantial progress** made by the Joint Undertaking since its establishment. In general, the Programme has followed the strategy set out in the MAIP: the portfolio of projects is focused on the aspirations of, and structured to address the challenges identified in the MAIP, including a mix of basic and applied research, and demonstration activities. Any identified gaps in the portfolio of projects arising from the AIP 2008 and 2009 are likely to have been already rectified in subsequent AIPs.

The FCH JU supported projects show a significant focus on commercialisation and industry leadership, compared with FP7 projects which by their very nature tend to be more breakthrough oriented. Its implementation through the FCH JU Projects appears to be resulting in higher levels of collaboration and interaction, enhanced awareness of competing technologies, and more emphasis on cost-efficient project management, including contingency actions, and progression plans. There is industry involvement in all projects, and in many cases industry plays a significant role in the leadership and steers the activities, interaction between industry and the research community being evident in the projects. SMEs are very well represented in most of the projects. If this is confirmed in future projects then the FCH JU is clearly having a positive impact on European innovation.

Progress is being made towards a range of critical objectives established in the MAIP, e.g. cost reduction, component and system durability and this is occurring across all Application Areas.

The FCH JU portfolio includes projects with very real prospects of advancing through the entire RTD cycle from basic research through applied research to demonstrations, and then, if successful, to commercialisation. Such virtuous cycles confirm the mission of the FCH JU.

Competing Technologies, Interaction and Collaboration

The FCH JU is however a relatively young organisation and not surprisingly **learning points** arise from the review.

Understanding the position of projects vis-à-vis competing technologies can however be further improved to the benefit of the FCH JU programme and project outcomes; in addition the commercial awareness and focus of all projects can be sharpened. The portfolio has a decidedly mixed experience in this area both in terms of awareness of alternatives to fuel cells and hydrogen such as batteries or renewable power systems, and the implications of the cost of fuel cell and hydrogen technologies. Many projects made only a cursory reference to these aspects.

Most of the reviewers, considered that all projects, regardless of their status, should have some view on the competing technologies and how their own technology developments will benefit the commercialisation goals for fuel cell and hydrogen technologies. Thus all developments should be able to trace their impact on cost and/or performance for example cost of catalyst, contribution to 40,000 hours durability for stationary fuel cell units, ability to deliver hydrogen at €5/kg.

Projects closer to market, in particular the demonstration projects were generally better in understanding the competitive position of fuel cell and hydrogen technologies with a better grasp of cost issues for example. However, even here there is room for improvement in setting out the market opportunities, the key competitive criteria and the impact of concurrent improvements to competing technologies, such as batteries, hybrid vehicles etc.

The FCH JU would benefit from encouraging and establishing interactions within the portfolio, e.g. early markets and hydrogen, through a range of mechanisms. The opportunity for shared learning is substantial, for example in the areas of new materials and degradation and lifetime fundamentals. Common workshops could be established by the FCH JU to ensure that the benefits of shared learning, standards and test procedures for accelerated testing of PEMFC for example, are available to all. This could be extended to other European supported research e.g. Energy materials research in the FP7 programme.

The FCH JU is having an impact on the fuel cell and hydrogen technology programmes of activities at the Member State level, through interactions with national projects and programmes, in the areas of both RTD and demonstrations. Some projects could serve as best practices examples since they are able to trace their development back to previous European and/or Member State supported projects and had clear plans to utilise the results and developments in the future. There is also evidence of active participation by projects at the international level, via the IEA. Interaction and collaboration within and between the FCH JU programme and projects and those of the member states and internationally can however still be enhanced and improved to the benefit of all parties. A real opportunity exists for projects and the portfolio as a whole to develop more and deeper relationships, with other fuel cell and hydrogen research programmes at the regional, European and International levels.

Although there will be complex issues associated with intellectual property rights, funding and timing, which probably preclude more formal linkages, more could be achieved in co-operation and collaboration with programmes regionally, at the MS and International levels e.g. Canada, Korea, USA and Japan. Several of the reviewers were non-Europeans and the opportunities available to interact with Japanese and USA projects through workshops, e.g. the US DoE Annual Merit Award Reviews and the US degradation working groups, were underlined. This applies especially to Cross-Cutting projects.

Furthermore, regulation, codes and standards activities were considered essential and as such could be expanded in coverage and with the involvement of a wider range of parties, especially industry. Consideration of whether these are best done in the Cross Cutting AAs or the others is required.

Future perspectives

The FCH JU has a limited lifespan with funds available to 2013, although project administration runs through to 2017. A successor initiative to or continuation of the current FCH JU in the Horizon 2020 programme provides the opportunity to consider substantive changes that could improve its effectiveness.

The MAIP targets could be revisited to ensure that they are relevant to the activities of the FCH JU, the FCH JU being only part of European efforts to commercialise fuel cell and hydrogen technologies; headline volume and cost targets could be supplemented by more relevant interim targets.

An opportunity to reshape the programme structure away from four parallel AAs each addressing basic and applied research and demonstrations to a 'funnel shaped' structure may be contemplated. This would acknowledge the fact that many basic research activities are relevant to all applications, and therefore can be undertaken in common activities, whereas demonstration activities would be identified for each application area.

Following on the foregoing, an option to institute deployment/ demonstration programmes over the lifetime of the FCH JU which follow a common strategy, have common objectives and which can be additive over time as more businesses and regions decide to join the effort, would be worth exploring.

Finally the longer term development effort, especially for basic research as well as training, education and awareness projects which span the lifetime of the FCH JU, is to be recognised and emphasized.

List of reviewers

Alan ATKINSON, Professor of Materials Chemistry in the Department of Materials at Imperial College, member of the Scientific Committee of the EU Joint Undertaking on Fuel Cells and Hydrogen.

Daniel CLEMENT, Deputy scientific director of ADEME (the French agency for environment and energy), expert for the French ministries, the International Energy Agency and for the European Commission.

Kristin DEASON, Director international cooperation for NOW, Germany's National Organization for Hydrogen and Fuel Cells.

Andreas DORDA, Managing Director of the Austrian Agency for Alternative Propulsion Systems, Member of the FCH JU scientific committee.

Antonio GARCIA-CONDE, Director of the Department of Aerodynamics and Propulsion in INTA (the Spanish National Institute of Aerospace Technology), Executive Committee Chairman of the International Energy Agency Hydrogen Implementing Agreement (2008-2011).

Knut HARG, Chair of the FCH JU scientific committee.

Thorsten HERBERT, Program Manager for Transportation in NOW GmbH (German National Organization Hydrogen and Fuel Cell Technology).

John KOPASZ, Technical Advisor to the U.S. Department of Energy Fuel Cell Technologies Program in the areas of fuel cells and hydrogen storage, Manager at Argonne National Laboratory for programs on materials related problems in energy production.

Florence LEFEBVRE-JOUD, Senior Scientist in the field of Materials for Energy and Program Manager in the field of Hydrogen, Fuel Cells and Biomass at CEA-LITEN, Grenoble France.
Vice Chair of the Scientific Committee of the FCH JU.

Pietro MORETTO, Action Leader of the project 'Hydrogen Safety for storage and transport' at the Institute for Energy and Transport of the Joint Research Center of the European Commission.

Andreas PFRANG, Researcher in the fuel cell activities and responsible for micro- and nano-structural analysis at the Institute for Energy and Transport of the Joint Research Centre in Petten, Netherlands.

Walt PODOLSKI, Technical Advisor to the U.S. Department Of Energy Fuel Cell Technologies Program, Leader of the Electrochemical Projects Support Group in the Argonne National Laboratory Chemical Sciences and Engineering Division.

Lars SJUNNESSON, Member of the FCH JU scientific committee.

Tomohide SATOMI, General Manager for planning division in Fuel Cell commercialization Conference of Japan (FCCJ), Member of the technical advisory committee in NEDO, Japan.

Michael SPIRIG, Advisor for the Swiss FCH Research Program and Swiss Research Program for Industrial Processes, Director of the European Fuel Cell Forum AG and CEO of Fomenta AG.

Georgios TSOTRIDIS, Action Leader of the Fuel cell department of the European Commission, Joint Research Centre, Institute for Energy and Transport, in Petten.

Shogo WATANABE, President of the Hydrogen Energy Test and Research Centre (HyTReC) in Japan.

Projects funded by the FCH JU

Transport and refuelling infrastructure
Hydrogen production and storage
Stationary applications
Early markets
Cross-cutting issues

Automotive Fuel Cell Stack Cluster Initiative for Europa (Auto-Stack)

Key Objectives of the project

The key objective of the work was to **'Make a proposal for establishing a competitive European automotive fuel cell stack industry'.**
The main objectives are:

- Comparatively assess the fuel cell stack R&D-activities within Europe
- Assess the European component supply industry
- Provide a fuel cell stack cost analysis tool
- Develop a technical and cost road map for fuel cell stacks and components used in FC-EV in a mass market.
- Explore the synergies between fuel cell applications in transport oriented markets.
- Assess the 'industrial landscape' for a stack integrator including the development of a business model.

The project links the technical and cost requirements of the fuel cell stack with application requirements and corresponding market volumes. It addresses research needs, application synergies, and avoids dead end development pathways. Using the project results, a better planning reliability can be achieved in all parts of the value chain.

Challenges/issues addressed

Fragmentation of the research and development landscape is a challenge for automotive stack development. Lack of collaboration at fuel cell stack level and specifically absence of a competitive European stack integrator is also a major issue.

Despite several attempts in the past, no substantial improvements have been achieved over the last couple of years. The project therefore aims to develop approaches to address the critical barriers for substantial improvement of collaboration between major stakeholders and establishing a solid business model for an independent European stack integrator.

Technical approach/objectives

The key milestones of the project are

- Define a common integration space and fuel cell system layout
- Assess the capabilities of the European fuel cell component supply industry
- Define a technical specification of the fuel cell stack
- Set up a consistent step by step development roadmap including research topics
- Set up a business concept for a European automotive fuel cell stack integrator.

Expected socio and economic impact

The Auto-Stack project combined key European players including automotive OEMs, component suppliers and research organizations in a structured approach to facilitate the development and commercialization of automotive fuel cells in Europe. The consortium assessed ways to identify and reduce the critical barriers for better collaboration between stakeholders and generate a more attractive business case for a European automotive stack industry during pre-commercial and early commercial phases.

Activities did include the development of a common OEM specification and stack platform concept, analysis of the potential for meeting the mid-term technical and cost targets by the European supply chain, establishment of a technology roadmap, and assessment of synergies with other applications and finally definition of a business concept for a European stack industry.

High power density to fulfill packaging requirements is not compatible wit low platinum loading in the foreseeable future. Projection of industrial MEA performance data shows a shallow cost minimum close to the power density targets.

Information

Project reference: FCH JU
Call for proposals: 2009
Application Area: Transport
Project type: Support Action
Topic: SP1-JTI-FCH.1.3 European fuel cell stack cluster
Contract type: Support Action
Start date: 01/01/2010 — **End date:** 30/09/2011
Duration: 21 months
Project total costs: € 2,827,448.20
Project funding: € 1,193,015.30

Coordinator
Ludwig Jörissen
Zentrum für Sonnenenergie-
und Wasserstoff-Forschung Baden-Württemberg
Helmholtzstr. 8
D-89081 Ulm, Germany

Partners
CEA
Daimler
DANA
CRF
FFCCT
JRC
PSI
SNECMA
SOLVAY
Solvicore
Umicore
Powercell Sweden
VW

Project website: http://autostack.zsw-bw.de

Clean Hydrogen in European Cities (CHIC)

Key Objectives of the project

The CHIC-Project is the next essential step leading to the full market commercialization of hydrogen powered fuel cell (FC) buses. This project will provide results from a demonstration run of more than 55 fuel cell buses. The key objectives are:

- Operation of 26 fuel cell buses and the respective infrastructure in 5 major European regions ('Phase 1 cities') for a period of 5 years
- Collaboration and transfer of key lessons learned from 'Phase 0' cities (~30 fuel cell buses in operation) to 'Phase 1' cities
- Assessment of the technology with a focus on environment, economy and society
- Dissemination to the general public as well as to cities and regions preparing for the technology in the next step and interested in setting up fuel cell bus and hydrogen projects ('Phase 2' cities).

Challenges/issues addressed

26 FC buses will operate in daily public transport operations in five locations across Europe: Aargau (Switzerland), Bolzano (Italy), London (UK), Milan (Italy) and Oslo (Norway).

The project is based on a staged introduction and build-up of FC bus fleets, the supporting hydrogen fueling stations and infrastructure in order to facilitate the smooth integration of the FC buses into Europe's public transport system. Furthermore, a sustainability assessment of the use of the buses will be provided in order to analyse their impact on sustainability. Therefore, the bus operation will be accompanied by several studies analysing the performance, environmental profile, cost development and the social acceptance of the operating buses. In general, the project will identify the advantages, improvement potential, complementarities and synergies of FC buses compared with conventional and alternative technologies and will help the technology on the way to commercialisation.

Technical approach/objectives

The project aims to achieve certain technical goals regarding the fuel cell bus operation and the H_2 infrastructure. The main technical goals for the installed hydrogen infrastructures are to achieve:

- a capacity of 200kg H_2 per day or minimum 5 vehicles per hour with a minimum of 50 vehicles per day (to be upgradeable to min 100 vehicles per day)
- an average availability of 98% (based on operation time)

Furthermore, the H_2 OPEX costs are planned to be less than 10 €/kg (excl. tax) and the production efficiency for the H_2 production will be between 50-70%.

The demonstration of the FC buses and hereby the use of H_2 is supposed to replace a minimum of 500.000l diesel fuel throughout the project.

The main technical goals of the bus operation focus on ecological and economical aspects such as low fuel consumption and a high rate of availability. Therefore, the main technical goals during the project are to achieve

- a fuel cell lifetime of >6000 h of operation
- an average availability of all FC buses greater than 85% (based on operation time)
- fuel consumption less than 13 kg/100 km (depending on drive cycle)
- a minimum running distance of 2.75 Mio km and a minimum of 160,000 hours of operation of the deployed FC bus fleet.

Expected socio and economic impact

Hydrogen and fuel cells play an important role in the reduction of local air pollutants, as well as in the decarbonisation of Europe's transport system. Fuel cells use hydrogen to generate electricity while emitting only water vapour. CHIC will reduce the 'time to market' for the technology and support 'market lift off' – two central objectives of the Joint Undertaking.

Information

Project reference: FCH JU
Call for proposals: 2009
Application Area: Transport
Project type: Collaborative
Topic: Demonstration
Contract type: Collaborative Project
Start date: 01/04/2010 — **End date:** 31/12/2016
Duration: 81 months
Project total costs: € 81 894 400
Project funding: € 25 878 334

Coordinator
Dr. Helmut Warth
Daimler Buses – EvoBus GmbH
Hanns-Martin-Schleyer-Straße 21-57
D-68301 Mannheim /Germany
Phone: +49 (0) 621 / 740 – 59 79
Fax: +49 (0) 621 / 740 – 42 50
E-Mail: Helmut.Warth@daimler.com

Project website: www.chic-project.eu

List of participants/partners

Participant organisation name	Country
EvoBus GmbH	DE
Air Products Plc	UK
Azienda Transporti Milanesi S.p.A.	IT
Berliner Verkehrsbetriebe A.ö.R.	DE
Element Energy Limited	UK
Euro Keys SPRL	BE
Air Liquide Hydrogen Energy	FR
HyCologne - Wasserstoff Region Rheinland e.V.	DE
European Regions and Municipalities Partnership on Hydrogen and Fuel Cells	BE
Infraserv GmbH & Co. Höchst KG	DE
BC Transit	CA
Linde AG	DE
London Bus Service Ltd	UK
PE INTERNATIONAL AG	DE
PLANET - Planungsgruppe Energie und Technik GbR	DE
PostAuto Schweiz AG	CH
SHELL DOWNSTREAM SERVICES INTERNATIONAL BV	NL
Spilett new technologies GmbH	DE
Suedtiroler Transportstrukturen AG	IT
TOTAL Deutschland GmbH	DE
UNIVERSITAET STUTTGART	DE
Vattenfall Europe Innovation GmbH	DE
Ruter AS	NO
Wrightbus Limited	UK
hySOLUTIONS GmbH	DE

H2moves.eu SCANDINAVIA

Lighthouse Project for the Demonstration of Hydrogen Fuel Cell Vehicles and Refuelling Infrastructure in Scandinavia - H2moves Scandinavia

Key Objectives of the project

The focus of this public-private partnership is to accelerate the market introduction of hydrogen powered fuel cell electric cars. The projects ambition is to launch the latest 'state-of-the-art'

hydrogen fuel cell vehicles and to consolidate the existing hydrogen fuelling network in the south of Norway and in Denmark by adding a new refuelling station in Oslo and delivering 19 fuel cell city and sedan cars in total (17 in Oslo, 2 in Copenhagen).

Accompanying activities shall accelerate the commercialization of fuel cell vehicles and hydrogen refuelling infrastructure by understanding the status of certification and the needs to adapt them across all of Scandinavia. Finally, the general public in Scandinavia shall be informed and it should become obvious that fuel cell cars and hydrogen are about to enter the European market.

Challenges/issues addressed

Obviously fuel cell vehicle and hydrogen technologies have reached a state of development allowing their deployment in mass markets soon in central Europe. Also in harsher European climates, such as in the North, performance data need to be assessed from everyday driving to understand in how far vehicles and fuelling equipment are ready for commercialisation under these conditions.

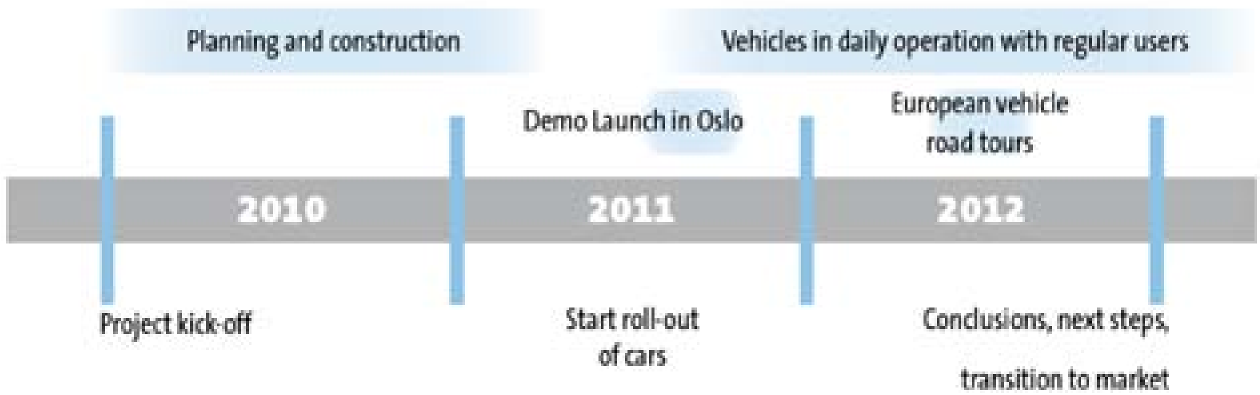
In sharp contrast it is perceived that the technical and comfort advantages of fuel cell cars have not yet been well communicated, such as rapid refuelling as well as driving range per refuelling and payloads acceptable for the customer. Hence communication activities should be an important part of the project.

Time consuming and expensive vehicle and refuelling station certification procedures are one burden to their accelerated market introduction across Europe. A safety study will contribute to understand the current state-of-play of legal procedures across all of Scandinavia and to derive best practices to reduce potential burdens.

Technical approach/objectives

Next to the daily operation of 17 fuel cell cars in Oslo (and 2 in Copenhagen) using an existing hydrogen refuelling station network and one additional station conveniently located in Oslo accompanying activities study car and station performance, asses today's certification procedures in Scandinavia and communicate about the project and its achievements in the public.

To attain customer acceptance, the hydrogen station in Oslo Gaustad was publically opened in November 2011 and a Road Tour across Europe is under preparation in the summer of 2012. By organising public events, such as test drives, the public is informed about this exciting



technology – sustainable fuel should be seen in normal operation as alternative to fossil fuel.

The experience from Nordic climate conditions will yield additional insights to ensure the vehicles are capable to perform within more extreme climatic markets.

Expected socio and economic impact

A widely visible launch event in Oslo with live broadcasting on several TV channels and a ride&drive event attached to it have resulted in a sound echo in Oslo and Norway. This has contributed to a better understanding of the role of fuel cell vehicles as one type of electric vehicle, characterised by the advantage of rapid refuelling, extended driving range per refuelling in combination with zero emissions of hydrogen from hydropower and noiseless driving with high vehicle acceleration potential. The project key messages of 'here today – everywhere tomorrow' and 'fun to drive' were well and widely communicated.

With the European Road Tour, the consortium expects to widely demonstrate that the project fuel cell car fleet extended by cars from other manufacturers can travel all across Europe already today even though refuelling infrastructure is scarce. It will also be shown that fuel cell vehicles are reaching the deserved attention in central as well as in Southern and Northern Europe.

Information

Project reference: FCH JU, Grant Agreement 245101
Call for proposals: 2008
Application Area: Transportation and refuelling infrastructure
Project type: Demonstration
Topic: SP1-JTI-FCH.1.1: Demonstration of Hydrogen fuelled road vehicles and refuelling infrastructure
Contract type: Collaborative Project, Large-scale demonstration of road vehicles and refuelling infrastructure
Start date: 01/01/2010 — **End date:** 31/12/2012
Duration: 36 months
Project total costs: 19.4 M€
Project funding: € 7.8 M€
The project is nationally co-funded by contributions from Transnova in Norway and EUDP in Denmark.

Coordinator H2moves Scandinavia
Dr. Ulrich Bünger
c/o Ludwig-Bölkow-Systemtechnik GmbH
Daimlerstrasse 15
D-85521 Ottobrunn/Germany
Tel: +49(89) 608 110 – 42
Fax: +49(89) 609 97 31
Mail: coordinator@H2moves.eu

List of participants/partners (organisation name, country)
Ludwig-Bölkow-Systemtechnik GmbH (Germany)
Daimler AG (Germany) with Bertel O. Steen (Norway)
Hyundai Motor Europe GmbH (Germany)
H2 Logic (Denmark)
Hydrogen Link Association (Denmark)
Hydrogen Sweden (Sweden)
SINTEF (Norway)
SP (Sweden)
TÜV SÜD (Germany)

Project website:
http://www.scandinavianhydrogen.org/h2moves

Hydrogen fuel Quality requirements for transportation and other energy applications (HyQ)

Key Objectives of the project

HyQ consists of pre-normative studies to provide a strong support to Regulation Codes and Standards organizations in order to normalize an acceptable fuel quality for PEMFC for automotive application. Depending on the way to produce and purify hydrogen, it can contain different kind of pollutants which impact the performances and the durability of PEMFC.

To facilitate the emergence of the potential mass market represent by the automotive application, a standard hydrogen quality is becoming a necessity. One of the objectives of HyQ is to increase knowledge on the impact of pollutants commonly find in the hydrogen produced by economically sustainable industrial processes. Thus, relevant scientific results from HyQ will give strong arguments in the discussion on the fuel quality for PEMFC. Another objective of the project is to improve the analytical methods used to guaranty the quality specified in the standard.

Challenges/issues addressed

One of the challenges addresses in HyQ is to evaluate the impact of pollutant on the PEMFC performance in the condition as representative as possible of the real application conditions. To the best of our knowledge, the results discussed for the determination of the standard had been obtained in conditions that are not representative of the real automotive application. Indeed, the impact of pollutant can be dramatically different depending on the conditions in which the test has been performed.

Another issues addressed in HyQ is to be able to propose standards that could be used to certify the purity level of hydrogen by assurance quality. By example, if no method exists (or are very expansive) to prove that the amount of an impurity in the hydrogen fuel is low enough to follow the standard, it is problem to certify the quality of the gaz. Formaldehyde and sulphur compound are in this case and their impact are addressed in HyQ to see if a so low level (respectively 0.01 ppm and 4 ppb) recommended in the actual standard are justified or not.

Technical approach/objectives

The approach developed in HyQ can be divided in two parts. The first one deals with the determination of the highest acceptable amount of impurities in H_2 which does not impact the fuel cell performance. To do that, 4 institutes are performing tests, firstly in identical conditions to check the reproducibility of the results (first year of the project) and then in different conditions to obtain maximum of results (second and third years of the project). In another part, partners specialized in gas analysis are improving analytical method to quantify the amount of impurities in H_2. The problem with the actual standard is that it's difficult to prove that H_2 reaches the quality requested and/or are costly. At the end of the project, after inter-laboratories comparison, report on the best measurement method and gas sampling will give input for the establishment of unified protocols.

Expected socio and economic impact

To sum up, HyQ results will give strong inputs to the Regulation, Code and Standard organisation. Accepted standards based on consensus between the actors of the hydrogen economy for automotive application will give strength to the development of a mass market. Of course, a special emphasis is put on the automotive application. Indeed, even if the potential widespread distribution of fuel cell vehicles could not reach the actual fleet of more than 1 billon cars all over the world. The money and matter flow that could be generated by this sector will be huge and an approved international standard will facilitate the negotiation processes between the actors of the hydrogen economy and will help also in unifying the links of the chain from gas producer to end-users. In the same way, results obtained here will be very helpful for the stationary application.

Information

Project reference: FCH JU 256773
Call for proposals: 2009-1
Application Area: pre-normative research on hydrogen quality.
Project type:
Topic: Topic SP1-JTI-FCH.1: Transportation and Refuelling Infrastructure; SP1-JTI-FCH.2009.1.6: Pre-normative research on fuel quality.
Contract type: Collaborative project, small or medium scale focused research project
Start date: 01 March 2011 — **End date:** on-going
Duration: 36 months
Project cost: € 3,718,853.00
Project funding: € 1,385,219.00

Coordinator
Commissariat à l'Energie Atomique et aux Energies Alternatives (CEA), France
(French Atomic Energgy Commission)

Pierre-André Jacques
17 rue des Martyrs
38054 Grenoble Cedex 9
France
+33(0)4 38 78 06 99
pierre-andre.jacques@cea.fr

Partners:

European Commision, Joint Research Centre (JRC)	Belgium
Zentrum fur Sonnenenrgie und Wasserstoff-Forschung (ZSW)	Germany
Air Liquide (AL)	France
Total Raffinage Marketing (Total)	France
Element Energy (EE)	UK
Axane (Axane)	France
National Physical Laboratory (NPL)	UK
VSL Dutch Metrology Institute (VSL)	The Netherlands
CCS Global group Ltd (CCS)	UK
Shell Downstream Services International (Shell)	The Netherlands
Linde (Linde)	Germany
VTT Technical Research Centre of Finland (VTT)	Finland

Website: (restricted access): https://www-hyq.cea.fr

NEXTHYLIGHTS

Supporting action to prepare large-scale hydrogen vehicle demonstration in Europe (NextHyLights)

Key Objectives of the project

NextHyLights was a Supporting Action of the Fuel Cell and Hydrogen Joint Undertaking (FCH JU) to **prepare** large-scale hydrogen vehicle demonstration in Europe. In parallel to already existing demonstration projects (Lighthouse Projects) NextHyLights was assisting the FCH JU to prepare the next consequent step, the planning and preparation of further large-scale demonstration projects for next-generation hydrogen vehicle fleets at additional demo sites across Europe.

NextHyLights has worked in close cooperation with and under the supervision of FCH JU to develop a strategy (consolidated work and roll-out plans) on how to bridge the gap between today's hydrogen demonstration projects and the start of market introduction.

Challenges/issues addressed

The approach to develop the consolidated plans required a parallel preparation of detailed work plans for the vehicle segments 'hydrogen passenger cars', 'hydrogen buses' and 'other hydrogen vehicles'. In the case of the buses segment a roll-out plan has been developed in addition, covering the early commercialisation phase. The vehicle segment specific work plans cover the time span including the next large-scale demonstration projects. The roll-out plan for the buses covers also the phase towards market introduction.

NextHyLights directly contributed to the FCH JU activities regarding the preparation of the next calls and was able to react flexibly on its requirements. It used the Multi Annual Implementation Plan (MAIP) as the basis and helped to detail it towards the coming Annual Implementation Plans (AIPs) taking the ambitions and opportunities of all stakeholders into account.

Technical approach/objectives

NextHyLights had been called for by FCH JU to assist the preparation of next large scale hydrogen & fuel cell electric vehicle (FCEV) demonstration projects in Europe, i.e.

- to understand the needs of industry and regions to actively participate in the demo projects on hydrogen and fuel cells for transport in AIP 2011 – AIP 2013,
- to provide insights, recommendations and instruments for adapting AIP 2011 and MAIP and developing AIP 2012 and AIP 2013 and
- to learn about the potential impact on global emissions and public acceptance.

The project has developed consolidated plans for large-scale demonstration projects across three parallel hydrogen fuel cell vehicle segments 'passenger cars', 'buses' and 'other vehicles'. In the case of the bus segment a roll-out plan covering the market introduction has also been developed. The vehicle segment specific work plans cover the time span including the next large-scale demonstration projects.

Expected socio and economic impact

Even if fuel cell electric vehicles will have a performance similar to conventional vehicles and be available at acceptable cost, they will only be successful if they meet with good social acceptance. In accordance with Ricci et al., acceptance has been defined as 'a lack of (explicit) public opposition to the introduction of hydrogen as fuel in the transport sector'. Three interrelated types of acceptance have been distinguished. Market acceptance is largely beyond the scope of the project, and the remainder of this section focuses on global and local acceptance.

The environmental impacts resulting from the implementation of hydrogen vehicles were assessed principally for demonstration projects and roll-out scenarios. This work has been performed for all three hydrogen vehicle segments. More information can be found at the project website.

Information

Project reference: FCH-JU-2008-1, Grant Agreement Number 245133
Call for proposals: AIP 2008
Application Area: SP1-JTI-FCH.1: Transportation & Refuelling Infrastructure
Project type: Support Action
Topic: Topic SP1-JTI-FCH.1.2 Preparation for large-scale vehicle demonstration in Europe
Contract type: Coordination and Support Action
Start date: 01/01/2010 — **End date:** 31/12/2010
Duration: 12 months
Project total costs: € 1,138,522
Project funding: € 499,303

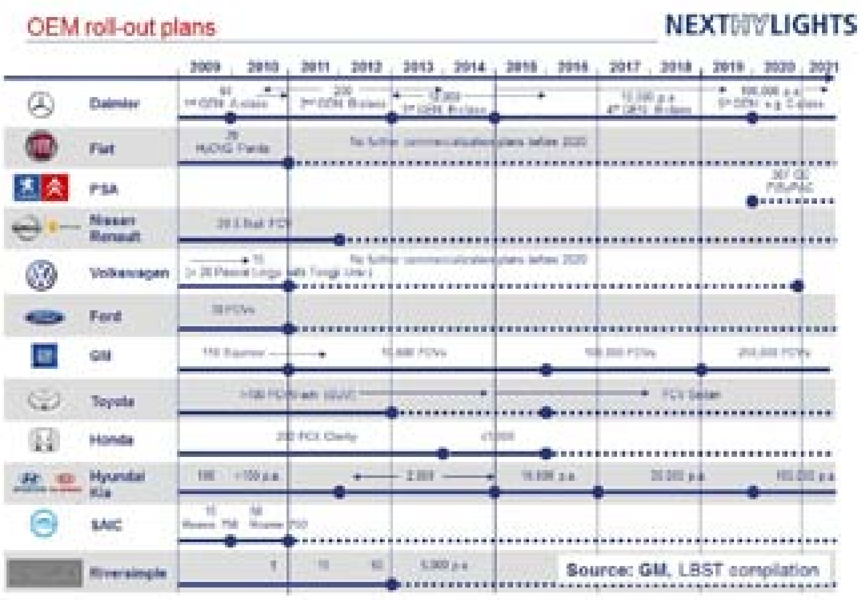
Coordinator
Hubert Landinger
Ludwig-Bölkow-Systemtechnik GmbH
Daimlerstr. 15
85521 Ottobrunn
Germany

coordinator@nexthylights.eu

List of participants/partners

LBST – Ludwig-Bölkow-Systemtechnik GmbH	Germany
AVL List GmbH	Austria
Bucher-Guyer AG	Switzerland
CRF – Centro Ricerche Fiat SCPA	Italy
Daimler AG	Germany
Element Energy	UK
ECN – Energy Research Centre of the Netherlands	Netherlands
Proton Motor Fuel Cell GmbH	Germany
Škoda Electric a.s.	Czech Republic
StatoilHydro ASA	Norway
Total Raffinage Marketing	France
Vattenfall Innovation GmbH	Germany

Project website: www.nexthylights.eu



PEM with Innovative low cost Core for Automotive applicatioN (PEMICAN)

Key Objectives of the project

Reduction in the catalyst costs (gram of catalyst per kW) should contribute greatly to the industrialisation of PEMFC for automotive applications. To date much work has been carried out on the catalyst but much less on other aspects of the active layers (structure, carbon and electrolyte) even though they play a crucial role on performance. PEMICAN proposes to reduce the catalyst cost down to 0.15 gram per kW by a twofold approach: i) increase catalyst use and power density by improving transport properties of Air Liquid; ii) reduce catalyst loading by controlling its distribution.

This technological approach is supported by a scientific one: i) numerical models to help defining catalyst improved distribution; ii) fundamental electrochemical experiments to improve the existing models.

Challenges/issues addressed

The global aim of PEMICAN is to manufacture active layers with reduced catalyst loading but keeping the power density as high as possible.

For this to happen, the first issue consists in developing and introducing specific electrolyte and carbon black into the active layers. These new raw materials should improve charge and gas transfers, increasing the electrical current delivered and consequently the power density. The other issue is to produce active layers with a reduced catalyst loading by locating it where it is most useful. Combination of both should allow reducing the catalyst loading with little influence on the power density.

Another challenge is to improve the existing numerical modelling to better link local properties of active layers to performance of the PEMFC. For this, specific new measurements will be performed on fundamental electrochemistry, charge and gas transfers and introduced into specific models to improve the active layers.

Technical approach/objectives

Three key Milestones are defined in the project.

MEA Level 1 is planned at Month 12: reaching around 0.6 g Pt/kW and 350 mW/cm^2.
Focus will be on the improvement of ink formulation (electrolyte and carbon) on the cathode side and on the manufacturing of anodes by Particle Vapour Deposition (PVD). Performance models will be used to foster improvement of the active layers.

MEA Level 2 is planned at Month 24: reaching around 0.4 g Pt/kW and 500 mW/cm^2.
Focus will be on gradients (electrolyte, Carbon, Pt) on the cathode side and on the manufacturing of anodes by PVD or by Direct Electro Deposition. Performance models will be improved (better characterization of transport properties, experimental validation) and used to help improvement of the active layers.

MEA Level 3 is planned at Month 36: reaching the final target at around 0.15 gPt/kW and 350-700 mW/cm^2. Focus will be on manufacturing active layers with precise Pt/Carbone/electrolyte localisation and properties. According to Autostack project's outputs, if high power density is difficult to reach with such low catalyst loading, priority will be given to increasing the power density (up to ideally 1 W/cm^2) even if higher catalyst loadings are necessary for this.

Expected socio and economic impact

PEMICAN will contribute to the cost reduction in PEMFC and consequently to its mass market development for automotive application. Whereas the project is focused on pure platinum its results will be useful also in the future when efficient non pure platinum is available to even reduce more the cost of PEMFC. Improved modelling developed in the project could also be used in the future as a baseline for design tools of PEMFC.

The project will contribute to the development of a low carbon driven European Industry and is a good example of collaboration between industry (manufacturers, end-users), research centers and universities.

First results have been obtained:
- simulation has been used to analyse first modifications of cathodes to deduce the reduction in catalyst loading with minor influence on performance
- active layers with reduced catalyst loading and with new ink formulations (electrolyte, carbon black) have been manufactured and tested
- feasibility checks have been carried out on the manufacture of active layers with gradients.

Screen printing machine to manufacture controlled active layers

Information

Project reference: FCH JU 256798
Call for proposals: 2009
Application Area: Automotive application
Project type: Research and Technological Development
Topic: SP1-JTI-FCH.2009.1.3 'Development and optimisation of PEMFC electrodes and GDLs
Contract type: Collaborative project
Start date: 01/04/2011 — **End date:** 31/03/2014
Duration: 36 months
Project cost: € 3.96 million
Project funding: € 1.86 million

Coordinator
Commissariat à l'Energie Atomique et aux Energies Alternatives (CEA), France
French Atomic and Alternative Energies Commission

Contact: Mr Joël PAUCHET
E-mail: joel.pauchet@cea.fr

List of participants

CEA	France
Opel	Germany
Solvay	Italy
Tecnalia	Spain
Timcal	Switzerland
Imperial College	United Kingdom

Project website:
https://www.pemican.eu (under construction)

Advanced Electrolyser for Hydrogen Production with Renewable Energy Sources (ADEL)

Key Objectives of the project

The ADEL project (ADvanced ELectrolyser for Hydrogen Production with Renewable Energy Sources) is developing a new steam electrolyser concept. This so-called Intermediate Temperature Steam Electrolysis (ITSE) aims at optimising the electrolyser life time by decreasing its operating temperature while maintaining satisfactory performance level and high energy efficiency at the level of the complete system including the heat and power source and the electrolyser unit. The relevance of the ITSE is an increased coupling flexibility. Improved robustness and operability will be assessed both, at the stack level based on performance and durability tests followed by in depth post test analysis, and at the system level based on flow sheets and global energy efficiency calculations.

Challenges/issues addressed

The challenge of the ADEL project is in the optimisation of materials for intermediate temperature operation allowing for reduced costs while maintaining sufficient performances with limited degradation. On the system level, an appropriate thermal integration of the overall devices with available electricity and heat sources is another key point. The project combines experienced partners having recognized knowledge and skills in separated fields. It particularly depends on their implementation from laboratory scale to technological scale for producing intermediate research and development tools and on their integration into a laboratory prototype constituting the final outcome of the project.

Technical approach/objectives

The project targets the development of cost-competitive, high energy efficient and sustainable hydrogen production based on renewable energy sources. For such an ambitious target the project is built on a two scales parallel approach:

- At the stack level, the adaptation and development of cell, interconnect/coating and sealing components for ITSE operation conditions (T down to 600°C) aims at increasing the electrolyser durability.
- At the system level, the development of flow sheets to analyse and quantify the coupling between the electrolyser unit and renewable heat and power sources aims at identifying the most energy efficient solutions.

The quantitative assessment of the coupling relevance of the ITSE unit with renewable energy sources such as solar or wind or with nuclear and the preliminary dimensioning of a proof of concept technology demonstrator including an operating ITSE stack constitute the final outcomes of the project.

Expected socio and economic impact

The project will contribute in developing a portfolio of sustainable hydrogen production liable to meet 10% - 20% of the hydrogen demand for energy applications from carbon-free or lean energy sources by 2015. One of the outcomes of the project is a preliminary specification of a proof of concept demonstrator that will pave the way to further demonstration and pre-commercialisation activities.

The project gathers a pool of complementary industries together to develop and bring to the market a sustainable H_2 production plant based on Intermediate Temperature Steam Electrolyser coupled to renewable energy sources. The project will help renewable hydrogen production to become cost competitive, and will prepare the ground for future large investments.

So far, the project has shown that high temperature electrolysis can reach reasonable performances at temperatures down to 700°C. On the system side, a basis for understanding the different operation modes has been established and various heat and electricity sources have been inventoried for further flow sheeting work.

Information

Project reference: FCH JU
Call for proposals: 2009
Application Area: Area SP1-JTI-FCH.2: Hydrogen Production & Distribution
Project type: Research and Technological Development
Topic: Topic SP2-JTI-FCH.2.3: New generation of high temperature electrolyser
Contract type: Collaborative Project
Start date: 01/01/2011 — **End date:** 01/01/2014
Duration: 36 months
Project total costs: € 4,373,548
Project funding: max € 2,043,518.00

Coordinator
Olivier Bucheli, HTceramix SA, 26 Avenue des Sports
CH-1400 Yverdon-les-Bains, Switzerland
olivier.bucheli@HTceramix.ch

List of participants/partners

Organisation name	Country
HTceramix SA	Switzerland
accelopment AG	Switzerland
Commissariat à l'Energie Atomique et aux Energies Alternatives	France
Deutsches Zentrum für Luft und Raumfahrt e.V.	Germany
European Institute for Energy Research	Germany
Eidgenössische Materialprüfungs- und Forschungsanstalt	Switzerland
Hynergreen Technologies S.A.	Spain
HyGear B.V.	Netherlands
Fundacion IMDEA Energia	Spain
JRC – Joint Research Centre – European Commission	Belgium
SOFCpower SPA	Italy
Topsoe Fuel Cell A/S	Denmark
Empresarios Agrupados Internaciona L SA	Spain

Project website: www.adel-energy.eu

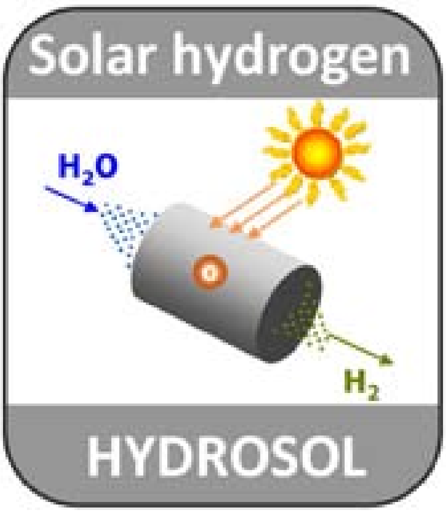
Scale up of thermochemical hydrogen production in a solar monolithic reactor: a 3rd generation design study (HYDROSOL-3D)

Key Objectives of the project

HYDROSOL-3D aims at the preparation of a demonstration of a CO_2-free hydrogen production and provision process and related technology, using two-step thermochemical water splitting cycles by concentrated solar radiation. This process has been developed within two relevant predecessor EU projects, HYDROSOL and HYDROSOL-II and through several steps of improvement has reached the status of a pilot plant demonstration in a 100 kW scale showing that hydrogen production via thermochemical water splitting is possible on a solar tower under realistic conditions. HYDROSOL-3D focuses on the next step towards commercialisation carrying out all activities necessary to prepare the erection of a 1 MW solar demonstration plant. The project concerns the pre-design and design of the whole plant including the solar hydrogen reactor and all necessary upstream and downstream units needed to feed in the reactants and separate the products and the calculation of the necessary plant erection and hydrogen supply costs.

Challenges/issues addressed

- Fine-tuning of materials composition and reactor configurations developed within HYDROSOL & HYDROSOL-II, in order to ensure long-term, reliable solar-aided H_2 production at industrially attractive yields.



- Design & development of a solar H_2 receiver/ reactor with enhanced transport, thermal and heat recovery properties.
- Demonstration of operation of more than 100 cycles under exposure to concentrated solar irradiation.
- Identification of investment and operational cost of a 1 MW demo plant for 2-step solar H_2 generation.
- Calculation of the cost necessary to erect a 1 MW demonstration plant, as well as H_2 production & supply costs, in a 1 MW scale on a solar tower.
- Techno-economic & market analysis to determine the feasibility of process scale-up to the MW scale.

Technical approach/objectives

The project starts from fine-tuning the materials compositions and reactor designs advanced through the Projects HYDROSOL and HYDROSOL-II to ensure long-term, reliable solar-aided Hydrogen production at industrially attractive yields. Emphasis is placed on improving the solar reactor performance by introducing designs and concepts that will enhance the long term thermal stability of materials and the reduction of radiation losses among others. The project then develops the control concepts, algorithms and procedures necessary for the operation of such a plant. Two alternative options are analyzed: adapting the hydrogen production plant to an already available solar facility or developing a new, completely optimised hydrogen production/solar plant. The most promising option will be analysed in detail, establishing the complete plant layout and defining and sizing all necessary components. Validation of pre-design components and process strategies by experiments (in laboratory, solar furnace, solar simulator and solar tower facilities) and a detailed techno-economic analysis covering market introduction complement the project.

Expected socio and economic impact

HYDROSOL-3D responds to the necessity of developing hydrogen production processes from carbon-free sources by 2015 and the need to demonstrate the technical and economical feasibility of thermochemical decomposition of water as a potential pathway for this goal. The Project aims at improving the technical and economic industrial-size feasibility of such processes by enhancing materials' performance, by introducing, designing and simulating real-sized components like solar reactors with enhanced efficiency and volumetric hydrogen productivity, by implementing and validating efficient solar process control strategies and schemes and by coupling of the above to hydrogen separation/purification technologies. HYDROSOL-3D aims to be the first demonstration of solar chemistry-based hydrogen production from water, with a future potential - when employed in combination with concentrated solar thermal power plants - to achieve a hydrogen cost competitive to that of non-sustainable, CO_2-emitting, hydrogen production.

Information

Project reference: FCH JU
Call for proposals: 2008
Application Area: SP1-JTI-FCH.2: Hydrogen Production & Distribution
Project type: Research and Technological Development
Topic: SP1-JTI-FCH.2.3 Water decomposition with solar heat sources
Contract type: Collaborative Project
Start date: 01/01/2010 — **End date:** 31/12/2012
Duration: 36 months
Project total costs: € 1,787,750
Project funding: € 984,375

Coordinator
Dr. Athanasios G. Konstandopoulos,
E-mail: agk@cperi.certh.gr
Aerosol and Particle Technology Laboratory / Center for Research and Technology–Hellas/ Chemical Process Engineering Research Institute (APTL/CERTH/CPERI)
GREECE

Contact: Dr. Christos Agrafiotis
E-mail: chrisagr@cperi.certh.gr

List of participants/partners

Deutsches Zentrum fuer Luft- und Raumfahrt e.V. (DLR)	Germany
Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT)	Spain
Total SA (TOTAL)	France
HyGear B.V. (HYG),	Netherlands

Project website: www.adel-energy.eu

Next Generation PEM Electrolyser for Sustainable Hydrogen Production (NEXPEL)

Key Objectives of the project

The main objective of the NEXPEL project is a successful demonstration of an efficient proton exchange membrane (PEM) electrolyser integrated with Renewable Energy Sources.

The NEXPEL project consist of a top class European consortium which is carefully balanced between leading R&D organizations and major industrial actors from 4 member states. The partners are devoted to developing new materials and stack design concepts to increase the efficiency and lifetime of PEM electrolysers and at the same time cutting costs. The three main goals for the NEXPEL project is to achieve

- Electrolyser efficiency greater than 75%
- A stack life time of 40 000 h
- A reduction in system costs to € 5,000/Nm^3 production capacity

The consortium is confident that the dissemination and exploitation of the project will create considerable impact especially in terms of Europe's energy security, reducing greenhouse gas emission and increasing Europe's competitiveness.

Challenges/issues addressed

Centralized and decentralized sustainable H_2 production using low temperature electrolyser technology requires further improvement in performance and reduction of costs. In this context, the PEM technology particularly adapted for applications in power levels up to 0.5 MW will be considered, with a strong focus on technology improvements to make the technology fit for integration with renewable energies for electricity/ H_2 generation.

Technical approach/objectives

NEXPEL will **develop and demonstrate novel components** that are essential for cost-competitive, high-efficiency PEM electrolysis systems through five key concepts:

- lower capital costs of the main stack components; membrane, electrodes and bipolar plates / current collectors
- higher performance, in particular of the membrane electrode assembly (MEA)
- longer life time of the most crucial PEM components,
- highly efficient advanced power electronics
- novel stack design for high pressure operation and low assembly costs.

Figure 1: Statoils Energy Park at Herøya, Porsgrunn, Norway. The energy park consists of two 6 kW wind turbines and two 2.1kW solar panels and is equipped with a 70 kWh lead acid battery storage system, and water electrolysers from NEL Hydrogen (Earlier Hydrogen Technologies).

Stack design simplification and cost reduction through the use of more cost effective materials is vital to lowering capital costs. Apart from lowering the catalyst loading, a further concept to reduce the system cost down to €5,000/Nm^3h^{-1} is the use of less expensive polymers for membranes and alternative materials for current collectors, bipolar plates and end plates.

Expected socio and economic impact

The results obtained so far in NEXPEL are promising and demonstrate a high probability for achieving improved performance and reduced cost of PEM water electrolysers. The main expected outcomes from the technological developments are:

- A new generation of polyaromatic membranes for PEM electrolysers with a significant enhancement in membrane lifetime and cost.
- New oxygen evolution catalysts with significant improvement in catalytic activity and potential for noble metal thrifting.
- Novel stack design, reducing construction material costs and easing assembly.

In addition, performed market analyses of the utilization of PEM electrolysers in different application areas (micro wind & PV for telecom, green H_2 stations and large scale H_2 production from renewable energy sources), will give a better understanding of the role of PEM electrolysers in a future hydrogen economy.

Information

Project reference: FCH JU 245262
Call for proposals: FCH-JU-2008-1
Application Area: SP1-JTI-FCH-2.1: Efficient PEM electrolysers
Project type: RTD
Topic: SP1-JTI-FCH-2.1: Efficient PEM electrolysers
Contract type: Collaborative Project
Start date: 01/01/2010 — **End date:** 31/12/2012
Duration: 36 months
Project total costs: € 3 353 549
Project funding: € 1 256 286

Coordinator contact details

Magnus Thomassen,
Senior Research Scientist, Dr. Ing

SINTEF Materials & Chemistry
New Energy Solutions
Postboks 4760 Sluppen
NO-7465 Trondheim
Norway
Phone: +47 98243439

List of participants/partners (organisation name, country)

Beneficiary number	Beneficiary name	Country
01 (Coordinator)	Stiftelsen SINTEF	Norway
02	The University of Reading	United Kingdom
03	FuMA-Tech GmbH	Germany
04	CEA LITEN	France
05	Fraunhofer Gesellschaft zur Förderung der angewandten Forschung e.V.	Germany
06	Hélion - Hydrogen Power	France
07	StatoilHydro ASA	Norway
08 (3rd party)	SINTEF Energiforskning AS	Norway

Project website: www.nexpel.eu

Pressurised PEM Electrolyzer stack (PrimoLyzer)

Key Objectives of the project

The primary objective of PrimoLyzer is to develop, construct, and test a cost-minimised highly efficient and durable PEM-electrolyser stack with a hydrogen production capacity of 1 Nm^3/h aimed for integrated with domestic µCHPs. The objectives will be reached through a combination of the following activities:

1. Specification done by the end-user [Hynergreen]
2. Basic material R&D on catalyst & membrane to increase durability & efficiency while reducing cost [FumaTech, VTT & Åbo Academy]
3. Process development to fabricate high performance MEAs [ECN & IRD]
4. Engineering of a durable, reliable, and robust high pressure stack [IRD & ECN]
5. Continuous test for 2,000 hours together with a 1.5 kW µCHP [IRD]
6. An evaluation headed by the end-user(s) [Hynergreen, FumaTech & IRD]

PrimoLyzer is phase I in a two step development, where phase II will comprise full integration of the electrolyser with a µCHP followed by a field test.

Challenges/issues addressed

Stationary µCHPs based on fuel cells are in demonstration all over the world. Almost all these systems are fed with reformed fossil fuel like natural gas. The FC-based µCHPs are more efficient than the technologies they replace, resulting in a substantial reduction in the CO_2 emission, calculated to be ≈1 tons CO_2/year/'single family house' when fuelled with natural gas. However, the emission reduction is *five times higher* when the µCHPs are fuelled with hydrogen produced with excess renewable energy e.g. wind power or photovoltaics. Hydrogen production by electrolysis of water is presently associated with substantial energy losses. Furthermore, small electrolysers are prohibitively expensive while larger electrolysers with a relative smaller plant investment cost require additional hydrogen distribution grids. The primary objective of the PrimoLyzer project is to develop, construct, and test a cost-minimised highly efficient and durable PEM-electrolyser stack aimed for integration with domestic µCHPs.

Technical approach/objectives

The PrimoLyzer key-targets are as follows:

- A) Stack capacity: 1 Nm^3 H_2/h
- B) P_{H2}: 10 MPa
- C) U_{Cell} @ BoL: 1.62 V @ 1.2 A/cm^2
- D) DU_{Cell}: <30 µV/h
- E) Stack cost: <5,000€ in series production

Furthermore, the stack will be liquid cooled to enhance durability and enable easy heat utilisation. This is important as a PEM electrolyser operated with renewable will run when the electricity is cheap and therefore not simultaneous with the µCHP.

The project is scheduled to last 2.5 years. The technical work is divided into six Work Packages. Nineteen deliverables and ten milestones are defined for the project to facilitate the completion of the ambitious project targets and to enable an easy monitoring of the project progress. The project is in very good progress, well performing MEAs (Fig.1) with low degradation rates (<37 µV/h) are obtained. A stack for high-pressure hydrogen production has been designed and successfully tested.

Expected socio and economic impact

The overall aim of PrimoLyzer is to develop a high efficiency electrolyser stack based on PEM technology. The project started with an analysis of solar and wind power followed by a specification to ensure that the stack can be integrated with Renewable Energy Sources. Experiences from this project will contribute to solving the future challenges in grid operation with balancing issues due to higher degree of distributed generation in the grid, high level of renewable energy based on wind/solar power in the grid, and the need for fast response in the activation of the distributed generation for grid balancing. The planned activities include a 2,000 hours prototype testing together with hydrogen fuelled dead-end µCHP system. The PrimoLyzer project will assist the European Union to reach their short- to medium term target on sustainable hydrogen production and supply chains demonstrated and ready for commercialisation by 2013.

Information

Project reference: FCH JU 245228
Call for proposals: year 2009
Application Area:
Project type: Basic Research; Research and Technological Development
Topic: SP1-JTI-FCH.2.1: Efficient PEM Electrolyzers & SP1-JTI-FCH.3.2 Component and system improvement for stationary applications
Contract type: Collaborative Project, Small or medium-scale focused research project
Start date: 01/01/2010 — **End date:** 30/06/2012
Duration: 30 months
Project total costs: € 2,615,270
Project funding: € 1,154,023

Coordinator contact details

Laila Grahl-Madsen, Director of Science and Technology
IRD A/S
Kullinggade 31
DK-5700 Svendborg
Denmark

Mail-address: LGM@ird.dk

List of participants/partners

VALTION TEKNILLINEN TUTKIMUSKESKUS
Advanced Materials
Sinitaival 6
Tampere 33101
Finland
www.vtt.fi

FumaTech -Tech Gesellschaft für funktionelle Membranen und Anlagentechnologie mbH [**FuMa**]
AM Grubenstollen 11
St. Ingbert 66386
Germany
www.fumatech.de

Hynergreen Technologies, S.A. [**AH**]
Avenida de la Buhaira 2
Seville 41018
Spain
www.hynergreen.com

Åbo Akademi University [**AABO**]
Inorganic Chemistry
Biskopsgatan 8
FI-20500 Åbo/Turku
Finland
www.abo.fi

And until the 1st of April, 2011 also

STICHTING ENERGIEONDERZOEK CENTRUM NEDERLAND [**ECN**]
Hydrogen and Clean Fossil Fuels/PEMFC
Westerduinweg 3
Petten 1755 LE
Netherlands
www.ecn.nl

Project website: www.PrimoLyzer.ird.dk

Fuel Cell Coupled Solid State Hydrogen Storage Tank - SSH2S

Key Objectives of the project

According to the requirements of the call, the main objective of SSH2S is to develop a solid state hydrogen storage tank fully integrated with a fuel cell and to demonstrate its application on a real system. A well assessed hydrogen storage material (i.e. mixed lithium amide/magnesium hydride system) will be considered as active material for the tank. A new class of material for hydrogen storage (i.e. mixed borohydrides) will be also explored. The application of the hydrogen tank on real system will be experimentally investigated with a 1 kW prototype on High Temperature Polymer Electrolyte Membrane (HTPEM) fuel cells. On the basis of the results obtained for the prototype system, an ON/OFF milestone will be considered. If suitable performances will be obtained, a scale-up of the tank will be applied to a 5 kW APU. The final goal is to clearly demonstrate the applicability of the proposed integrated system in real applications, also on the basis of a critical techno-economic evaluation.

Challenges/issues addressed

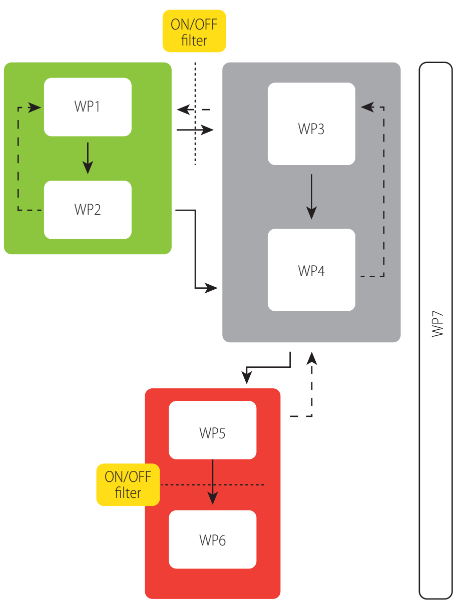
Hydrogen storage for automotive is currently achieved with high pressure (about 70 MPa) compressed gas. This approach implies several efficiency and safety limitations, so alternatives are necessary. Solid state hydrogen storage has been already demonstrated to be suitable for stationary applications, but it needs further scientific and technological improvements for mobile applications. The key challenge of the project is the integration of a solid state hydrogen storage tank with a HT-PEM fuel cell. The system will act as an Auxiliary Power Unit (APU) to be installed in a Light Transport Vehicle (LTV). This goal needs the development of new materials with high gravimetric and volumetric energy density and with technically relevant (i.e. close to ambient) sorption temperature and pressure. The loading time and the stability after several cycles will be a crucial parameter to test the performances of the integrated system. Finally, low cost has to be reached.

Technical approach/objectives

At the beginning of the project, the design and the synthesis, as well as the physico-chemical characterization, of existing and novel materials for solid state hydrogen storage will be carried out. Ab-initio and thermodynamic calculations will drive the selection of materials. In fact, the selected material should be characterized by improved capacity and efficiency, in terms of thermodynamic and kinetic properties, resistance to cycling and thermal behaviour. Synthesis of material will be performed by ball milling. The characterisation will be performed by a combination of structural and spectroscopic experimental techniques.

Two fluido-dynamic modelling of different tank concepts, as well as the experimental validation of the models in a lab-scale tank will be addressed as well as the development of a prototype tank optimized for the use with the selected materials. The project and the development of prototype tank will be driven by industrial partners.

The results will be used for the integration of the materials/tank systems with a low power HT-PEM Fuel Cell (1 kWel). To this aim, on the basis of the obtained properties and simulation results, a suitable material composition will be defined for a scale-up production.



The final goal of the project is the application of the integrated system as 5 kWel APU to be installed in a LTV. The decision about possible scale up will be taken after a critical techno-economic evaluation. ■

Expected socio and economic impact

The development of a material for solid state hydrogen tank with capacities up to 4.5 H_2 wt%, fully reversible at 180°C and with high stability on cycling has never been obtained in previous European Projects. In addition, new concepts on design and the coupling of solid state hydrogen tank with HT-PEM fuel cells will represent a significant achievement of the project. Finally, the development of a prototype 1 kW integrated system and the possible application to a 5 kW APU are a real novelty in the field.

The results of the project can be of significant economical impact for large industries, as well as for SMEs industrial partners. The possibility to couple the HTPEM with a compact and safe hydrogen storage system will greatly enlarge the business opportunities of SER and TD partners. The availability of safe hydrogen tanks at low pressures is expected to contribute to the social acceptance of hydrogen technologies. ■

Information

Project reference: FCH JU (GA n. 256653)
Call for proposals: 2009
Application Area: Hydrogen production and storage
Project type: Research and Development
Topic: SP1-JTI-FCH.2009.2.4: Improved solid state H2 storage systems
Contract type: Collaborative Project
Start date: 01/02/2011 — **End date:** 01/08/2014
Duration: 42 months
Project total costs: € 3 501 749,00
Project funding: € 1 595 685,00

Coordinator

Prof. Marcello Baricco
NIS Centre of Excellence
Dipartimento di Chimica
Università di Torino
Via P. Giuria, 9
I-10125 Torino (Italy)
Tel: + 39 011 670 7569
Fax: + 39 011 670 7855
e-mail: marcello.baricco@unito.it

List of participants/partners (organisation name, country):

UNITO - Università di Torino (Italy)
IFE - Institute for Energy Technology (Norway)
KIT - Karlsruhe Institute of Technology (Germany)
DLR - Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany)
TD - Tecnodelta s.r.l. (Italy)
SER - Serenergy A/S (Denmark)
CRF - Centro Ricerche Fiat (Italy)
JRC - Joint Research Centre of European Commission (Belgium)

Project website: www.ssh2s.eu

Anode Sub-System Development & Optimisation for SOFC systems (ASSENT)

Key Objectives of the project

The objective of this project is to find optimal anode subsystem concepts that are validated for small-scale and large-scale SOFC systems to be implementable into a real system to fulfil performance, lifetime and cost targets for stationary applications. To find optimal anode subsystems to be validated, conceptual analysis and evaluation of the feasibility of the different recycle solutions for the anode subsystem will be carried out. In addition, sensing techniques are tested, evaluated, and also developed, where available techniques are not sufficient. Optimum components should be viable for mass production.

Challenges/issues addressed

Whilst much effort and resources are devoted to cell and stack issues, less attention has been paid to the balance of plant, or components and sub-systems required for an operational system. Components and sub-systems such as fuel processing, heat and thermal management, humidification, fluid supply and management, and power electronics are as fundamental to successful commercialisation of fuel cell systems as the cell and stack. This is the main reason and basic idea which lead our consortium to propose this work. In this proposal the development work specifically addresses SOFC technology but some of the results might also support development of MCFC technology.

Technical approach/objective

The focus of this project is on evaluating different process approaches for fuel and water management in the case of natural gas and biogas. Possible process approaches include e.g. fuel and recirculation management with a recycle blower-based approach and/or an ejector-based approach, and water circulation with condensing from the anode offgas/exhaust gas and evaporating back to loop. Relevant process options are first evaluated on conceptual level and the results are used as a basis for detailed feasibility evaluation. The aspects taken into account in the conceptual analysis are effects on electric efficiency and process simplicity implying easiness of controllability, and requirements on diagnostics accuracy to provide insights into failure mode prevention. In detailed evaluation, the suitable approaches are analysed more thoroughly in terms of component availability and reliability, achievable diagnostics accuracy, controllability, effects on reformer, mechanical integration feasibility to whole system, safety control, failure mode prevention, cost effects etc.

Expected socio and economic impact

SOFC technology is immature, but is seen as having more potential than other fuel cell technologies both in terms of applications and efficiencies and costs. Based on lower cost ceramic materials SOFC technologies are believed to have the greatest potential in becoming cost competitive with incumbent technologies. High electrical and CHP efficiencies will directly impact fuel supplies, whilst low or negligible NOx and SOx emissions and no particulate matter will contribute to cleaner air. SOFC units can therefore improve fuel security, sustainability, competitiveness, efficiency and flexibility, and lower carbon emissions that will contribute to meeting the objectives of Europe's Energy Policy. Looking into the future the fuel flexibility of SOFC systems will allow units to transition from the common hydro-carbon fuels of today through to future potential fuels such as bio-fuels and hydrogen. The focus will be on technologies for SOFC units with the potential for costs less than 1500-2000 €/kW or 3000-4000 €/kW for large- and small-scale applications respectively, have 40 000 - 60 000 hours durability and efficiencies of 45-60% in power generation mode and 80% + for CHP mode.

Information

Project reference: FCH JU
Call for proposals: 2008
Application Area: Stationary Power Generation & CHP
Project type: Research and Technological Development
Topic: SP-JTI-FCH.3.2: Component and system improvement for stationary applications
Contract type: Collaborative Project
Start date: 1/1/2010 — **End date:** 31/12/2012
Duration: 36 months
Project total costs: 4 854 760 €
Project funding: 1 954 675 €

Coordinator contact details
Dr. Jari Kiviaho
Chief Research Scientist
VTT, Fuel Cells
Biologinkuja 5, Espoo
P.O.Box 1000, FI-02044 VTT
Finland
Tel: +358207225298
GSM: +358 50 5116778
Fax: +358 20 722 7048

List of Partners

Organisation name	Country
Technical Research Centre of Finland	Finland
HTceramix	Switzerland
EBZ Entwicklungs- und Vertriebsgesellschaft Brennstoffzelle mbH	Germany
Wärtsilä Finland Oy	Finland
Hexis AG	Switzerlan
Forschungszentrum Jülich GmbH	Germany

Project website: http://assent.vtt.fi/

Asterix3
a FCH JU Project

ASsessment of SOFC CHP systems build on the Technology of htceRamIX 3 (ASTERIX III)

Key Objectives of the project

The main objectives of this project are to further develop a micro combined heat and power (µCHP) system based on solid oxide fuel cells (SOFC). The important parameters to be in focus are lifetime, reliability and robustness. This will include tolerance to thermal cycling and improving quality of the individual components of the system and an integrated automated control system. Also the system efficiency both thermal and electrical will be increased.

Achieving these objectives will enable us to demonstrate a residential µCHP concept fulfilling market requirements, and we can start working on the next step towards commercialization; validation of fuel cell system readiness, field trials and preparation for large scale production.

Challenges/issues addressed

The residential µCHP system based on SOFC technology has the potential to produce both heat and power in a very efficient way. The heat and power is produced in the private home where used and hence, transmission loss can be neglected. The units are fueled by natural gas. The high efficiency of the fuel cell will secure, that the µCHP system will reduce the CO_2 food print of the family installing the µCHP. The challenges of the project are to develop the µCHP SOFC fuel cell technology to achieve proof-of-concept in order to make the technology ready for demonstration in residential environments. The important issues addressed in the project are:

- Lifetime of fuel cell stack
- Electrical an thermal efficiency
- Cost reduction
- Integration in residential environment

Technical approach/objective

System simulations will be used to explore key Fuel cell system parameters and suggest optimized system dimensions. This will be used in the design of two generations of the Proof of Concept system. Subsequently the project focuses on the optimization of the system components such as the SOFC subsystem, the heating system and the inverter. The SOFC system will further be engineered and optimized with an emphasis on the stack, the heat exchanger, the post-combustion and the insulation. Individual components will be improved with a constant attention on their assembly. Increased stack and system performances, wider operating range, and more robustness are aimed for the SOFC subsystem. For the heating system, besides improvements on the heat storage and the inverters, a significant innovation will be aimed with the integration of a heat pump as an auxiliary heater for the micro CHP system instead of an auxiliary burner.

Ultimately, the objective is to test and validate the Asterix3 micro-CHP appliance. As a first step an experimental program will be established to test the system in various conditions. The test program will be defined with respect to the testing procedures drafted in the upcoming International standard IEC 62282-3-2 (test methods for stationary fuel cell systems), which is currently under development. The testing conditions will be established to demonstrate extended continuous operation, thermal cycling, and normal and emergency shutdown conditions.

The objectives are to reach costs slightly higher that a normal condensing boiler and an electrical efficiency that is higher than to days typical large power plant.

Expected socio and economic impact

The project takes a vital step towards the commercialization of the SOFC power systems for application in private homes. The switch from traditional gas boilers to SOFC µCHP systems will heighten the efficiency and promote decentralizing of power production. SOFC µCHP power systems can provide energy security and independency of nuclear and large coal fired power plants. The high efficiency of the SOFC CHP systems provide once reasonably priced, a massive incentive for switching from conventional centralized power generation to decentralized heat/cooling and power production. This will lead to reduction of distribution losses and thus lower CO_2 missions.

Information

Project reference: FCH JU
Call for proposals: 2009
Application Area: Research and Technology Development
Topic: R&D to achieve proof-of-concept of µCHP fuel cell system
Contract type: Collaborative Project
Start date: 01/01/2011 — **End date:** 31/12/2013
Duration: 36 months
Project total costs: € 3.096.000
Project funding: € 1.361.000

Coordinator contact details

Per Balslev, Director Business Development
Dantherm Power A/S
Majsmarken 1
DK 9500 Hobro
Denmark
peb@dantherm.com

List of Partners

HTCeramix	Switzerland
EIFER	Germany
CNR-ITAE	Italy

Project website:
www.asterix3.eu

Cathode Subsystem Development and Optimisation (CATION)

Key Objectives of the project

This project would bring improvements to the current state-of-the-art cathode side subsystem, thermal and fluid supply management of SOFC systems and may lead into the novel design solutions and optimized subsystems which will significantly increase SOFC system efficiency, reliability, controllability and lifetime, and will decrease overall cost. With this novel cathode subsystem solution the new stationary 250 kWe SOFC system should reach 55% electrical efficiency, and achieve 40000 hours of lifetime with over 90% availability. The optimization of SOFC cathode subsystem also leads into significant reduction of piping and supporting structures. With layout-wise optimized components and structural and insulation solutions, major benefits can be achieved in compactness and weight of the unit and in cost of piping and supporting structures.

Challenges/issues addressed

Whilst much effort and resources are devoted to cell and stack degradation issues, less attention has been paid to the balance of plant, or components and sub-systems required for an operational system. Cathode side subsystem including stacks and system components such as high temperature heat exchangers, burners and blowers etc. can be significant factors decreasing the electric efficiency of the whole system. Relatively high mass flows and corresponding pressure drops together with non-optimal components, sub-system solutions and the overall system layout can decrease the total electrical efficiency many percent points, and may drop the cost-effectiveness of the whole system below commercial profitability. This can be one of the main barriers preventing commercialization of a final fuel cell system for stationary power production.

Technical approach/objective

This project will give a thorough evaluation into alternatives for the SOFC system's cathode side subsystems (fluid and thermal management and mechanical solutions including stack/system interface) and one of them could be implemented into new ~250 kWe SOFC system demonstrations based on the development achieved in the proposed project. The optimization of SOFC cathode subsystem also leads into significant reduction of piping and supporting structures. With layout-wise optimized components and structural and insulation solutions, major benefits can be achieved in compactness and weight of the unit and in cost of piping and supporting structures. This project would bring improvements to the current state-of-the-art cathode side subsystem, thermal and fluid supply management of SOFC systems and may lead into the novel design solutions and optimized subsystems which will significantly increase SOFC system efficiency, reliability, controllability and lifetime, and will decrease overall cost. With this novel cathode subsystem solution the new 250 kWe SOFC system should reach 55% electrical efficiency, and achieve 40000 hours of lifetime with over 90% availability.

Expected socio and economic impact

Even if the SOFC technology is immature compared to MCFC and PEM technologies, it can be clearly seen as having more potential than these other fuel cell technologies in terms of applications, efficiencies and cost. Based on lower cost ceramic materials SOFC technologies are believed to have the greatest potential in becoming cost competitive with conventional technologies. Thus SOFC solutions with efficiencies above 60% in power generation mode and 90% plus for CHP mode are possible for the medium to longer term. High electrical and CHP efficiencies will directly impact fuel supplies, whilst low or negligible NOx and SOx emissions and no particulate matter will contribute to cleaner air. SOFC units can therefore improve fuel security, sustainability, competitiveness, efficiency and flexibility, and lower carbon emissions. This will contribute to meeting the objectives of Europe's Energy Policy. Looking into the future the fuel flexibility of SOFC systems will allow units to move from the common hydro-carbon fuels of today, notably natural gas, through to future potential fuels such as hydrogen and biofuels.

Information

Project reference: FCH JU
Call for proposals: 2009
Application Area: Stationary Power Generation & CHP
Project type: Research and Technological Development
Topic: SP1-JTI-FCH.2009.3.4: Component and system improvement for stationary applications
Contract type: Collaborative Project
Start date: 1/1/2011 — **End date:** 31/12/2013
Duration: 36 months
Project total costs: 7 194 680 €
Project funding: 2 625 680 €

Coordinator contact details

Dr. Jari Kiviaho
Chief Research Scientist
VTT, Fuel Cells
Biologinkuja 5, Espoo
P.O.Box 1000, FI-02044 VTT
Finland
Tel: +358207225298
GSM +358 50 5116778
Fax: +358 20 722 7048

List of Partners

Technical Research Centre of Finland	Finland
Wärtsilä Finland Oy	Finland
AVL List GmbH	Austria
Topsoe Fuel Cells A/S	Denmark
Bosal Research NV	Belgium
Centro per lo Sviluppo della Sostenibilita dei Prodotti	Italy

Project website:
http://cation.vtt.fi/

DC/DC COnverter-based Diagnostics for PEM systems (D-CODE)

Key Objectives of the project

The D-CODE project aims at developing an innovative diagnostic procedure to detect PEM fuel cell stack faults and support stack degradation level analysis. The stack electrochemical impedance spectrum (EIS) is used for on-line diagnosis during on-field operations. Thanks to both new DC/DC converter hardware and diagnosis algorithms, faults and potential failures associated with electrochemical processes, components faults (blower, power electronics, actuators) or having external origin (erroneous control, critical load) can be detected on-line while system runs.

Main Objectives:

- Innovative FC stack monitoring to change radically the concept of on-line diagnostic.
- EIS-based diagnosis-oriented DC/DC converter to be installed on low and high temperature fuel cell systems.
- Transpose EIS from lab scale to on-field for monitoring and diagnosis.
- Power stage and control strategy of a DC/DC converter to obtain the stack EIS on-board.
- A set of indicators from the spectrum to evaluate differences between the actual status and the nominal one.

Challenges/issues addressed

The D-CODE main challenge is the on-line determination of the FCS state-of-the-health through the information provided by the impedance spectrum. Therefore, single information will guarantee a holistic analysis of the stack. To achieve this goal several technological issues are addressed, among others:

- Design and build an improved DC/DC converter; the new DC/DC hardware improves interface between power generators and load/grid.
- Implementation of power electronics controllers aimed at immunizing the stack from the load disturbance.
- Implement EIS functions on-board of the DC/DC converter.
- Develop EIS-based diagnostics for low and high temperature PEM fuel cells.
- Embed the EIS-based diagnostic tool in the electronic control unit.
- Derive FC degradation/diagnostic information while the system runs.
- Analysis of EIS to diagnose incipient failures caused by either faults or cell degradation.

See figure 1 for the FC system sketch with the main components and functions.

Technical approach/objective

The approach focuses on the experimental activity to characterise both low temperature (LT) and high temperature (HT) fuel cell systems and to test diagnostic hardware and related strategies. The hardware design and realization of the DC/DC power converter to perform EIS has to be achieved as well as the development of the algorithms for the diagnosis. Finally, the development of the management system is needed in order to drive the DC/DC converter for EIS purposes and to improve the FCS control strategies taking advantage of the information gathered from EIS-based diagnosis.

Expected socio and economic impact

Total performance during the life of a PEM system plays a very important role in the overall economics of the FC system. Therefore, the system needs to operate in such a way as to limit or prevent degradation and highly damaging failures. It is therefore very important for the commercialisation of PEM system to develop good diagnosis tools that can be used on board when diagnosing systems failures.

Diagnostics tools developed in D-CODE offer potential for instrumentation cost reduction, thus significantly reducing the required investment cost for PEM systems. Additionally, system on-demand servicing becomes possible by utilizing a diagnosis tool that monitors and predicts PEM system and stack failures. On-demand servicing can decrease the operation and maintenance costs of the PEM systems, as the components are serviced and replaced just prior to their end-of-life date. The lifetime of the PEM stacks can be increased by means of a diagnosis tool that indentifies degrading operating conditions and provides information on a stable operating window for the PEM system. This will decrease O&M costs as the time between servicing and replacement of the stacks is extended.

Information

Project reference: FCH JU
Call for proposals: 2009
Application Area: SP1-JTI-FCH.3: Stationary Power Generation & CHP
Project type: Research and Technological Development
Topic: SP1-JTI-FCH.2009.3.3: Operation diagnostics and control for stationary applications
Contract type: Collaborative Project
Start date: 1/3/2011 — **End date:** 28/2/2014
Duration: 36 months
Project total costs: € 2215767.40
Project funding: € 1173818.00

Coordinator
Cesare Pianese
Dept. of Industrial Engineeting – University of Salerno,
Via Ponte don Melillo
1, 84084 – Fiaciano (SA), Italy
pianese@unisa.it

List of Partners

Beneficiary name	Beneficiary short name	Country
University of Salerno	UNISA	Italy
European Institute for Energy Research	EIFER	Germany
Université de Franche-Comté	UFC	France
Dantherm Power A/S	DANTH	Denmark
CIRTEM	CIRTEM	France
Bitron S.p.a	BITRON	Italy
inno TSD	INNO	France

Project website:
http://www.d-code.unisa.it
https://dcode.eifer.uni-karlsruhe.de/

'Understanding the Degradation Mechanisms of Membrane-Electrode-Assembly for High Temperature PEMFCs and Optimization of the Individual Components' (DEMMEA)

Key Objectives of the project

The state of the art high temperature polymer electrolyte, PEM, fuel cell technology is based on H_3PO_4 imbibed polymer electrolytes. The most challenging areas towards the optimization of this technology are: (i) the development of stable long lasting polymer structures with high ionic conductivity and minimal cost and (ii) the design and development of catalytic layers with novel structures and architectures aiming to reduced Pt loadings and more active and stable electrochemical interfaces with minimal Pt corrosion. In this respect the objective of the present proposal is to understand the functional operation and degradation mechanisms of high temperature H_3PO_4 imbibed PEM and its electrochemical interface. The fundamental understanding of the failure mechanisms can be used to guide the development of new materials and the development of system approaches to mitigate these failures.

Challenges/issues addressed

The goal of this project is to study and understand the physical origin of the degradation phenomena that take place during the operation of an MEA of a high temperature PEM fuel cell. The ultimate milestone of the project is the combined use of advanced experimental techniques that will lead to the design and development of prediction tools for the MEA's performance. Despite conventional techniques, in-situ spectroscopy and locally resolved measurements are developed and adopted for the first time for this purpose. The degradation mechanisms will be thoroughly studied. This will permit the tailormade optimization of the MEA through the proposal of new materials (PEMs and catalysts) into a commercially reliable product for stack manufacturers.

Technical approach/objective

For the achievements of the project's goals, ex-situ and in-situ testing methodologies must be applied for the examination of the polymer electrolytes (PEMs), the catalytic layers and MEAs.

- Two groups of HT PEMs are employed: a) PBI and variants as control group and b) the advanced state of the art MEAs based on aromatic polyethers bearing pyridine units. The polymer electrolytes have been prepared and characterized in terms of their chemical stability and proton conductivity under various conditions.
- Pt based electrocatalysts have been prepared using new modified carbon supports and characterized as to their physicochemical properties and electrochemical performance. The objective is to achieve a stable electrocatalytic layer with full metal electrocatalyst utilization at the electrode/electrolyte interface in order to lower Pt loadings and increase durability.
- MEAs preparation and combined in situ electrochemical and spectroscopic investigation techniques and ex-situ post mortem characterization are used in order to study thoroughly the degradation mechanisms aiming to the development of a series of diagnostic tests. MEAs are studied and tested in single fuel cells with regards to their operating conditions' effect on performance, their long term stability and the determination of Pt electrocatalytic utilization and durability. Innovative characterization methods have been developed and employed.
- The information of the aforementioned experimental methodologies are used as a feedback for the development of a mathematical model intended as a predicting tool for the MEA's long term and transient performance.

Expected socio and economic impact

The main direct and indirect socio-economic benefits from the DEMMEA project include cost reduction of the MEA components and thus the overall fuel cell, achievement of reliable and efficient operation and therefore opening/broadening of the fuel cell market with the obvious economic (employment, rural regions) and environmental beneficial impact.

Results to date: Certain failure mechanisms of the current technology MEAs have been identified. Novel polymer electrolytes have been prepared aiming to stable structures at elevated temperature. The novel electrocatalytic systems with new architectures prepared so far seem to overcome certain limitations of current state of the art formulations towards the improvement of performance and stability of the HT MEAs. The expected outcome at the end of the project is a commercially reliable product.

Information

Project reference: FCH-JU-2008-1
Call for proposals: 2008
Application Area: SP1-JTI-FCH.3: Stationary Power Generation & CHP
Project type: Research and Technological Development
Topic: 3.3 Degradation and lifetime fundamentals
Contract type: Collaborative Project
Start date: 01 January 2010 — **End date:** ongoing
Duration: 36 months
Project cost: 3.1 M€
Project funding: 1.6 M€

Coordinator
Advanced Energy Technologies
Greece

Contact: Dr. Stylianos Neophytides
E-mail: neoph@iceht.forth.gr

List of Partners

1. Advanced Energy Technologies
2. Foundation for Research and Technology Hellas-Institute of Chemical Engineering & High Temperature Chemical Processes
3. Paul Scherrer Institute
4. Centre National de la Recherche Scientifique
5. FUMATECH GmbH
6. Institute of Chemical Technology Prague
7. Next Energy - EWE-Forschungszentrum für Energietechnologie e.V.
8. Technical University of Darmstadt

Project website:
demmea.iceht.forth.gr

Degradation Signature Identification for Stack Operation Diagnostic (Design)

Key Objectives of the project

The overall objective of the DESIGN project is to provide a sound diagnostic method for insidious phenomena that slowly accelerate the degradation at the commercial stack level, through understanding of the local responses of sub-stack elements. The main outcome of the project will be the identification of relevant sensors and signals monitored to diagnose full stack degradation phenomena. Data analysis methodology is to be applied to measured signals; A set of characteristic signatures for the different degradation phenomena at the local and stack level, to diagnose long-term degradation conditions; Recommendations for operation recovery, once a degradation condition is identified at the cell, SRU or stack level.

Challenges/issues addressed

The main challenges addressed are the identification of specific signatures at the local cell /SRU / small stack level and their transposition from local signatures to full stack with limited instrumentation.

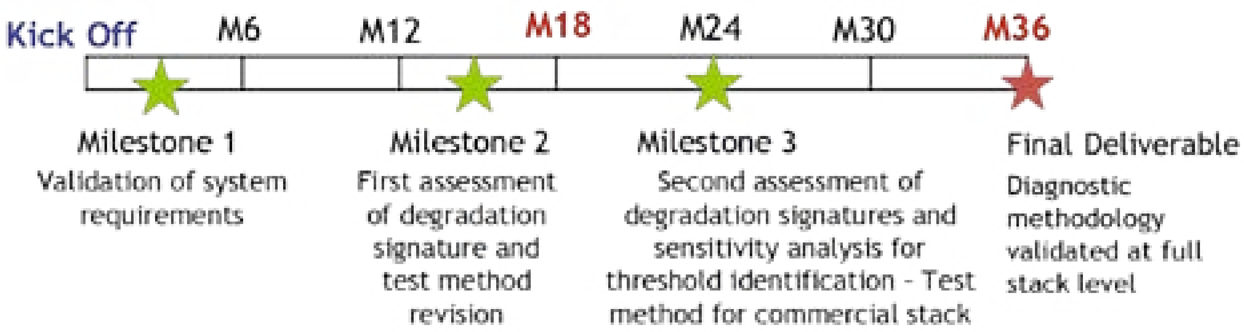
Technical approach/objective

The DESIGN project follows the complete loop from an identified problem (i.e. the list of degradation phenomena studied), set by a group of industry partners, to the development of a solution (core study) and finally the assessment of the resulting recommendations, again with the implication of industry. After the specification and prioritisation of the different long-term degradation phenomena to be considered (Milestone M1), a test matrix and test protocols to be used will be defined. 3 iterations are scheduled encompassing test matrix definition, experiments and data analysis addressing respectively, the characterisation of separate phenomena, the investigation of a potential threshold for detection and fine-tuning the data analysis methods. Each iteration is launched by a Milestone. Up-scaling of the diagnostic method from sub-components to stack diagnostic will conclude the project with some diagnostics developed in DESIGN, applied on commercial full-size stacks.

Expected socio and economic impact

During the first year of the project, the Design partners have identified and prioritized phenomena (operating conditions generating degradation) to be investigated in the project. This has been done with the external participation of the Genius consortium. Three main mechanisms have been selected due to their having a clear signature that could be distinguished from other degradations and because they have a potential of at least partial recovery. They are 1) Anode re-oxidation by locally increased fuel utilizations, 2) Carbon deposition and 3) Small leakages at anode side.

Specific test matrix and test protocols have been defined that will be achieved iteratively at cell, Single Repeating Unit, short and large stack level, with adapted measures. In particular Electrochemical Impedance Spectroscopy (EIS), will be performed to identify through, data analysis the degradation signatures of each phenomenon.



Information

Project reference: FCH JU collaborative project GA 256693
Call for proposals: AIP 2009
Application Area: Stationary Power Generation & Combined Heat and Power
Project type: Applied Research;
Topic: 3.3 Operation Diagnostics and Control for Stationary Power Application
Contract type: Collaborative Project
Start date: 01/01/2011 — **End date:** 31/12/2013
Duration: 36 months
Project total costs: € 3'266'000
Project funding: € 1'746'000

Coordinator

Dr. Florence Lefebvre-Joud
CEA – Grenoble /LITEN
17 rue des Martyrs
38054 Grenoble Cedex 9, France
Tel: +33 438 78 40 40
Fax: +33 438 78 25 56
Mail: florence.lefebvre-joud@cea.fr

List of participants/partners

Partner Name	Partner short name	Country
Commissariat à l'Energie Atomique et aux Energies Alternatives - Grenoble	CEA	France
Europäisches Institut für EnergieForschung	EIFER	Germany
Università Degli Studi di Salerno	UNISA	Italy
Ecole Polytechnique Fédérale de Lausanne	EPFL	Switzerland
HyGear Fuel Cell Systems BV	HFCS	Netherlands
HTceramix SA	HTC	Switzerland
EBZ Entwicklungs und Vertriebsgesellschaft Brennstoffzelle mbH	EBZ	Germany

Project website:
www.design-sofc-diagnostic.eu

Generic diagnosis instrument for SOFC systems (GENIUS)

Key Objectives of the project

In order to comply with the constraints of stationary generators during operation, it is necessary to develop monitoring devices that could either be used as On Board Diagnostic or as 'off-line' diagnostic. In the former case, the tool sends an alarm in order to guarantee installation safety and the respect of regulations. Once a fault identified, counter measures could then be taken by the control system and a recovery strategy could be defined to limit degradations or performance drop. In the latter case, the tool helps the maintenance operations or repairs.

The objective of GENIUS project is to develop a 'GENERIC' approach based on different algorithms that would only use process values (normal measurements and system control input parameters) to diagnose the state of health of different SOFC systems. If the approach remains generic, the final tool will be adapted to the specificities of the different systems in which it will be integrated and validated.

Challenges/issues addressed

In order to compete with current boilers and entering the market, SOFC systems need to reach similar reliability, lifetime and costs level:

- no inconvenience at the customer place, limited cost for operation and (at worst) yearly maintenance.
- 40 000 hrs llifetime with a degradation rate < 0.5%/1000hrs.

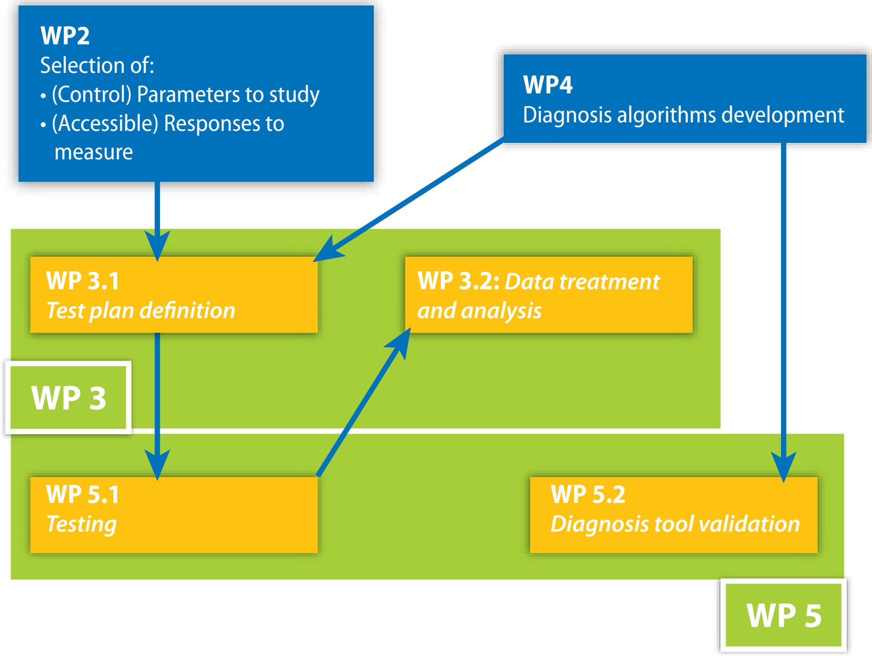
But, these systems' state of health is currently difficult to evaluate, which makes difficult to handle faults or degradation with an appropriate counter measure. As a consequence, abovementioned requirements cannot be achieved. That's why state of health diagnostic tools are needed

Technical approach/objective

The purpose of this project is to develop diagnostic tools that would be validated on real systems. For this, main faults and failures that occur on a SOFC system together with their impacting parameters were identified. On this basis, test plan were defined according to the specificities of each stack/system and on each test bench. A permanent loop is established between testing, algorithm development and test plan definition, in order to create diagnostic algorithms that will be validated on three different µ-CHP systems.

Expected socio and economic impact

GENIUS contributes directly to the commercialization of the SOFC power systems. Indeed, along with costs, the reliability and lifetime of SOFC stacks remain as barriers for the market penetration of the SOFC power systems. Significant improvements in these aspects can be expected by utilizing sophisticated diagnosis tools, that just use the normal measurements and their control input parameters, for the monitoring, the prediction and the prevention of stack failures and degradation. In this way, counter measures can be taken and degradation minimized by appropriate operation even in dynamic load conditions. The implementation of such tools in real systems could therefore be of great benefit for the technology by increasing the trust of utilities.



Information

Project reference: FCH JU 2008-1
Call for proposals: 2008
Application Area: Stationary Applications
Project type: Research and Technological Development
Topic: SP1-JTI-FCH.3.1 Operation diagnostics and control for stationary applications
Contract type: Collaborative action
Start date: 01/02/2010 — **End date:** 31/01/2013
Duration: 36 months
Project total costs: € 3 928 509
Project funding: € 2 067 785

Coordinator contact details:
Philippe MOÇOTÉGUY
R&D Project Manager
Distributed Energy Group
EIFER
Europäisches Institut für Energieforschung
Institut européen de recherche sur l'énergie
European Institute for Energy Research
Emmy-Noether Strasse 11
D-76131 Karlsruhe
Germany
Tel: +49 721 6105 1337
Fax: +49 721 6105 1332

List of participants/partners (organisation name, country)

Beneficiary name	Beneficiary short name	Country
European Institute for Energy Research	EIFER	Germany
Ceramic Fuel Cells Limited	CFCL	UK
EBZ GmbH	EBZ	Germany
Université Technologique de Belfort-Montbéliard	FCLAB	France
Université de Franche Comté	UFC (third party of FC LAB	France
Hexis AG	Hexis	Switzerland
HTCeramix	HTC	Switzerland
Topsoe Fuel Cell	TOFC	Denmark
University of Genoa	UNIGE	Italy
University of Salerno	UNISA	Italy
Technical Research Center of Finland	VTT	Finland
Wärtsilä	WAR	Finland
inno TSD	INNO	France

Project website: https://genius.eifer.uni-karlsruhe.de/

'Knowledge to Enhance the Endurance of PEM fuel cells by Accelerated LIfetime Verification Experiments' (KeePEMalive)

Key Objectives of the project

KeePEMalive aims at establishing improved understanding of degradation and failure mechanisms, by developing and approving accelerated stress test protocols, a sensitivity matrix and a lifetime prediction model for Low Temperature Proton Exchange Membrane Fuel Cells (LT PEMFC) to enable a lifetime of 40 000 h at realistic operation conditions for stationary systems, in compliance with performance and costs targets.

Challenges/issues addressed

KeePEMalive particularly addresses the degradation challenge by focusing on the following issues:

- Identify the relevant stressing conditions for µ-CHP by assessing data from field operations as well as laboratory tests.
- Establish a robust and efficient methodology for identification and quantification of the conditions causing degradation and failure.
- Develop *ex situ* accelerated ageing tests for individual MEA component, and relate results to observed degradation rates for single cell and stacks.
- Verify and validate proposed materials' improvements.
- Develop Accelerated Stress Test (AST) protocols that enable quantification of the impact of selected stressors on single cells and stacks.
- Provide validated recommendations for degradation mitigation strategies.
- Establish a model that reliably predicts lifetime on the basis of AST results.

Technical approach/objective

The concept of this project contains the following elements (also illustrated on next page):

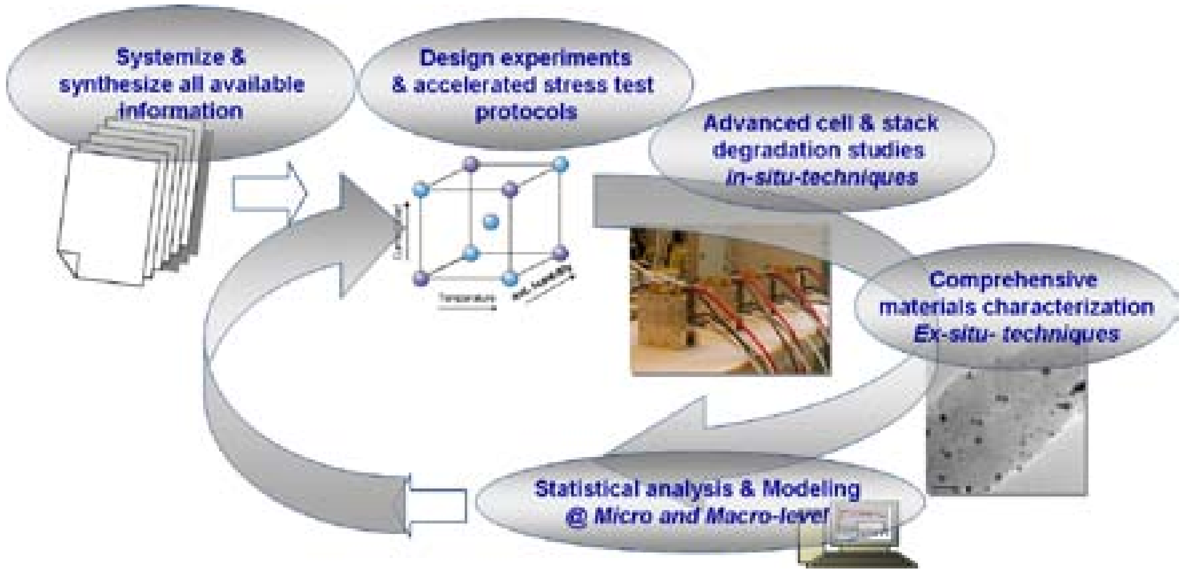
- Systemizing and synthesising all available information on degradation and failure mechanisms
- Designing experiments and accelerated stress test protocols
- Carrying out comprehensive cell and stack testing utilising the latest and most advanced in situ electrochemical as well as effluent analysis techniques
- Complementing the in situ tests by post mortem characterising fuel cell materials by ex situ techniques
- Analysing the data utilising powerful statistical tools
- Developing a model for prediction of lifetime and failure.

The KeePEMalive project is of an iterative nature, initially using state-of-the-art materials and stacks supplied by European fuel cell manufacturers for detailed analyses and characterisation. As the project progresses and the understanding of degradation and failure mechanisms is enhanced, recommendations for improved materials and stack components as well as degradation mitigation strategies will be provided.

Expected socio and economic impact

The KeePEMalive project contributes to achieve the principal technical and economic requirements needed for PEMFCs to compete with existing energy conversion technologies (e.g., natural gas burners, resistive heating) for stationary heat generation, and in addition provide electricity by efficient cogeneration of power. The project has a strong link to the Danish Vestenskov stationary fuel cell demonstration project, where 35 PEMFC based µ-CHPs will be placed in households, utilizing hydrogen from wind in a weak grid. Real-life operation data from this demonstration project feed into the KeePEMalive project and forms, together with experimental laboratory test data, the basis for improving materials and developing a lifetime prediction model. The increased understanding of degradation mechanisms achieved in the KeePEMalive-project will eventually contribute to develop mitigation strategies, thereby ensuring longer lifetimes for PEMFCs and hence lower cost of energy (electricity and heat) compared to current state-of-the-art stationary fuel cells.

Results obtained from KeePEMalive will be of a generic nature and are thus highly relevant for all PEMFC systems, including High Temperature PEMFC and PEMFCs for automotive applications, be it that the impact on the lifetime and failure will be different and that other mitigation strategies will be required.



Information

Project reference: FCH JU
Call for proposals: 2008
Application Area: Stationary Power Production and CHP
Project type: Basic Research or Research and Technology Development
Topic: *SP1-JTI-FCH.3.3: Degradation and lifetime fundamentals*
Contract type: Collaborative Project
Start date: 01/01/2010 — **End date:** 30/06/2013
Duration: 42 months
Project total costs: € 2,9 mill
Project funding: € 1,3 mill

Coordinator contact details
Dr. Steffen Møller-Holst
Vice President Marketing
Hydrogen & Fuel Cell Technologies
SINTEF

Postal Address:
SINTEF Materials and Chemistry
Postboks 4760 Sluppen
NO-7465 Trondheim
Norway

Tel (direct line): +47 926 04534
Switch board: +47 4000 3730
steffen.moller-holst@sintef.no

List of participants/partners (organisation name, country)

Beneficiary Number	Beneficiary name	Beneficiary short name	Country	Date enter project	Date exit project
1 coordinator	Stiftelsen SINTEF	SINTEF	NO	1	42
2	IRD Fuel Cells A/S	IRD	DK	1	42
3	Stichting Energieonderzoek Centrum Nederland	ECN	NL	1	14
4	Centre National de la Recherche Scientifique, Institut Charles Gerhardt	CNRS	FR	1	42
5	FuMA-Tech GmbH	FuMA	DE	1	42
6	EIfER – European Institute for Energy Research	EIfER	DE	1	42
7	Technische Universität Graz	TUG	AT	1	42
8	SEAS-NVE	SEAS	DK	1	42
9	European Commission Joint Research Centre, Institute for Energy	JRC	BE	1	42

Project website:
http://www.sintef.no/Projectweb/KEEPEMALIVE/

'Long-life PEM-FCH &CHP systems at temperatures ≥100°C' (LoLiPEM)

Key Objectives of the project

The key objective of the LoLiPEM project is to give a clear demonstration that long-life SPG&CHP systems based on PEMFCHs operating at temperatures higher than 100°C can now be developed on the basis of knowledge on the degradation mechanisms of membranes disclosed by some LoLiPEM partners. Stable perfluoro sulfonic acid (PFSA) and new stable non-perfluorinated ionomers, such as sulfonated aromatic polymers (SAPs), are the materials mostly used in this project for the membranes development for the MEAs preparation. These innovative MEAs will be developed for operating above 100°C.

Challenges/issues addressed

A PEMFCH operating in the temperature range of 100-130°C is highly desirable and could be decisive for the development of SPG&CHP systems based on PEMFCHs. LoLiPEM aims to operate in this temperature range exceeding the state-of-the-art (70-80°C). The lower temperature is the main drawback for PEMFCH development. Several advantages including easier warm water distribution in buildings, reduced anode poisoning due to carbon monoxide impurities in the fuel, improved fuel oxidation kinetics, etc. would be gained by operating above 100°C.

Technical approach/objective

The key milestones and deliverables include

- The preparation of PFSA and SAPs membranes stable at a temperature higher than 100°C
- Development of new long-life catalytic electrodes and MEAs operating in the above temperature range
- Accelerated ageing tests and long-term single cell tests
- Development of a prototype of a modular SPG&CHP system based on multi-PEMFCHs also utilizing the new long-life MEAs.
- Benchmarking the single-cell and the modular prototype performance at temperatures above 100°C against the best literature results

New protocols for the evaluation of mass transport properties of membranes and MEA as well as for the testing of MEA in fuel cell have been elaborated and successfully applied.

Expected socio and economic impact

Novel PFSA and SAP membranes able to withstand temperatures higher than 100°C have been prepared and successfully tested. Innovative electrodes have been prepared with a new electrodeposition process which allows all the electrocatalyst nanoparticles to be in contact with both the ionically conducting ionomer and the electronically conducting electrode materials. MEAs have been prepared and tested at operating temperatures above 100°C.

Information

Project reference: FCH JU - Grant Agreement no. 245339
Call for proposals: year 2008
Application Area: SP1-JTI-FCH.3: Stationary Power Generation & CHP
Project type: Research and Technological Development
Topic: SP1-JTI-FCH.3.3 Degradation and lifetime fundamentals
Contract type: Collaborative project
Start date: 01/01/2010 — **End date:** 31/12/2012
Duration: 36 months
Project total costs: € 2.927.174
Project funding: € 1.360.277

Coordinator contact details:
Dr. Giuseppe Barbieri
The Institute on Membrane Technology - National Research Council (ITM-CNR)
Tel: +39 0984 492029
Fax: + 39 0984 402103
E-mail: g.barbieri@itm.cnr.it
giuseppe.barbieri@cnr.it

List of participants/partners (organisation name, country)

1. CNR-ITM, Italy
2. The University of Rome 'Tor Vergata', Italy
3. The University of Provence, France
4. The University of Saarbrucken, Germany
5. EDISON SpA, Italy
6. Fumatech, Germany
7. Matgas 2000, Spain
8. Cracow University of Technology, Poland

Project website: www.LoLiPEM.eu

Low Temperature Solid Oxide Fuel Cells for micro-CHP Applications (LOTUS)

Key Objectives of the project

The main objective of the project will be to develop a proof-of-concept fuel cell system:

- based on state of the art Solid Oxide fuel cell technology
- operating on as low stack temperature as possible, with a target of 650°C, to solve the known failure mechanisms of HT SOFC systems
- Reducing down time by integrating a low cost, high efficient Gas Air Delivery system based on mass produced and field proven components
- integrate all needed power electronics, components and connections for a direct replacement of conventional heating appliances
- use a modular concept and design practices from the heating appliances industry to reduce maintenance and repair downtime and costs
- an electrical system efficiency of minimal
- a total system efficiency of minimal 80%.

Challenges/issues addressed

State of the art SOFC technology runs at temperatures around 800-900°C which imposes high thermal stress on the materials used in the SOFC stack. Running at lower temperatures (650-700°C) could improve the stability of the stack and therefore increase the reliability. It has been proven on a single cell and stack level that at these lower temperatures the performance of the SOFC materials is sufficient. In the LOTUS project a micro-CHP system will be designed and a prototype built based on the 650°C operating stack which meets cost and efficiency targets. Next to the reduced temperature the biggest challenge is the integration of components to reduce parts and heat loss.

Technical approach/objective

During the 1st year the system will be defined and modelled and materials for the stack module improved. This will lead to the delivery of a full stack at the end of year 2. In the mean time the other modules: desulfurization, external reformer, burner and heat exchangers will be developed. To reduce system costs, mass-produced off-the-shelf components will be used where possible.

In the end of year two all module developments culminate in the prototyping of a system and testing it in the last 6 month of the project.

Expected socio and economic impact

The use of distributed combined heat and power will greatly increase the energy efficiency compared with conventional power plants and boilers. When the production and transportation of the same amount of electricity and heat to a home by conventional means will take up to about 170 units, producing those with a SOFC system at the point of use, only 100 units are needed. This will reduce the energy consumption between 35 to 40% with accompanied similar CO_2 emission reductions.

Information

Project reference: FCH JU 256694
Call for proposals: 2009
Application Area: Stationary power generation and CHP
Project type: Research and Technological development
Topic: SP1-JTI-FCH.2009.3.5: Proof-of-concept fuel cell systems
Contract type: Collaborative project
Start date: 01 January 2010
End date: 31 December 2013
Duration: 36 months
Project cost: € 2.954.984 Project funding: €1.632.601

Coordinator:
Hygear Fuel Cell systems
The Netherlands

Contact: Mr. Ellart de Wit
E-mail: ellart.de.wit@hygear.nl

Other participating organisations:

SOFCPower	Italy
Fraunhofer-Institut für Keramische Technologien und Systeme	Germany
Domel, d.d.	Slovenia
University of Perugia	Italy
European Commision, Directorate-General Joint Research Centre	Belgium

Project website: www.lotus-project.eu

MembrAnEs for STationary application with RObust mechanical properties (MAESTRO)

Key Objectives of the project

MAESTRO aims to establish methods to increase the mechanical stability of state of the art low equivalent weight perfluorosulfonic acid membranes for stationary application of proton exchange membrane fuel cells (PEMFC) to increase their durability and cell lifetime. The concept will be validated by the integration of the robust, mechanically stabilised membranes into MEAs, which will be tested in realistic conditions, including stability under dynamic conditions, start/stop events and stand-by mode, in compliance with performance targets of the Multi-Annual Implementation Plan.

Challenges/issues addressed

An issue clearly highlighted in the Multi-Annual Implementation Plan in the stationary application area is the need to address lifetime requirements of 40,000 hours for cell and stack, and the call for improved materials leading to step change improvements over existing technology in terms of performance, endurance, robustness and cost. In general, failure mechanisms of PEMFC membranes are of two main types: chemical (e.g. from attack by peroxide radicals on susceptible polymer end groups), and mechanical, which originates from weak intermolecular interactions between polymer chains. While methods of chemically stabilising the polymer end groups have been developed, failure due to insufficient membrane mechanical properties limits cell and stack lifetime. The problem is exacerbated by the trend in use of membranes of thickness only 25-30 µm (compared with the use of membranes of ca. 175 µm some 10 years ago), and the desire to employ lower equivalent weight membranes that can enable higher temperature operation, but which are inherently mechanically weaker and negatively impact membrane strength.

Technical approach/objective

The MAESTRO project is developing solutions to the above bottlenecks through a range of approaches to improve the mechanical stability of state of the art perfluorosulfonic acid (PFSA) type PEM fuel cell membranes via improved polymer chemistries and manipulation of membrane architecture. The final project target for the membrane is to have increased the tensile strength (compared with the benchmark material at the project beginning) by 50%, with a milestone at the mid-term stage of improvement by 20-25%. In terms of the MEA integrating the mechanically stabilised membranes, the target is for 4000 hours of operation under conditions relevant to stationary application, with performance degradation less than 10% compared to beginning of life.

Key technical items delivered in year 1 of the project include: Protocols for characterisation of membranes and MEAs including accelerated stress testing and long-term operation; Elaboration of benchmark MEAs and their characterisation according to these protocols; Development of membranes having elastic modulus increased by 78% compared with that of the project benchmark, while retaining conductivity of ca. 0.01 S cm^{-1} at 25% relative humidity and 0.2 S cm^{-1} at 90% relative humidity; State of the art report on approaches to membrane mechanical stabilisation.

Expected socio and economic impact

The long lifetime resulting from excellent chemical stability and enhanced mechanical properties, associated with sufficiently high operation temperature will contribute to reliability and costs reduction of stationary power generation systems, and improve European competitiveness in this market area.

The availability of mechanically robust and performant membranes will also have positive impact on fuel cell application in other sectors such as, for example, transportation.

Information

Project reference: FCH JU 256647
Call for proposals: 2009
Application Area: Stationary
Project type: Research and Technological Development
Topic: SP1-JTI-FCH.2009.3.2: Materials development for cells, stacks and balance of plant
Contract type: Collaborative project
Start date: 01/01/2011 — **End date:** 31/12/2013
Duration: 36 months
Project total costs: € 2264765
Project funding: € 1040049

Coordinator:
Deborah Jones
Centre National de la Recherche Scientifique
Université Montpellier 2
Institut Charles Gerhardt
Montpellier, France
Deborah.Jones@univ-montp2.fr

Other participating organisations:

Beneficiary name	Country
Centre National de la Recherche Scientifique (Montpellier)	France
Solvay-Solexis	Italy
Johnson-Matthey Fuel Cells	United Kingdom
Università di Perugia	Italy
Pretexo	France

Project website: http://www.maestro-fuelcells.eu

Molten Carbonate Fuel Cell catalyst and stack component degradation and lifetime: Fuel Gas CONTaminant effects and EXtraction strategies (MCFC-CONTEX)

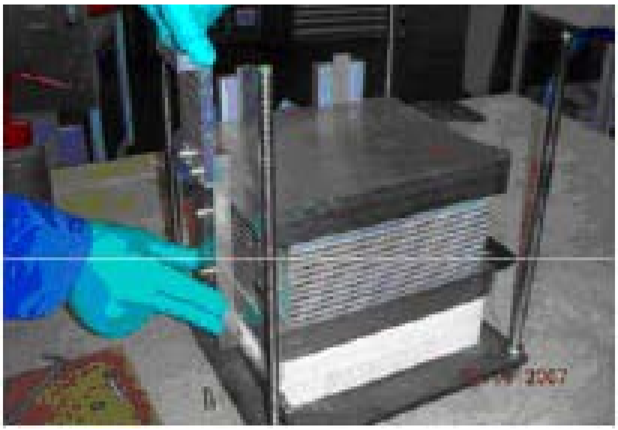
Key Objectives of the project

Reducing the carbon footprint of our society is imperative. This can be achieved both by capturing and confining anthropogenic CO_2 emissions as by replacing fossil-based fuels with renewable or waste-derived fuels. MCFCs are unique in being able to do both these things. However, the degradation caused by the contaminants in these gases must be addressed. MCFC-CONTEX aims to tackle the problem of degradation by trace contaminants from two sides:

1) investigation of poisoning mechanisms caused by alternative fuels and applications and precise determination of MCFC tolerance limits for long-term endurance;
2) optimization of fuel and gas cleaning to achieve tailored degrees of purification according to MCFC operating conditions and tolerance.

Challenges/issues addressed

1) (accelerated) experimental investigation in realistic conditions of the effects of H_2S, HCl, HF, Siloxanes on the anode, and of SO_2, NOx at the cathode
2) Numerical modelling of MCFC performance and long-term behaviour under clean and poisoned conditions
3) Development of an industrially suited, transportable device for high-resolution real-time gas analysis and trace detection through innovative laser techniques (LIBS – laser-induced breakdown spectroscopy – and Raman)
4) Characterization of commercial adsorbents and catalysts for optimized cleaning in terms of cost-effectiveness, and development of a prototype cleaning system.



Technical approach/objective

The first line of activity requires extensive long-term testing of the MCFC. It is an important step, involving harmonization of test procedures and equipment within the consortium. The gas analysis system is developed as well as the LIBS part of the device is now complete and under calibration.

The second line of investigation entails characterization and development of clean-up materials and processes, focusing on the most promising options to be selected at the start of the project. Ultimately a pilot-scale gas cleaning unit optimized for the applications considered will be developed and run.

Expected socio and economic impact

MCFC-CONTEX actively contributes towards the development of technologies that need to take over from conventional energy supply systems in the near future, due to EU policy measures as well as mere necessity of sustainability. In particular, the results aimed at in gas analysis and biogas clean-up systems will be widely applicable across the entire field of renewable energy conversion. Optimizing the operating conditions of the MCFC allows to tap into the huge and expanding European market of small-medium-scale, anaerobic digestion waste treatment. And separation of CO_2 from power plant exhaust fumes using the MCFC (producing power instead of consuming it) has a potentially colossal global market. So far, promising results have been obtained in the determination of poisoning mechanisms by H_2S and SO_2; in the selection of adequate cleaning materials and design of a suitable gas clean-up system; in the development of the high-resolution, real-time gas analysis device, and in the set-up of the basic numerical model.

Information

Project reference: FCH JU 245171
Call for proposals: 2008
Application Area: S
Project type: Research and Technological Development
Topic: Topic SP1-JTI-FCH.3.3: Degradation and lifetime fundamentals
Contract type: Collaborative project
Start date: 01 January 2010 —
End date: ongoing (01 October 2013)
Duration: 36 months
Project cost: € 4,429,336.10
Project funding: € 1,841,929.27

Coordinator:
Organisation
Italian Agency for New Technologies, Energy and sustainable economic development (ENEA)
Via Anguillarese 301
00123 – Rome, Italy

Contact: Mr Angelo MORENO
E-mail: angelo.moreno@enea.it
Mr Stephen McPHAIL
mcphail@enea.it

Other participating organisations:

MTU On Site Energy (MTU) *	Germany
Ansaldo Fuel Cells (AFC) *	Italy
Technical University Munich (TUM)	Germany
Marmara Research Centre (MAM)	Turkey
University of Genoa (UNIGE)	Italy
Royal Institute of Technology (KTH)	Sweden
OVM-ICCPET Institute (OVM)	Romania
Joint Research Centre	Belgium

* Quit the project as of month 18 (01 July 2011)

Project website: http://mcfc-contex.enea.it/

Premium Act

PREdictive Modelling for Innovative Unit Management and ACcelerated Testing procedures of PEFC (PREMIUM ACT)

Key Objectives of the project

A general objective is to contribute to the improvement of stationary PEFC systems durability, one of the main hurdles to overcome before successful market development, knowing that the target required is 40000h.

Premium Act specific objectives are to propose a reliable method to predict lifetime, to benchmark components and to improve operating strategies of real systems, in order to reach the following achievements:

- **Relative prediction of durability** - the ranking of durability predicted between different MEAs is in agreement with ranking obtained in real conditions;
- **Absolute prediction of durability** - the method is successful in predicting the observed lifetime with reduced testing duration thanks to accelerated tests;
- **Innovative unit management strategies** – the strategies allow a measurable durability increase in the stacks and systems of the industrial partners without negative impact on the customer needs' fulfilment.

Challenges/issues addressed

Main issue is the durability of fuel cell system for micro Combined Heat and Power applications.

It is necessary to first identify and understand the causes of fuel cells degradation in real conditions. Degradation is mainly related to the degradation of the Membrane Electrodes Assemblies (MEAs), core of the fuel cells where electrical power is produced. This degradation is double: decrease of the electrical power with time and degradation of the components. As multiple factors induce degradation (materials used for the catalysts or for the membrane, operating conditions such as cell temperature, gases composition), it is also necessary to understand the link between the different degradation mechanisms.

The challenges of Premium Act are related to the approach which is to combine specific experimental and modelling tools to study the degradation at different scales from fuel cell performance down to microstructure of materials.

Additional issue is the consideration of two strategic fuel cell technologies for stationary markets: DMFC (Direct Methanol Fuel cell) power generators and CHP systems fed by reformate hydrogen.

Technical approach/objective

The technical approach has been built on technical tasks interconnected in the right way to complete the challenging objectives described above.

First step is to identify and understand the causes of degradation, particularly of Membrane Electrode Assemblies, in real conditions (with a focus on the accelerating features). These conditions are thus reproduced on small devices to estimate MEAs' lifetime. Then, analyses are conducted on the components, to elucidate how their microstructure or their properties are degraded during fuel cell operation.

In parallel, multi-physics models are developed to enable the description of the phenomena appearing during the ageing at the different scales of the cell and for different conditions, considering as well the decrease of the electrochemical performance as the alteration of the MEA materials features (catalysts, electrodes and membranes); models validation being conducted through specific single cell tests.

The core technical part of the project will be to combine all the information coming from the experimental tests or analyses and from the modelling to propose and validate **relevant accelerated tests able to couple various degradation factors** and to assess different MEAs' lifetime more rapidly than with normal tests. Final expected outcomes are **operating strategies able to improve the lifetime** of the systems considered and a **methodology to predict the life time of their MEAs**.

Expected socio and economic impact

The project contributes directly to the development of the European fuel cell activities at least related to the three industrial partners involved.

Premium Act aims at developing a methodology adaptable to the multiple PEFC technologies for the improvement of systems durability. In this sense, the success of the project should help to overcome one of the main bottlenecks preventing fuel cells market development for European providers of stationary fuel cell systems and will contribute to cross cutting issues relevant for European R&D and fuel cell industry development. Thus, reliable systems corresponding to the technical specifications of the energy global market could be widespread, which will change the end-user habits towards the stationary energy management and will help to reduce greenhouse gas emission.

The project also deals with education by involving post-doctoral researchers, PhD and MSc students in activities at CEA, DLR & POLIMI. To have the best impact as possible on the PEFC early market community, results and data collected in the project will be disseminated through scientific papers & conferences but also with a **Public workshop on 'Characterization and quantification of MEA degradation processes' organized at CEA/Grenoble the 26 & 27th September 2012**.

This project could otherwise contribute to Safety, Regulations, Codes and Standards for future standards definition thanks to project outcomes on traditional and accelerated testing & on degradation models.

Information

Project reference: Grant agreement n° 256776
Call for proposals: FCH JU 2009 - 1
Application Area: stationary FC systems
Project type: research
Topic: SP1-JTI-FCH.2009.3.1: Fundamentals of fuel cell degradation for stationary power applications
Contract type: Collaborative Project
Start date: 01 March 2011 — **End date:** 28/02/2014
Duration: 36 months
Project cost: € 5.4 million
Project funding: € 2.5 million

Coordinator:
CEA - LITEN
France
Contact: Mrs Sylvie Escribano
E-mail: sylvie.escribano@cea.fr

Contact: Mr Angelo Moreno
E-mail: angelo.moreno@enea.it
Mr Stephen McPhail
mcphail@enea.it

Other participating organisations:

IRD FUEL CELLS A/S	Denmark
DLR	Germany
JRC IE	European Commission
POLITECNICO DI MILANO	Italy
ICI CALDAIE	Italy
SOPRANO	France

Project website: https://www-premiumact.cea.fr
but non public web-site at the moment

Robust Advanced Materials for metal SupportEd Solid fuel cell

Robust Advanced Materials for Metal Supported SOFC (RAMSES)

Key Objectives of the project

The RAMSES project aims at developing an innovative high performance, robust, durable and cost-effective Solid Oxide Fuel Cell based on the Metal Supported Cell concept i.e. the deposition of thin ceramic electrodes and electrolyte on a porous metallic substrate.

Both planar and tubular cells will be developed. By considering advanced materials tailored for this application, such cells will be able to operate at 600°C not only in hydrogen but also in methane steam reforming. Degradation upon thermal and redox cycling is also considered.

Challenges/issues addressed

The achievement of such performance needs several key-developments to be addressed:

- manufacturing of a durable metallic substrate
- deposition of the ceramic layers without affecting the substrate microstructure, with a special emphasis on the dense electrolyte deposition
- proof-of-concept via the integration of the cells into a short stack, supported by inspection techniques to evaluate the good quality of components at each step of the process
- testing activities to determine the performance and durability of cells and stacks, and to investigate specifically identified failure mechanisms.

Technical approach/objective

The technical objective of this project is the development of a SOFC cell with an improved lifetime due to the low operating temperatures (600°C) while achieving high performances by applying advanced low-temperature electrodes and electrolyte materials. The Metal Supported Cell concept (MSC) will in addition reduce statistically based mechanical failures, since this type of cell is intrinsically more mechanically robust, and decreasing manufacturing cost by decreasing the amount of expensive ceramic materials to minimum. Cost reduction of Balance-of-Plant components will also be achieved because of the lower operating temperature (e.g. insulation, heat exchangers and recycle blowers).

Two technological objectives are targeted:
The development of a performing, durable and cost-effective Metal-Supported Cell. Metal-supported Cell development will include both the metal-substrate development and the cell development itself. The major innovative activities will be focused on the design of the cell and the development of manufacturing processes, with a major focus on the deposition of the electrolyte, which is a key issue of this project.

Manufacturing and integration of the new MSC technology into a short stack for a final proof-of-concept. For the proof-of-concept, the target is to produce full-scale cells, with the best architecture, materials and processes and to integrate them into a planar short stack (approx 100 W) and a tubular stack (approx 75 W). Performance will be evaluated at 600°C with hydrogen as well as with internal steam methane reforming (ISR).

Expected socio and economic impact

Fuel cell applications can contribute significantly to European public policy objectives for energy security, air quality, reduction of greenhouse gas emissions and industrial competitiveness. According to the European Hydrogen and Fuel Cell Technology Platform and to the IPHE, cost and durability/reliability are the two major impediments to SOFC widespread development and commercialization. Within the EU supportive policy framework to stimulate research, development and deployment, the 3 year RAMSES project will produce a robust, highly performing and durable cell for stack manufacturers addressing the Combined Heat and Power (CHP) application. The expected impact of the project will be the availability of a stable competitive SOFC cell, with significantly improved mechanical reliability, as well as combined redox-thermal cycling, and lower manufacturing costs, particularly regarding materials. As a result it will contribute to make SOFCs more attractive and affordable, for a market entry in CHP applications at the horizon 2015 – 2020.

Information

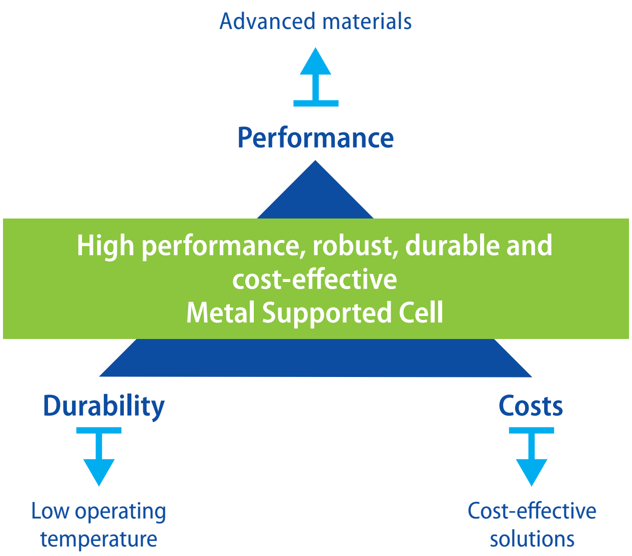
Project reference: FCH JU 256768
Call for proposals: 2009
Application Area:
Project type: Research and Technological Development
Topic: Topic SP1-JTI-FCH.2009.3.2: Material development for cells, stacks and balance of plant (BoP)
Contract type: Collaborative project
Start date: 01 January 2011 — End date: ongoing
Duration: 36 months
Project cost: € 4.7 million
Project funding: € 2.1 million

Coordinator:
Julie Mougin
Commissariat à l'Energie Atomique et aux Energies Alternatives (CEA)
DRT/LITEN/DTBH/LTH
17 rue des Martyrs
F-38054 Grenoble Cedex 9
France
E-mail: Julie.mougin@cea.fr

List of participants/partners:

Organisation name	Organisation short name	Country
Commissariat à l'Energie Atomique et aux Energies Alternatives	CEA	France
SOFCpower S.r.l.	SP	Italy
Centre National de la Recherche Scientifique	CNRS-BX	France
Höganäs AB	HÖGANÄS	Sweden
Baikowski	BAIKOWSKI	France
AEA S.r.l	AEA	Italy
Stiftelsen SINTEF	SINTEF	Norway
Ikerlan S. Coop.	IKL	Spain
Copreci S. Coop.	COPRECI	Spain
National Research Council Canada	NRC	Canada

Project website: www.ramses-project.org



ROBANODE

Understanding and minimizing anode degradation in hydrogen and natural gas fuelled SOFCs (ROBANODE)

Key Objectives of the project

One of the main obstacles for commercialization of Solid Oxide Fuel Cells (SOFCs) is insufficient durability, which is largely due to degradation of the anode electrode. Anode degradation in hydrogen fuelled SOFCs corresponds mainly to micro-structural changes due to thermal and/or electrochemical sintering and oxidation/reduction of the anode, due to interruption of the fuel supply. Anode degradation in SOFCs using natural gas or other hydrocarbon fuels is additionally due to carbon deposition and sulphur poisoning, which result in severe decrease of both the electrocatalytic activity of the anode and its catalytic activity for internal reforming or direct oxidation of the fuel. The **key objective of ROBANODE** is the development of an integrated strategy for understanding the mechanism of anode degradation in SOFCs. This is envisaged through a combination of theoretical modelling with experiments over an extended range of operating conditions, using a large number of modified state-of-the-art (SoA) Ni-based cermet anodes.

Challenges/issues addressed

The project's aim is to develop a detailed study of the mechanism of the anode degradation processes, through identification of similarities/differences in the degradation behaviour of unmodified and modified (via different methods and modifiers) state of the art Ni-based cermet anodes, assisted by detailed characterization of the anode materials (as-prepared and used). An important point of the proposed strategy is the development of a theoretical model for the description of the performance and degradation of the anode, with non-adjustable parameters, which will accept as input values of parameters which will be experimentally determined.

Technical approach/objective

The main objective of ROBANODE is to understand the interrelations between the degradation factors so that targeted modifications in the structure and morphology of the Ni based anodes can be made. To achieve this objective modelling in combination with experimental observations is used, aiming at simulating the physicochemical and electrochemical process taking place at the electrochemical interface and on the catalytic surface of the anode. In this way diagnostic tools will be developed by a combination of short-term experimental observations and modelling so that the long term prediction of the functional performance of the anode can be achieved.

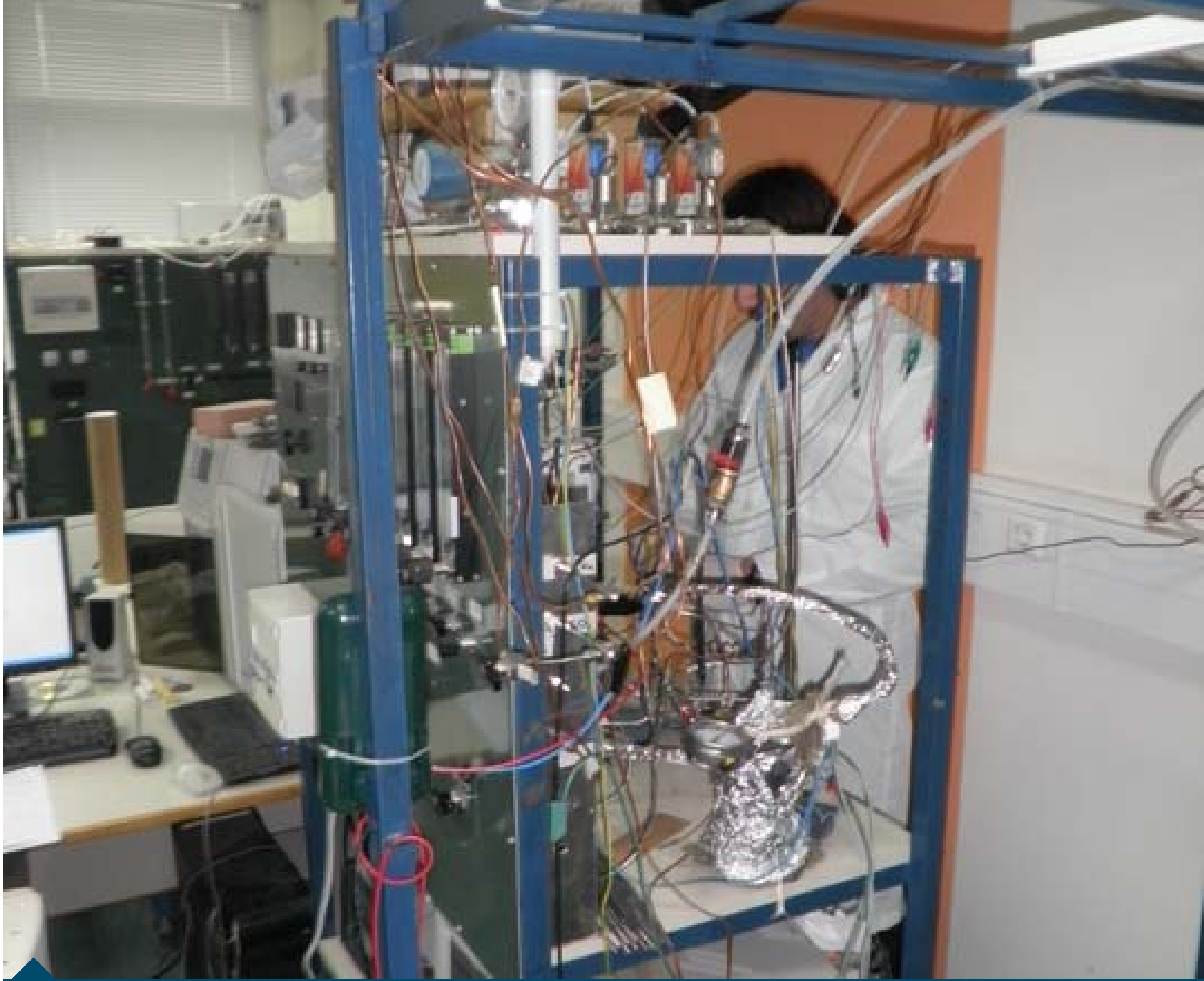
Expected socio and economic impact

The direct economic benefits that may result from ROBANODE can be summarized as follows:

- Reduction in the degradation rate of state of the art SOFCs which operate with H_2 or natural gas
- Long-term durability and reduction of the commercial cost of hydrocarbon fuelled SOFCs.

Indirect socio-economic benefits are additionally expected, since commercialization and wide use of SOFCs will result in a significant reduction of air pollution. These general socio-economic benefits which are expected to result from ROBANODE can be summarized as follows:

- Exploitation of the existing natural gas and liquid petroleum gas (LPG) network and easier introduction of SOFCs into households and public buildings.
- Easier market penetration of fuel cell and renewable energy technologies with a highly positive impact on the reduction of air pollution, health and environment.
- Development of renewable energy sources for decentralised energy supply.
- Creation of highly specialized jobs in different regions of the European Union.



Information

Project reference: FCH JU 245355
Call for proposals: 2008
Application Area: SP1-JTI-FCH.3: Stationary Power Generation & CHP
Project type: Research and Technological Development
Topic: SP1-JTI-FCH.3.3: Degradation and lifetime fundamentals
Contract type: Collaborative project
Start date: 01/01/2010 — **End date:** 31/12/2012
Duration: 36 months
Project total costs: € 3 394 888.00
Project funding: € 1 568 530.00

Coordinator:
Dr. Symeon Bebelis
Associate Professor
Foundation for Research and Technology Hellas
Institute of Chemical Engineering and High Temperature Chemical Processes (FORTH/ICE-HT)
Greece
e-mail: simeon@chemeng.upatras.gr

List of participants/partners:

FORTH/ICE-HT (Coordinator)	Greece
Technische Universität Clausthal (TUC)	Germany
National Technical University of Athens (NTUA)	Greece
Ecole Polytechnique Fédérale de Lausanne (EPFL)	Switzerland
Agencia Estatal Consejo Superior de Investigaciones Cientificas (CSIC)	Spain
Centre National de la Recherche Scientifique (CNRS)	France
Ceramics and Refractories Technological Development Company (CERECO S.A.)	Greece
Saint-Gobain Centre de Recherches et d' Etudes Europeénnes (Saint Gobain)	France

Project website: http://robanode.iceht.forth.gr/

Sulphur, Carbon, and re-Oxidation Tolerant Anodes and Anode Supports for Solid Oxide Fuel Cells (SCOTAS-SOFC)

Key Objectives of the project

Solid oxide fuel cells (SOFCs) have a great advantage in their fuel flexibility compared to other fuel cells (such as PEMFC), and thus are particularly suited for stationary cogeneration of heat and power based on natural gas or other hydrocarbon fuels. The aim of the project is to demonstrate a new more robust type of solid oxide fuel cell for application in small scale, combined heat and power systems (micro CHP). Thus, the project is a material based approach to increase micro CHP robustness, simplify operation strategies and thus reduce system costs. It addresses in particular critical issues in the StartUp/Shut Down phase and during grid outage/system failures.

Challenges/issues addressed

The metal nickel is a major material in today's SOFCs and commonly used together with ceramic as a composite material for the fuel electrode and support. Although it performs satisfactory and is stable at the reducing conditions and operating temperatures of SOFCs, the choice of nickel makes the fuel electrode very sensitive to carbon deposition at low steam / oxygen contents, deactivation by traces of sulphur present (e.g. as odorants in pipeline natural gas) and mechanical failure of the electrode during re-oxidation caused by loss of fuel during operation. These three major failure mechanisms have to be addressed today at the system level.

The project will demonstrate a new full ceramic SOFC cell with superior robustness as regards to sulphur tolerance, carbon deposition (coking) and re-oxidation (redox resistance). Having a more robust cell will thus enable the system to be simplified, something of particular importance for small systems, e.g. for combined heat and power (CHP).

Technical approach/objective

Oxide ceramics based on strontium titanates have been investigated in previous EU projects (Real-SOFC and SOFC600) and developed up to button cell sizes. The approach in this project is to integrate three of the most promising compositions into a full cell and thus evaluate their performance under application relevant conditions.

Key milestones have been the selection of three candidate compositions and the evaluation of test routines within the first year of the project and the selection of the best suited materials for anode and support structures at mid term. The final assessment of the cell concept will take place at stack level according to test conditions specified by the industrial partners. At the end of the project a 1 kW stack built on these new cells is scheduled to be tested in a real micro CHP system, namely the Galileo system from Hexis AG.

Expected socio and economic impact

It is expected that the outcome of the project will be improved anode and anode support materials, which improves the performance in regards to the identified failure mechanisms for fuel tolerance (sulphur and carbon) and re-oxidation resistance in SOFCs. Thus, the project can contribute significantly to fulfilling the electrical efficiency, lifetime and target costs requirement for SOFCs used with the relevant types of fuels and applications.

A further socio–economic factor is the replacement of nickel (nickel oxide during fabrication) by a more environmentally friendly ceramic as a major element in the fuel electrode and support structure.

The project has so far proven that sufficient performance levels can be reached and technically relevant cell sizes be fabricated. At present optimisation of the cell fabrication for systematic cell and stack testing is on focus.

Information

Project reference: FCH JU 256730
Call for proposals: 2009
Application Area: Stationary Power Generation & Combined Heat and Power (CHP)
Project type: Research and Technological Development
Topic: Topic SP2-JTI-FCH.3.2: Materials development for cells, stacks and balance of plant (BOP)
Contract type: Collaborative Project
Start date: 01/10/2010 —
End date: 30/09/2013 (ongoing)
Duration: 36 months
Project total costs: € 4.4 million
Project funding: € 1.7 million

Coordinator:
Dr. Peter Holtappels
Danmarks Tekniske Universitet
Department of Energy Conversion and Storage
Frederiksborgvej 399
4000 Roskilde
Denmark
peho@dtu.dk

List of participants/partners:

Forschungszentrum Juelich GmbH	Germany
Hexis AG	Switzerland
Topsoe Fuel Cell A/S	Denmark
University of St Andrews	United Kingdom

Project website: www.scotas-sofc.eu

Solid Oxide Fuel Cells – Integrating Degradation Effects into Lifetime Prediction Models (SOFC-Life)

Key Objectives of the project

The project addresses the quantification and understanding of the details of major Solid Oxide Fuel Cells (SOFC) continuous degradation effects. The goal is to isolate effects occurring on the anode and cathode side of SOFC and **developing descriptions of the degradation mechanisms** as functions of distinctive operating parameters (mainly temperature, atmosphere and current density). These functional descriptions are to represent the physical and chemical changes of basic materials and layer properties over time. **This information will be integrated into higher level models** that are then capable of predicting single degradation phenomena and their combined effect on SOFC cells and single repeating units.

Challenges/issues addressed

Long-term stable operation of Solid Oxide Fuel Cells (SOFC) is a basic requirement for introducing this technology to the stationary power market. Electricity generating equipment usually is designed for lifetimes of 10 years and well above, corresponding to 40 000 to over 100 000 hours of operation. The continuous degradation of fuel cell voltage commonly observed has to be reduced such that the loss of power remains within acceptable limits during the lifetime. **The project aims at a better understanding of the degradation phenomena as a tool for mitigating these effects and as a first step towards developing accelerated testing methods.**

Technical approach/objectives

The project follows a systematic approach to analysis of some of the most important degradation mechanisms. It concentrates on the 'continuous' (baseline) degradation phenomena determining stack behaviour in the long term. By deconstructing the SOFC stack into isolated elements and interfaces, these are exposed to the physical conditions found in typical SOFC system operation (and beyond). At regular intervals specimen are taken form the experiments and thus a time series of the gradual development of degradation effects recorded. This time-lapse photography type approach is designed specifically to allow the modelling of physical change over time.

Key milestones, deliverables

- Anode sub-model
- Cathode sub-model
- Integrated model(s) for predicting cell and SRU level degradation
- Identification, Assessment and Simulation of Major Degradation Parameters - Concluding report (M36)

Expected socio and economic impact

The project aims at **improving the longevity of SOFC** and such contributes towards market introduction and economic development of the stationary fuel cell sector.

Achievements/Results to date

First experiments have been conducted and the evaluation is under way.

Information

Project reference: FCH JU 526885
Call for proposals: 2009
Application Area: 3 (Stationary)
Project type: Basic Research
Topic: SP1-JTI-FCH.3.1: Degradation and lifetime fundamentals
Contract type: Collaborative Project
Start date: 01/01/2011 — **End date:** 31/12/2013
Duration: 36 months
Project total costs: 5.700.000 €
Project funding: 2.400.000 €

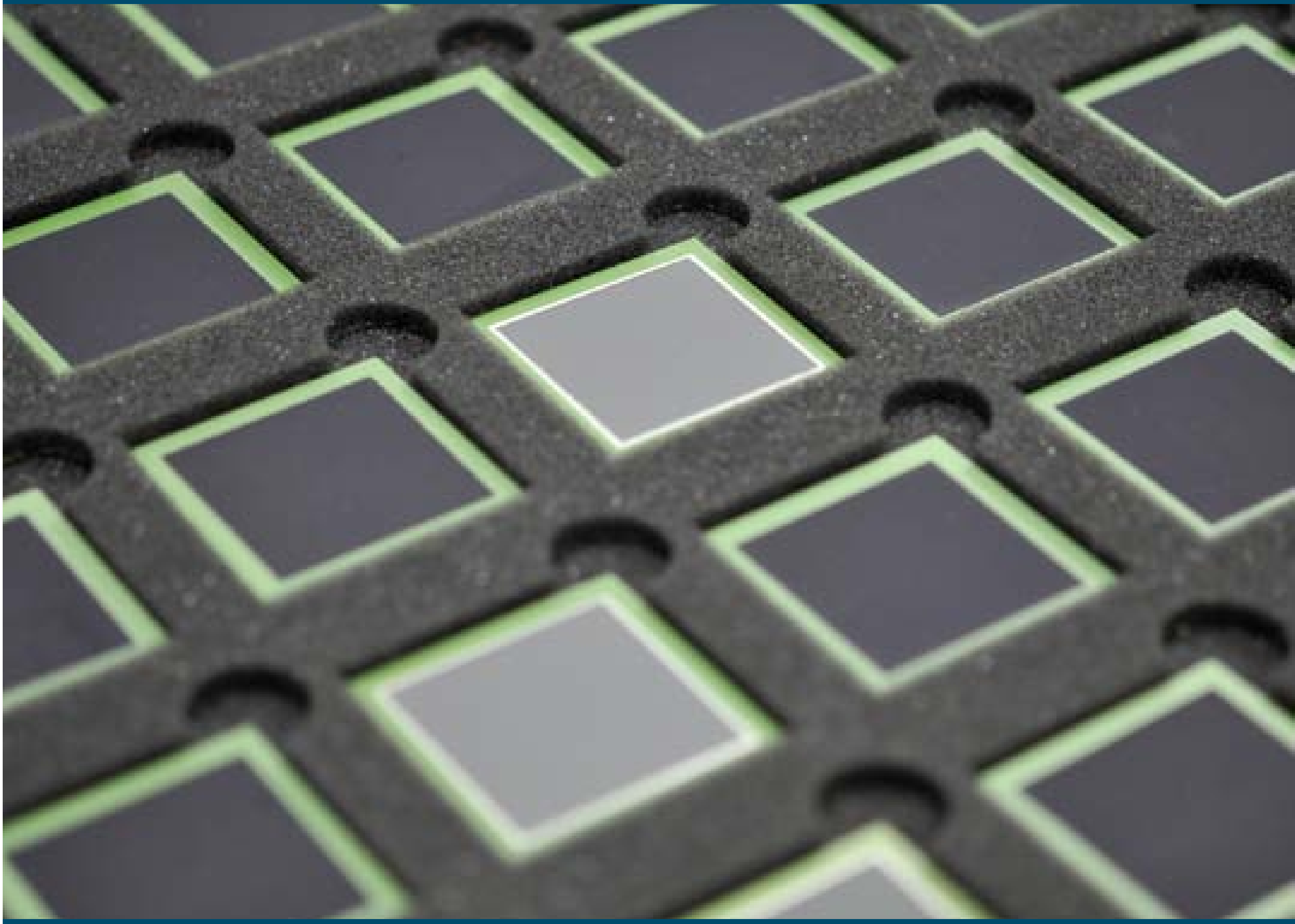
Coordinator contact details

J. Mertens
IEK-9, FZ Jülich GmbH
52425 Jülich
Germany
jo.mertens@fz-juelich.de

List of participants/partners (organisation name, country)

Hexis AG,Switzerland; HTceramix, Switzerland; Topsøe Fuel Cell A/S, Denmark; Commissariat à l'Energie Atomique, France; Risø-DTU, Denmark; Eidgenössische Materialprüfungs- und Forschungsanstalt, Switzerland; Institute of High Temperature Electrochemistry, Russia; Teknologian tutkimuskeskus VTT, Finland; Ecole Polytechnique Fédérale Lausanne, Switzerland; Imperial College, United Kingdom; Electricité de France, France; Zürcher Hochschule für Angewandte Wissenschaften, Switzerland

Project website: n/a



STAYERS - STAtionary PEM fuel cells with lifetimes beyond five YEaRS

Key Objectives of the project

Economical use of PEM fuel cell power for stationary applications demands a lifetime from the fuel cells of at least a minimum of 5 years, or more than 40,000 hours of continuous operation. This, in contrast to the large scale application for automotive use, which has dedicated PEM research on low cost production techniques with practical lifetimes of the fuel cells of 5,000 hours.

The main objective of STAYERS is materials research leading to the production of a full size, 10 kW prototype PEM fuel cell stack, capable of operating continuously during 40,000 hours in a system for stationary power generation in a chlor-alkali plant.

The lifetime of the 40,000 hours will be proven by extrapolation over a long duration data. The initial phase of the project consists in establishing the dominant degradation mechanisms of the state-of-the-art MEA and setting up the initial framework for the theoretical model.

Challenges/issues addressed

The PEM fuel cell consists of several alternatingly stacked components, such as membrane-electrode-assemblies (MEAs) and bipolar plates, pressed together by housing. The MEA consists of subcomponents like gas diffusion layers, catalyst layers and a thin membrane, separating reactant gases. The bipolar plate is a carbon composite, electrically connecting neighbour cells and distributing reactant gases throughout the MEA electro-active area.

All these components face harsh conditions imposing chemical and mechanical stress that during operation, change the structure and composition, thereby lowering the power output of the fuel cell and limiting the lifetime.

As well as operating conditions like temperature, gas humidification and gas feed play a role in the fuel cell lifetime.

Within the project it will be attempted to determine the dominant degradation mechanisms in a real life stationary PEM Power Plant. Subsequently these components and operational parameters will need optimising to reach the goal of 40,000 hours of continuous operation.

Technical approach/objectives

The project foresees the following steps:

1. Duration experiments in a real-life stationary fuel cell plant from Nedstack and at SINTEF and SolviCore at lab-scale with stacks composed of the state-of-the art reference materials, like the membrane provided by Solvay Specialty Polymers Italy.
2. Model improvement and analysis of on-line and off-line measurements by JRC. Post-mortem analysis on stacks returning from durability experiments yields data on the degradation processes. Based on these results improved MEA's and stack components will be produced as well as a fine tuned model.
3. A second series of duration experiments is started and SINTEF will also perform accelerated lifetime tests.
4. The final period starts with the most promising stacks. From the model and from data extrapolation the lifetime can be predicted.

Expected socio and economic impact

One of the main aims of the FCH-JU is: '... placing Europe at the forefront of fuel cell and hydrogen technologies worldwide and enabling the market breakthrough of fuel cell and hydrogen technologies ...' To reach this goal, it is essential that the durability of the stack and its components is significantly improved and at a well mature and cost competitive level. STAYERS will contribute to this by developing a stationary PEMFC stack with 40,000 hours lifetime.

The project will also strengthen the knowledge about degradation mechanisms in PEM fuel cells. At the same time STAYERS will create business opportunities, not only for its partners, but also for the whole of the fuel cell community. Commercial prospects for PEM FC-generators are very promising if a guaranteed stack lifetime of 5 years can be given. Society will benefit by less CO_2-emission, pollution-free, low noise transport, and clean silent generators.

Information

Project reference: FCH JU 256721
Call for proposals: 2009
Application Area: Stationary power
Project type: Research and Technology Development
Topic: SP1-JTI-FCH.2009.3.2: Materials development for cells, stacks and balance of plant (BoP)
SP1-JTI-FCH.2009.3.1: Fundamentals of fuel cell degradation for stationary power application
Contract type: Collaborative project
Start date: 01 January 2011 —
End date: 31 December 2013
Duration: 36 months
Project cost: € 4.1 million
Project funding: € 1.9 million

Coordinator:
NEDSTACK FUEL CELL TECHNOLOGY BV
The Netherlands
Contact: Mr Martijn Mulder
E-mail: martijn.mulder@nedstack.com

Other participating organisations:

SOLVICORE GMBH & CO KG	Germany
SOLVAY SOLEXIS S.P.A	Italy
SINTEF	Norway
JRC-JOINT RESEARCH CENTRE-EUROPEAN COMMISSION	United Belgium

Project website: www.stayers.eu

Fuel cell field test demonstration of economic and environmental viability for portable generators, backup and UPS power system applications (FITUP)

Key Objectives of the project

The FITUP project demonstrates the technical viability and economic maturity of UPS (Uninterruptible power supply) backup power systems based on fuel cell technology. The goal of the project is to increase the visibility of fuel cells as a real alternative to conventional backup power sources (batteries and diesel generators) and prove their advantages to potential customers in different industries.

A total of 19 fuel cell backup power systems with power levels in the range of 3-12 kW have been manufactured by two suppliers. 13 of these systems have been installed at the telecommunication operator's sites in Italy, Switzerland and Turkey for real-life condition tests while the rest have been installed at R&D centres in Netherlands and Turkey for benchmarking tests.

The key objectives of the project are to:

- Demonstrate the technology in various ambient conditions.
- Compare systems performance in laboratory and in real-life conditions of operation.
- Prove the viability of systems by reaching:
    - Reliability with greater than 95% availability
    - Durability with more than 1500 hours of operation
    - More than 1000 start-stop cycles
- Foster the systems adoption by increasing their visibility through a structured plan for dissemination results.

Challenges/issues addressed

One of the biggest hurdles faced by fuel cell technologies is the high costs, mainly due to the low number of systems produced and immaturity of the market. This situation could well be alleviated when mass production of fuel cell systems takes place. However, even with the current market situation there are still some potential areas, the so called early markets, where fuel cell technology could well be feasible. Backup power systems, which this project deals with, are one of those early markets for fuel cells to be considered. The FITUP project intends to demonstrate that fuel cell backup power systems are indeed a feasible alternative to conventional systems for telecommunication operators concerning both the economical and operational aspects.

Another challenge faced by fuel cell technologies is the lack of legislation, normally the case with any emerging technology. In response to this, FITUP intends to develop a certification procedure valid for all countries where fuel cells will be either produced or tested, under the expert advice of TUV Sud.

Technical approach/objectives

This project is comprised of three major steps. First, the systems will be produced and installed at the R&D centres and telecommunication operator sites. In this phase, both the final users and installation partners will be trained to maintain safety procedures and acquire in-depth knowledge of fuel cell and hydrogen systems. Related legislation will also be compiled and applied alongside these system installations.

The second phase includes testing of the systems at the R&D centres and final user sites. Final user sites will not only provide real operational data but also periodic system simulation results to evaluate system behaviour at different geographical and weather conditions. Tests at the R&D centres will provide ideal results under controlled operating conditions constituting a base for benchmarking the system performance.

The third phase consists of evaluation of the systems and suggestions for optimizing the systems based on the results of the tests. Furthermore, a thorough analysis will be carried out for assessment of environmental, technical and economic feasibility of the use of this technology compared to conventional solutions commercially available.

Expected socio and economic impact

The main outcome of this project expected is an increased awareness and acceptance of the fuel cell technology as a viable alternative to conventional power systems. At the end of this project fuel cell systems will be proven to be a more economical solution when the cost of ownership is considered. FITUP will also pave the way for deeper market penetration for fuel cell systems by disseminating the successful results of the project. The Project will also help establish a clearer understanding in society and demystify the fears of safety in the use of hydrogen systems and show that there are actual rules in place to assure these safety aspects.

The socio-economic aspect of the FITUP project foresees a direct effect on the participant companies with the opportunity of generating more sales and jobs, aside from the indirect effect of having a proven, commercial success story in hydrogen and fuel cells that can be showcased as an example of competitiveness of such technologies.

Information

Project reference: FCH - JU 2009-1 n. 256766
Call for proposals: 2009
Application Area: SP1-JTI-FCH.4: Early Markets
Project type: Demonstration
Topic: Topic SP1-JTI-FCH.2009.4.2: Portable generators, backup ad UPS power systems
Contract type: Collaborative project
Start date: 01 November 2010
End date: 31 October 2013
Duration: 36 months
Project total costs: € 5.386.469
Project funding: € 2.475.978

Coordinator
Electro Power Systems S.p.A.
Italy
Contact: Mrs Ilaria Rosso
E-mail: Ilaria.rosso@electrops.it

Other participating organisations:

Organisation name	Country
FutureE Fuel Cell Solutions	Germany
Environment Park	Italy
Lucerne University of Applied Sciences	Switzerland
UNIDO-ICHET	Austria
Joint Research Centre	Netherlands
TÜV SÜD Industrie Service GmbH	Germany
Swisscom (Schweiz) AG	Switzerland
Wind	Italy
Betriebskommission Polycom Nidwalden	Switzerland

Project website: www.fitup-project.eu

European demonstration of hydrogen powered fuel cell material handling vehicles (HyLIFT-DEMO)

Key Objectives of the project

The overall purpose and ambition of HyLIFT-DEMO is to conduct a large scale demonstration of hydrogen powered fuel cell material handling vehicles, which enables a following deployment and commercial market introduction starting no later than 2013.

The detailed HyLIFT-DEMO project objectives are the demonstration of at least 30 material handling vehicles as well as the demonstration of the corresponding hydrogen refuelling infrastructure at end-user sites.

The project partnership will conduct accelerated laboratory durability tests and validate the value proposition of the technology and the reaching of the commercial and environmental targets.

Further objectives are to plan and to secure the initiation of Research and Development (R&D) of the 4th product generation.

Finally, the project will contribute to the establishment of an appropriate Regulations, Codes and Standards (RCS) framework which enables smooth commercialisation as well as to the motivation of European, national and regional stakeholders by performing adequate dissemination activities.

Challenges/issues addressed

The project is conducted by a consortium of European companies that for several years have invested significantly in developing and testing hydrogen and fuel cell technology for material handling vehicles.

The technology is now advanced to a 3rd generation level that allows for a large scale demonstration before commencing market deployment. Also extensive market analyses have encouraged the partners to focus on the market segments of 2.5-3.5 tons forklifts and airport tow tractors, as these segments provide the strongest value proposition for fuel cell vehicles in the material handling sector within Europe. Thus the demonstration activities can lead directly to a following market deployment with a solid and proven value proposition for the vehicle end-users.

Technical approach/objectives

The fuel cell system is to be demonstrated in material handling vehicles from three vehicle manufacturers, representing various market segments and system integration approaches.

The demonstration is expected to be handled in fleets of at least 3-4 vehicles; end-users envisaging larger fleets will be preferred. Larger fleets would lead to a more viable business case for the supporting hydrogen refuelling infrastructure, but also to an efficient service and maintenance set up. As well as minimizing the final number of demonstration sites, the project will endeavour to place these as close as possible to each other as this lowers costs both for maintenance trips and for hydrogen distribution.

The supply of hydrogen for the sites will either be from local sources or through commercial subcontracting tendering from local gas suppliers. The refuelling infrastructure will either be owned and / or operated by project partners, the end-user or other local partners or projects.

Expected socio and economic impact

HyLIFT-DEMO addresses a specific and proven value proposition where hydrogen and fuel cells replace use of diesel/LPG in 2.5-3.5 ton material handling vehicles where batteries cannot provide a satisfying solution. The higher energy efficiency of the fuel cell compared to the combustion engine enables the end-user to gain savings on fuel costs that lead to a payback time of 3 years, at commercial price targets.

The ambition and driving force of the HyLIFT-DEMO activities and partners are to enable a following deployment and market introduction starting no later than 2013. Therefore the targets to be reached within the project as well as the demonstration model and relations to end-users are set-up with a future commercial value chain in mind. One work package within the project will be dedicated to planning the commercialisation and ensure initiation of market deployment.

Information

Project reference: FCH - JU 2009-1 n. 256766
Project reference: FCH-JU-2009-1, Grant Agreement Number 256862
Call for proposals: AIP 2009
Application Area: SP1-JTI-FCH.4: Early Markets
Project type: Demonstration
Topic: Topic SP1-JTI-FCH.4.1 Demonstration of fuel cell-powered materials handling vehicles and infrastructure
Contract type: Collaborative Project
Start date: 01/01/2011 — **End date:** 31/12/2013
Duration: 36 months
Project total costs: € 7,077,942
Project funding: € 2,881,245

Coordinator
Hubert Landinger
Ludwig-Bölkow-Systemtechnik GmbH
Daimlerstr. 15
85521 Ottobrunn
Germany
E-mail: coordinator@hylift-demo.eu

List of participants/partners:

LBST – Ludwig-Bölkow-Systemtechnik GmbH	Germany
H2 Logic A/S	Denmark
DanTruck A/S	Denmark
DTU – Technical University of Denmark	Denmark
Linde AG	Germany
JRC – European Commission, Directorate-General Joint Research Centre, Institute for Energy	Belgium
Stiftelsen SINTEF	Norway
HyER – Hydrogen Fuel Cells and Electro-mobility in European Regions & EHA – European Hydrogen Association c/o The Italian Federation of Scientific and Technical Associations	Italy
TÜV SÜD Industrie Service GmbH	Germany

Project website: www.hylift.eu

Development of an Internal Reforming Alcohol High Temperature PEM Fuel Cell Stack (IRAFC)

Key Objectives of the project

Polymer Electrolyte Membrane Fuel Cells (PEMFCs), which typically consume H_2 and O_2, operate at 80-100°C and produce electricity without polluting the environment, seem to be the most technically advanced energy conversion system for stationary/mobile applications and have the highest potential for market penetration. However, the absence of a worldwide infrastructure for transport and distribution of pure hydrogen, in addition to the presence of well-established and developed fossil fuel-based network, favors the short term solution of on-site (stationary) or on-board (mobile) hydrogen production from reforming of various hydrocarbons (e.g. natural gas, gasoline) or alcohols (e.g. methanol, ethanol).

Therefore, the ultimate goal of the project is to provide High Temperature PEM Fuel Cells, which operate up to 210°, and to combine them with a methanol reformer operating at the same temperature range and deliver a compact internal alcohol reformer-high temperature PEM fuel cell (IRAFC) device that can be fed with liquid methanol.

Challenges/issues addressed

The complexity of the balance of plant of a **fuel cell-fuel processor** unit challenges the design and development of compact and user friendly fuel cell power systems. The main concept in this project is the incorporation of an alcohol reforming catalyst into the anodic compartment of the fuel cell, so that methanol reforming takes place inside the fuel cell stack. The development of an **Internal Reforming Alcohol - High Temperature PEM Fuel Cell (IRAFC)** poses an ambitious technological and research challenge which requires the effective combination of various technological approaches as regards materials development, chemical reaction engineering and stack design. The proposed fuel cell comprises of:

- A high temperature membrane electrode assembly (HT-MEA), able to operate at temperatures of 190-220°C.
- A steam reforming catalyst, which can either be (i) present together with the Pt-based electrocatalyst in the anode, (ii) deposited on the gas diffusion layer or (iii) deposited on the surface of monolithic structures, which should be functional at the operating temperature of the fuel cell.

Technical approach/objectives

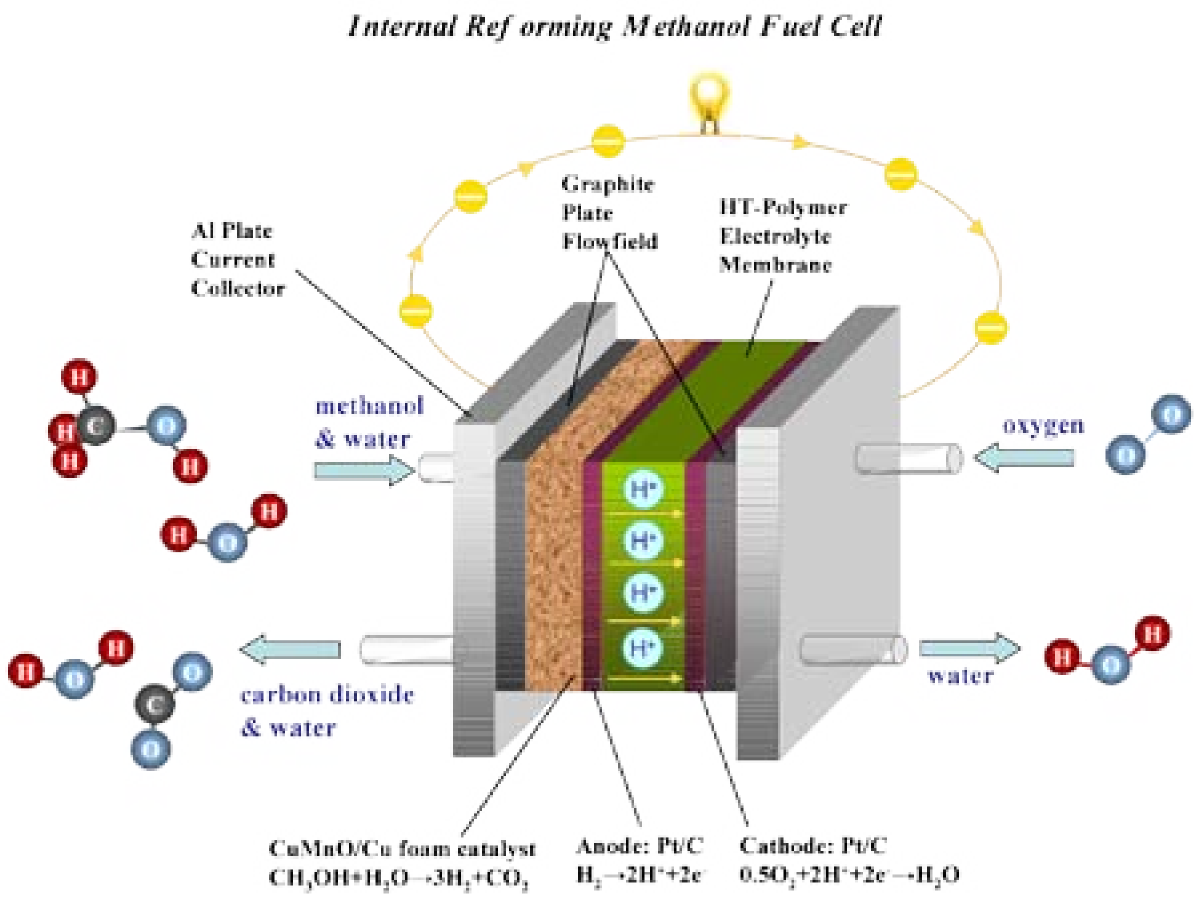
The main objective of the proposal is the development of an internal reforming alcohol high temperature PEM fuel cell. Towards this end, the following goals should be accomplished:

- Design and synthesis of robust polymer electrolyte membranes for HT-PEMFCs, which enable operation within the temperature range of 190-220°C.
- Development of alcohol, (methanol or ethanol) reforming catalysts, for the production of low carbon monoxide content hydrogen, in the temperature range of HT-PEMFCs, i.e. at 190-220°C.
- Integration of steam reforming catalyst and high temperature MEA in a compact **Internal Reforming Alcohol - High Temperature PEMFC**. Integration may be achieved via different configurations as related to the position of the reforming catalyst.

The proposed compact system differs from conventional fuel processors and allows for efficient heat management, since the 'waste' heat produced by the fuel cell is in-situ utilized to drive the endothermic reforming reaction. The targeted power density of the system is 0.15 W/cm^2 at 0.7 V.

Expected socio and economic impact

- Internal alcohol reforming - Fuel cell development will intensify the mass production of renewable fuels (like methanol by the CO_2 reduction) with positive economic effects.
- The reduction on oil dependence will increase economic security.
- Energy produced by a fuel cell will be characterized as high quality energy because of the high conversion efficiency from chemical to electrical energy (~50%) almost twice as high compared to internal combustion engines, and because of the zero emissions of pollutants and greenhouse gases (due to the recycling of CO_2 to produce renewable fuels) to the environment.
- The extensive use of fuel cells will reduce air pollutants in metropolitan areas.



Information

Project reference: FCH-JU-2008-1
Call for proposals: 2008
Application Area: SP1 Cooperation
Topic: SP1-JTI-FCH-4.2: Fuel supply technology for portable and micro FC
Contract type: Joint Technology Initiatives – Collaborative Projects (FCH)
Start date: 01 January 2010 — **End date:** ongoing
Duration: 36 months
Project cost: € 2.5 million
Project funding: € 1.4 million

Coordinator
Advanced Energy Technologies
Country: Greece
Contact: Dr. Joannis Kallitsis
E-mail: jkallitsis@advent-energy.com

List of participants/partners (organisation name, country):

1. Advent Technologies S.A. – Greece
2. University of Maria Curie-Sklodowska - Poland
3. Nedstack Fuel Cell Technology BV – The Netherlands
4. Centre National de la Recherche Scientifique - France
5. Foundation for Research and Technology HELLAS, Institute of Chemical Engineering and High Temperature Processes – Greece
6. Institut für Mikrotechnik Mainz GmbH – Germany

Project website: http://irafc.iceht.forth.gr/index.php

In situ H_2 supply technology for micro fuel cells powering mobile electronics appliances (ISH2)

Key Objectives of the project

The key objective of the project is to develop a fuelling system for micro-fuel cells. The concept is based on in-situ production of hydrogen. Two novel solutions are proposed: one is based on using NaBH as the fuel and the other one on utilizing catalyzed electrolysis of methanol. The primary application area is fuel cell based power sources of mobile and portable electronic appliances. The ISH2 project concentrates on research and development of the hydrogen cartridge technology and the electrical system. Development of micro-fuel cells is excluded, validation of the fuelling system will be performed with commercially available small fuel cells. The main practical targets are to prove the feasibility of each fuelling technology and to fulfill the RCS requirements of mobile/portable electronic appliances in consumer markets, and to scheme a logistics system for disposable or recyclable cartridges used for fuelling the proposed system.

Challenges/issues addressed

The targeted power range is 5 – 20 W. Within this range there are many electronic appliances for mobile use, like phones, laptops, cameras, etc, which suffer short operation time caused by easily draining batteries. We like to develop fuel cartridges for the chargers or use-extenders of those devices. Challenges are related in addition to safety issues, to technical design making the cartridges usable for common people and finally to environmental issues making them recyclable or disposable. Borohydrid ($NaBH_4$)-technology to make hydrogen producing cartridges is already well known, but needs still studying and development to make it functioning well in small scale and for a long use period. Catalyst based electrolysis of methanol is a new method, which needs more basic studies. In the project we have studied use of two catalysts, platinum and an enzyme. At present state of the project the platinum catalyst has been chosen for further development because of problems to obtain high enough energy efficiency in hydrogen production when the enzyme catalyst is used.

Technical approach/objectives

The technical approach adopted by the project is to develop the two cartridge technologies in parallel and test them in two application devices during the last project year. The test devices chosen are a smart mobile phone and a laptop computer. Both these devices are standard commercial appliances for which the project will build a specific hydrogen driven non-grid charger or use-extender. The key targets in the development phase are:

- Prototype of 20 Wh $NaBH_4$-cartridge for a mobile phone charger (CEA, myFC).
- Prototype of 120 Wh $NaBH_4$ container for a fuel cells power pack (CEA, Hydrocell).
- Electrolyser cartridge-fuel cell system prototype for a non-grid long term power source for 10 W devices (Aalto, Hydrocell).
- Electrolyser-PEM fuel cell system prototype with a better methanol conversion (Wh/ml) than DMFCs (Aalto)
- Control electronics for the both fuelling concepts

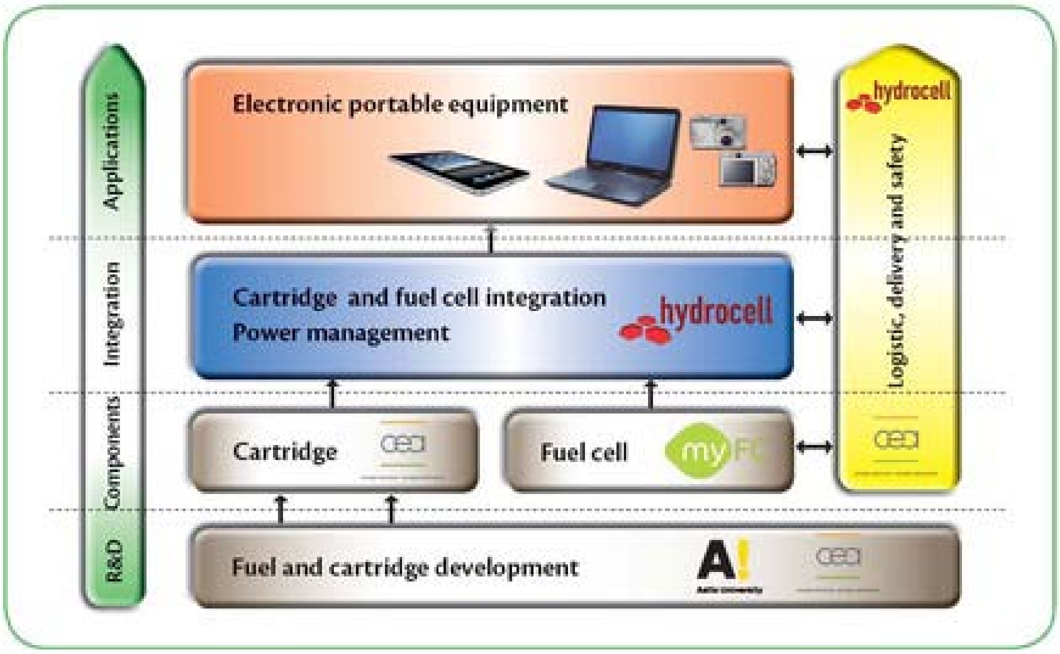
The project will produce reports as well three different cartridge prototypes as the deliverables.

Expected socio and economic impact

The project is targeting to prototypes, which will open up possibilities for further product development. Decisions to that direction will be made during 2012.

Both of the concepts of in-situ production of hydrogen are not limited to the small power range. Preliminary investigation to enlarge the area to 100 W – 1kW will be done during the project. This will open applications e.g. to portable tools, small backboard motors etc.

As a future perspective, electrolysis by the aid of enzyme opens up interesting possibility to produce hydrogen from different kind of bio-decomposable wastes including alcohols or sugars. The energy level around 3 W/l H_2 can be reached, which is considerably lower than that of water electrolysis. Simultaneously the BOD value of the waste water could be decreased. This is one way to continue the study made in the project with biocatalyst.



Information

Project reference: FCH JU
Call for proposals: 2008
Application Area: Early Markets
Project type: Research and Technological Development
Topic: Early Markets 4.2. Fuel Supply technology for portable and microfuel cells
Contract type: Collaborative Project
Start date: 01/01/2010 — End date: 31/12/2012
Duration: 36 months
Project total costs: € 1,7 M
Project funding: € 1 M

Coordinator contact details
Professor Aarne Halme
Aalto University
School of Electrical Engineering
Department of Automation and Systems Technology
visiting address: Otaniementie 17, FI-02150 Espoo, Finland
postal address: P.O. Box 15500, FI-00076 Aalto, Finland
tel: +358 505553390
email: aarne.halme@tkk.fi

List of participants/partners (organisation name, country):

Aalto University (former TKK)	Finland
CEA	France
myFC	Sweden
Hydrocell	Finland

Project website: http://autsys.tkk.fi/en/ISH2

Mobility with hydrogen for postal delivery (MobyPost)

Key Objectives of the project

MobyPost aims to implement hydrogen and fuel cell technology systems in material handling vehicles, according to an environmentally respectful strategy. The approach is generating significant data which will prove the viability of the technology and, initiate its commercialization in this specific niche market. MobyPost aims to develop electric vehicles powered by fuel cells using hydrogen locally produced by renewable energy means: solar panels installed on the roofs of the buildings. MobyPost will implement low pressure storage solutions for hydrogen in two fleets of five vehicles on two different sites for postal mail delivery. Development of the vehicles and the associated refueling stations will be carried out, in line with all certification processes required and, taking into account public acceptance of this mobility system.

Challenges/issues addressed

MobyPost addresses the following challenges:

- Complete solar-to-wheel solution developing an innovative concept for fuel cell electric vehicles and incorporating hydrogen production into existing postal buildings for its utilization on the spot.
- Fuel cell electric vehicle used every day on heavy duty cycle and under demanding climatic conditions (including summer and winter time).
- Autonomous energy production - Hydrogen is produced on-site by coupling an electrolyser to solar panels at the different MobyPost sites.
- Implementing metal hydride tanks for hydrogen storage - to guarantee safety, MobyPost will use low pressure storage which considerably improves on-board safety.

Technical approach/objectives

Expected socio and economic impact

The MobyPost project will first and foremost contribute to the achievement of 2020 EU's objectives in terms of sustainable development by demonstrating the reality of a real-life existing decarbonized mobility system whose development will rapidly accelerate in the near future.

The expected outcomes are:
- Favor the transferability of developed technologies to other delivery services.
- Accelerate and effectively support the emergence and consolidation of the Fuel Cell Electric Vehicle industry.
- Disseminate the project outcomes at local and European levels in order to promote innovative and sustainable transportation means.

The second main impact is the acceleration of social acceptance for novel technologies. The MobyPost concept will be tested directly by professionals who are in daily contact with the public - The Postmen. This will increase the project's visibility and knowledge that people have on this technology.

Achievements/Results to date

The first year dedicated to the design of both infrastructure and vehicle has allowed for clearly defining the requirements for both sub-systems (hydrogen production and fuel cell electric vehicle). The consortium partners have already started to design their components in order to adapt them to the project needs (Fuel cell, tanks, electrolyzers), in parallel with the creation of the model and first level of simulation. The first models for vehicle framework and ergonomics have been issued. As defined, the final design should be achieved during 2012, in parallel with the modification of the buildings and sites for welcoming the MobyPost experiment.

Information

Project reference: FCH JU 256834
Call for proposal:2009
Application area: Early Markets
Project type: Demonstration
Topic: SP1-JTI-FCH.2009.4.1 Demonstration of fuel cell powered materials handling vehicles and infrastructure
Contract type: Collaborative project
Start date: 01/02/2011
End date: 31/01/2014
Duration: 36 months
Project total costs: € 8,209,872
Project funding: € 4,262,057

Coordinator contact details
Nathalie O**riol**, Institut Pierre Vernier
24 rue Alain Savary, 2500 Besançon, France
nathalie.oriol@institut-vernier.fr

List of participants/partners (organisation name, country):

Institut Pierre Vernier	France
Steinbeis Europa Zentrum	Germany
European Institute for Energy Research	Germany
MaHyTec sarl	France
Ducati Energia S.p.a	Italy
La Poste	France
MES	Switzerland
UTBM	France
H2Nitidor s.r.l	Italy

Project website: www.mobypost-project.eu

Ammonia based, Fuel Cell Power for Off-Grid Cell (NH34PWR)

Key Objectives of the project

The technology of mobile telecommunications has reached a level of maturity in those industrial regions where a reliable electrical grid powers the mobile base station infrastructure. However, the absence of a grid in many global regions now presents market needs for remote power units providing cleanly generated electricity more cost effectively. This project proposes to bring a fuel cell system to a position of commercial readiness to address this opportunity. The system will obviate the need for a hydrogen fuel infrastructure, and this will be achieved by employing a novel solution based on anhydrous liquid ammonia as the fuel, a widely available commodity. Thus, a novel catalytic cracker will convert the ammonia to hydrogen and this, in turn, will fuel a set of PEM fuel cells. By this means, an emissions free power source (PowerCube™) has been developed. This now has the potential to be deployed and operated remotely providing electricity more cost effectively with considerations to cost of ownership and long term reliability.

The key objectives are as follows:

- To demonstrate that a fully-integrated, turn-key power system (PowerCube™) is technologically viable and can be readily manufactured to meet the cell phone operators' targets of reliability, longevity and low-maintenance. The benchmark in this respect is the polluting diesel generator technology which is unreliable and requires high maintenance with theft and adulteration of diesel fuel being widespread. The development targets will be set against the most likely customer specific systems performance requirements.
- A further key project objective is to deploy several power systems (PowerCubes™) as customer acceptance trial units in multiple sites across several climate zones and principally in sub-Sahara Africa. This will follow the development and field evaluation of a refuelling, maintenance and repair infrastructure. The latter will further benefit from a remote monitoring and control system which will be developed and will enable predictive maintenance.

Challenges/issues addressed

A major challenge has been to produce the PowerCube at a cost that ensures there is a viable customer value proposition. Without achieving this it would be impossible to secure trials in Africa.

To cost engineer down it will be necessary to source fuel cell sub systems externally and not to assemble in house and to try and use commercially available off the shelf components wherever possible.

Technical approach/objectives

The objective for Diverse Energy is to design and manufacture a power generation product using ammonia as a base fuel. We use an APG (alternative power generation) system to heat ammonia sufficiently to separate the gases in hydrogen and other gases. The hydrogen is provided to PEM fuel Cells to generate electrical power to the customer. The APG system we have designed is a unique compact unit producing hydrogen-on-demand for continuous use.

Diverse Energy have produced ten (10) PowerCubes, four (4) are being trialled in Africa on live customer sites to provide power to telecoms operators for off grid applications.

In parallel to the customer trials, the supply chain is being established to accommodate the expected volume customer orders forthcoming from successful completion of the three (3) month trials.

Expected socio and economic impact

The product will benefit local communities since it delivers clean power for telephone communication, without diesel exhaust and engine noise. The provision of cell phone communication has been shown to significantly enhance GDP and economic growth in under-developed countries and this is especially marked in rural and areas exhibiting extreme poverty (income less than $1 per day). MTN (South Africa) a telecommunications operator has estimated that a 10% penetration of mobile phone use increases GDP growth by 1.2% and other studies commissioned by Ericsson and based on India stated that is a further compounding of poverty alleviation via the creation and increased efficiency of small business which arises when mobile phone penetration exceeds 35% of a region.

Ammonia has been used in commercial settings for decades without significant risk. Some developing countries have not developed as stringent health and safety requirements encountered in the 'Western world'. This project will ensure the best world-wide safety standards are used in this project over and above any legal requirements in the country, primarily through adhesion to the ammonia suppliers world-wide co-operate standards (Linde Gas).

So far 10 PowerCubes have been completed, pre- deployment tests have been conducted on all four PowerCubes and two of these have subsequently been moved to Botswana in preparation of deployment to a customer. The final negotiations and commercial terms for the Botswana units are currently underway with anticipated finalisation in Q1 2012.

Information

Project reference: FCH JU 256856
Call for proposals: 2009
Application Area: Stationary Power
Project Type: Demonstration
Topic: SP1-JTI-FCH.2009.3.6: Validation of integrated fuel cell system readiness
Contract type: Collaborative Project
Start date: 01/09/2010 — **End date:** 31/08/2013
Duration: 36 months
Project total costs: € 8.2m
Project funding: € 3.06m

Coordinator contact details

Diverse Energy Ltd
Spring Copse Business Park
Slinfold
West Sussex, RH13 0SZ
UK
Phone: +44(0)1403 792010
Fax: +44(0)1403 792011
Contact: Mrs Amanda Willox
E-mail: awillox@diverse-energy.com

Participant organisation name:

Diverse Energy Ltd	United Kingdom
Linde Gas AG	Germany
NedStack Fuel Cell Technology BV	Netherlands
WaterstofNet vzw	Belgium
Balton CP Ltd	United Kingdom
L2S2 Ltd	United Kingdom

Project website: N/A

Sustainable Hydrogen Evaluation in Logistics (SHEL)

Key Objectives of the project

The overall purpose of the SHEL project is to demonstrate the market readiness of the technology and to develop a template for future commercialization of hydrogen powered fuel cell based materials handling vehicles for demanding, high intensity logistics operations.

This project will demonstrate 10 Fuel Cell ForkLift Trucks (FC FLT) and associated hydrogen refuelling infrastructure across at least 3 sites in Europe. Real time information will be gathered to demonstrate the advantages of using fuel cells to current technologies and fast procedures will be developed to reduce the time required for product certification and infrastructural build approval. Moreover, to ensure the widest dissemination of the results, the project will build a comprehensive Stake Holder Group of partners to pave the way for wider acceptance of the technology.

Challenges/issues addressed

Up to now analysis of the current State of Art across various FC FLT international demonstration has been done.

According to the FC system, the consortium is now in the phase of purchasing the FC systems and assembling the fleet.

Related to the demonstrations, the site assessments have been carried out following the AMFE methodology, and main Codes & Standards have been reviewed in order to obtain the certification procedure.

Technical approach/objectives

This project will show 10 FC FLTs and associated hydrogen refueling infrastructure across 3 sites in Europe: Turkey, UK and Spain. The Turkish site will be within the Petkim Petrokyma (Turkey´s largest chemical complex), where the demonstration will use industrial off-gas hydrogen for 1 year; the UK demonstration will be at the Port of Felixstowe for 6 months and the Spanish demonstration will be at the CEGA Logistics site in Vitoria for one year. An additional demonstration site is envisaged at a Greek Supermarket chain.

The demonstration will therefore be used to investigate commercial operation of the trucks in three likely early market sectors under real conditions.

Key milestones

The project, started on January 2011, has a well defined strategy to demonstrate 10 FC FLT and associated hydrogen supply mechanisms across a minimum of 3 countries. Each site will demonstrate a different type of infrastructure based upon future possible commercial hydrogen resources available in Europe.

The main objective of the project is the delivery of 9 optimised FC FLTs for the demonstration, using an existing FLT FC prototype design developed by UNIDO-ICHET and their partner CUMITAS. Two types of vehicles will be used to the demonstration: counterbalance and reach type, will utilise an existing Fuel Cell Module but will investigate the development of next generation energy saving technologies which can greatly improve the fuel cell operation lifecycle.

Expected socio and economic impact

The consortium brings together a strong cluster of partners from Europe's hydrogen and fuel cell sector with key industrial partners -a gas company (AP), a Fork Lift truck OEM (Cumitas) and a logistic company (CEGA).

The project contributes to achieving the following impacts:

Impact 1: Demonstration of two types of FC-based vehicles (10 vehicles in total) across three different sites in Europe. The demonstration will give the participant partners in-depth field experience to accelerate medium term commercialization of FC vehicle across the EU member states.

Impact 2: Prove durability of fuel cell concept, functionality of hydrogen refuelling infrastructure and demonstrate end user acceptance of the project.

This demonstration of pre-commercial products will confirm system specifications, lifecycle costs and training needs for product installation and use, and demonstrate public acceptance.

Impact 3: Development of certification procedures
It will identify and improve the speed of certification from the relevant European Agencies, promoting international standards and developing procedures for certification within the European member states.

Achievements/Results to date

- Both FC purchasing bids have been launched.
- The site assessment study has been carried out following a FMEA methodology. For the FMEA top level hazards/events related to equipment/components/processes have been identified, potential failure modes and effects defined, and inherent safety and potential prevention and/or mitigation corrective actions designed.
- Main codes and standards have been revised and checked with local authorities in order to define the certification process.

Information

Project reference: FCH JU
Call for proposals: FCH-JU-2009-1
Application Area: SP1-JTI-FCH.4: Early Markets 10.3
Project type: Demonstration
Topic: SP1-JTI-FCH-2009.4.1 Demonstration of fuel cell-powered materials handling vehicles and infrastructure
Contract type: Collaborative Project
Start date: 01/01/2011 — **End date:** 31/12/2013
Duration: 36 months
Project total costs: 4,645,500.00 €
Project funding: 2,443,095.00

Coordinator:
Dr. Oscar Miguel (Energy Department Manager)
omiguel@cidetec.es
IK4-CIDETEC
Parque Tecnológico de San Sebastián
Paseo Miramón, 196. 20009 Donostia - San Sebastián

List of participants:
1. IK4-CIDETEC, Spain
2. International Centre for Hydrogen Energy Technologies, UNIDO-ICHET, Turkey
3. Air Products (Europe), AP, UK
4. Centre for Renewable Energy Sources & Saving, CRES, Greece
5. Commission of the European Communities - Directorate General Joint Research Centre, JRC, Netherlands
6. Instituto Tecnológico del Juguete, AIJU, Spain
7. Instituto Nacional de Técnica Aerospacial, INTA, Spain
8. Fundación para el Desarrollo de las Nuevas Tecnologías del Hidrogeno en Aragón, FHA, Spain
9. University of Hertfordshire, UH, UK
10. Federazione delle Associazioni Scientifiche e Techniche, FAST/EHA, Italy
11. Hygear BV, HYGEAR, Netherlands
12. CEGA Logistics, CEGA, Spain
13. Cukurova Makina Imalat ve Ticaret, CUMITAS, Turkey

Webpage: www.shel.eu

Evaluating the Performance of Fuel Cells in European Energy Supply Grids (FC-EuroGrid)

Key Objectives of the project

The main objective of the project is to establish technical and economic targets and benchmarks that allow the assessment of fuel cells in stationary power generation. The fuel savings and CO_2 emission reductions will be a function of the electricity grid structure and the fuels employed.

Using these results it will be possible to determine, whether a fuel cell installation effectively improves fuel use and improves the CO_2 footprint, amongst other criteria.

This leads up to a more focused allocation of research funding, identification of R&D gaps and objective comparison of fuel cell with competing technologies.

The project will discuss the methodology adopted with EU and worldwide stakeholders in order to established a recognised assessment and benchmarking frame of reference.

Challenges/issues addressed

Stationary fuel cells operate under a variety of constraints which are defined by the energy supply grid they are integrated into and the application they serve. Generally, stationary fuel cells offer the advantages of high efficiency operation with low emissions, low noise and modular design. Nevertheless, it must be acknowledged that the GHG savings from a fuel cell operated on the German grid will very much differ from those of a fuel cell producing electricity in France –due to the difference in carbon footprint of the French electricity supply system.

Different fuel cell types (PEFC, HT-PEFC, MCFC, SOFC) display different efficiencies in electricity production from natural gas.

As a result of this complex situation there is no simple means of predicting the advantages a stationary fuel cell system will offer in any given energy supply environment. The task of setting minimum benchmark targets for projects to be awarded funding under the FCH JU scheme was therefore abandoned since there was no sensible way of setting general conditions that would apply independently of technology and system integration across the whole of Europe.

Technical approach/objectives

The project will establish pertinent application categories (among them: μCHP, CHP, decentralised electricity production, etc.), establish benchmarks from the performance of competing power generating technology (in the different EU countries), identify the technical and economic targets for the key applications, and review the potential of the different fuel cell technologies to fulfil them. The goal is to collect all data necessary in evaluating the performance of stationary fuel cells in the European energy markets (predominately heat and electricity) and paving the way to objective criteria of best practice and minimum standards, as well as an appraisal of the type of applications that actually lead to reductions in gross energy consumption, emissions and depletion of fossil energy resources.

Key milestones, deliverables

The main milestones refer to the finalisation of project work and the onset of discussion with the FCH JU and stakeholders from approx. month 16 onwards.

Key deliverables include data collections ('atlas') of European electricity grids, handbook of methodology and benchmarking, and the status and gap analysis for stationary fuel cell systems.

Expected socio and economic impact

The project will supply:

- a quantifiable technical understanding of the interaction of stationary fuel cell technology with various European electricity supply grids with respect to greenhouse gas abatement and improved economy of fuel,
- associated benchmarks and indicators suitable to describe the superiority (or inferiority) of specific fuel cell concepts vis à vis competing technologies with respect to efficiency, emissions, economic and operational data etc.,
- targets for fuel cell development and criteria for the selection of best performing project proposals, and
- status reports on the development status of stationary fuel cells and the technology gaps that remain to be shut, along with indications for the focus of future development work.

Achievements/Results to date

The cataloguing and benchmarking data have been compiled and the development of the methodology of technology comparison is under way.

Information

Project reference: FCH JU 256810
Call for proposals: 2009
Application Area: 3 (Stationary)
Project type: Support Action
Topic: SP1-JTI-FCH.2009.3.8: Applications specific targets for stationary power generation and related technology benchmark
Contract type: Coordination and Support Action
Start date: 01/10/2010 — **End date:** 30/09/2012
Duration: 24 months
Project total costs: 849.684 €
Project funding: 588.982 €

Coordinator
Dr. Robert Steinberger-Wilckens, University of Birmingham, Department of Chemical Engineering, Edgbaston, Birmingham B15 2TT, United Kingdom, R.SteinbergerWilckens@bham.ac.uk

List of participants/partners
European Institute for Energy Research, Germany; E.ON Ruhrgas, Germany; Teknologiantutkimus-keskus VTT, Finland; ENEA, Italy; Grontmij AB, Sweden; Institute of Power Engineering, Poland; EBZ GmbH, Germany; University of Birmingham, United Kingdom

Project website: not yet implemented

Guidance document for performing LCAs on Hydrogen and Fuel Cell Technologies (FC-HyGuide)

FC-HyGuide includes two autonomous projects and consortia: HyGuide and FC-Guide.

While FC-Guide focuses on fuel cell technologies, HyGuide addresses hydrogen production systems.

The two consortia, led by PE INTERNATIONAL resp. ENEA agreed during the project negotiation phase to collaborate closely over the course of the project. The collaboration included a common work programme, interlinked work packages, and mutual choices on key overall LCA methodological topics. The advisory board / review panel and the technical expert group were also shared by both consortia. The reason for the collaboration between the two consortia was to produce more value for the FCH JU funding and to avoid contradictory results. For that reason, the only public domain used, is FC-HyGuide.

Key Objectives of the project

The overall goal of the project is to develop a specific guidance document(s) for application to hydrogen and fuel cell technologies, and related training material with courses for practitioners in industry and research. These documents (one on hydrogen supply technologies, one on fuel cells) are based on and in line with the International Reference Life Cycle Data System (ILCD) Handbook, coordinated by the European Commission's JRC-IES.

The main objective of the FC-HyGuide project is the development of guidance documents and accompanying LCA report templates to evaluate the environmental benefits of new technologies in the field of fuel cell and hydrogen applications.

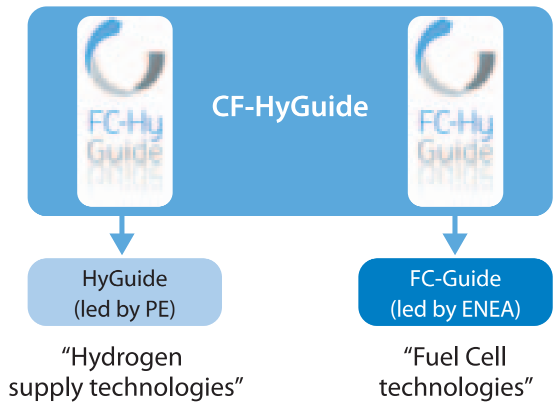
It is foreseen that the guidance documents developed within FC-HyGuide will be applied in all on-going and future FCH JU projects calling for Life Cycle Assessment (LCA).

Challenges/issues addressed

The challenge of FC-HyGuide is to provide consistent, widely accepted and applicable rules (following the ISO 14025 approach: product category rules) for performing LCA of hydrogen and fuel cell systems. The guidance documents (HyGuide and FC-Guide) can serve as these rules, which define 'how' LCA must be conducted within projects funded by the FCH JU.

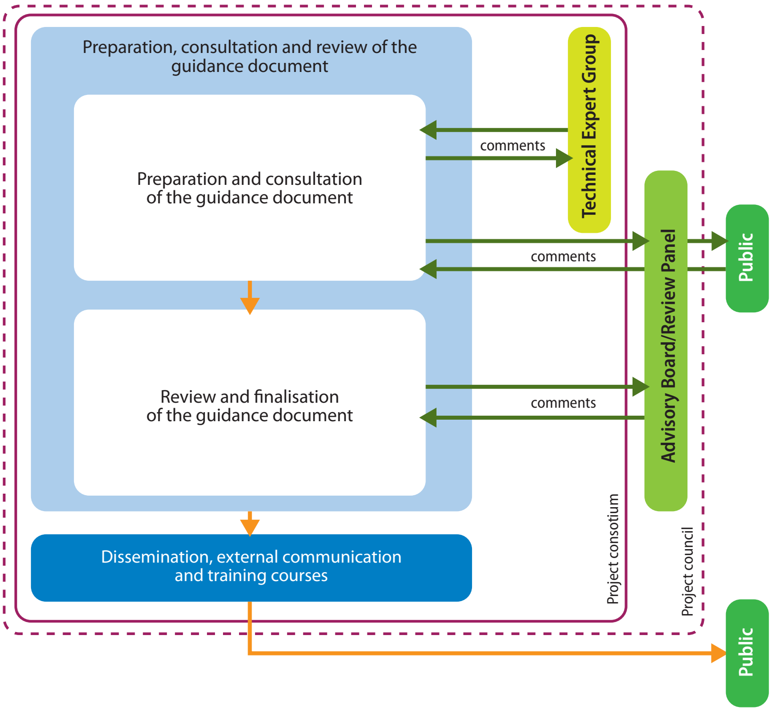
Technical approach/objectives

The guidance documents were developed in a multi stage stakeholder approach. In the first stage a draft version of the guidance documents were developed by the project consortia and introduced to the technical expert group of the project. Feedback gained during the expert group workshop was integrated and advanced versions of the guidance documents were prepared. In the following stage they passed a second consultation round. This consultation was public. Before the documents were finally released, an independent external third party review process was performed to ensure the quality of the documents. Dissemination and communication were core elements which were performed during the entire project period. Two training courses on the developed guidance documents completed the project. A graphical overview of the concept of stakeholder involvement within FC-HyGuide is given in the following graph.



Expected socio and economic impact

The FC-HyGuide project is finalized. The outcome of the project can be used in all hydrogen and fuel cell application areas (horizontal approach) asking for LCA. FC-HyGuide facilitates a more effective policy evaluation and decision making by providing guidance for evaluating the environmental performance of fuel cell and hydrogen systems.



Information

Project reference: FCH JU Grant Agreement No. 256328
Call for proposals: 2009
Application Area: Cross-Cutting Issues
Project type: Support Action
Topic: SP1-JTI-FCH.2009.5.5 LIFE CYCLE ASSESSMENT (LCA)
Contract type: Coordination and Support Action
Start date: 01/10/2010 — **End date:** 30/09/2011
Duration: 12 months
Project total costs: € 366.318
Project funding: € 366.318

Coordinator
Dr. Oliver Schuller
PE INTERNATIONAL AG
Hauptstr. 111-113
70771 Leinfelden-Echterdingen
Germany
o.schuller@pe-international.com

Partners:

- Universitaet Stuttgart (USTUTT), Germany
- Karlsruher Institute of Technology (KIT), Germany
- European Hydrogen Association (EHA), Belgium, represented by The Italian Federation of Scientific and Technical Association (FAST), Italy
- European Commission represented by Joint Research Centre (JRC-IE), The Netherlands

Project website: http://www.fc-hyguide.eu/

Enhanced Design Requirements and Testing Procedures for Composite Cylinders intended for the Safe Storage of Hydrogen (HyCOMP)

Key Objectives of the project

Currently, the most mature technology for storing hydrogen is in compressed form in high-pressure cylinders. To improve volumetric and gravimetric performances, carbon fibre composite cylinders are currently being developed. However, current standards do not allow cylinder design to be optimized. In particular, the safety factor relative to the burst pressure ratio appears to be conservative, which results in the cylinders being overdesigned and thus costly.
In this context, this project aims at:

- To develop a better understanding of the damage accumulation processes in composite cylinders and the degradation rate as a function of the type of load and environmental conditions,
- To enhance design requirements for composite cylinders for storage or transport of compressed hydrogen,
- To improve the full set of requirements defined for ensuring the structural integrity of the cylinders throughout their service life,
- To improve procedures for type approval and batch testing.

Challenges/issues addressed

Current regulations do not allow exploiting the full potential of carbon fibre materials. New and revised standards are in process, but the work is done based on a traditional and conservative way of determine the performance of a cylinder. Furthermore, the requirements in these standards are often not based on degradation processes in composite materials, but have been adapted from standards covering metallic cylinders.

Therefore a potential clearly exists to enhance the standards for achieving further improved levels of safety while avoiding overly conservative construction requirements, in particular through a better understanding of the degradation mechanism actually occurring in carbon fibre composite materials. The objective of HyCOMP is to bring this potential to fruition for producing improved type approval and batch testing protocols.

The main outcome of the project will be a documentation of the real performance of composite cylinders to support Authorities and Industry in making enhanced RCS.

Technical approach/objectives

HyCOMP is based on an experimental and numerical approach that will provide a comprehensive scientific basis of damage accumulation mechanisms that occur in the composite wrapping under typical loads in service. The final objective of HyCOMP is to improve the full set of requirements while ensuring the structural integrity of the cylinders. For that, the following technical approach is performed.

Damage mechanisms and failure modes of composite vessels are first identified at a material scale on plate specimens and then at a structural scale on cylinders, under cyclic, static and hybrid loads, representative of service conditions for three different applications: stationary, transportable and automotive uses. The most relevant parameters characterizing service life in terms of gas pressure-related loads and temperature are identified in order to check that the critical operational loads have been properly characterized in the test program.

Knowing that carbon fibre reinforced plastic (CFRP) materials mainly damage by fibre breakage, a non-destructive test based on acoustic emission has been preferred to quantify the level of damage produced in the composite wrapping. Nevertheless, a destructive burst test is finally performed to

estimate the influence of damage on the cylinder residual strength. Furthermore, a particular attention is paid on material and manufacturing parameters that should be subjected to a quality assurance plan because they strongly impact cylinder performances (initial strength as well as long-term properties of cylinders).

Numerical models are then developed in agreement with experimental results and observations in order to predict damage accumulation in the composite wrapping and then cylinder failure. The estimation of the probability of failure for a required lifetime will be used to define the acceptable safety factor.

Based on the findings from the experimental work, appropriate testing protocols will be defined to demonstrate the cylinder fitness for service and resistance to its anticipated service life. Finally, findings and recommendations will be summarized and disseminated so that they can be used by the international hydrogen and fuel cell community, in particular for Regulation, Codes and Standards initiatives.

Expected socio and economic impact

The outcome of the project will have a direct economic and social impact on high pressure composite cylinders intended for the storage of hydrogen.

First, the project will provide all the data necessary to argue in favour of a decrease of the cylinder safety factor. A direct consequence is then a decrease of the composite thickness, so a decrease of the quantity of carbon fibre. Knowing that carbon fibre represents the largest part in the final cost of a cylinder, a decrease of the cylinder cost is thus expected.

Furthermore, the structural integrity of high pressure composite cylinders will be demonstrated during the project by determining appropriate testing protocols and defining pass/fail criteria to ensure the cylinder fitness for service and resistance to its service life. These results will contribute to a better social acceptance of hydrogen as an energy vector.

Information

Project reference: FCH JU 256671
Call for proposals: 2009
Application Area: Hydrogen production and storage
Project type: Research and Technological Development
Topic: SP2-JTI-FCH.1.5 – Pre-normative Research on Composite Storage
Contract type: Collaborative Project
Start date: 01/01/2011 — **End date:** 31/12/2013
Duration: 36 months
Project total costs: 3 802 542 €
Project funding: 1 380 728 € (36%)

Coordinator
Clémence Devilliers,
Air Liquide - Centre de Recherche Claude Delorme,
1, chemin de la Porte des Loges - Les Loges en Josas - B.P. 126
78354 Jouy-en-Josas Cedex – France
Tel: +33 1 39 07 60 66
clemence.devilliers@airliquide.com

Partners:

Air Liquide	France
Armines	France
Bundesanstalt für Materialforschung und Prüfung (BAM)	Germany
The CCS Global Group LTD	United Kingdom
Commissariat à l'énergie Atomique (CEA)	France
EADS Composites Aquitaine	France
Faber Industrie	Italy
Raufoss Fuel System	Norway
Wroclaw University of Technology (WUT)	Poland
Joint Research Centre of the EC, Institute for Energy and Transport (JRC-IET)	Netherlands
Alma Consulting Group	France

Project website: http://www.hycomp.eu

Identification, Preparation and Dissemination of Hydrogen Safety Facts to Regulators and Public Safety Officials (HyFacts)

Key Objectives of the project

The HyFacts project aims to develop and disseminate fully up-to-date contemporary material for customized training packages for regulators and public safety experts providing accurate information on the safe and environmentally friendly use of hydrogen as an energy carrier for stationary and transport applications under real conditions. The training material will focus on the fundamental aspects of hydrogen safety and on the safety approaches and criteria developed in standards and according to which hydrogen systems are engineered for the safe use of hydrogen under all circumstances.

Challenges/issues addressed

Main goal of the HyFacts project is the gathering, analysis, synthesis and dissemination of the technical content identified in the first stage of the project by providing an adequate format which can easily be absorbed by the target group. Depending on the different target groups, the material will be delivering a different depth of information, reflecting on the needs of the respective persons representing different levels of one regulating institution.

In order to achieve a good learning result, short courses have proven to be one of the adequate means of spreading excellence to specific target groups along with distance learning.

Technical approach/objectives

The project aims to develop modular material for training of regulators and safety officials by focusing on hydrogen safety approaches and standards. Safety auditors and permitting officials are considered as a main target group. The second step is to develop a vision and road-map for permanent training activities, draft teaching material outline and report on existing training material. Finally, the HyFacts is organising, in face to face mode, a series of three Short Courses based on the training packages developed during the project. These Short Courses will be of interest for Regulators, Public Safety Officials, Project Managers, Hydrogen Safety Engineers and other stakeholders, providing accurate information on the safe and environmentally friendly use of hydrogen, as an energy carrier for stationary and transport applications under real conditions. The technical content of the course will be continuously updated to reflect new knowledge in this dynamically developing area. The feed-back from trainees on technical and organisational aspects of short courses will be gathered, analysed and used to improve the content, format and delivery channels. It is planned that these short courses will be accredited as continuous professional development courses (CPD) by professional bodies.

Expected socio and economic impact

The project addresses the Regulators and Public Safety Officials who are certifying hydrogen installations. Most of the staff representing institutions dealing with issues like building regulations, local regulations, public safety and permission of technical installations does not have the sufficient knowledge to take decisions regarding safety aspects based on real facts. They shall be trained in order to have a better understanding what hydrogen is and how hydrogen installations can be implemented and operated in a safe way without putting up too high and sometimes the wrong barriers for the certification. They should even be brought to a supportive attitude.

Impact will be to shorten approval process for hydrogen installations. Future perspective foresees the use of the HyFacts training material by commercial training entities to develop and deploy customized training offers.

The general structure of the training material has been defined and most of the content has been finalized. Questionnaires have been sent out to the target audience in Germany, UK and France. The answers have been analysed and the scope of the training material as well as the training structure has been adopted to their specific requirements. Posters as well as hand out brochures have been produced and the project website is online with a lot of information on the project. The first short course will be conducted soon and the first draft training material will be tested.

Information

Project reference: FCH JU
Call for proposals: year 2010
Application Area:
Project type: Coordination and Support Action
Topic: Fuel cells and Hydrogen
Contract type: Coordination and support action
Start date: 01/02/2011 — **End date:** 01/07/2013
Duration: 36 months
Project total costs: € 1 M€
Project funding: € 1 M€

Coordinator
Christian Machens
Project Manager HyFacts Project
TÜV SÜD Akademie GmbH
Wiesenring 2
D - 04159 Leipzig, Germany
Tel: +49 (0) 3 41 – 4 65 33 89
Fax: +49 (0) 3 41 – 1 49 91 92
GSM: +49 (0) 1 51 – 24 155 887

Partners:

TÜV SÜD Akademie GmbH	TUV	Germany
Air Liquide Hydrogen Energy	AL	France
The CCS Global Group Ltd.	CCS	UK
Federazione delle Associazioni Scientifiche e Tecniche	FAST/EHA	Italy
Health and Safety Laboratory	HSL	UK
University of Ulster	UU	UK

Project website: www.hyfacts.eu

Development of educational programmes and training initiatives related to hydrogen technologies and fuel cells in Europe (HYPROFESSIONALS)

Key Objectives of the project

Today's technicians and students are the next generation of potential fuel cell users and designers, and education now is a critical step towards the widespread acceptance and implementation of hydrogen fuel cell technology in the near future.

Development of training initiatives for technical professionals will be started aiming to secure the required mid- and long-term availability of human resources for hydrogen technologies.

The work will be carried out for vocational education and including industry, SMEs, educational institutions and Authorities. Coordination and cooperation are key factors to fulfil the objective: develop a well-trained work-force which will support the technological development.

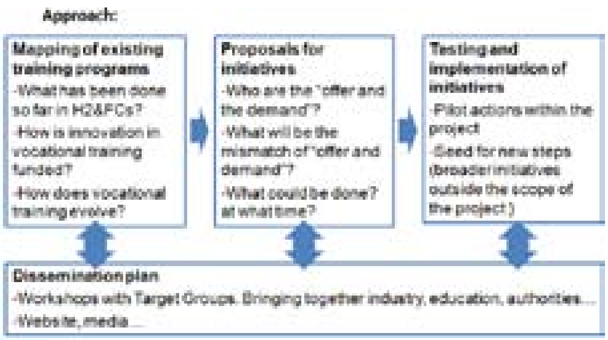
Challenges/issues addressed

The main challenge is to identify existing training programs related to hydrogen and fuel cells in the EU that may provide a good base for educational activities (Mapping). Also important is the development of specific initiatives, proposals, guidelines and projects to get consolidated educational programs for technical training at different levels, implementing the results of this project and involving different stakeholders (industry, SMEs, educational entities, authorities,...).

Furthermore, the dissemination of the results at different target audiences to facilitate acceptance and implementation of these technologies by means of education has been achieved as well as pilot actions (minimum) involving different European countries have been fixed.

Furthermore, we aim to increase in the number of state and local government representatives which receive information and understand the concept of a hydrogen economy, and how it may affect them. The participation of different EU countries (7) and the celebration of workshops (2 minimum) to involve different stakeholders will favour this objective.

Technical approach/objectives



Expected socio and economic impact

The expected socio and economic impact of the project is to set up the road map for conventional educational system in order to add in their educational programs the new hydrogen technologies. This manner, industry and SMEs will have on the mid-term a well-trained work-force.

On the short-term a library with educational resources about hydrogen and fuel cells will be available on the project website. Same way, it will be some pilot actions for teaching different targets groups like vocational training students, university students, engineering students, engineers, graduates, technicians and teachers.

Information

Project reference: Grant Agreement nº: 256758

Call for proposals: FCH-JU-2009-1
Application Area: AA5 –Cross-cutting issues
Project type: Support Action
Topic: SP1-JTI-FCH.2009.5.1: Development of educational programmes
Contract type: Coordination and Support Action
Start date: 01/01/2011 — **End date:** 31/12/2012
Duration: 24 months
Project total costs: 432.116,00 €
Project funding: 373.537,00 €

Coordinator
Name: Luis Correas Usón
Affiliation: Foundation for the Development of New Hydrogen Technologies in Aragon.
Address: Parque Tecnológico Walqa. Ctra. Zaragoza N330A, km 566. 22197. Cuarte (Huesca)
Country: Spain
Email: director@hidrogenoaragon.org

Contact for communication:
Name: Marieke Reijalt
Email: info@h2euro.org

List of participants/partners (organisation name, country)

Participant no. *	Participant organisation name	Country
1 (Coordinator)	Foundation for Hydrogen in Aragon	Spain
2	FAST, Federation of Scientific and Technical Association	Italy
3	San Valero Foundation	Spain
4	UNIDO ICHET	Austria
5	European Commission, Directorate-General Joint Research Centre, Institute for Energy	Belgium
6	WBZU	Germany
7	Association PHYRENEES	France
8	Environment Park	Italy
9	CPI, Centre for Process Innovation	United Kingdom

Project website: www.hyprofessionals.eu

Preparing socio and economic evaluations of future H_2 lighthouse projects (Prepar-H_2)

Key Objectives of the project

The overall project goal is to suggest a systematic social and economic context for hydrogen lighthouse projects. Prepar-H2 wants to identify patterns that are common in well functioning demonstrations, find missing links in the social context and list important recommendations based on broad methodological approach and new experience.

Challenges/issues addressed

During the past decade hydrogen technology has been tested and demonstrated throughout Europe. The reason is mainly that people have high hopes for this new energy carrier that can be made from various local feed stocks but hydrogen technology is quite different from carbonated fuels that we are used to so people have come up with innovative ways to put this emerging technology to the test.

In many cases there have been gaps between EU funded projects and the local national goals and objectives. For example, national funded project do not always disseminate results at European level and therefore sometimes it is difficult to get information on what was done, how, results etc.

Technical approach/objectives

Two main deliverables were delivered from the project along with the final report. These two reports are:

a) *'Social studies in context with hydrogen deployment: Analysis, quality, gaps and recommendations'*
b) *'Economic aspects related to introduction of Hydrogen as transportation fuel'*

Both reports are public and are available on the project web page among other information from the project.

Expected socio and economic impact

The project is finished. As this is a socio- economic study then the key impact is in that field. The key outcome is: The goal for PreparH2 was to gain insight to experiences of those actually carrying out responsibilities in projects at all levels. Many of these field workers have not been allowed to express themselves in public due to restrictions set by main stakeholders so far. By collecting this feedback recommendations were created for future H_2 light-house projects so that they could better address topics of relevance in the field of project management and socio and economic issues.

The outcome is a list of recommendations which are published along with all other documents the project web page. The recommendations are meant to help future projects to conduct correct engagement and emphasis on socio-economic issues and also point out key issues which should be incorporated into future demo projects.

Information

Project reference: FCH JU 245332
Call for proposals: 2009
Application Area: Hydrogen demo/research – cross cutting issues.
Project type: Basic research
Topic: SP1-JTI-FCH-5.1 & SP1-JTI-FCH-1.2 Cross cutting issues
Contract type: Coordination and support action
Start date: 01 January 2010 — **End date:** 30 June 2011
Duration: 18 months
Project cost: € 563.000
Project funding: € 257.000

Coordinator
Icelandic New Energy Ltd
Iceland
Contact: Mr Jón Björn Skúlason
E-mail: skulason@newenergy.is

Partners:

SINTEF	Norway
Techniske Universitet Berlin	Germnay
Hydrogen Link Denmark	Denmark
ENEA	Italy

Project website: www.newenergy.is/en/preparh2

Building Training Programmes for Young Professionals in the Hydrogen and Fuel Cell Field (TrainHy)

Key Objectives of the project

The project aims at:

- deriving specifications for a Fuel Cell and Hydrogen education and training curriculum for post-graduates (young professionals, master of sciences and doctoral students) from the review of existing training programmes specific to FCH in Europe (with respect to scope, effectiveness, structure and cost),
- designing a curriculum and organisational structure to supply high-level professional training to the above mentioned group of students in the areas of Fuel Cell and Hydrogen technologies,
- building a financing scheme and business model oriented at a long-term sustainable performance of such a curriculum,
- initiating such a structure and performing first test elements of these courses,
- evaluating the suitability and success of the initiated activities, suggesting further action and presenting an action plan with organisational and financial information.

Challenges/issues addressed

Post-graduates are offered the opportunity to improve and complete the skills most relevant to their current occupation without interrupting their professional life – therefore making the curriculum and education & training structure valuable for businesses and academic institutions alike since it does not remove the trainees from their ongoing assignments. The course content and the choice of course elements by the student can interact with the necessities of her or his main profession.

The course programme offers ECTS points to those who desire to obtain them, especially university students. It will also offer 'Continuous Programme of Development' (CPD) credits. The project intends to introduce a coherent coordination between different suppliers of training courses. In order to achieve the highest quality of the measures, the cooperation will be performed on the basis of stringent quality control and compatibility with the educational goals and general acceptance of the course(s) in the academic world.

Technical approach/objectives

The approach of the project is to develop a curriculum for the field of Fuel Cell and Hydrogen technologies aimed at post-graduate students and young professionals. Elements of this curriculum, namely summer school events, will be held in 2011 and 2012. They will be used to verify and evaluate the applicability of the curriculum concepts and develop a course and e-learning structure within which the educational programme can be organised. Universities will be invited to adopt the curriculum and the courses offered within their training programme, including grant of ECTS points. The developed programme and organisational structures are intended to be further sustained after termination of the project.

The main milestones include a public workshop on project outcomes and a summer course which will be implemented and operational in the end of summer 2012.

While the key deliverables include data collections ('atlas') of European Training Measures for Young Professionals, presentation materials, handouts, experimental materials for trainers (experimentation materials and textbooks) and two summer school courses.

Expected socio and economic impact

- The project directly addresses the problem of building suitable human resources for the unrestricted development of European Fuel Cell and Hydrogen businesses. It contributes in enforcing the competitiveness of the European economic area.
- It develops a concept for an educational system across a number of post-graduate educational levels.
- It establishes selected course elements and assesses their potential to increase hiring rates of course participants.
- It will lead to the establishment of the developed curriculum concept within the European post-graduate educational system and the programmes of life-long learning in the framework of vocational Continuous Development Programmes.

Achievements/Results to date

The 1st Joint European School on Fuel Cell and Hydrogen Technology took place in Viterbo, Italy, from 22.8-02.9.2011. It consisted of four separate courses

- A Primer on Hydrogen and Fuel Cell Technology, 21 August - 27 August 2011
- An Introduction to Solid Oxide Fuel Cell Technology, 21 August - 27 August 2011
- An Introduction to Low Temperature Fuel Cell Technology, 28 August - 02 September 2011
- Solid Oxide Fuel Cell Design and Modelling, 28 August - 02 September 2011.

Information

Project reference: FCH JU 256703
Call for proposals: 2009
Application Area: 5 (Cross Cutting)
Project type: Support Action
Topic: SP1-JTI-FCH.20095.1: Development of educational programmes
Contract type: Coordination and Support Action
Start date: 01/10/2010 — End date: 30/09/2012
Duration: 24 months
Project total costs: 345.722 €
Project funding: 269.105 €

Coordinator
Dr. Robert Steinberger-Wilckens
University of Birmingham
Department of Chemical Engineering
Edgbaston, Birmingham B15 2TT
United Kingdom
E-mail: R.SteinbergerWilckens@bham.ac.uk

Partners:

Forschungszentrum Jülich GmbH	Germany
Risø-DTU	Denmark
University of Ulster	United Kingdom
Heliocentris	Germany
University of Birmingham	United Kingdom

Project website: http://www.hysafe.org/TrainHyProf

Projects managed by the European Commission

Understanding of Degradation Mechanisms to Improve Components and Design of PEFC (DECODE)

Key Objectives of the project

The main objective of the planned project DECODE was to increase the life-time of fuel cells for automotive applications. It is well-known that liquid water plays a crucial role in the degradation processes of fuel cells.

The DECODE project aimed at identifying characteristic behaviour regarding degradation and malfunctions with special emphasis on liquid water interactions. In the analysis phase the relevant degradation mechanisms were investigated quantitatively with the operation of PEFC under steady-state and cycling conditions. In the improvement phase the superior durability was tested based on improved materials and adapted operating conditions. It was taken care that liquid water interactions in comparison to dry conditions were present in the study. The main goals specified are:

- Investigation and understanding the degradation mechanisms and processes in PEFC for the individual fuel cell components
- Identification of the main degradation processes and their ranking regarding importance
- Modelling of the degradation processes in PEFC
- Improvement of various components, namely bipolar plates, gas diffusion layers and catalyst coated membranes and to improve the operating conditions
- Demonstration of an improved lifetime by using improved components and operating conditions

Challenges/issues addressed

Lifetime of PEFC fuel cells is a main problem for most applications. The DECODE project`s main challenge was to increase the lifetime of fuel cells for automotive applications under dynamic conditions and with liquid water present in the cell. For this purpose the understanding of the individual degradations processes under dynamic conditions was necessary. The main challenge of the project was to improve the understanding of the relationship of water management and degradation and improve the fuel cell components by modifying the materials and adapting the operating conditions in order to reduce the degradation rate and increase the lifetime. Modelling was used to achieve a better understanding. The improvement of durability was shown in short stack tests.

Technical approach/objectives

The first task of the project was the definition of the state-of-art fuel cell components, test cells and operating conditions for the investigation of the degradation processes. In the next phase the degradation processes of the PEFC and the fuel cells were investigated by in-situ and ex-situ experiments and characterizations. Sophisticated analysis methods (e.g. x-ray tomography, XPS, AFM, TEM etc.) as well as dynamic fuel cell testing were employed. In addition, the degradation processes were modelled with different methodologies; namely molecular dynamics for the MPL; Lattice Boltzmann and Monte Carlo as well as pore network modelling for the gas diffusion media (GDL), performance modelling and CFD analysis for cells and stacks. Literature studies on the known degradation effects were performed for each fuel cell component in the first half of project for evaluating the ranking of importance of degradation mechanisms taking into account the results obtained in the project. Significant advances in the understanding and description of the most important degradation processes were achieved for membranes, electrodes, GDLs and bipolar plates. A special focus of the project was the degradation due to liquid water interactions which was investigated experimentally (change of transport properties and chemical changes as well as by CFD modelling.

After identification of the most relevant degradation processes and their ranking, the individual components were modified (improved material properties, novel coatings, new MEA design) in order to increase cell durability. The improved components were tested and characterized by the same methods used for the identification of the degradation processes. At the end of the project the improved components were tested in order to demonstrate the increased lifetime. A 1000 h test in short stack with metallic bipolar plates demonstrated a significant durability improvement.

Expected socio and economic impact

Achievements are scientific and economic. The industrial partners had the possibility to improve their materials and components with the help of extensive testing, sophisticated analysis tools and sophisticated modelling of research partners. Thinking tools and predictive models were developed which resulted in various publications. The improvement of durability was demonstrated with a new MEA design, modified GDL hydrophobic properties and novel coatings for the metallic bipolar plate. An advancement of the components as well as stacks operation was demonstrated benefitting the DECODE industrial partners. This may result in economic benefits in the future due to better products.

Information

Project reference: FP7 – Energy2007
Call for proposals: 2007
Application Area: Degradation in PEFC
Project type: Research and Technological Development
Topic: Energy 2007.1.1.1
Contract type: Collaborative Project
Start date: 01/01/2008 — **End date:** 03/31/2011
Duration: 39 months
Project total costs: € 5.500.000
Project funding: € 3.699.996

Coordinator
Prof. K. Andreas Friedrich
DLR-TT
Pfaffenwaldring 38-40
D-70569 Stuttgart
Germany
email: andreas.friedrich@dlr.de

List of participants/partners:
Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Germany
Chalmers University of Technology, Sweden
Friedrich-Alexander-Universität Erlangen, Germany
Commissariat à l'Energie Atomique (CEA), France
DANA Sealing Products – Victor Reinz, Reinz-Dichtungs GmbH, Germany
Adam Opel GmbH, Germany
European Commission, DG Joint Research Centre, Institute for Energy, (JRC-IE) Belgium
SGL Technologies GmbH, Germany
Solvay Solexis S.p.A., Italy
Volvo Technology AB, Sweden
Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW), Germany

Project website: http://decode-project.eu

Efficient and robust fuel cell with novel ceramic proton conducting electrolyte (EFFIPRO)

Key Objectives of the project

EFFIPRO shall establish the first set of chemically and mechanically robust PCFC electrolyte and electrodes that demonstrates acceptable single cell performance, and in this manner lead towards a future superior fuel cell technology for power production from reformed fossil as well as hydrogen-based renewable energy. On long term a PCFC shall run at 0.1 Ωcm^2 per each of the four essential loss processes (electrolyte, anode, cathode, interconnect contacts) at > 95% fuel utilisation and 600°C. The project goals are 0.2 Ωcm^2, 90%, and 700°C. The project seeks to achieve this by applying new non-Ba- or Sr-based electrolytes produced in thin (micrometer-range) films and equipped with compatible support, anode and cathode materials.

Challenges/issues addressed

Challenges comprise a) increasing the proton conductivity of non Ba- or Sr-based oxides, b) synthesis, phase purity, and stability of ternary oxides with no cation non-stoichiometry (line compounds), c) production of error-free micrometer-thick films, d) identifying suitable mixed proton-electron conducting electrode materials, e) using in an electrode cermet an ionic conductor with only moderate proton conductivity.

Technical approach/objectives

To develop separately sufficiently high proton conductivity, thin electrolyte film, compatible cathode and anode materials, and low electrolyte-electrode halfcell overpotentials. A set of success criteria are set for midterm, and revision of plans and go or no-go decision is made.

Expected socio and economic impact

The project is a beginning of a development towards a new, more simple and efficient type of fuel cell that can reduce society's consumption of fuels – notably hydrogen – by 10%.

At midterm we reached the midterm-targeted film thickness and anode performance, but not the increased proton conductivity of the material (Ca-doped $LaNbO4$) and not the cathode performance. A new electrolyte, a lanthanum tungstate ('LWO') was therefore substituted, and the remaining materials developed from scratch.

To date (9/10 of project done) we have reached the final targeted electrolyte conductivity, but not the electrode performances.

The project has led to one patent and one new EU 7FWP NMP follow-up project (passed through to 2nd round) and been accompanied by a national company startup and several projects. The technology is thus underway, but with expected impact only after 2020.

Information

Project reference: FP7-Energy-NMP-2008-1
Project contract no.: 227560
Call for proposals: 2008
Application Area: Energy
Project type: Basic research
Topic: Energy; Novel Materials for Energy Applications
Contract type: Collaborative project
Start date: 01/05/2009 — **End date:** 30/04/2012
Duration: 36 months
Project total costs: € 3,155,010
Project funding: € 2,540,258

Coordinator
Prof. Truls Norby
Univ. Oslo
+47-22840654
truls.norby@kjemi.uio.no

Coordinator contact details in more detail:
Truls Norby
Professor
Department of Chemistry, University of Oslo

Head of FERMiO (Functional Energy Related Materials in Oslo)
Member of Centre for Materials Science and Nanotechnology (SMN)

Postal and visiting address:
FERMiO, Forskningsparken, Gaustadalleen 21,
NO-0349 Oslo, Norway

Telephone: +47-22840654(office),
+47-99257611(cellular), +47-63992453(priv)
Fax: +47-22840651
Email: truls.norby@kjemi.uio.no
Web: http://folk.uio.no/trulsn

Project website: http://www.mn.uio.no/smn/english/research/projects/effipro/

Fluorine Substituted High Capacity Hydrides for Hydrogen Storage at Low Working Temperatures (FLYHY)

Key Objectives of the project

At present no solid state hydrogen storage material fulfils all requirements for mobile applications at the same time, i.e. high storage density, temperatures and heats of operation compatible with PEM fuel cells, fast hydrogen loading and low production costs. FlyHy focused on the first three points. High hydrogen capacity materials like alane or borohydrides as well as Reactive Hydride Composites were modified by substituting halogens for part of the hydrogen or hydrogen containing complexes to (i) exploit previous results on materials destabilisation and stabilisation resp. by halogen substitution in order to improve the thermodynamic properties of these materials exhibiting the highest hydrogen capacities known at present, (ii) to obtain an in depth scientific understanding of the sorption properties of the substituted materials by extended structural and thermodynamical characterisation and modelling, (iii) to determine tank relevant materials properties like e.g. heat conductivity, and (iv) to do first tests in a prototype tank.

Challenges/issues addressed

FLYHY investigated, whether the novel approach of substituting halogen for part of the hydrogen could solve the issue of too high stability of solid state hydrogen storage materials with capacities larger than 6 wt.% (alane, boron hydrides, reactive hydride composites) by halogen induced destabilisation and/or change of reaction paths; furthermore, whether halogen substitution improves reaction kinetics for faster hydrogen loading and unloading at lower reaction temperatures, whether it leads to materials with sufficient cycling stability, and whether the substituted materials could be synthesised at acceptable cost.

Technical approach/objectives

The FLYHY project focused on the challenges mentioned above by employing **a novel path** of synthesising high capacity hydrogen storage materials, which was expected to allow tailoring physical properties of the materials such as working temperatures: **Anion substitution in nanostructured high capacity hydrogen storage materials**.

By substituting halogens for part of the hydrogen, it was expected, that this might change the bond strength of the remaining elements and thereby may facilitate release and uptake of hydrogen. In this way, a breakthrough in improving the thermodynamic properties in the storage materials to meet the requirements for mobile hydrogen storage was anticipated.

FLYHY focused on fundamental scientific investigations of high capacity hydrogen storage materials, namely thermodynamically too stable (e.g. Lithium-Boronhydride LiBH4 with a capacity of 18.5 wt% hydrogen) and unstable compounds (e.g. Alane AlH_3, 10.1 wt% H_2, Aluminium-Boronhydride $Al(BH_4)_3$, 16.8 wt% H_2), as well as compounds, where especially the speed of hydrogenation should be improved (e.g. the Calcium based Reactive Hydride Composites, 8.5 wt.%). In addition, it was investigated whether halogen substitution could enhance the poor kinetics and reversibility of hydrogenation for these compounds. It was expected that the replacement of hydrogen by a halogen reduces the total hydrogen storage capacity, but starting from hydrides with high hydrogen storage capacities the resulting substituted hydrides/halides would still have above 6 wt% in these compounds.

FLYHY was based on work done by the partners HZG and IFE in the European Integrated Projects NESSHY and STORHY and the Marie Curie RTN COSY as well as work done by Aarhus University.

Expected socio and economic impact

The main impacts of FLYHY therefore are novel cost effective routes for materials synthesis, an improved scientific understanding of the role and effects of halogen substitution in advanced hydrogen storage materials, improvement of techniques for experimental and theoretical materials characterisation and development, and opening up of routes for future improvement of solid state storage materials. The developed routes for materials synthesis as well as the employed hydrogen storage tank technologies are especially suitable for manufacturing by SME's.

Information

Project reference: FP7-Energy-NMP-2008-1 'Novel Materials for Energy Applications'
Call for proposals: year 2008
Application Area: FP7 Energy NMP
Project type: Basic Research
Topic: - (c.f. Project reference
Contract type: Collaborative Project
Start date:01/01/2009 — **End date:** 31/12/2011
Duration: 36 months
Project total costs: € 2,749,818
Project funding: € 2,099,200

Coordinator
Dr. Klaus Taube
Helmholtz-Zentrum Geesthacht
Max-Planck-Strasse 1
D-21502 Geesthacht
Germany
klaus.taube@hzg.de

List of participants/partners

- Helmholtz-Zentrum Geesthacht, Geesthacht, Germany
- Institutt for Energiteknikk, Kjeller, Norway
- Aarhus University, Denmark
- Università di Torino, Italy
- Consejo Nacional de Investigaciones Cientificas y Tecnicas, Instituto de Investigaciones Fisicoquimicas Teoricas y Aplicadas, La Plata, Argentina
- Tropical S.A., Athens, Greece

Project website: http://www.flyhy.eu

Materials and components for Hydrogen production by sulphur based thermochemical cycles (HycycleS)

Key Objectives of the project

The objective of HycycleS was to provide detailed solutions for the design of specific key components, and in particular on the materials needed for sulphur based thermochemical cycles for hydrogen production. The focus was one of the most challenging sections of such processes: the high temperature section for the thermal decomposition of sulphuric acid. The components targeted were a compact heat exchanger for sulphuric acid decomposition suitable for operation by solar and nuclear heat, a receiver-reactor for solar sulphuric acid evaporation and SO_3 decomposition, and an oxygen separator for SO_2 and oxygen as promoter of the SO_3 decomposition.

Challenges/issues addressed

The major challenges of sulphur based processes are the high temperatures and corrosive environments present in their key operational steps. The conditions require advanced materials for the key components. Special design and fabrication methods for those components were needed. Materials suitable for these components require good to excellent temperature and corrosion resistance – potentially also achievable by suitable coatings, good thermal conductivity, ductility, mechanical properties. Good manufacturability, weld ability or bonding, commercial availability, and cost-competitiveness are essential. Intelligent design is necessary to minimise losses which can be significant at the relevant operation temperatures. Experimental validation of all components is obligatory to proof their reliability.

Technical approach/objectives

Potential construction materials have been analysed. Silicon Carbide (SiC) turned out as the material of choice for the components facing the most corrosive environment of the process: the sulphuric acid evaporator and decomposer. Samples have been successfully tested under the relevant conditions for up to 5000 hours of treatment time. Candidate catalyst for the high temperature reduction of sulphur trioxide have been screened and analysed – mainly considering oxides of transition metals. Their catalytic activity and their durability has been investigated and quantified experimentally. The most suitable candidates have been identified.

Based on the use of the highlighted construction and catalyst materials prototype decomposers have been developed and tested. The successful fabrication and testing of a large size heat exchanger/reactor prototype composed of SiC plates shows promise with respect to its use for sulphuric acid decomposition – let it be a nuclear or a solar powered process. A solar specific decomposer prototype was developed, realised and tested on sun in a solar furnace. It has been designed for a direct coupling of concentrated solar radiation into the process. Sulphuric acid was successfully decomposed to provide the required SO_2 product with yields close the respective thermodynamic value and with high reactor efficiencies.

A novel approach of using dense oxygen transport membranes, made from novel and complex ceramics, for oxygen removal from the H_2SO_4 decomposition product in order to shift the equilibrium in favour of increased decomposition was investigated. The membranes stability and suitability for carrying out this separation was investigated experimentally.

Parallel to this a conventional oxygen separator, a low-temperature wet scrubbing system, was addressed as well. The necessary materials information, in terms of reliable thermodynamic data on the equilibrium between oxygen and the solutions of SO_3 and SO_2 downstream of the decomposition reactor, did not exist in the literature and yet represented a major obstacle to the immediate design of an operating cycle.

The safety of operation of nuclear and solar powered thermochemical processes for hydrogen production has been assessed. Some specific measures necessary to avoid hazard due to the interaction of energy source and chemical plant have been identified. All in all the safety of such plants is regarded as manageable. Finally, the process economics and a demonstration scenario have been depicted and analysed.

Expected socio and economic impact

HycycleS has significantly contributed to a proof of the technical viability of such thermochemical cycles for water splitting. The project has paved the path for a demonstration of the technology in a relevant scale, e.g. an on-sun demonstration of the solar version of the process on a solar tower. Different sections of the project have prospects of wider potential commercial use. The Implementation Plan of the European Hydrogen & Fuel Cells Technology Platform requests '…a new generation of hydrogen production processes will be necessary if the full benefits of hydrogen as the alternative energy carrier to electricity are to be realised…' beyond 2020. To achieve this 'development of advanced production pathways based on the thermal-electrical-chemical decomposition of water at high temperature…' was proposed. HycycleS has provided some key elements to achieve this.

Information

Project reference: EU FP7
Call for proposals: 2007
Application Area: Hydrogen Production
Project type: Research and Technological development
Topic: Thermochemical Cycles
Contract type: Collaborative Project
Start date: 01/01/2008 — **End date:** 31/03/2011
Duration: 39 months
Project total costs: € 5,123,432
Project funding: € 3,748,823

Coordinator

Deutsches Zentrum für Luft- und Raumfahrt e.V.
Institute of Solar Research
Dr. Martin Roeb
Tel: +49-2203-601-2673
Fax: +49-2203-601-4141
E-mail: martin.roeb@dlr.de

Consortium:

Deutsches Zentrum fuer Luft- und Raumfahrt e.V. - DLR	D
Commissariat à l'Energie Atomique – CEA	F
University of Sheffield – USFD	UK
Aerosol and Particle Technology Laboratory / Center for Research and Technology–Hellas/ Chemical Process Engineering Research Institute	GR
Joint Research Center Petten – JRC	B
Ente per le Nuove tecnologie, l'Energia e lo Sviluppo Economico Sostenibile - ENEA	I
Eidgenoessische Technische Hochschule Zürich - ETHZ	CH
Empresarios Agrupados - EA	E
Boostec Industries – Boostec	F

Project website: www.hycycles.eu

Innovative Dual mEmrAne fueL-Cell (IDEAL-Cell)

Key Objectives of the project

The IDEAL-Cell project aims at developing an innovative high temperature fuel cell concept based on a dual membrane (conducting both O^{-2} and H^{+}) and operating at intermediate temperature, ideally 600°C. This new system combines the benefits of state-of-the-art PCFCs and SOFCs while evading their disadvantages (associated to the presence of water at the electrodes). It consists in assembling the anode/electrolyte compartment of a PCFC (figure 1a) and the cathode/electrolyte compartment of a SOFC (figure 1b) via a porous central membrane (CM) wherein pure water is formed (figure 1c) by the combination of H^{+} and O^{2}- ions.

The key objectives of the project were then:

- to proof the concept
- to fabricate and optimize single dual cells
- to fabricate a short stack

After the EC experts recommendations at the mid-term review, the focus was put more on the understanding of the basic mechanisms and improvement of performances instead on the realization of a short stack, even if the consortium did significant progresses in that direction.

Challenges/issues addressed

To fulfil the objectives of the projects, a number of challenges were to be overcome:

- to establish proof of concept criteria, to realize a first prototype and test it on a dedicated set-up
- to shape the cell by the most appropriate processes or sequence of processes
- to understand the new mechanisms at work
- to model theoretically the cell (kinetic, charge and mass transfer, morphology…)
- to increase the performances
- to compare those performances with that of 'comparable' SOFCs and PCFCs
- to develop a specific interconnect material and design
- to develop dedicated specific testing set-ups
- to fabricate a short IDEAL-Cell stack (2 cells) and test it

Technical approach/objectives

The technical approach was a systematic 1 by 1 step approach that tackled first the cathode compartment, then the anode compartment, then the dual central membrane to reach the proof of concept validation after 2 years. When the concept was validated, the consortium strengthened the basic knowledge on each compartment in view of a better understanding of the basic mechanisms, improvement of materials, components and cell (alone and in a short stack), with a strong focus on the dual conducting central membrane.

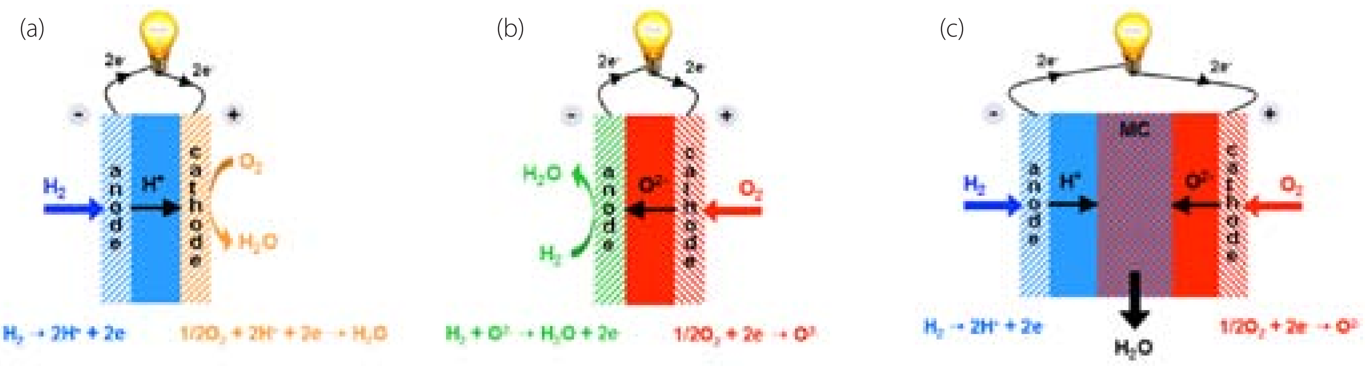


Figure 1: Scheme of (a) a PCFC, (b) a SOFC and (c) the IDEAL-Cell concept.

Expected socio and economic impact

The IDEAL-Cell project was a highly challenging project that proposed a totally new high temperature fuel cell concept. In that sense, it presents all the well-known advantages of these elder SOFC and PCFC concepts, which will take part to the hydrogen economy and be an important step toward the spreading of RES. In spite of a real interest raised amongst big companies, in a world in which the fuel cell business is extremely difficult, the IDEAL-Cell concept is still considered not mature enough to be included into an industrial development strategy, and a fortiori to be the focus of a commercial evaluation.

Achievements/Results to date

A number of excellent results were recorded, either on the improvement of electrode, electrolyte and interconnect materials, via dedicated testing (i.e. Differential Impedance Analysis, 2-atmosphere or 3-chamber testers, X-ray microtomography and 3D mathematical morphological reconstruction) or on the fundamental understanding of the mechanisms at work (via kinetic, mass and charge transfer and mathematical modelling). To be noted, at 600°C, the level of O^{2-} and H^+ conduction in BCY15 was proved theoretically and experimentally to be equivalent when fed by the appropriate gas, which opened the route for a monolithic configuration (patented). In addition, the IDEAL-Cell was proved to work even better also in reverse operation (HT electrolyzer), for which a new conduction mechanism was discovered.

All these advances gave a solid ground for fast increasing cell performances, which are to be considered in the perspective of a new born concept (proof of concept in 2010) with respect to much older SOFCs (almost as old as the use of YSZ as an oxygen conductor) and PCFCs (the first works on protonic ceramics are about 30 years old).

Information

Project reference: FCH JU
Call for proposals: FP7-ENERGY-2007-1-RTD
Application Area:
Project type: Research and Technological Development
Topic: ENERGY-2007-1.1-03 (Fuel Cells)
Contract type: Collaborative project
Start date: 01/01/2008 — **End date:** 31/12/2011
Duration: 48 months
Project total costs: € 4,368,742.00
Project funding: € 3,309,045.00

Coordinator contact details

Prof. Alain Thorel
ARMINES/MINES ParisTech
Centre des Matériaux
Evry
France
alain.thorel@mines-paristech.fr

List of participants/partners

ARMINES	France
Université de Bourgogne	France
Consiglio Nazionale delle Ricerche (CNR)	Italy
German Aerospace Center (DLR)	Germany
Bulgarian Academy of Sciences	Bulgaria
NAXAGORAS	France
AGH University of Science and Technology	Poland
Marion Technologies	France
VISIMBEL	Germany

Project website: http://www.ideal-cell.eu

Development of next generation metal based SOFC technology - METSOFC

Key Objectives of the project

The objective of the METSOFC project is develop next generation stack technology based on metal-supported cells to improve robustness, cost effectiveness and functionality including the objective to reach a robustness of SOFC stacks which fulfils the requirements defined by the transportation sector. The development of the METSOFC cells and stacks has encompassed the introduction of a novel cell architecture including new metallic alloys, radical innovative anodes and new processing methods. One primary objective has been to select and verify effective manufacturing methods suitable for up-scaling. The target was to test the developed stacks up to the 1 kWe level aiming at functionalities and operation parameters defined by heavy duty APU mobile applications. The metal-supported concept is attractive because such a new platform is expected to yield improvements in cell cost, component handling, operational constraints, mechanical robustness, and operational temperature, which would also make way for cheaper system and stack components. Initially the following targets and benchmark values had to be taken into account regarding heavy duty truck applications in quasi-steady operation mode:

- Sulphur tolerance up to 10 ppm
- 5.000 operating hours with outlook on 10.000 operating hours
- 500 thermal and full redox-cycles (i.e. warm-up and cool down in air)
- System costs <800 Euro/kW (with < 45% stack costs)

Testing procedures considering the boundary conditions and system requirements had to be developed in accordance with the product definitions on the one hand and FCTESTNET / FCTESQA on the other hand. A special emphasis was put on dynamic and cycling tests (load-, redox-, thermal cycles).

Challenges/issues addressed

To ensure cost effectiveness and up-scalability of the novel cell concept, it has been a prerequisite to rely upon a metal support layer based on powder metallurgy and co-sintering. The choice of powder composition and particle size distribution has been evaluated in order to fulfill the following criteria: adequate high temperature corrosion resistance, chromium evaporation, mechanical durability and process ability. Metal-supported cells were manufactured using powder based on the state-of-the-art ferritic chromium steel developed by Sandvik/Osprey using gas atomization. The cells were then tested to provide benchmark performance data. 5 types of different powder alloys were manufactured and evaluated in an iterative development sequence. The design process utilised an effective LEAN spiral concept upon which the METSOFC project has been structured successfully. In overall terms it was concluded that the alloy compositions and particle size requirements evaluated within the METSOFC project could be manufactured effectively in pilot scale manufacturing equipment.

The different powder alloys developed were used to fabricate metal supports with focus on processing compatibility with other cell components, porosity, microstructure, and corrosion resistance. All metal supports were fabricated based on tape casting. Quantitative targeted performance values were established for different components, including the metal support. In order to have improved corrosion resistance of the metal support the available surface area for corrosion of the metal support should be < 0.02 m^2/g with porosity around 25%. Corrosion testing on metal supports and half cells was carried out to give feedback during the iterative optimization of metal powder compositions. The results obtained also provided important feedback on how to optimize the microstructure of the metal support to have as low corrosion as possible of the metal component. Furthermore, the effect of some selected protective coatings on the corrosion behavior has been evaluated. Establishment of an effective integrated manufacturing concept focusing of co-processing of ceramics and metals has represented a major challenge including many unknowns.

Because the typical mechanical failure mechanism of metallic supports are different from failures of ceramic supports (electrolyte or anode supported cells), a radical different treatment of mechanical properties and behaviours was needed in this project. To truly understand the possibility of a viable metal supported cell, the difficult relationship between the elastic and plastic response of the metal supports had to be investigated at both room temperature and high temperature, as this relationship becomes more complex at elevated temperatures as creep and corrosion also enters as significant mechanisms. An increased understanding of the complexity of the mechanical characterization of the novel metal supported cell has been obtained and some modifications of the plans regarding mechanical testing had to be implemented.

Technical approach/objectives

Metal supported cells have been up-scaled from 4 cm^2 to 144 cm^2, and even a few cells with 300 cm^2 foot prints have been produced to demonstrate the potential in the fabrication process. The ASR performance of the button cells tested have been improved from about 0.8 Ωcm^2 to <0.5 Ωcm^2 measured at 650°C which is better than the project target. The degradation rate has been improved from 4.5 to 0.9% per 1000 hours. These numbers are in good accordance with the key milestones. The novel metal-supported cells have proved to exhibit significantly better red-ox cycle resistance than current SoA anode supported cells. Stack up to 25 cells have been assembled and tested. To ensure lifetime and cost effectiveness a new continuous strip steel coating concept for metallic interconnects has been developed. The Cr evaporation rate from the coated steel is well below the targeted value of 0.1 mg/cm^2 per 1000 hours after the first 1000 hours of operation.

Expected socio and economic impact

The specifications for SOFC APU systems in heavy duty truck applications as compiled in METSOFC can be applied generally in future APU development project and in the engagement of end users. The results of the METSAPP project have paved the way towards a fulfilment of the very aggressive cost targets for SOFC components in APU applications. The METSOFC cell and stack concept builds upon cheaper materials and minimization of use of Nickel in comparison with current anode-supported cells based on Ni/YSZ support layers Generally the lower operation temperature in combination with metallic alloys promises improved robustness, reliability and further reductions of cost. As a spin off from METSOFC a new EU FCH JU project METSAPP has been launched by the end of 2011 aiming at further improvement of durability and lifetime for residential applications. Furthermore, the cell and stacks developed in the two projects will be evaluated for potential implementation in the APU development project EU FCH JU DESTA.

Information

Project reference: FCH JU No 211940
Call for proposals: 2007
Application Area: ENERGY.2007.1.1.2 Basic research on materials and processes for High Temperature Fuel cells
Project type: Basic Research
Topic: High Temperature Fuel Cells (SOFC)
Contract type: Collaborative Project
Start date: 01/04/2008 — **End date:** 31/12/2011
Duration: 36 months
Project total costs: € 5.571.441
Project funding: € 3.587.846

Coordinator
Niels Christiansen
Topsoe Fuel Cell A/S
Nymoellevej 66
2800 Lyngby
Denmark
nc@topsoe.dk

Consortium:
Topsoe Fuel Cell A/S
AB Sandvik Materials Technology
Sandvik Osprey Limited
Danish Technical University Risø
AVL List GmbH
KIT University of Karlsruhe

Project website: www.metsofc.eu

NANOHy
Novel Nano Composites for Hydrogen Storage Applications

Novel Nanocomposites for Hydrogen Storage Applications (NANOHy)

Key Objectives of the project

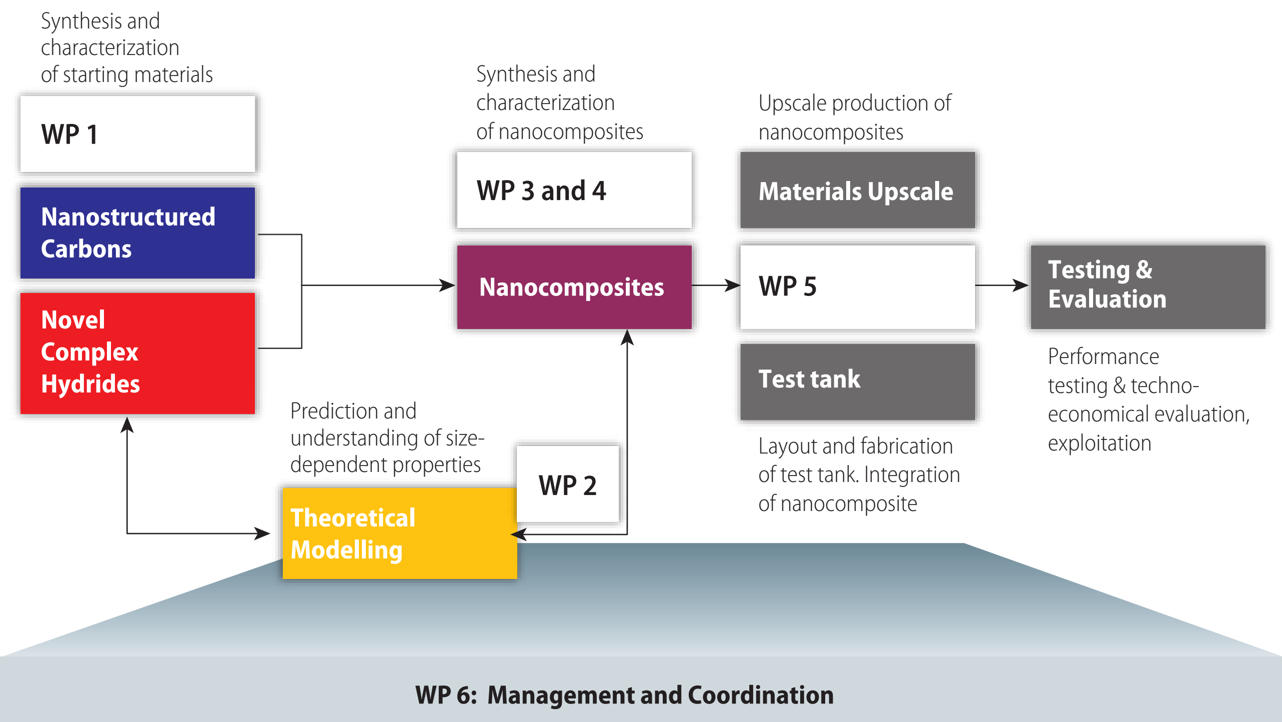
The main goal of the project is to produce nanocompositic materials for hydrogen storage which have altered properties with respect to working temperature and pressure, an enhanced reversibility, and controlled interaction between the hydride and the environment, leading to improved safety properties.

Materials of this kind could mitigate or solve principal and practical problems which have been identified recently in other projects working on H storage materials. The composites developed in NANOHy are synthesized out of novel complex hydrides with very high hydrogen content and of nanocarbon templates. Alternatively, hydride colloids are coated in a Layer-by-Layer self-assembling process of dedicated polymers. Computational methods are used to model the systems and predict optimal materials/size combinations for improved working parameters of the systems. Sophisticated instrumental analysis methods are applied to elucidate the structure and the properties of the nano-confined hydrides.

Challenges/issues addressed

Hydrogen storage is regarded one of the most critical issues, which has to be solved before a technically and economically viable hydrogen economy can be established. One of the greatest challenges in this direction is H_2 storage for mobile and for stationary applications. The overall techno-economical evaluation in NANOHy shall be based on comparisons with analogous results obtained in the literature with other storage technologies. The technical and economic performance will be evaluated and assessed of the new solid storage material and the respective storage system including safety issues, environmental considerations and certification aspects.

The general NANOHy objectives outlined above require a significant progress in the fundamental understanding of the properties of nanoscale high hydrogen content hydride materials, as well as a technical progress in developing nanoscale systems with improved properties in bulk amounts and the system integration in a laboratory scale tank.



Technical approach/objectives

So far, preliminary evidence of the upscale production feasibility is available. Also, the first nanocomposite is synthesized with H desorption temperature that is lowered by > 20 K compared to the bulk material. Alternatively, the nanocomposite may also produce 100% higher H_2 equilibrium pressure. Moreover, production process is identified for the upscale of sufficient amounts of hydride and nanocarbon for the test tank. Finally, heat conductivity of target material has been developed in NANOHy differs by a factor of 3 from the materials developed in NESSHy.

Expected socio and economic impact

The work in the four years of NANOHy has been very successful in that several scientific breakthroughs were achieved, from showing that very small complex hydride nanoparticles can really be prepared in a microporous scaffold to the first demonstration that complex hydrides may show altered thermodynamic properties when nanodispersed in microporous carbon scaffolds. In addition, it was shown for the first time that the well-known MgH_2 does also change its thermodynamic properties when it is infiltrated in microporous carbon supports. Moreover, an upscale of nanoconfined hydride materials and their integration into a test tank has not been done before and was achieved in NANOHy for the first time.

Information

Project reference: FCH JU (Grant Agreement No. 210092)
Call for proposals: 2007
Application Area: Hydrogen production and storage
Project type: RTD
Topic: ENERGY-2007-1.2-04: Novel nanostructured materials for hydrogen storage
Contract type: Collaborative Project
Start date: 01/01/2008 — **End date:** 31/12/2011
Duration: 48 months
Project total costs: € 3.131.953
Project funding: € 2.399.629

Coordinator contact details:
Dr. Maximilian Fichtner
Karlsruhe Institute of Technology
Institute of Nanotechnology
Germany
m.fichtner@kit.edu

Consortium:

Beneficiary no.	Beneficiary name	Beneficiary short name	Country
1 (Coordinator)	Karlsruhe Institute of Technology	KIT	Germany
2	CNR-ISC Firenze	CNR	Italy
3	CNRS	CNRS	France
4	FutureCarbon GmbH	FC	Germany
5	Institutt for Energiteknikk	IFE	Norway
6	Max-Planck-Institut	MPI-KGF	Germany
7	NCSR Demokritos	NCSRD	Greece
8	University of Oslo	UniO	Norway
9	Korean Institute of Science and Technology	KIST	South Korea

Project website: www.nanohy.eu

Nanostructured Photoelectrodes for Energy Conversion (NanoPEC)

Key Objectives of the project

The key objective of NanoPEC is to develop advanced, nanostructured composite photoelectrodes that can significantly enhance hydrogen production by way of photo-electrochemical (PEC) water splitting. More specifically, the aim consists in building and testing: (i) a 1 cm^2 test-device that converts solar energy to hydrogen energy with a sustained 10% efficiency and a maximum performance decay of 10% over the first 5'000 hours of operation; (ii) a 100 cm^2 test-device with a sustained 7% efficiency and similar stability, representing a performance standard that goes well beyond the state-of-the-art.

Challenges/issues addressed

Sustainable, cost-efficient large-scale production of hydrogen can, in principle, be established by solar photo-electrochemical (PEC) water splitting, where semiconductor electrodes absorb sunlight to drive water electrolysis: $2 H_2O \rightarrow 2 H_2 + O_2$. Despite four decades of worldwide intensive research on PEC water splitting, this challenge has not been met yet, largely because of material limitations. Photoelectrode materials for solar water splitting must meet multiple and severe criteria such as efficient absorption of sunlight, separation and collection of photogenerated carriers, catalysis of water splitting reactions, chemical stability and durability for a long period as well as abundance. No single material is likely to meet all of the criteria needed to achieve competitive solar hydrogen production by water splitting. Thus, the challenge is to design innovative composite nanostructures in which each component performs specialized functions, overcoming the basic materials limitations that have hindered development so far.

Technical approach/objectives

NanoPEC employs innovative concepts and new methods, enabled by nanotechnology, to design nanocomposite photoelectrodes for solar water splitting, where each component performs specialized functions to overcome intrinsic limitations of single-phase materials. Advanced nanostructures that maximize performance of photoanodes and photocathodes are designed, fabricated, characterized, and optimized. Newly-developed p- and n-type semiconducting oxides and oxynitrides are explored and nanostructured into innovative structures, as well as device architectures designed to achieve high solar-to-hydrogen conversion efficiency, balancing the trade-off between light harvesting, charge separation and collection, stability and durability. In parallel, fundamental studies and investigations of model systems are carried out to improve quantitative understanding of the effect of material properties, defects and interfaces on PEC processes. These investigations provide guidelines for materials optimization and nanocomposite electrode structures designed for high efficiency, while their performance is evaluated using advanced testing and analytical setups.

Expected socio and economic impact

Significant progress in PEC water splitting was achieved within NanoPEC. In particular, small-size Cu_2O photoelectrodes exhibited a photocurrent as high as a 7.6 mA/cm^2 with an applied voltage of 1.23 V, i.e. STH efficiency of 10% in an ideal tandem configuration, exceeding the project target. The inherent instability of Cu_2O was overcome by newly-developed protective overlayers. A large electrode of Cu_2O exhibited a photocurrent of a 4 mA/cm^2, corresponding to 87% of the project target. Small-size Fe_2O_3 showed a photocurrent of a 3.3 mA/cm^2 at 1.23 V, the highest performance ever reported for hematite. The efficiencies of PEC water splitting are still low, typically in the range of 1–10%, although PEC cells exhibit positive energy balance, in contrast with electrolysers that intrisincally consume extra energy input. The production price of hydrogen via PEC solar water splitting is estimated to be 7–14 € H_2 kg^{-1}, provided a PEC device is active 8h/day and last 20 years. This is still more expensive than the target (5 € H_2 kg^{-1}) established by the European Hydrogen & Fuel Cell Technology Platform.

Information

Project reference: FCH JU
Call for proposals: 2008
Application Area: H_2 production, photoelectrochemical H_20 splitting, nanostructured materials, solar energy
Project type: Research
Topic: Novel materials for energy applications (Joint call with Energy)
Contract type: Collaborative project
Start date: 1/1/2009 — **End date:** 31/12/2011
Duration: 36 months
Project total costs: € 3,589,188.00
Project funding: € 2,699,909.00

Coordinator contact details
Prof. Michael Grätzel – Head, Laboratory for Photonics and Interfaces
Ecole Polytechnique Fédérale de Lausanne - Switzerland
michael.graetzel@epfl.ch

List of participants/partners (organisation name, country)

- Ecole Polytechnique Fédérale de Lausanne (EPFL) - Laboratory of Photonics and Interfaces
- Uniwersytet Warszawski - Laboratory of Electroanalytical Chemistry
- Universidade do Porto - Laboratory for Process, Environment and Energy Engineering
- Universitetet i Oslo - Micro- and Nanotechnology Laboratory
- Delft University of Technology - Materials for Energy and Storage
- Israel Institute of Technology (Technion) - Electroceramics Materials & Devices Laboratory
- Ecole Polytechnique Fédérale de Lausanne - Energy Center
- ENI S.p.a - Laboratory of Photochemistry for Solar Hydrogen
- Eidgenössiche Materialprüfungs- und Forschungsanstalt (EMPA)

Project website: http://nanopec.epfl.ch

Quasi-anhydrous and dry membranes for next generation fuel cells (QuasiDry)

Key Objectives of the project

The objective of QuasiDry is to develop the fuel cell electrolyte membranes of the next generation of fuel cells. The increase of proton conductivity with temperature, including at low RH, will allow continuous increase in fuel cell performance with temperature, rather than the drop in performance for all sulfonic acid functionalised membranes above ca. 80-90°C. QuasiDry membranes will be validated within the project by electrode and MEA development, to the scale of small-scale (50 cm^2) single cell demonstrators. The end result will be a step-change in the properties of the materials, as is required to underpin the future of European fuel cell research. QuasiDry builds on some of the achievements of FP6 Autobrane by concentrating efforts on some of the most promising long-term options developed in its framework where radical upgrade in materials properties is possible.

Challenges/issues addressed

In recent years, a vast number of polymers have been proposed and evaluated as possible materials for proton exchange membrane fuel cells (PEMFC), in particular for automotive application. Despite the wide use of state of the art perfluorosulfonic acid membranes, their maximum performance in a fuel cell is at moderate operation temperatures (≤80°C). This falls significantly short of industry long-term targets, and the too low temperature of operation and the need for humidification of current polymer exchange membrane fuel cell membranes is an obstacle to introduction of fuel cell vehicles and efficient micro cogeneration units. The high temperature/low RH membranes bottleneck to the development of FC technology requires basic materials research to develop the particular and demanding set of properties required for fuel cell application.

Technical approach/objectives

New concepts have evolved over the last decade engaging alternative proton carriers that mark a move towards reducing the need for high levels of hydration of the fuel cell membrane. Recent work in the partner laboratories convincingly demonstrates that phosphonic acid functionalised and phosphoric acid complexed polymers are viable alternatives to sulfonic acids for high temperature operation. The potential of phosphonic acid functionalised polymers as membrane materials having high proton conductivity that demonstrates little variation with temperature and relative humidity will be shown in the QuasiDry project, and they will be validated by integrating them into membrane electrode assemblies.

Key technical items delivered in year 1 of the project include: Protocols for characterisation of membranes, novel catalyst supports, electrocatalysts and MEAs including accelerated stress testing; First generations of double functionality (sulfonic and phosphonic acid) membranes, of composite membranes incorporating highly phosphonic acid functionalised organic crystals, of partially fluorinated block copolymers selectively grafted with poly(vinylphosphonic acid), of membranes with high acid doping levels; Inorganic conductive supports showing corrosion currents 2-3 orders of magnitude lower than carbon black; Novel PtXY ternary catalyst formulation that matches baseline stability with 20% activity improvement; Development of electrode structures appropriate for high temperature operation with non-PFSA electrolytes; First MEA data with benchmark and novel membranes.

Expected socio and economic impact

QuasiDry is expected to achieve high impact on strengthening the European scientific and technical base in fuel cell energy research. The results will further consolidate the position of the institute/university partners as international research leaders and will provide an international competitive advantage to the European industries involved for the future commercialisation of high temperature fuel cell technologies. The project team comprises a strong participation of companies with established development, manufacturing and commercial activities within the fuel cells business sector.

Information

Project reference: 256821
Call for proposals: 2009
Application Area: N/A
Project type: Research and Technological Development
Topic: ENERGY-2010-10.2-1: Future Emerging Technologies for Energy Applications (FET)
Contract type: Collaborative project
Start date: 01/12/2010 — **End date:** 3/11/2013
Duration: 36 months
Project total costs: € 2528205
Project funding: € 1728239

Coordinator contact details

Prof. Michael Grätzel – Head, Laboratory for Photonics and Interfaces
Ecole Polytechnique Fédérale de Lausanne - Switzerland
michael.graetzel@epfl.ch

List of participants/partners (organisation name, country)

Beneficiary name	Country
Centre National de la Recherche Scientifique (Montpellier)	France
Lund University	Sweden
Max-Planck Institut für Polymerforschung	Germany
Consiglio Nazionale delle Ricerche – Institute for Advanced Energy Technologies	Italy
Johnson-Matthey Fuel Cells	United Kingdom
Funktionelle Membranen und Anlagentechnologie GmbH	Germany
Pretexo	France

Project website: http://www.quasidry.eu/

Innovative Solid Oxide Electrolyser Stacks for Efficient and Reliable Hydrogen Production (RelHy)

Key Objectives of the project

The RelHy project targeted the development of novel or improved, low cost materials (and the associated manufacturing process) for their integration in efficient and durable components for the next generation of electrolysers based on Solid Oxide Electrolysis Cells (SOEC). It was specifically tailored for i) optimisation of novel or improved cell, interconnect and sealing materials and ii) achievement of innovative designs for SOE stacks to improve durability.

Challenges/issues addressed

The main challenges addressed were the simultaneous achievement of both, lifetime (degradation close to 1% for 1000 h on single repeat units at 800°C) and efficiency (0.03 to 0.04 $gH_2/cm^2/h$, i.e. approximately 1 A/cm^2 with water utilisation >60%). These operation points and degradation values yield an efficiency of up to 80% (LHV) at the system level with >99% availability. Cost issues have also be addressed by considering cost effective materials and processes in order to meet the 'non energy' 1€/kg H_2 target.

Technical approach/objectives

To achieve these goals, the RelHy project was based on the improvement of state of the art SOFC components characterised either separately or integrated into instrumented single repeating units (SRUs) and short stack. Data analysis has been supported by simulation tools (from cell to stack scale).

M6	Testing protocols defined for performance and durability assessment
M12	Test benches available for single cell, single repeating units and short stacks
M18	
M24	Selection of most promising materials (cells, interconnects and coatings, sealants)
M30	Selection of materials for the 25-cell prototype
M36	
M42	Assessment of materials and design for 25 cell stack prototype Kick off of the 25-cell stack prototype operation

Expected socio and economic impact

The RelHy project has allowed successful material improvement: Two types of cells have been studied. With O_2 electrode made of LSCF/CGO, cathode supported cells exhibited very high cell performances. Their degradation rate was found to be promising as a stabilisation plateau (around 1% per 1000h) was obtained after few 100 hours at intermediate current densities. Electrolyte supported cells with 3YSZ electrolyte showed greatest durability whereas with 10Sc1CeSZ electrolyte high performances were reached.

Protective and contact coating made of Co_2MnO_4 spinel deposited on Crofer by PVD and of screen-printed LSM showed stable ASR at 800°C in ex situ testing and in operation.
Several glass seals, either commercial or homemade, were shown to withstand electrolysis conditions and to ensure tightness for more than 4000h.

Thanks to simulation, it was shown that in stack configurations, with limited heat dissipation, significant thermal gradient can occur across cells and upon transient temperature excursions are unavoidable.

Two tests campaigns have been achieved with SRUs and short stacks including performances and long duration tests (4000h) on reference and improved components. Some conditions could be found with no degradation, and high current densities at degradation rates < 5% per 1000h were reached in SRU and short stack. Scaling up to 25-cell stack has been achieved and the stack is being operated.

Information

Project reference: FP7 collaborative project GA 213009
Call for proposals: 2007
Application Area: Theme 5 Energy
Project type: Research and Technological Development;
Topic: 1.2.1 'New Materials and Processes for advanced Electrolysers'
Contract type: Collaborative Project
Start date:. 01/01/2008 — **End date:** 31/12/2011
Duration: 48 months
Project total costs: € 4,535,000
Project funding: € 2,900,000

Coordinator contact details
Dr. Florence Lefebvre-Joud
CEA – Grenoble /LITEN
17 rue des martyrs
38054 Grenoble Cedex 9
France
Tel: +33 438 78 40 40
Fax: +33 438 78 25 56
Mail: florence.lefebvre-joud@cea.fr

List of participants/partners

Partner Name	Partner short name	Country
Commissariat à l'Energie Atomique et aux Energies Alternatives - Grenoble	CEA	France
Danish Technical University	DTU-Risoe	Denmark
European Institute for Energy Research	EIFER	Germany
Energy Research Centre of the Netherlands	ECN	Netherlands
Imperial College London	IC	United Kingdom
Topsoe Fuel Cell A/S	TOFC	Denmark
HELION - Department H_2 Energy AREVA	HELION	France

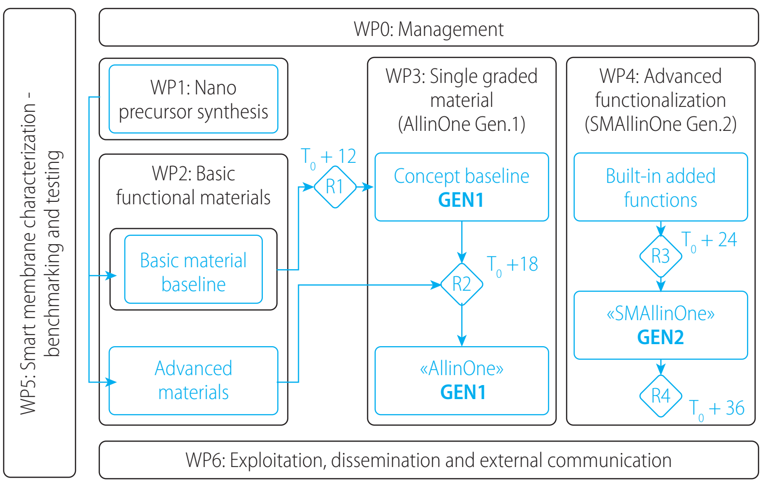
Project website: www.relhy.eu

Smallinone: Smart Membrane for hydrogen energy conversion: All fuel cell functionalities in One Material

The SmallinOne project addresses an architecture that strongly differs from the classical PEM fuel cell architecture. The catalysts and the membrane are deposited step by step on a porous substrate using vacuum techniques. It is aimed to obtain a graded material consisting, starting from the substrate, in a Pt finely dispersed anode nanocomposite layer gradually evolving in an acid groups rich membrane, and ending again with a catalytic cathode.This architecture can be compared to the 'top down integration' approach that is common in microelectronic. With respect to classical PEM fuel cells, this modifies drastically the morphology of the fuel cell materials.

The first issue we had to face was the synthesis of precursors suitable for the deposition of proton conductive membrane. Another issue comes from the synthesis of performing ionic membrane via vacuum techniques: the literature already reports various paths for depositing proton conductive membrane via vacuum techniques, however, these materials present ion conductivities far below from the actual target of 100mS/cm. Another challenge comes from the fact that both the catalyst and the proton conductive membrane should be made in the same vacuum tool, with is not obvious from a technical point of view since both processes strongly differs. The integration of these materials is especially critical: the synthesis method being totally different, the testing structure must be adapted, and especially the substrate for deposition of the MEA.

The project is highly ambitious and the diagram inserted below recapitulates the key milestones of the project:
In the light of the results, we think that the initial commercial targets of the project should be refocused on small scale, portable application rather than the more demanding automotive or stationary applications, with a particular emphasis on planar micro-power fuel cells for portable electronic devices. Indeed, the materials itself as well as the solution proposed for their integration might bring very interesting opportunities to miniaturize the systems. Regarding automotive or stationary application, we can point out various drawbacks for using vacuum deposited membranes, related to the low growth rate, cost and lack of mechanical stability. However, part of the material developed within the project might be of interest of stationary and automotive applications: even if the results we had with the composite catalyst materials do not reach the required, we still have a margin to progress, and the developed processes might be competitive, especially regarding the catalyst composites.



SMAllinOne PERT diagram

R1 Basic Materials properties
- Proton conductivity superior to 100mS/cm
- catalysts: specific surfaces superior to $100cm^2/cm^2$ and Pt load of 0..1mg/cm^2

R2 Allinone concept
Integration of the materials in a FC with an open circuit voltage superior to 500mV

R3 Optimized Allinone concept
OCV>800mV OK
Enhancement by a factor 10 if the power outputs
Indicative target: 100mW/cm^2

R4 Optimized Allinone concept
OCV>800mV OK
Indicative target: 1000mW/cm^2
Performances improvement from MEA improvement and 3D texturation

Information

Project reference: Grant agreement n° 227177-2
Call for proposals: 2008
Application Area: NMP4-ENERGY5
Project type: Collaborative project/ Small-scale focused research project
Topic: ENERGY.2008.10.1.2/ NMP-2008-2.6-1: Novel materials for energy applications (Joint Call)]
Contract type: collaborative project FP7
Start and end dates: 1st of April 2009 to the 31 of March 2012
Duration: 36 months
Project total costs: € 2 416 723
Project funding: € 1 825 000

Coordinator:
CEA LITEN DTNM
France
J. Thery: Jessica.thery@cea.fr

List of participants/partners

Partner	Beneficiary Name	Country	Role
1	CEA	France	Coordination and material developments
2	UNIBA	Italy	Material development via vacuum technique and precursor syntesis
3	BIU	Israel	Nanoprecursor synthesis
4	SIL	UK	Material developments via ASPD
5	IRD	Danemark	Material and Fuel cell benchmark / test
6	FMSP	France	Up scalability
7	ALMA	France	Administrative

Project website: http://www.smallinone.eu/

Nanodesigned electrochemical converter of solar energy into hydrogen hosting natural enzymes or their mimics (SOLHYDROMICS)

Key Objectives of the project

The project aims at the development of a photo-electrochemical device capable of splitting water into pure hydrogen and oxygen by exploitation of solar irradiation, with the **efficiency target of 10%, which is mandatory to achieve market penetration and serve the Hydrogen Economy**. A picture of the design concept of the device is provided in Fig. 1. It includes:

- an electrode exposed to sunlight carrying a water-splitting enzyme (PSII) or catalyst;
- a membrane enabling transport of both electrons and protons via e.g. carbon nanotubes or TiO_2 connecting the two electrodes and ion-exchange resins, respectively;
- a cathode carrying the hydrogenase enzyme or an artificial mimic to recombine protons and electrons into pure hydrogen.

Challenges/issues addressed

The time has come to establish an extensive research effort to develop concepts and technologies to exploit the enormous amount of solar energy which falls on our planet. **The annual global energy consumption rate at present is about 15 TW and will rise towards 20 TW within this decade. The rate of energy provided by solar radiation is over 100,000 TW**. At present **about 11% of global fuel demand comes from biomass (combustion and fermentation) while 85% is de¬rived from fossil fuels**. In terms of solar energy conversion the early stages of photosynthesis, including the water split¬ting reaction, are highly efficient, while the production of biomass is much less so. Hence, **the SOLHYDROMICS technology** is aimed at carrying out water splitting to get directly purified H_2 in an intensified system compared to that taking place in photosynthesis organisms. Therefore **SOLHYDROMICS has the potential to solve the problem of energy procurement for mankind and thus have an impact much broader than those hypothesised now for biofuels**.

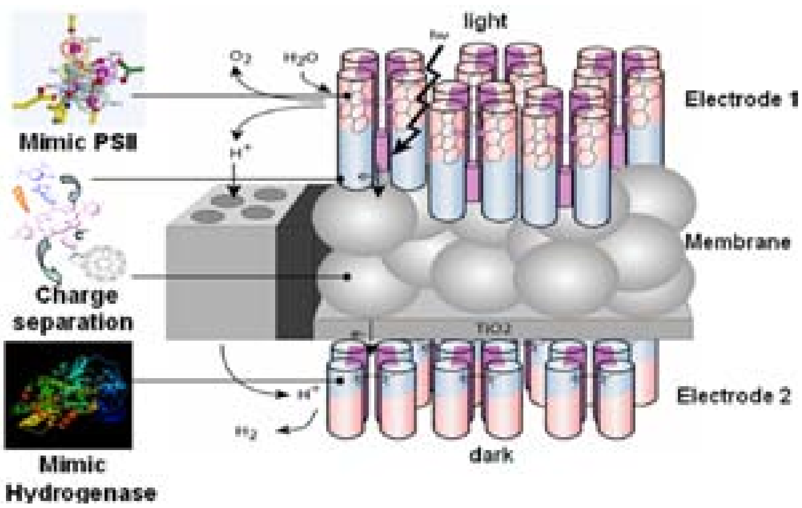


Fig. 1: Picture of the Solhydromics photo-electrochemical reactor

Fig. 2: The first Solhydromics prototype

Technical approach/objectives

The Solhydromics project work-plan is focused on the production of two photo electrochemical reactor prototypes. The first one, already delivered in February 2011 (Fig. 2), was based on natural enxymes (PSII and hydrogenase). In a sort of 'Frankenstein-type' device, the idea was to extract natural enzymes from plants and let them function in vitro in the water-splitting device after being deposited on to pristine FTO-based electrodes sandwiching a mixed-conducting membrane developed ad hoc. Despite successes with this approach the resulting device had limited stability owing to rapid deactivation of the water splitting enzyme. To overcome this problem, a second prototype will be delivered by June 2012, based on the same membrane-electrode assembly, but hosting inorganic catalysts mimicking natural ones (a Co-based catalyst for water splitting and a Pt-based one for hydrogen recombination).

Expected socio and economic impact

This project will pave the way to reducing the production cost of solar hydrogen below 5 €/kg, i.e. well below the current value of 7 €/kg currently achieved by Si-based photovoltaics coupled with an electrolyser. This is expected to give a step-wise change in the competitiveness of renewable hydrogen. With a solar light to hydrogen conversion efficiency of 10%, an average solar radiation input of 1000 kWh per m^2 in Europe, a lifetime of 20 years of the Solhydromics panels (i.e. a depreciation of 5% p.a.) and a money capitalization of 5%, one could afford costs up to 140 €/m^2 of the Solhydromics panels including the installation. This appears realistically achievable at a mass production stage if the following neighbouring technologies are considered:

- DSC photovoltaic cells: Today: 500 €/m^2, Projected 80 €/m^2
- PEM fuel cells for car applications: Today: 60 €/m^2; Projected 30 €/m^2

Information

Project reference: FCH JU
Call for proposals: FP7-ENERGY-2008-FET
Application Area: ENERGY.2008.10.1.1
Project type: Research and Technological Development
Contract type: COLLABORATIVE PROJECT
Topic: ENERGY
Start date: 01/01/2009 — **End date:** 30/06/12
Duration: 42 months
Project total costs: € 3.654.027,00
Project funding: € 2.779.679,00

Coordinator contact details

POLITECNICO DI TORINO
Corso Duca degli Abruzzi
24 10129
Torino - Italy
Prof. Guido Saracco
Tel: +39 011 0904618
Fax: +39 011 0904699
guido.saracco@polito.it

List of participants/partners

- NANOCYL S.A. – BE - julien.amadou@nanocyl.com, fluizi@nanocyl.com
- SOLARONIX SA – CH - toby.meyer@solaronix.com
- BIODIVERSITY SPA – IT - nicola.rota@biodiv.it
- HYSYTECH S.R.L. – IT - massimiliano.antonini@hysytech.com
- IMPERIAL COLLEGE OF SCIENCE, TECHNOLOGY AND MEDICINE- UK - b.alasya@imperial.ac.uk, g.gilardi@imperial.ac.uk, p.stanger@imperial.ac.uk
- HELMHOLTZ-ZENTRUM GEESTHACHT ZENTRUM FUR MATERIAL- UND KUSTENFORSCHUNG GMBH - DE - andrea.griep@hzg.de, mauricio.schieda@hzg.de

Project website: http://solhydromics.org/

Water Electrolysis at Elevated Temperatures (WELTEMP)

Key Objectives of the project

The strategic development of the WELTEMP project was an elevated operating temperature of the PEM electrolyser. This is expected to significantly improve the energy efficiency because of the decreased thermodynamic energy requirement, enhanced electrode kinetics, and the possible integration of the heat recovery. Key issues to achieve this strategic target were fundamental materials developments. Thus, the WELTEMP project should work on the development of active and stable anodic catalysts, temperature-resistant membrane electrolytes based on composite PFSA, and other polymers, as well as highly conducting and corrosion-resistant tantalum thin surface coatings as current collectors and bipolar plates. Based on these materials, the target working temperatures of at least 120°C should be demonstrated for single cells, and furthermore a setup for running and evaluating similar larger cells in stacks (kW-range) was to be built. In addition to this, research on development of alkaline PEM electrolysers, was also a part of the planned activities.

Challenges/issues addressed

It was initially intended to introduce phosphoric acid PBI membranes, known from 'high temperature PEM fuel cells' for steam electrolysis. However, sufficient durability was never obtained for any of the PBI containing membranes. The focus therefore changed to modification of PFSA membranes, attempting to improve their mechanical properties and their conductivity at temperatures above 120°C. For electrolysers working under steam conditions, the doping of the membranes with phosphoric acid.was an important step forward.

The temperatures above 120°C, and the acidic conditions in combination with the oxidative potential at the anodes, makes the conditions extremely corrosive here. Thin coatings of tantalum metal on cheaper steel material demonstrated very high corrosion resistance.

Technical approach/objectives

Important milestones were:

- M12: Selection of 'basemetals' for bipolar plates and current collectors
- M18: Selection of surface coating methods for bipolar plates and current collectors
- M24: Membrane types and MEA fabrication techniques finalized
- M28: Design of stack ready, Preparation methods of all materials ready
- M30: MEAs for final stack ready
- M32: Stack ready for test.

Expected socio and economic impact

Steam electrolysis on PEM cells was carried out, typically at 130°C. PFSA membranes was made conductive at such temperatures by phosphoric acid doping. Short side chain PFSA (Aquivion) showed the best performance performance. However, PTFE reinforced Nafion membranes were also prepared, showing even better performance when the cells were run under pressurised conditions (up to 10 bar, liquid water feeding).

The use of tantalum coatings on porous steel current collectors as well as on bipolar plates was important for ensuring sufficient chemical stability and good electrical contact.

A flexible setup for running and evaluating larger cells in stacks (kW-range) at elevated temperatures as well as pressures, was built at IHT.

In addition to this, significant progress was made within development of the alkaline PEM electrolysers, although working temperatures of only 60°C were reached for these systems. Such electrolyser cells was recently made commercially available by the Weltemp partner ACTA-Nanotech

Information

Project reference: FP7/FCH JU, Grant agreement no. 212903
Call for proposals: 2007
Application Area: Energy
Project type: Small or medium-scale focused research project
Topic: Energy-2007-1.2-01: New materials and processes for advanced electrolysers
Contract type: Collaborative project
Start date: 01/01/2008 — **End date:** 30/04/2011
Duration: 40 months
Project total costs: € 3.166.926
Project funding: € 2.377.940

Coordinator contact details:

Niels J. Bjerrum
Professor, Department of Energy Conversion and Storage, Technical University of Denmark,
Kemitorvet Build. 207, DK-2800 Kgs. Lyngby, Denmark
Email: njb@kemi.dtu.dk

Contact for communication: Erik Christensen, Senior Researcher, Department of Energy Conversion and Storage, Technical University of Denmark
Kemitorvet Build. 207, DK-2800 Kgs. Lyngby, Denmark
Email: erc@kemi.dtu.dk

List of participants/partners

Technical University of Denmark	Denmark (Coodinator)
Institute of Chemical Technology Prague	Czech Republic
The Norwegian University of Science and Technology	Norway
IHT Industrie Haute Technologie SA	Switzerland
Acta S.p.a.	Italy
Tantalum Technologies A/S	Denmark
Danish Power Systems ApS	Denmark
Institute of Macromolecular Chemistry ASCR,	Czech Republic

Project website: www.weltemp.eu

Nanostructured electrolyte membranes based on polymer / ionic liquids / zeolite composites for high temperature PEMFCs: ZEOCELL

Key Objectives of the project

ZEOCELL puts forward an innovative concept to overcome the current limitations of commercial available PEMFCs based on the use of multifunctional nanostructured materials, capable to withstand temperatures in the range 130º-200º C with the following properties:

- High ionic conductivity: higher or equal than 100 mS/cm at 150ºC.
- Suitability for operating at temperatures between 130-200ºC (the membrane materials are expected to be thermally stable up to 200ºC. Membrane performance will be validated on single cells at temperatures of at least 150ºC).
- Good chemical, mechanical and thermal stability up to 200ºC.
- Durable (<1% of performance degradation during the first 1000 working hours).
- Low fuel cross-over (<five times lower than Nafion methanol permeability lower or equal than $3x10^{-7}$ cm^2 s^{-1}).
- Reduced manufacturing costs (< 400 EUR/m^2).

Challenges/issues addressed

Cost reduction seems to be the main challenge to a widespread PEM Fuel Cell commercialization, which is based on four main pillars with strong interdependencies: i) manufacturing costs reduction through the use of new materials with lower costs and suitable for mass production; ii) efficiency increase to allow reducing operation costs and equipment size through the use of new materials with improved properties or new concepts for stack configuration; iii) durability increase; and iv) fuel availability to become a real alternative to fossil fuels. The advantages of high temperature Polymer Electrolyte Membrane (PEM) fuel cells include the simplifications of the balance of plant, the generation of more useful high-grade waste heat and improvements in the catalyst activity. Starting from the well-known PBI polymer, Zeocell pushes the 'state of the art' with the development of nanostructured electrolyte membranes based on the synergic combination of porous PBI, protic ionic liquids and microporous inorganic nanocrystals. The final aim is to use the advantages of each primary building block by choosing a proper electrolyte membrane configuration.

Technical approach/objectives

ZEOCELL puts forward an innovative concept to overcome the current limitations of commercial available PEMFCs based on the use of multifunctional nanostructured materials, capable to withstand temperatures in the range 130º-200º C. Seven electrolyte membrane compositions have been studied. As the polymer membrane architecture plays the key role to ensure proton transport through heterogeneous media, dense and porous (random or straight pores) PBI films have been deployed as proton conductor supports. Phosphoric acid doping and/or protic ionic liquid embedding have been mainly studied in the project. The incorporation of microporous materials either as inorganic fillers to the membrane casting solution or as thin film coatings onto pre-existing porous PBI membranes has been considered. To gain insight the synergic effects provided by materials combination, different membrane categories, ranging from 1 component (i.e. Pure Polymeric Ionic Liquid Films), through binary (supported ionic liquid membranes in track-etched porous PBI substrates, supported ionic liquid membranes in randomly porous PBI substrates, reinforced polymeric ionic liquid membranes on porous PBI supports, acid doped track-etched porous PBI substrates), ternary composites (hybrid acid doped dense or porous PBI and hybrid dense or porous PBI embedding ionic liquid) to the final nanostructured electrolyte membranes based on four components (i.e. PBI, phosphoric acid, ionic liquid and microporous materials) have been deeply studied.

Expected socio and economic impact

ZEOCELL was dedicated to basic research on nanostructured electrolyte membranes with the aim of reducing cost and improve performance of PEMFCs. Accordingly, ZEOCELL has contributed to strength the European scientific and technological base in fuel cell energy research. The main outcome from ZEOCELL is the development of three novel electrolyte membranes fulfilling all the requirements originally claimed for high temperature PEM fuel cells in stationary applications with the exception of durability issues.

The manufacture requirements have been present throughout the project as a criterion to guide the research and development to obtain a PEM able to be mass manufactured in market competitive conditions. The preliminary industrial evaluation of the basic materials proposed in the project (i.e. PBI, protic ionic liquids and zeolites/zeotypes) reveals that neither raw material and energy costs, nor chemicals availability are limiting factors for the commercialization of membranes significantly cheaper than the commercially available membranes for HT applications. Furthermore, the principles of Green Chemistry have been followed to synthesize selected ionic liquids in good agreement with the requirements for a safe and efficient large scale production. Finally, our assessment of intellectual property on the basic materials used indicates that they shouldn't be an obstacle for a potential implementation at industrial level.

Information

Project reference: Grant Agreement nº 209481
Call for proposals: ENERGY.2007.1.1.1
Application Area: Basic research for materials and processes for Polymer Electrolyte Membrane Fuel Cells (PEMFC)
Project type: Basic Research
Topic: Basic research for materials and processes for Polymer Electrolyte Membrane Fuel Cells (PEMFC)
Contract type: Collaborative
Start date: 01/01/2008 — **End date:** 31/12/2010
Duration: 36 months
Project total costs: 2.655 k€
Project funding: 1.917 k€

Project Coordinator name:
Dr. Jesús Santamaría (Dr. María Pilar Pina)

Project Coordinator organisation name:
Institute of Nanoscience of Aragon (INA)
University of Zaragoza (UNIZAR).
Mariano Esquillor s/n. 50018. Zaragoza (SPAIN).
jesus.santamaria@unizar.es (mapina@unizar.es)

List of participants/partners

Participant Nr	Beneficiary Name	Short	Country
1	Institute of Nanoscience of Aragon (University of Zaragoza)	INA	Spain
2	Centro de Tecnologías Electroquímicas	CIDETEC	Spain
3	University of Twente	UTWENTE	The Netherlands
4	Foundation for Research and Technology Hellas / Institute of Chemical Engineering and High Temperature Process	FORTH	Greece
5	Centro Ricerche FIAT	CRF	Italy
6	Solvionic, S. A.	SOLVIONIC	France
7	Celaya Emperanza y Galdós, S. A. / Celaya Emperanza y Galdós Internacional, S. A.	CEGASA	Spain

Project website: http://ina.unizar.es/zeocell/default.htm