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European Fuel Cell and Hydrogen Projects 1999-2002

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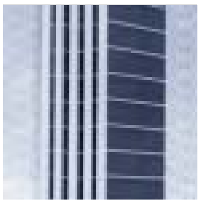

IP-SOFC Multi-cell Modules.

Scale-up of the IP-SOFC to multi-tens of kW level

MF-SOFC

Objectives

In the late 1980s Rolls-Royce undertook an evaluation of fuel cell technologies and concluded that the Solid Oxide Fuel Cell (SOFC) was likely to be the most competitive fuel cell technology for stationary power generation applications. Rolls-Royce developed the Integrated Planar Solid Oxide Fuel Cell (IP-SOFC) which combines the benefits of conventional planar and tubular approaches. The concept is based on series connected cells fabricated on a fuel carrying porous support tube. The MF-SOFC project aims to scale-up the technology from kW to tens of kW.

Problems addressed

The project covers a wide range of challenges which need to be resolved to allow successful scale-up. The work packages of the project focus on the areas of stack design, scale-up of manufacture, cell performance, mechanical modelling and testing.

Project structure

The consortium brings together the wide range of skills and experience required to achieve the goal, from fundamental materials science to end user knowledge.

Advanced Ceramics Limited, a ‘Small to Medium Enterprise’, has extensive experience of technical ceramic manufacture and, within this project, is responsible for the implementation of technology to prove the concept and capability of production scale-up. The cell development effort has been carried out in close collaboration with Risø National Laboratories. Risø have many years of experience in SOFC research and development and there is a long history of collaboration with Rolls-Royce spanning several EC programmes. Extensive studies were carried out at Imperial College London with the objective of assessing and improving the mechanical reliability of the cells and stacks in both manufacture and operation. Work on module and stack testing has been led by Gaz de France (GdF). As one of the worlds largest public service utilities, GdF has extensive knowledge of end users’ requirements, ensuring commercial imperatives are taken into account.

Expected impact and exploitation

Extensive market and system studies have concluded that capital cost targets for the stack and system would be best met by a pressurised hybrid system at 1MW scale. This work also showed that the most important parameters in reducing system cost ($/kW) is stack volume (kW/litre) and correspondingly weight. An evaluation of the first generation multi-channel support module in this context revealed that an improvement in stack volumetric power density was required to meet the cost targets. An agency company Roll-Royce Fuel Cells Systems (RRFCS) has been formed to bring this technology to commercialisation. This company is wholly-owned by Rolls-Royce plc and draws support from a number of internal organisations for specific services in research and development, finance, quality and human resources. This project forms an essential first stage in the move from technical evaluation to technology scale-up. Results will be fed directly into the development programme of RRFCS with the aim of a commercial 1MW pressurised hybrid product.

Progress to date

The support structure was re-worked resulting in a revised concept based on tubes with significantly reduced thickness. These tubes are manifolded in a serpentine arrangement. A major advantage of this design is its ability to provide overall geometrical compliance, even if built from stiff ceramic materials. This broadens the range of concepts that can be used when manifolding the bundles into larger stack units or ‘strips’. The strips each produce several kW and the MF-SOFC stack will consist of an array of these strips. Strip level manifolding requires an order of magnitude less components than would otherwise be required to manifold individual tubes if the serpentine bundle design was not used.

An investigation was carried out to evaluate the applicability of ceria-NiO anodes in the IP-SOFC concept. Modules containing both YSZ and ceria

Testing facilities at Gaz de France in Paris used to evaluated IP-SOFC Multi-cell Modules.

Results of Stress Analysis of Bundle Assembly: Modelling carried out at Imperial College London.

based cermets were studied and detailed comparison between the two revealed that the Ni-CGO anode gave only a slightly improved performance over those based on Ni-YSZ. The Ni-CGO was more active than Ni-YSZ for direct CO oxidation, whereas there was little difference between them when operating on H_2-CO_2 mixtures, where a mixture of H_2 and CO would be present. This suggests that Ni-YSZ anodes should be suitable for operating on reformed hydrocarbon mixtures, provided that they display sufficient durability. Work has also been carried out to optimise the cathode microstructure. This work has revolved around manipulation of the composite and current collecting layers. This has resulted in stable structures that have exhibited excellent durability. Similar levels of durability have been demonstrated in module tests.

Mechanical analysis modelling has been used to compute the stresses induced in the modules and bundles resulting from the thermal fields or misalignments in manufacture. The analysis is fully elastic and requires as input the measured values of the elastic moduli of the constituent materials. This analysis has proved invaluable in the verification of the module and stack design under a range of operating conditions. This work is carried out in parallel to the stack design activity. Utilisation of these tools have provided a direct link to further steer the design process and provide critical input into the final design for modules and bundles.

During the initial stages of the programme, parallel testing facilities were set up in the UK and France. Both testing facilities allow detailed experimentation to be carried out and the multi-cell modules can be evaluated in a computer-controlled system under an extensive range of gas compositions and flow rates. The test results obtained in the two facilities showed good correlation for open circuit voltages and when tested under load. Each facility has used modules fabricated in a similar manner and the similar test results provide a high level of confidence in the validity of the testing procedure. The testing programme also showed an excellent reproducibility. This has provided confidence in the baseline upon which the effect of changes in design or manufacturing process can be evaluated. Test results have shown the effect of fuel flow on performance for the higher power density module design. The dependence on fuel flow is markedly less than experienced with the multi-channel design. The results showed very little performance improvement above very low fuel flow rates. Extrapolation of results of dilution studies from single module to bundle size indicate that 75% fuel utilisation is achievable under commercial operating conditions.

INFORMATION

References: ENK5-CT-1999-00003

Programme:
FP5 - Energy, Environment, Sustainable Development

Title:
Scale-up of the IP-SOFC to multi-tens of kW level (MF-SOFC)

Duration: 42 months

Partners:
- Rolls-Royce Fuel Cells Systems (UK)
- Risø National Laboratory (DK)
- Imperial College of Science, Technology and Medecine (UK)
- Gaz de France (F)
- Advanced Ceramics (UK)

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Status: Ongoing

Photo-rendered impression of packaged 20kW SOFC system with footprint 1.6 x 0.8 m^2.

Compact, low-cost power plant based on planar SOFC

PROCON

Objectives

Solid Oxide Fuel Cells (SOFC) offer the highest electrical efficiencies of all the fuel cell types when operating on natural gas so they could play an important role in reducing CO_2 emissions. To be commercially attractive, SOFC systems must be designed to reduce plant size and complexity and minimise the cost and numbers of components that make up the complete balance-of-plant. Realising these low-cost concepts requires an integrated approach to SOFC stack and system development.

Currently the main cost component of a SOFC system is the stack. Planar stack geometries offer high power densities and potentially low manufacturing costs, which can be further reduced if the operating temperature can be lowered sufficiently to allow the use of stainless steels in their construction. The objective of this project was to test the feasibility and performance of a novel, planar SOFC stack operating at reduced temperature and to investigate its integration into a compact and low-cost power plant design.

Challenges/Problems addressed

There remain several important technical hurdles to be solved, but the key to the future commercial success of SOFC systems will be their cost. SOFCs based on planar cells offer the potential for high power densities and cost-effective manufacturing. A significant boost to the reduction in cost of planar SOFC would be achieved if readily available and easily formed metals, such as ferritic stainless steels, could be used for the interconnect plate and gas manifolding. However, the problems of high temperature corrosion mean this is only realistic if the stack operating temperature is reduced to temperatures below around 800°C.

One route to achieve this temperature reduction is to use anode-supported-cells. Conventionally, planar cells use the electrolyte to support thin electrodes on either face. This limits minimum electrolyte thickness to around 150 μm. By using a thick, structural anode, much thinner electrolytes can be used with a concomitant reduction in cell resistance. Work at Forschungszentrum Jülich, as well as elsewhere, indicates that anode-supported cells will enable stack-operating temperatures around 750°C compared to the 900°C necessary for electrolyte-supported, planar cells. As well as lower stack costs, reduced temperature stack operation should also allow a reduction in balance-of-plant costs, by enabling lower cost components, such as heat exchangers, fans and compressors, to be specified.

To exploit the real benefits of planar SOFC stacks, they must be integrated into compact, low-cost systems offering high overall efficiencies. This requires the investigation of innovative system cycles and the specific design of components in order to achieve the necessary level of integration.

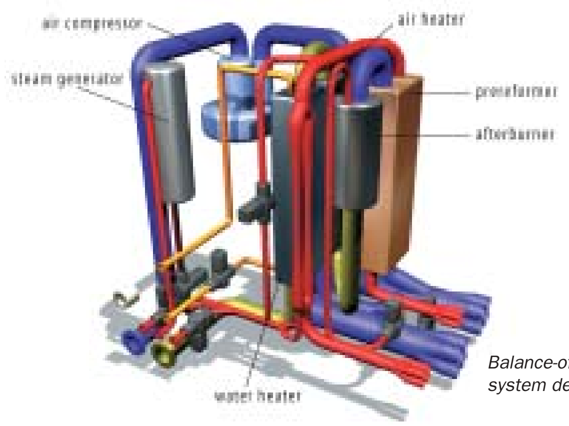
Project structure

The project consortium consisted of ALSTOM Research and Technology Centre (ART, part of the ALSTOM T&D Sector), Forschungszentrum Jülich (FZJ) and Prototech AS. Based on the target of a compact, efficient 20 kW SOFC system, the partners derived and modelled plant concepts that would meet the initial specification for the unit. The selected design and flow sheet data provided the basis for the ongoing system design and analysis. In parallel, an SOFC stack module based on an anode-supported cells concept was developed in preparation for a proof-of-concept test at the 5 kW-scale. As well as project co-ordination, the role of ART was to develop a dynamic model of the SOFC system for control and operability studies and to investigate the design of the DC/AC converter. Prototech's responsibility was the conceptual design of the 20 kW system and to perform the detailed engineering of key system components, namely the natural gas reformer and recycle ejectors. The role of FZJ was to investigate the design of the 20 kW SOFC module, comprising 4 X 5 kW stacks. In parallel, FZJ performed the detailed engineering of the 5 kW stack and produced the fully instrumented rig for the subsequent test.

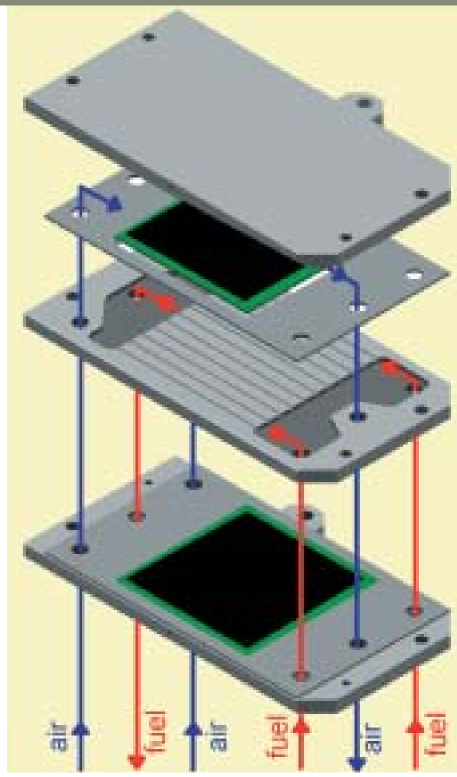
The project was supported by the ongoing programme of development at FZJ on an SOFC stack based on anode-supported cells, including work on the BMWi-project, Zellen und Stacks (ZEUS).

Expected impact and exploitation

With predicted electrical conversion efficiencies above 50%, SOFC systems should be significantly more efficient than conventional generating technologies. SOFC plant is therefore expected to make more efficient use of fossil fuels and cut emissions of CO_2. Other emissions of pollutants



Balance-of-plant layout for 20 kW system design.



Schematic of E-design stack based on 20 cm x 20 cm anode-supported cells, with internal manifold.

(UHC, SO_X, NO_X and CO) should also be at least an order of magnitude lower than those from combustion-based generators.

The ongoing deregulation of electricity markets is being accompanied by a move from centrally generated electricity towards distributed energy resources (DER). This movement offers the consumer a number of potential advantages including reduced energy costs and security of supply. SOFC systems should be ideally suited to the distributed generation market with their high efficiency at full and part-load. There is also the opportunity to use the high grade exhaust heat in co- or tri-generation mode.

The technology is still several years from commercialisation, but the successful results from this project contribute to the growing European Research Area in SOFC and establish the EU as a leading player in this emerging technology.

Results

A conceptual 20 kW SOFC system has been designed based on a specification for a grid-connected generator that is compact and potentially low-cost. Novel recycle loops for the anode and cathode exhaust gases have been included which ensure high system efficiency and reduce the system size. A detailed dynamic model of the system has been developed which includes simulated control loops, which demonstrate the robust and controllable operation of the system at full and part-load, as well as start-up from cold and safe shutdown.

Detailed engineering of key components of the conceptual 20 kW system has also been performed. This includes a novel, natural gas pre-reformer; ejectors for exhaust gas recycling and the power conditioning system that will enable connection of the system to the grid.

In parallel with the system development, an innovative SOFC stack module has been designed and its performance modelled. The stack module is based on a planar SOFC stack using anode-supported cells, which is designed for operation at temperatures below 800ºC. A fully instrumented test facility has been designed, built and commissioned. To date, performance of a 40-cell stack giving outputs up to 5.4 kW on reformed methane has been demonstrated.

The project results demonstrate that cost-effective and very compact SOFC systems can be developed that are based on intermediate temperature SOFC stack technology. Further work must continue to address issues of stack reliability and lifetime as well as cost reduction through design and manufacturing scale-up.

INFORMATION

References: ENK5-CT-1999-00026

Programme:
FP5 - Energy, Environment and Sustainable Development

Title:
Decentralized Power Generation Plants based on Planar SOFC Technology; Proof of Concept (PROCON)

Duration: 31 months

Partners:
- ALSTOM Research and Technology Centre (UK)
- Forschungszentrum Jülich (D)
- Prototech (NO)

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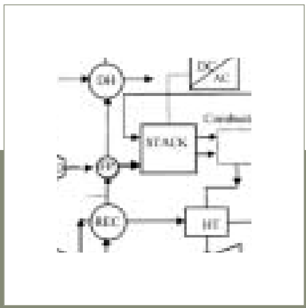
Status: Completed



Integrated modelling study of FC/GT hybrids

IM-SOFC-GT

Objectives

Fuel Cell/Gas Turbine (FC/GT) hybrid systems can dramatically improve both local and global environmental impact of power generation. This is achieved through their near-zero emissions of NO_x, SO_x, CO and particulates, low noise characteristics and their potential to generate electricity at efficiencies above that of large conventional generation plants.

The main objective of the project is to develop the capability to assess the performance of FC/GT hybrids using a close integration of system and stack models and set performance requirements for FC/GT hybrid based generation systems through a technology characterisation. A wide range of system configurations is explored to find solutions with a balance of system efficiency, low emissions and low cost.

Challenges

The project focuses on stationary power generation systems primarily fuelled with natural gas. Three types of sub-systems are considered for atmospheric and pressurized configurations: sub-MWe high efficiency distributed generation systems, 1-3MWe systems suitable for CHP schemes and 20-30MWe power systems. The development of different complex cell models is necessary to perform the integration between cell and conventional hybrid system components. Thus, generic and detailed (finite volume) cell models are adapted to Rolls-Royce FC technology and they require proper validation against experimental data.

The system modelling work focuses on cell model integration, turbo-machinery, heat exchangers and other components. Co-operation between gas turbine manufacturers, utility companies and modellers has been essential to bring a wide range of on- and off-design data for the three power size ranges.

Finally, the project assesses how market pressures map into product requirements.

Project structure

The project consortium consists of 10 partners from four different EU countries plus Switzerland. Two Universities: Genova and Lund; one FC stack manufacturer Rolls-Royce Fuel Cell Systems; two utility companies: ENEL Produzione Spa and Sydkraft AB; four GT manufacturers: Turbomeca SA, ABB Turbo Systems Ltd, Alstom Power Sweden AB and Turbec AB; and one consulting company: PA Consulting Group.

The project is centred on four main activities: stack modelling capability, system modelling capability, system concept design and performance requirement.

The performance requirement activity analyses all of the economic, commercial, operational and environmental data/methods, helps characterize the technology and defines the performance requirements of future FC/GT hybrids. The stack modelling capability activity adopts a progressive approach to develop and validate a tool for stack modelling. The system modelling activity develops a tool for both on and off-design performance of integrated systems based on FC/GT hybrids. The system concept design activity generates preliminary systems designs to meet market requirements provided by the performance requirement activity.

The project has required a very close co-operation between these four activities to deliver useful results.

Expected impact

This represents the first overall system design of SOFC/GT hybrids performed in cross-European co-operation between manufacturers of both FC and GT, universities and end-users.

The latest technology of hybrid concepts is applied to the design of FC systems intended as commercial products. The models are validated using experimental data from the Rolls-Royce Integrated Planar SOFC stacks. Detailed market information is used in combination with the latest stack and component technologies to steer system development towards commercially attractive SOFC/GT hybrid designs.

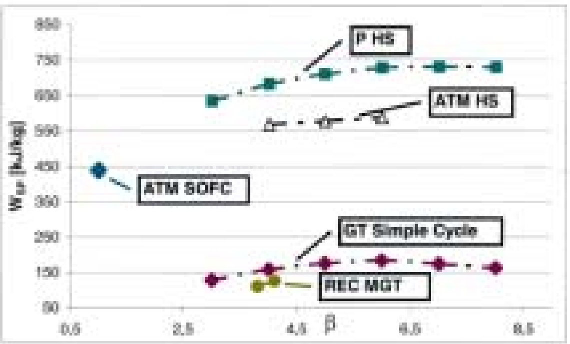


Figure 1: Systems comparison; Specific Power (W_{sp}) vs Pressure ratio ß.

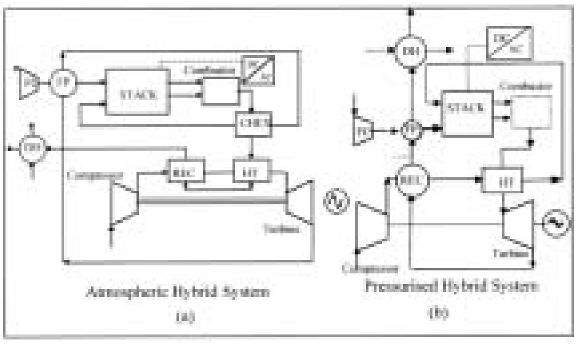


Figure 2: System Layout.

The suppliers of energy system components, end-users and universities will gain an improved understanding of the technology and economy of FC/GT hybrid based power generation systems. Importantly, it will be possible to formally express strategic objectives to develop such hybrid systems and the three main sub-systems identified in this project: sub-MWe, 1-3MWe and 20-30MWe.
This project will increase the competitiveness of European clean SOFC technology and accelerate the market introduction of the FC/GT hybrids.

Results

The project will be completed by the end of July 2003.
A first result has been obtained by comparing pressurized hybrid systems (P-HS) with atmospheric hybrid systems (ATM-H) and other power plants, see Figure 1 showing specific power [kWe/(kg/s)$_{air}$] versus pressure ratio b. The main characteristic of P-HS is their higher specific power than the other systems. This is mainly due to the very high efficiency of the pressurised fuel cells. Also, the high value of specific work denotes a more compact hybrid system design.
A second set of results has been obtained from a more detailed comparison between P-HS and ATM-HS in the 1-2MWe power size range. The layouts of the complete plants (atmospheric and pressurised) are shown in Figure 2 (a) and (b).
First, P-HS have less critical components than atmospheric plants. The main constraints are related to the compatibility between the characteristics of the exhaust gases of the Fuel Cell stack and the flow properties required for the turbine. In particular, the water content in the expanding flow is higher than the typical value for standard turbo-machinery. This has already been addressed with steam injection or humid cycle. In addition, the turbine inlet temperature must agree with the technological limit for small sized un-cooled gas turbines (about 900-950°C).
Second, the efficiency of the pressurised system is more than 10% higher than the atmospheric one.
Finally, the ATM-HS has more stringent technological constraints related to the high temperature heat exchanger design. The heat exchanger will require high cost material and manufacture processes.

In conclusion, the main result of this work is the evident superiority of the pressurised configuration versus atmospheric, in terms of efficiency, specific power and cost of electricity.

INFORMATION

References: ENK5-CT-2000-00302

Programme:
FP5 - Energy, Environment and Sustainable Development

Title:
Integrated Modelling Study of FC/GT Hybrids (IM-SOFC-GT)

Duration: 30 months

Partners:
- Rolls-Royce (UK)
- Turbec (S)
- ABB Turbosystems (CH)
- Turbomeca (F)
- Sydkraft (S)
- University of Genova (I)
- University of Lund (S)
- Alstom Power (S)
- ENEL Produzione (I)
- PA Consulting Group (F)

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Status: Ongoing

SOFC stack as used for teaching purposes.

CORE-SOFC increases stack life

CORE-SOFC

Objectives

The Solid Oxide Fuel Cell (SOFC) consists of a dense solid electrolyte and two porous electrodes in contact with an interconnect on either side. The electrochemical electrode reactions occur near the interfaces with the electrolyte, i.e. oxygen reduction in the cathode and hydrogen oxidation in the anode at temperatures of 1000°C or below. SOFCs can be realised in planar or tubular designs. Recent developments tend towards cost-effective planar concepts that have thin electrolytes allowing lower temperature operation and cheap and commercially available metallic interconnects. In particular, this project aims to improve the component reliability (giving the acronym CORE) of planar SOFC systems using ferritic steels as interconnects for cost competitive reasons, and in general, to demonstrate a loss in performance of less than 0.75% per 1000 hours of operation during long-lasting experiments, including thermal cycling under realistic operating conditions.

Problems addressed

It is widely recognised that the degradation rate of an SOFC should be significantly below 1% voltage loss per 1000 h of operation time as when stationary applications like small power plants or remote power supply stations are envisaged. The proposed project focuses exclusively on planar SOFCs with 10-30 μm thin film electrolytes and with metallic interconnects and stacking parts, for which, however, the low degradation rate still needs to be demonstrated. The main technological drawback of such very efficient fuel cell systems is a degradation rate in the range of 2-20% during stack tests. It has been realised that the long-term behaviour of the interconnect material plays a crucial role in SOFC stack operation. Therefore the corrosion behaviour and the interaction of the metallic interconnect materials with adjacent ceramic components are of special concern in the project. However, the materials selection is only the first step towards the verification of durable performance of an SOFC stack. Therefore the electrochemical and mechanical stability of the SOFCs used in this project are investigated. The combination of the fuel cells with the interconnect materials are tested in contact resistance measurements and electrochemical endurance tests. It is an additional aim of the project to minimise the electrical resistance at the metal/ceramic interfaces reaching a contact resistance of less than 50 mW/cm^2. Furthermore, the mechanical assessment of SOFCs helps to pinpoint critical design issues and lead to stacks that can withstand thermal cycles.

Project structure

The three leading research centres of SOFC technology in Europe – Forschungszentrum Jülich, ECN Petten and Risø National Laboratory – are the main project partners. Due to the advanced fabrication facilities at ECN in a pilot plant scale, the project benefits from fast and “uniform” fuel cell production. A further contribution of ECN is test rigs for long-term reliability tests and contact resistance measurements. Risø with their long experience in fuel cell development are well equipped with electrochemical testing facilities and with metallographic characterisation methods, which are indispensable for the oxidation studies in this project. Jülich delivers the interconnects and contact layers and has sophisticated mechanical testing rigs available, with which the thermal cycling of cells and stacks and also *in-situ* observations are possible. Jülich has made significant progress during the recent years in construction and assembling of fuel cell stacks and provides the test facility for stack tests to prove the achieved long-term stability under oper-ating conditions.

Haldor Topsøe and Rolls-Royce, both involved in fuel cell development, supply ceramic powders and stacks to the project, respectively. Whereas Haldor Topsøe’s perovskite powders are used for the fabrication of cathodes and cathode contacts, Rolls-Royce is concerned with improving the performance and lifetime of their stacks.

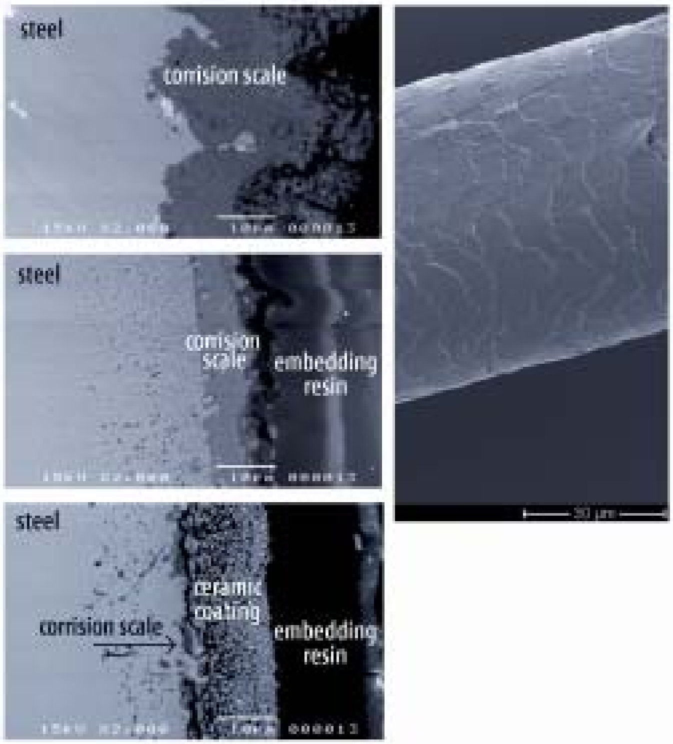

Figure 1: Left-hand side from top to bottom: Two steels and one steel sample coated with a porous ceramic layer after exposure in air at 850°C for 1000 h. Even the worst corrosion scale (top image) having a thickness of 10 µm is about six times thinner than a human hair shown on the right side for comparison in the same magnification.

Expected impact and exploitation

Reduction of degradation rates in SOFC stacks has a substantial impact on the commercial viability of SOFC systems. As an example of small SOFC systems for residential applications, it is expected that the fuel cell stack will comprise approximately 30% of the total system cost. A reasonable expected system cost for a 1 kW system is approximately 1000 €. If a 2-year (17,500 hours) stack life is considered, then the present value of stack replacements, assuming a 10% rate of return, over a 10-year period will be about 270 €. By comparison, a 50,000 hour stack life yields a present value of stack replacements of approximately 130 €. The 140 € difference, when compared to a 1000 € system cost, is significant and therefore reduction in degradation rates is critical for the economic success of SOFCs in residential applications. However, this example gives only an estimate of the financial difference. The truth is, that neither in household nor in industrial applications is it acceptable to exchange the SOFC every two years or even earlier. In such a case the reputation of the producer of heaters, power plants or cars will be strongly dam-aged and will cause severe problems with the overall business of the respective company.

Progress to date

Although the first technical objective, the use of commercially available ferritic steels, sounds simple, the first year of the project has shown that it is much more difficult than expected because either applicable interconnect materials are often only available when an order of more than 50 tons is placed or the geometry of the available semi-finished products is not suitable for the tasks in the project. From the 6 steels used in the project, it is expected that one or two steels will be good candidates to achieve low ohmic resistances due to the low contents of Al and Si in the alloy.

Combinations of interconnect/ceramic contact layers have been tested electrochemically and in oxidation exposure experiments. Apart from the steels two of the considered contact layer mate-rials show a smaller reaction zone with these two steels than the other contact materials (see Figure 1). During the coming months it will be decided with which materials a final long-term stack test will be performed.

Currently the electrochemical operating conditions for the ECN cells are varied and especially for the anode compartment, the use of different fuel gases and fuel utilisation are of special concern. Three different anode-supported cells were investigated by mechanical methods to determine the fracture stress and the critical defect sizes that may lead to failure. Significant differences by a factor two in the modulus of rupture were found. Initial model stack tests showed that the curvature of the cells does not change as long as the sealing material remains intact.

INFORMATION

References: ENK5-CT-2000-00308

Programme:
FP5 - Energy, Environment and Sustainable Development

Title:
Component Reliability in Solid Oxide Fuel Cell Systems for Commercial Operation (CORE-SOFC)

Duration: 42 months

Partners:
- Forschungszentrum Jülich (D)
- Energieonderzoek Centrum Nederland (NL)
- Risø National Laboratory (DK)
- Haldor Topsøe (DK)
- Rolls-Royce (UK)

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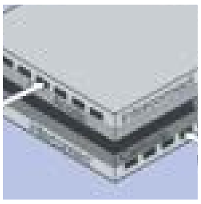
Status: Ongoing



SOFC stacks by using advanced spray techniques

CEXICELL

Objectives

Solid Oxide Fuel Cells (SOFC) enabling the direct conversion of the chemical energy of hydrocarbons into electricity are drawing increasing interest as a power generation system. They posses high power generation efficiency (up to 70%), which is the highest conversion efficiency compared with any of the other developed fuel cells.
SOFC could be used today in big, high power applications including industrial and large-scale central electricity generating stations. Some developers also see SOFC use in motor vehicles and are developing fuel cell auxiliary power units.
The objectives of this project are to reduce the cost of SOFC cells by at least 50% through the development of cost effective high performance planar-type SOFCs by optimisation of their fabrication using the advanced and cheap thermal deposition (spray) techniques.

Challenges/Problems to be solved

Strong effort on research and development on the SOFC technology has led to production of system prototypes for demostration but no commercial units or even prototypes based on the SOFC technology will be produced in Europe by 2010. The main issues for fast commercialisation of fuel cells remain the high manufacturing cost and the lifetime of the system. Today, we can assume that to manufacture a SOFC, it is necessary to spend about 3000 €. For wide use of SOFC the price of 1 kW should be at least below 1500 €.
The objectives of this project are to demonstrate the potential to reduce the manufacturing costs of SOFC cells from more than 3000 €/kW to less than 1,500 €/kW by using advanced thermal spraying techniques. This project targets lowering the manufacturing cost of 11-13 cells necessary for a 500 W SOFC stack to about 500 €.
In order to achieve this general objective, the first task of the project will be to develop new powders to be used to develop the material of the fuel cell elements. These powders should allow the deposition of material such as Ni(O)-ZrO_2 for the anode, YSZ for the electrolyte, $La_{1-x}Sr_xMnO_3$ for the cathode, LaMn/CoO_3 and $La_{1-x}Sr_xCrO_3$ as auxiliary coatings etc. Thereafter the objective will be to develop coatings by advanced thermal spray techniques.

Technical target

The coatings developed by advanced thermal spray techniques should have the following properties:
Electrolyte:
- Closed Porosity
- Gas Tight at <50micron thickness
- Leakage rate<10^{-4} mbar l/ (cm_s)

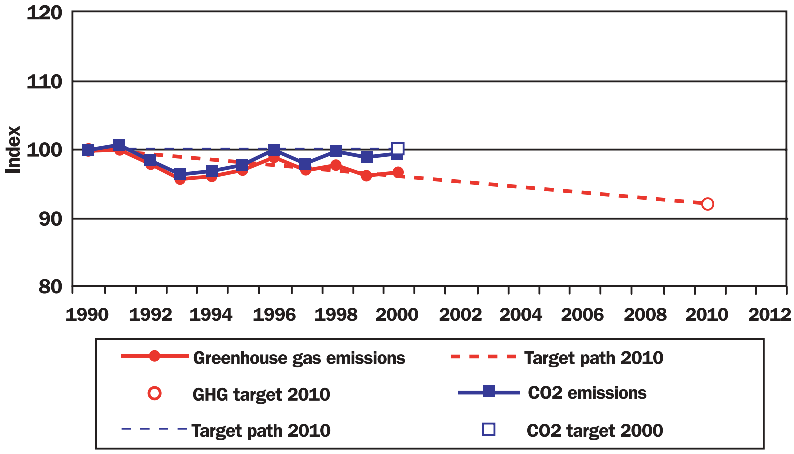
Anode and cathode:
- >25 vol.% porosity
- Electronic conductivity at 800ºC>10^4 S/cm
- Dimensional integrity and lack of distortions
- Interlayer contact and low resistance (ASR<1 Ohm.cm)

Interconnecting coatings:
- Dense layer (<1%) with high conductivity
- Chemical stability in the working environment

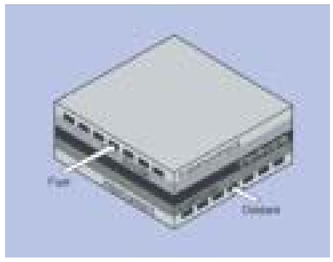
The targeted properties of SOFC cells and stacks for stationary application are as follows:
- Cells 100x100 mm (each cell having a min. 45W power at 800ºC, 0.7 V)
- Operating temperature: 800ºC
- Voltage: 0,7 V
- Current density: 0,7 A/cm
- Stack power: 500 W (11-13 cells)
- Degradation: <1% / 1000 h
- Overall efficiency >80%

Project structure

The achievement of the goals described calls for multi-disciplinary and complementary actions. In this respect, this project needs to associate the many different competencies which are included in this consortium.
The consortium comprises 5 partners from 4 different countries (Spain, Switzerland, Germany and France). The consortium is thus well balanced in terms of the European dimension, but also in terms of complementary expertise (technology providers, R&D centres and end-users).
Previous collaboration exits between the different partners in bilateral ways, but this European project will be a major step for the treatment of the solution at the continental level, and will increase profitable networking in this domain.



Total EU greenhouse gas emissions in relation to the Kyoto target.



The three components of a solid-oxide fuel cell form a modular unit that can be connected to other cells in a fuel cell stack.

Expected impact

This project wil allow more effective and cost effective use of SOFCs for stationary applications (indutrial application and household applications). It will have direct impact on:

- Green House Gases (GHG) emissions reductions: FC systems emit only small amounts of GHG.
- Energetic efficiency of energy supplying systems: SOFC produces electricity but heat produced could also be used for Combined Heat and Power co-generation.
- Security of Energy supply in Europe: SOFC uses gas as fuel. Russia, Norway and UK are the main European gas producers and suppliers. Strong relations between EU and Russia especially in the energy area has been initiated in the last three years.

The objectives of the project are in accordance with the Energy, Environment and Sustainable Development Programme: RTD on SOFC and related technologies such as reformers and hydrogen technologies for transport, co-generation in buildings and decentralised electricity production, that should aim at a strong cost reduction in order to achieve a comparable or lower cost than for conventional technologies and substantially lower CO_2 and pollutant emissions.

Progress to date

To date the project has achieved the first objectives. The main tasks were the following: Selection of the materials to be used for fabrication of the coatings for electrolyte, cathode and anode; definition of the thermal spray techniques and parameters to be applied to produce coatings with the necessary structural characteristics; the specification of the fuel cell stack design and the development of the substrate of the SOFC. Now in the second phase, the work is focused on the development and characterisation of spray powders with chemistries already defined and on morphologies suitable for the envisaged coating properties.

INFORMATION

References: ENK5-CT-2002-00642

Programme:
FP5 - Energy, Environment and Sustainable Development

Title:
SOFC Stacks by using Advanced Spray Techniques (CEXICELL)

Duration: 36 months

Partners:
- Fundacion INASMET (E)
- Forschungszentrum Jülich (D)
- Sulzer Markets and Technology (CH)
- Elecnor (E)
- Gaz de France (F)

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Status: Ongoing

Natural gas SOFCs for co-generation of electricity and chemicals

NG-SOFC-COGEN

Objectives

Solid oxide fuel cells (SOFCs) are electrochemical reactors that directly convert a chemical fuel to electricity with high efficiency and in an environment-friendly way. There is a growing interest in the use of alternative fuels, such as methane a major component of natural gas, an inexpensive and abundant natural resource.

The objective of this project is the study and development of improved methane fuelled SOFCs for cogeneration of electricity and useful chemicals (e.g. synthesis gas). This is being accomplished by a careful search for new anode electrode materials with improved catalytic and electrocatalytic properties for selective oxidation of methane. In parallel with this, the known conventional technology will be improved by study and development of alternative fuel cell configurations and modes of operation, namely (i) simplified SOFCs with no separation of the oxidant and fuel streams and (ii) SOFCs operating under forced periodic reversal of flow.

Problems to be solved

The majority of relevant studies over numerous catalysts have shown that the partial oxidation of methane to syngas follows the indirect scheme i.e. total oxidation to CO_2 and H_2O. This is followed by reforming of unconverted methane, which presents the disadvantage of local hot spot formation and irreversible damage of the active catalyst, due to the high exothermicity of the complete oxidation of methane. The main drawbacks concerning anode development for CH_4 fuelled SOFCs is carbon deposition on the exposed electrocatalyst resulting in severe degradation of the electrocatalytic activity of the anode. This can be overcome by the development and manufacture of electrocatalysts that resist carbon formation and have high electrocatalytic activity for the selective methane oxidation. Four types of materials are potentially promising candidates for CH_4 fuelled anodes: (i) Ni based bimetallic compounds (e.g. NiMo, NiAu, NiLi etc.), (ii) finely dispersed Ru or Rh on thin TiO_2 films, (iii) mixed metal oxides of perovskite type (e.g. $La_{1-x}Sr_xFe_{1-y}Co_yO_{3\pm\delta}$, $LnCoO_3$ Ln=La, Gd, Sm, Nd $La_{1-x}Sr_xCr_{1-y}Mn_yO_{3\pm\delta}$), and (iv) Ag containing intermetallic compounds which possess sufficient activity for the electrooxidative CH_4 partial oxidation to C_2-hydrocarbons. The selection and development of the proper anode electrode has been the aim of the present project and required detailed study and evaluation of the catalytic and electrocatalytic properties of the above mentioned potential catalyst-electrodes.

Project structure

The project consortium consist of seven partners: Keele University School of Chemistry and Physics (United Kingdom), Institute of High Temperature electrochemistry and Boreskof Institute of Catalysis (Russia), Swiss Federal institute of Technology (Switzerland), University of Chemical Technology and Metallurgy (Bulgaria), Institute of Organic Catalysis and Electrocatalysis (Kazakhstan), and finally Institute of Chemical Engineering and High temperature Processes (Greece) which is the coordinator of the project.

Expected impact

Improvement of SOFC is relevant to development of environmentally friendly and efficient technologies for energy conversion and storage. At the forefront of these technologies SOFC can potentially find widespread application for the cogeneration of electricity and useful chemicals. In this respect SOFCs applications in the chemical industry can be of vital importance in the production of chemicals and efficient management of the energy distribution in the chemical industries. The project aim of developing a more efficient, environmentally friendly and economically attractive way of using the natural gas supplies, has obvious technical economic and social benefits.

Progress to date

The electrocatalytic activity of a number of promising anodes for methane partial oxidation

Figure 1: SOFCs testing unit.

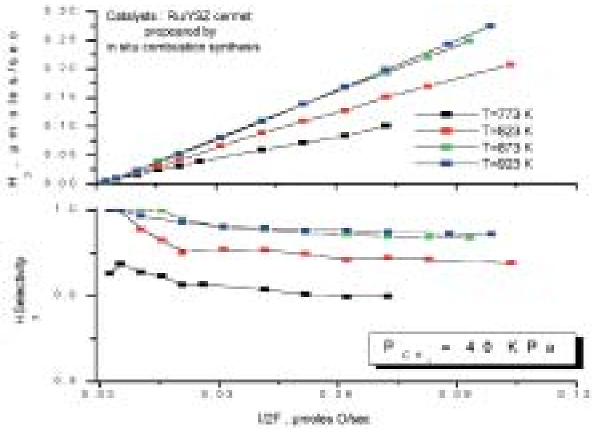

Figure 2: Effect of temperature and applied current on H_2 formation and selectivity.

is now under study. Among them, bimetallic catalysts such as NiAu, NiMo, NiTi as well as combined metal oxide compounds as for example Rh-TiO_2-YSZ and Ru-YSZ and Pt-YSZ have shown the most promising properties concerning resistance to carbon deposition. The catalytic performance of prepared catalysts is compared with conventional catalysts like nickel/zirconia. The influence of doping level of various metals, from as little as 1% to effectively true bimetallic systems, is studied along with the influence of the preparation method and pre-treatment procedure. Various conditions such as a broad range of fuel flow rates, cell potentials, and operating temperatures have been examined. In addition to steady-state electrocatalytic measurements, transient experiments like pulsing and *in situ* temperature programmed reaction spectroscopy measurements have been carried out as well.

The results have shown that the intermixing of gold, molybdenum and lithium with nickel can have a beneficial effect either by improving the catalytic activity and product selectivity or by reducing the rate of carbon formation. Therefore the use of additives offer considerable potential for the development of SOFC's running purely on natural gas, with cogeneration of synthesis gas. The most dramatic reduction in the rate of carbon formation was observed when gold was incorporated into the nickel/YSZ and nickel/CGO anodes, with the optimum performance occurring for a 5 mol% gold-doped Ni/YSZ anode fired at 1300°C, followed by post-impregnation of gold and subsequent calcinations and reduction at 900°C. Our findings demonstrate that gold-doping of nickel cermet anodes offers genuine potential for the development of SOFCs running on pure natural gas feed, with significant and selective cogeneration of synthesis gas and avoiding any coke formation.

Important results also came up using the *in situ* combustion method for the electrode preparation on the YSZ substrate. Non-polarizable electrodes of Ni/YSZ, Ni-Mo/YSZ and Ru/YSZ were studied and tested in the temperature region between 823 K and 973 K using the single cell shown in Figure 1. The non-polarizability of the electrode even at these low temperatures reveals the potential advantages of the in situ combustion method for the electrode preparation for SOFCs.

One of the most promising catalysts under investigation is Ru/RuO_2-YSZ prepared by combustion. At temperatures 773 K and 823 K the rate of both CO and H_2 formation increase with increasing temperature while selectivity passes through a maximum at low currents (≈3mA) and decreases afterwards with increasing current. Exceeding 873 K it becomes obvious that CO and H_2 are almost selectively formed with selectivities approaching 97% (see Figure 2). Such behaviour implies that the catalytic step leading to CO and H_2 formation is significantly faster compared to that resulting in the formation of CO_2 and water. It is also worth mentioning that no carbon deposits were detected after the reaction during the Temperature Programmed Oxidation experiment. Thus, it can be concluded that the preparation of Ru/RuO_2-YSZ by the combustion synthesis method leads to an electrocatalyst with very high selectivity towards the electrochemical production of synthesis gas, which is non-polarizable even at temperatures as low as 770 K.

INFORMATION

References: ICA2-CT-2000-10030

Programme:
FP5 - Energy, Environment, Sustainable Development

Title:
Natural gas SOFCs for Co-Generation of Electricity and Chemicals (NG-SOFC-COGEN)

Duration: 36 months

Partners:
- Foundation of Research and Technology Hellas (GR)
- University of Keele (UK)
- Institute of High Temperature Electrochemistry (RU)
- Boreskov Institute of Catalysis (RU)
- Ecole Polytechnique Fédérale de Lausanne (CH)
- University of Chemical Technology and Metallurgy (BG)
- Institute of Organic Catalysis and Electrochemistry (KZ)

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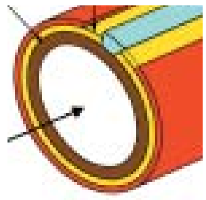


1 MW SOFC – hybrid fuel cell/micro-turbine system

1 M W S O F C

Objectives

The objective of the programme was to demonstrate the feasibility of a Solid Oxide Fuel Cell (SOFC) power plant system of the MW class, based on existing tubular SOFC technology. A pressurised hybrid SOFC/MTG power system was to be tested using an available Micro-turbine Generator (MTG) adapted to the requirements of the SOFC module to achieve an electrical efficiency above 55%.

This programme was planned to be a joint project between USA (financed by the Dept. of Energy (DOE) and Siemens Westinghouse Power Corporation) (SWPC) and Europe (financed by the EC and the European partners).

A very important step towards the price target of 1000 to 1300 Euro/kW is the development and demonstration of a MW class system, proving the reliable operation of the integration of SOFC and MTG. To advance towards this goal a pressurised hybrid power system will be integrated with the adapted available MTG.

Challenges

The programme addressed the design, manufacture and operation of a natural gas fuelled pressurised hybrid SOFC/MTG power system. The specific issues to be addressed, that will contribute to advancing the technology for SOFC power systems in Europe, include:

- Designing the SOFC module for MW-class systems and pressurised SOFC operation
- Availability of a recuperated MTG that can satisfy the pressure, air inlet temperature and air flow characteristics required for direct integration with the pressurised SOFC module
- European supplier development to maximise the European content in the pressurised hybrid power systems
- Module cost reduction and system design simplification to reduces cost of the commercial prototype pressurised hybrid system
- Cost effective, skid mounted component packaging
- Satisfying European code and safety requirements

The main technical targets of the proposed programme are:

- Operation of the first MW-class SOFC power system of European design and containing significant European content
- System efficiency >55% (approaching 60%) for the pressurised hybrid system

Project structure

The project consortium consists of Electricité de France (EDF, France), Energie Baden-Württemberg (EnBW, Germany), Gaz de France (GDF, France), Siemens AG (SAG, Germany), Siemens Westinghouse Power Corporation (SWPC, USA) and Tiroler Wasserkraft AG (TIWAG, Austria). SWPC as advisor is reporting to the DoE, EnBW as project co-ordinator is reporting to the EC.

The main work packages are:

- Product Specifications
- SOFC Module
- System Engineering / Design / Assembly
- Microturbine Generator / Thermal Management System
- Site Preparation
- Installation, Shakedown and Acceptance
- System Test

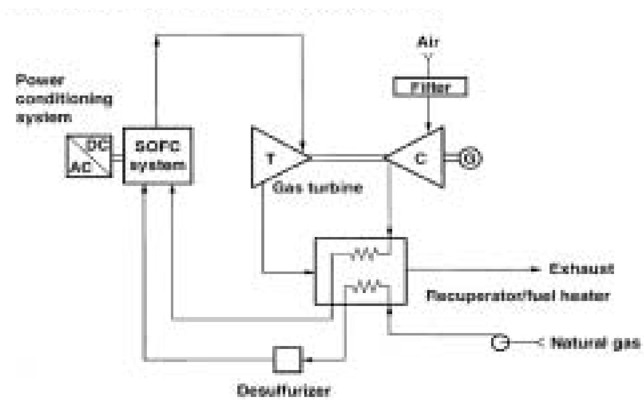
Expected impact and exploitation

Economic and technical interest in decentralised power production is steadily growing. Market research predicts an increasing share for decentralised technologies in power production. The high efficiency in combination with the very low emissions gives a competitive edge to fuel cell technology, especially SOFC technology, over comparable decentralised power stations in the power range up to several MW.

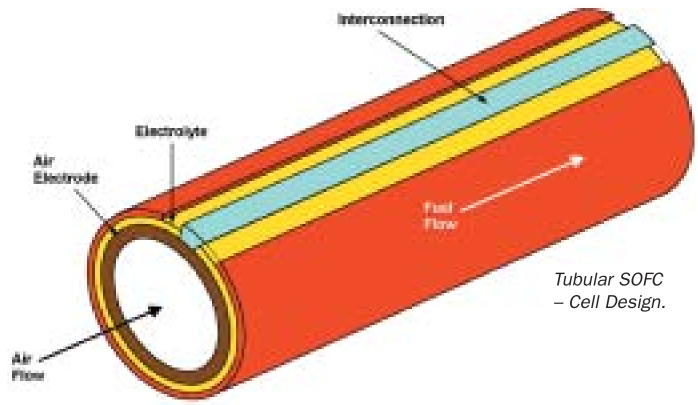
Therefore the use of highly efficient SOFC fuel cell technology in stationary decentralised power production would have a saving in fossil fuels in electricity production, lower the emissions of noxious flue gases and also reduce specific greenhouse gas emissions.

For the widespread introduction and use of the decentralised and environmentally friendly power production the engagement of leading utilities is of paramount importance. The participation of utilities in this project would to a high degree validate the market and enable market penetration of the technology once commercialisation occurs. This would give a strong push to the propagation of new energy conversion technologies.

The change in energy technology is connected to new manufacturing technologies and new components, which will partly replace known technologies. By early adaptation of the technology



Process Schematic for a Simple Pressurized SOFC Gas Turbine Combined Cycle Concept.



Tubular SOFC – Cell Design.

developed by the leading US manufacturer, job security can be enhanced and additional jobs will be created in the European industry.

Results

The Consortium evaluated the feasibility of constructing the MEGASOFC demonstration project to be located in Marbach, Germany. The preliminary design work completed indicated that the micro-turbine generator required for optimum technical success and to achieve the highest efficiency was not available as an off the shelf product.

Specifications were prepared for a micro-turbine in the range of 250 kW to 350 kW with low pressure ratios to enable the proper characteristics to achieve high efficiencies in the range of 55% to 60%. Several turbine manufacturers were solicited, however, no company was able to offer a product to achieve the technical specifications. Companies were interested in developing turbines, however, the time frame and investment required was deemed not in the best interests of the Consortium.

Consequently, the consortium decided unanimously not to build the demonstration plant intended. A press release was issued on 19/12/2002. The status of the European project contract is currently under discussion.

The Consortium considers hybrid products of megawatt scale to be of interest for Distributed Generation applications as well as grid support. The feasibility, however, needs further definition from a product standpoint as well as customer requirements.

The Consortium will continue to work together to evaluate market opportunities and further product definitions of hybrid systems that can be cost effectively deployed in key utility distribution and generation applications.

INFORMATION

References: NNE5-1999-00173

Programme:
FP5 - Energy, Environment and Sustainable Development

Title:
Demonstration of a MWel Class Power System using High Temperature Fuel Cells (SOFC) combined with Micro-Turbine Generators (1MWSOFC)

Duration: 48 months

Partners:
- Electricité de France (F)
- Energie Baden-Württemberg (D)
- Gaz de France (F)
- Siemens (D)
- Siemens Westinghouse Power Corporation (USA)
- Tiroler Wasserkraft (A)

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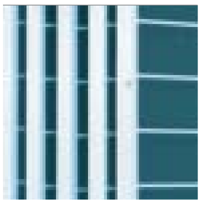
Status: Completed



Pressurized IP-SOFC: a path to successful SOFC/Hybrids

PIP-SOFC

Objectives

In the course of Framework 5, the European Commission has undertaken the major projects MF-SOFC and IM-SOFC-GT to develop key technology for SOFC stacks and SOFC/GT hybrids respectively. This project will build further on these initiatives and extend MF-SOFC technology to operation on hydrocarbon fuels (principally natural gas) within pressurised hybrid configurations. Advances in stack and system modelling achieved in part within IM-SOFC-GT will underpin this work.

The project's main aims are to develop a pressurized 10kWe Fuel Cell (FC) block with integral internal reforming and operate it with a hydrocarbon fuel representative of operation on natural gas.

It is intended that smaller support tubes and low cost high lateral conductivity current collector materials will be provided by a proposed US DOE funded SECA project in return for this project making available 10kWe stack blocks for system testing.

Challenges

The project focuses on development of a pressurised stack block primarily aimed at stationary power generation in a fuel cell / gas turbine (FC/GT) hybrid system. Previous stack development has been conducted at atmospheric pressure on hydrogen fuel and the main challenges within this project are around extrapolating this previous work to pressurised operation with simulated natural gas fuel.

Pressurisation provides power density improvements but with associated challenges in achieving electrochemical performance, maintaining durability, sealing and most importantly controlling temperature, and air flow and heat balance within the system.

Operation on a realistic hydrocarbon fuel requires the development of an internal reforming system. The key challenges are: controlling the heat load, avoiding carbon deposition, achieving durability and integrating heat management with the stack.

Additionally the project will need to manufacture the stack components in a repeatable and cost effective manner and build test facilities to demonstrate the newly developed technologies.

Last but not least, the project needs to interact with the proposed US DOE SECA project "Low cost modular fuel cell hybrid systems" and other EC funded projects to ensure an overall co-ordinated approach.

Project structure

The project consortium consists of 5 partners from four different EU countries. One University: Genova; one FC stack manufacturer Rolls-Royce Fuel Cell Systems; one ceramics manufacturer: Morgan Matroc Ltd; one utility company: Gaz de France; and one research centre: Risø National Laboratory.

The project is centred around six main work packages.

Active bundle: the development of the stack building block "bundle" see Figure 1. **Reforming bundle**: the development of the internal reforming bundle technology. **Flow and re-circulation**: the functional design of the cathode and anode flows. **Strip and short block**: the development and manufacture of larger stack components to be tested. **Interaction**: the management of the interactions with other projects. **Test and validation**: the building of test rigs and testing of fuel cell hardware.

Expected impact

The pressurized IP-SOFC stack programme was started at Rolls-Royce in 1992 and it is currently considered one of the best stack concepts due to its inherent low cost of manufacture. The high temperature solid oxide technology used in this project is widely considered to have the best long term promise for new entrants with efficiencies of between 60-70% in hybrid cycles at prices of less than $1000/kW. The technology has been demonstrated successfully in operation up to kW scale. Based on market assessments, it is clear that fuel cell hybrids could capture a significant market share if these are used to serve community power.

This project provides an important element in allowing the EU to compete internationally in high temperature fuel cell development. Commercial success of SOFC power plants will have significant impact on reducing emissions and complying with the Kyoto objectives. Indeed, SOFC/GT hybrids are characterised by their near-zero emissions of NOx, SOx, CO and particulates. They also generate low noise and electricity at efficiencies above that of large conventional generation plant.

Progress to date

The project (duration: 36 months) has not started yet. It is expected to kick-off at the beginning of April 2003.

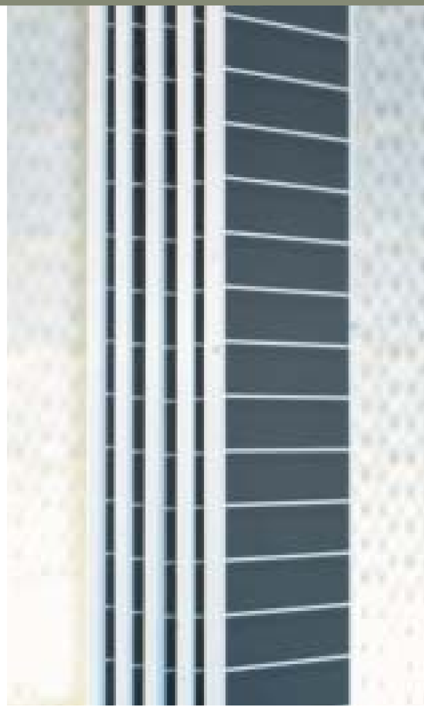


Figure 1: Rolls Royce Fuel Cell Systems Limited - Bundle.

INFORMATION

References: NNE5-2001-00791

Programme:
FP5 - Energy, Environment and Sustainable Development

Title:
Pressurized IP-SOFC: a path to successful SOFC/Hybrids (PIP-SOFC)

Duration: 36 months

Partners:
- University of Genova (I)
- Rolls-Royce Fuel Cell Systems (UK)
- Morgan Matroc (UK)
- Gaz de France (F)
- Risø National Laboratory (DK)

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Status: Ongoing

Ribe Biogas plant in DK (Krüger©).

Biogas – MCFC systems as a challenge for sustainable energy supply

EFFECTIVE

Objectives

It is well known that Molten Carbonate Fuel Cells (MCFC) have high efficiencies. For example the efficiency of MTU's HOT MODULE is approx. 47% (AC) and close to 90%, if the thermal energy can be used, even when the module is fuelled with Biogas. MCFC's are currently (among all types of FC's) best suited for Biogas and enable electricity generation in avoidance of valueless heat, usually occurring when conventional CHP's (Combined Heat and Power Units) with an efficiency of approx. 36% (AC) are used. Since biogas is a mixture of methane and carbon dioxide it is surprising that the MCFC solely among all types of fuel cells gains an advantage of the presence of carbon dioxide. Carbon dioxide takes part in the electrochemical cell reaction and has a determining role in the formation of the electrochemical potential.

A precondition for the use of Biogas in MCFC's is the elimination of accompanying traces of detrimental gases. Therefore the RTD-work is twofold: two gas upgrading units have been developed, and the endurance of MCFC's for Biogas use must be confirmed. Major reasons why renewable energy projects fail, is the one-sided focus on technical aspects. That is why non-technical barriers shall be taken into account.

Challenges

Anaerobic digestion (AD) involves the breakdown of organic waste by bacteria in an oxygen-free environment. The biogas produced as a result is, as a renewable energy CO_2 neutral. By converting the chemical energy into electrical energy in a high temperature fuel cell, it is possible to increase the electricity output in comparison to conventional CHP).

This does not only produce less CO_2 emissions per produced kWh (in comparison with classical CHPs) but it also has been proven that using biogas as fuel is followed by a drastic decrease of regional emissions of methane.

Furthermore, MCFC's have the lowest NOx, SO_2 and VOC emission-levels compared to other conventional systems. Another feature of the high temperature fuel cell is that a part of the thermal energy, which is created in the electrochemical process, can be consumed directly at the location where it is released. This internal heat removal happens during the conversion of the methane into the electrochemical active species, hydrogen, which is an endothermal process and known as "Internal Reforming".

Until now, hardly any experience has been gained concerning the utilization of biogas in fuel cells. Innovative aspects are the development of the gas cleaning units for biogas, to remove especially H_2S, as well as endurance and performance information on MCFC – gas cleaning unit. Finally a novel technique, based on adapted Quality Function Deployment (QFD) for the holistic technology integration is used. QFD will enable the identification of optimal locations for the MCFC-Biogas plant compound in Austria, Spain and Slovakia.

The major innovative step is however the combination of MCFC's and Biogas technology. Therefore answers concerning i) the gas upgrading (reliability, costs…), ii) the endurance and performance of the MCFC system with slightly changing gas quality and composition and iii) the integration of the technology in the market have to be analysed and/or improved.

Project structure and approach

The multidisciplinary and multisectorial approach of the project and the composition of the consortium promises successful teamwork. The needed critical mass is achieved through a well balanced consortium: on the one hand a fuel cell supplier and fuel cell specialists (MTU FC and CIEMAT), gas upgraders (PROFACTOR and SEABORNE), socio-economists (STUDIA), biogas experts (UNI NITRA) and end users (URBASER & LINZ AG).

The RTD-work is twofold: Two gas cleaning units have been developed, one based on a biological and the other on a chemical principle, that reduce e.g. H_2S in Biogas from 300 ppm (=state of the art) to under 10 ppm. The expected endurance of MCFC's using Biogas as fuel is to be confirmed with two testbeds, each comprising a 300 W MCFC-lab size stack (figure 1), manufactured by MTU, and their respective gas cleaning units. One of the testbeds (mobile) is coupled with the chemical gas cleaning unit and is being tested in three different locations with different gas qualities. The second testbed (stationary) is coupled with the biological gas cleaning unit and is meant to be used for long term tests. Non-technical barriers such as economic, logistic, legal and social aspects are being assessed in Austria, Spain, Germany and Slovakia for the technology integration of the systems compound.

Figure 1: Assembly of MCFC stack at MTU premises.

Figure 2: MCFC Testbed (left MCFC unit, right controlling unit) at the Seaborne premises.

Expected impact and exploitation

The large potential for biogas coming from biogas producing facilities in both agricultural as well as industrial sectors shows a virgin area of core business for the involved sectors. The exploitation of the results is clearly focused on the promotion of the implementation of Biogas Plants using MCFC's. The gas upgrading systems are to be further developed and commercialized after the finalization of the project.

Progress to date

The work performed on the technical side of the project was the development of both the chemical as well as the biological gas cleaning units with their subsequent analytical tests. This included the setting of common interfaces between the gas cleaning units, biogas plants and the MCFC unit.

Biological gas cleaning unit: Preliminary results show that the H_2S concentration in the outlet biogas is always under 10 ppm with an inlet of approximately 400 ppm H_2S. The **chemical biogas upgrading system** has achieved together with the first MCFC test cycle also values of under 10 ppm.

Single cell tests have been performed in order to find out the impact of NH_3 on the cells. The observations were the following: (1) A slight break through of ammonia was observed. (2) The amount of ammonia, which broke through, depended on the applied load. (3) The ammonia did not cause any additional corrosion on the cell components during the operation time of about 2000 h. Additional tests should however be done in order to find explanations for the ammonia break through.

The construction of the 2 **testbeds** (figure 2) proved to be more complicated than expected, in part due to the high safety standards set by the German TÜV.

Progress to date

The first test cycle was performed at SEABORNEs location, in Owschlag, Germany. The burn-out procedure was started on this stack in April 2002 at the facilities of MTU in Ottobrunn, Germany. Then the stack was cooled down and delivered to Seaborne, where it was reactivated at the end of May. After 2,500 h operation the tests were terminated.

It is likely that the gas composition was not stable during the experimental run and the CH_4:CO_2-ratio was shifted towards higher amounts of the CO_2. Therefore the real electrical efficiency (DC) should be expected to be in the range between 35 and 52% (DC). Results on the test operation in Nitra will soon be available.

INFORMATION

References: ENK5-CT-1999-00007

Programme:
FP5 - Energy, Environment and Sustainable Development

Title:
Biogas – MCFC Systems as a Challenge for Sustainable Energy Supply (EFFECTIVE)

Duration: 48 months

Partners:
- Profactor Produktionsforschung (A)
- Centro de Investigaciones Energeticas Medioambientales y Tecnologicas (E)
- Linz (A)
- MTU Fuel Cells (D)
- Seaborne Environmental Research Laboratory (D)
- Slovenska Polnohospodarska Universitá v Nitre (SK)
- Schlierbach Studienzentrum für Internationale Analysen (A)
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Status: Ongoing

Integrated research on materials, technologies and processes to enhance MCFC in a sustainable development

IRMATECH

Objectives

- **Reduce cost of MCFC from about 8000 to about 1000 €/kW for the whole plant in the next 10 years through a cost reduction for materials and manufacturing processes of 50%-70%.**
- **Improve the compactness of the MCFC by 40%.**
- **Increase the stack lifetime from 20000 hours to 40000 hours.**
- **Minimise the environmental impact and used energy relating to some manufacturing processes through an optimisation of raw materials selection and of porous component manufacturing, and the substitution, where applicable, of potentially noxious organic solvents with water (direct impact).**
- **Accelerate of the development of the environment-friendly MCFC technology towards commercial applications (indirect impact).**
- **Make an early analysis of stack life cycles and identify actions suitable to avoid potential environmental impact from decommissioning of spent stacks through an adequate management of noxious materials.**

Problems to be solved

MCFCs commercialisation is presently limited since the state-of-the-art is not yet totally suitable for successfully facing the challenging market of energy systems. The most advanced MCFC solutions still suffer from some limitations:

- Capital cost: MCFC are still too expensive to be introduced on the market.
- Size: the large space required by current MCFCs results in important costs and limits some applications.
- Lifetime: the operating conditions and the high temperature place severe demands on the corrosion, stability and life of cell components.
- Environmental impacts: there is a need to minimise the environmental impact and used energy relating to some manufacturing processes involved.
- Hybrid cycles: the integration of MCFC and microturbines, which is recognised as the key card in increasing system performance, still represents a problem not fully solved.

Expected impact

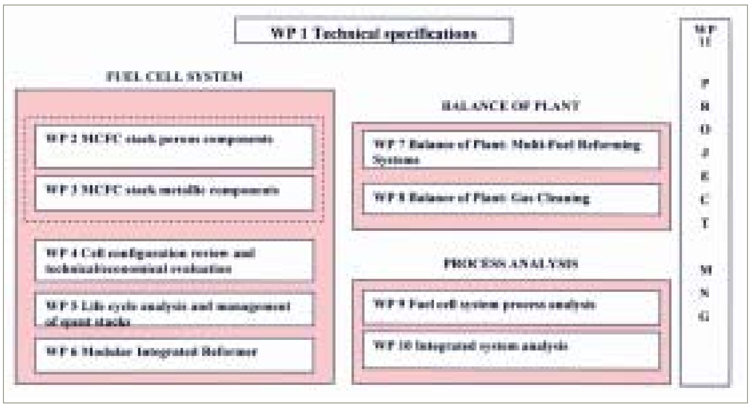
The main end result will be clean and flexible power generation systems with special features in terms of modularity, efficiency, cogeneration, multi-fuel capability and environmental impact.
If the project is successful, then starting from 2005, it is expected to exploit the results to bring the present MCFC technology to an industrially relevant product, in terms of performance and costs.

The exploitation of results from IRMATECH is threefold:

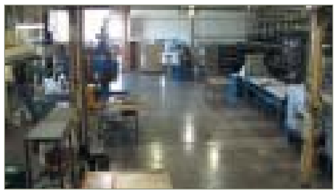
1. The internal exploitation, i.e., the integration of the final results by the industrial partners.
2. The R&D Exploitation, the scientific results are envisaged to be of potential interest to other applications and industries and to future use of IRMATECH results.
3. The external exploitation, the Exploitation Team, co-led by CESI, (for electric end-users) and by Eni Tecnologie (for power-gas end- users) will exploit the IRMATECH results through consultancy services for different sectors and companies having an interest in MCFC technologies, especially through the network and activities of CESI.

A strong partnership

The work programme will cover three specific areas namely 1) The fuel cell system (stack porous and metallic materials, configuration and technical/economic review), 2) Balance of Plant (multifuel reforming, system gas cleaning) and 3) Process Analysis (fuel cell system and integrated system analysis).
The achievement of the technical goals calls for multi-disciplinary and complementary actions. In this respect, this project needs to associate the many different competencies included in this consortium.
The consortium of the project is formed by a strong European partnership.



Project structure.



Porous component manufacturing facility.

The partners have been sought to create a balanced structure of interests of technology/ services providers, and R&D centres, and with the support of end-users. The consortium has 14 partners from 7 different countries.
Moreover, the impact of the project results on the industrial use of this technology will be high, since the partners of the project are major actors in their fields of activity.

The technology and services providers consist of:
- AFCO, Italy
- BALCKE, Germany
- CESI, Italy
- TP/KTI, Italy
- RICH MÜLLER, Denmark
- EPS, Italy
- ET, Italy

The academic support and expertise from the scientific point of view will be provided by:
- FHG-UMSICHT, Germany
- TUBITAK-MRC, Turkey
- CNRS-ENSCP, France
- ENEA, Italy
- CSIC, Italy
- KTH, Sweden
- UNIGE, Italy

This consortium has been designed to be efficient and to gather all the necessary competencies to prove technical viability as well as economical perspectives. This consortium is well balanced, with complementary profiles of its members, and the partners have quite similar motivations, which is a guarantee of coherent work.
To summarise, the partnership has been defined as a gathering of highly skilled organisations with similar industrial motivations and common interest to the success of the project.

Progress to date

The project started in January 2003 and is still in the initial phase. The official kick off meeting took place in Genova during February 2003.

INFORMATION

References: ENK5-CT-2002-00647

Programme:
FP5 - Energy, Environment and Sustainable Development

Title:
Integrated Research on Materials, Technologies and Processes to Enhance MCFC in a Sustainable Development (IRMATECH)

Duration: 30 months

Partners:
- Ansaldo Fuel Cells (I)
- Fraunhofer Institute for Environment, Safety and Energy Technology (D)
- Balcke-Dürr (D)
- Tubitak – Marmara Research Centre (TR)
- Centre National de la Recherche Scientifique (F)
- ENEA (I)
- Consejo Superior de Investigaciones Cientificas (E)
- Kungliga Tekniska Hoegskolan (S)
- Centro Elettrotecnico Sperimentale Italiano (I)
- EniTecnologie (I)
- Electric Power Systems (I)
- Technip/KTI (I)
- University of Genova (I)
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Status: Ongoing

MCFC hybrid power plant overview.

MCFC Twinstack® Powered – first of a kind

TWINPACK

Objectives

The purpose of this project is the design, construction and testing of a pressurised MCFC Clean Power and Heat Cogeneration Compact Plant (including stack), sized for a power output up to 500 kW (named "Series 500"). The proposed project is aligned with the present market trend, which is oriented to the distributed generation that is becoming a new way of addressing energy industry deregulation. Power Generation systems must offer a broad range of power outputs and operating characteristics to meet the various needs of prime power, peaking, peak shaving, and continuous base-load operation. MCFC plants contain many of these features and they also offer advantages that distinguish this technology and permit their application for distributed power, fuel flexibility, quiet and clean operation, fully dispatchable, remotely controlled unattended operation and modularity.

Problems to be solved

In order to render the MCFC power plant suitable for commercial application it must be competitive in terms of performance with traditional power plant solutions of the same size (also making heat for cogeneration). The overall dimensions need to be limited by locating both the stack and its integrated reformer linked to the catalytic burner inside one suitable vessel. The number of components must be reduced to simplify the maintenance procedures and reduce the servicing. The stack life needs to be enhanced and the layout optimised in order to locate the whole plant on a skid.

The present configuration will also be used as a “building block” for larger size power systems. In this last case, the Balance of Plant (BoP) will be optimised in terms of suitable integration of some components in order to reduce space requirements and costs.

Technical target

The targeted data of the plant are:

- Current: 1200 A
- Voltages: 104 V/stack
- Electrical power: 500 kW
- Emissions: NO_x <0.003 kg/MWh
  SO_x <0.0005 kg/MWh
  CO <0.001 kg/MWh

Project structure

The project consortium is made up of four major contractors: Ansaldo Fuel Cells (AFCo), Iberinco (IBO), ENEA, Balcke-Dürr GmbH and Azienda Municipale Gas Palermo (AMG). AFCo co-ordinates the project and is in charge of the administrative and economic management and the general design of the plant. It also designs and constructs the electrochemical modules.

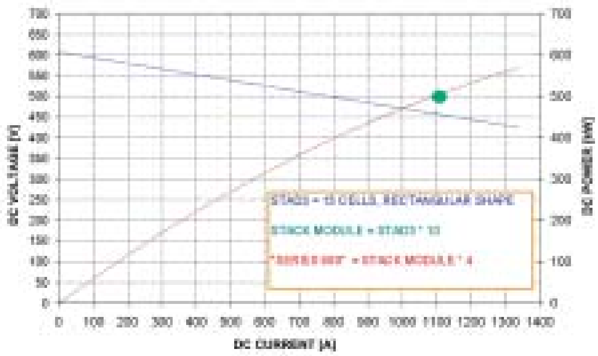
IBO participates in the installation of the Fuel Cell System and commissioning and monitoring of the plant. It supplies all the auxiliary systems and, as owner of the site, gathers all the necessary permissions and performs the modifications to the Guadalix existing stack test facility. It provides the erection, commissioning and monitoring activities. ENEA gives a significant contribution to the project in the area of porous component characterisation and manufacturing. BALCKE-Dürr designs, supplies and participates in the installation and testing of new components and heat exchangers. AMG participates in this project as end user and disseminator of information.

Expected impact

The project builds on the results obtained by the partners with previous experience for each R&D stage, and is aimed at the design, manufacturing and testing of a pre-commercial “Series 500” MCFC Clean Power and Heat Cogeneration Compact Plant.

The main characteristics of the project are: the integration of the plant on a skid with the arrangement of the stacks, integrated reformers

MCFC "Series 500" scale-up.



and catalytic burners inside a pressurised vessel. All other auxiliary systems are installed on the same skid as the control systems and power conditioning system with the attached electrical boards.

The plant will have high efficiency, low environmental impact, easy adjustment to site and rapid response to load change, simply being in parallel with the external grid. The success of the project will give the opportunity of entering the market of on site dispersed energy production for low-medium size (from 500 kW to some MW of power) with a plant which is entirely based on European technology and fabrication capability.

A catalytic burner strictly integrates the module with its reformer section in order to utilise, with negligible thermal losses, the heat coming from the catalytic combustion of the anodic and cathodic exhaust streams. In this way a high reforming temperature occurs inside the integrated reactor, which is external to the stack. This is a great advantage for the reformer catalyst requirements, treatment and refilling. The hot gases are then suitably utilised by a turbocharger that pressurises the process air and produces additional AC energy thanks to an electric generator connected to the machine. This electric energy together with the DC energy produced by the stacks and converted to AC is returned into the grid.

Other expected results are the validation of the existing manufacturing lines as well as their relevant upgrading, already in progress, on a pre-commercial production base.

Progress to date

The detailed engineering and interface optimisation phases of the project are almost finished. The Guadalix existing stack test facility has already been modified while the activities concerning manufacturing, purchasing, vendor activities for development and construction of each component are started (heat exchangers, MCFC stacks, fuel reformers, air process system) or are completed (fresh streams treatments, on field instruments, valves, control system, blowers, pipes and other connections).

INFORMATION

References: NNE5-1999-00236

Programme:
FP5 - Energy, Environment, Sustainable Development

Title:
MCFC Twinstack® Powered – First of a Kind (TWINPACK)

Duration: 46 months

Partners:
- Ansaldo Fuel Cells (I)
- Iberdrola Ingeneria y Consultoria (E)
- Azienda Municipale Gas Palermo (I)
- ENEA (I)
- Balcke-Dürr (D)

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Status: Ongoing

MCFC hybrid power plant overview.

MCFC/MTG Hybrid Power Plant Toward Low-cost Production

MOCAMI

Objectives

The main objective of this project is to develop and demonstrate a small-sized hybrid system with a combination of Molten Carbonate Fuel Cells (MCFC) technology and Micro Gas Turbines (MTG). The development of such a small-sized hybrid system will allow lowering the production costs through the implementation of new and simpler processes (innovative on-site stack conditioning) with a better quality control (development of a remote control system) and a higher yield for the different components.
This hybrid plant will be suitable for the development of a dispersed generation system, suitable for Combined Heat and Power (CHP) supply at high electrical efficiency and very favourable environmental impact. The chosen technology should provide effective solutions in the 100 – 500 kW range, corresponding to a very wide potential market (residential, agricultural, small industries); this approach should facilitate the end users and the Energy Services Companies adopting this solution.

Problems to be solved

The MOCAMI project addresses a number of technical issues, each of them being related to better opportunities for energy efficiency, cost reduction and user advantages. The on-site stack conditioning is the critical final phase of fuel cells production and involves significant costs and logistic constraints; the new procedure should allow drastically reducing costs and shorten the time required for exploitation. The problem faced is related to the strategic task of cutting the fuel cell stack investment costs, currently one of the most critical barriers for market penetration. The MCFC/MTG integration faces complex technical problems, especially regarding control and operation strategies. Moreover, significant expected improvement in plant efficiency is crucial both for the rational use of energy policies and for customer acceptance (reduction of operating costs). From the engineering point of view, the complete automation and remote operation of such plant is clearly feasible. The testing programme includes a long period of "unmanned" operation. If successful, this demonstration will be a fundamental condition for the economic competitiveness of decentralised CHP generation by medium size fuel cells.

Technical target

The technical objectives for the hybrid plant that will be developed within this project are:

- Investment cost: 4500 €/kW
- Running cost: 12 cents €/kWh
- Electrical efficiency production: 50-55%
- Overall efficiency production: 75%

Project structure

The MOCAMI consortium consists of five partners from EU member states (i.e. Italy, Germany and United Kingdom) and one Candidate Country (Turkey).
The consortium involves competent RTD partners, technology suppliers and end-users. Each of them is a technology leader in its field, with their fields being completely complementary on the global manufacture and use chain. Ansaldo Fuel Cells (AFC) as co-ordinator of the project and MCFC developer, defines plant layout and process parameters and manages all the commissioning and testing phases. CESI implements the control and data acquisition system to allow unmanned operation. AFC performs basic and detailed design of the plant and participates in the testing and operation phases. Balcke-Dürr designs, supplies and participates in the installation and testing of new components and heat exchangers., Bowman Power System (BPS, supplies a specifically adapted MTG. ENEL defines the test programme

The MCFC stack.

A micro gas turbine.

and evaluation of the compliance with the expected electrical interface parameters. TUBITAK – Marmara Research Centre addresses plant operation and testing. Ansaldo Energia (AEN) provides analysis of the fuel cell combustor – gas turbine system and optimisation of combustion chamber and gas turbine material.

Expected impact

Fuel Cell-based power plants are too expensive today to be introduced to any great extent on the market. Their high cost is partially due to the stack conditioning and to the Balance of Plant. As a consequence of the planned objectives of this project, it is expected to reduce the investment for the hybrid system 50 – 70% compared to today's price. According to the market prospect evaluation, market volumes ranging from 80 to 1500 MW/year seem reasonably attainable in Europe until 2010. With a target price around 1400 €/kW for the pre-commercial plants tending to 1000 €/kW for the commercial ones, a business volume ranging from 120 to 1500 M€/year would be reached. A total increase of employment from 400 to over 10,000 people could be expected in the high technology and service sector. Important added benefits of this approach will also be the capability of European industry competing, in MCFC technology, with USA and Japanese companies presently leading in fuel cell technologies.

Progress to date

The project is about to begin.

INFORMATION

References: NNE5-2001-00651

Programme:
FP5 - Energy, Environment, Sustainable Development

Title:
MCFC/MTG Hybrid Power Plant Toward Low-cost Production (MOCAMI)

Duration: 36 months

Partners:
- Ansaldo Fuel Cells (I)
- Centro Elettrotecnico Sperimentale Italiano (I)
- Balcke-Dürr (D)
- Bowman Power System (UK)
- Tubitak – Mamara Research Centre (TR)
- ENEL Distribuzione (I)
- Ansaldo Energia (I)

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Status: Ongoing

Hydrogen-based Electrical energy system for Local Power Storage

HELPS

Objectives

The Polymer Electrolyte Membrane Fuel Cell (PEMFC) is a promising technology for producing electrical energy in a reliable way without pollutant gas and noise emissions. For emergency backup power applications, PEMFCs are of great interest with regard to replacing conventional diesel engines, whose operation needs monthly testing and maintenance.
The first objective of this project is to develop a highly reliable emergency backup power system which could be competitive with conventional technologies to supply critical equipment (e.g. in telecommunications, nuclear plants, hospitals).
This technology is also of a great interest for other applications related to energy networks:

- **electrical energy storage for renewable energies in autonomous networks,**
- **power peak shaving and load levelling devices for grid connected users.**

The HELPS project will prove the reliability of the system and perform a first industrial application for PEMFC.

Problems addressed

HELPS is a complete system, including new and pre-existing technologies. The system consists of 5 main functional subsystems:

- Power generation: PEMFC, including the stack and its auxiliaries,
- Fuel regeneration by electrolysis,
- Fuel storage: Hydrogen as metal hydride and in conventional storage tanks, and oxygen in conventional storage tanks,
- Power conditioning: switches on the grid for charging, or on the fuel cell for autonomous operation,
- Control system that allows the proper operation of all the components.

For the completion of the project, challenges exist at all levels:

1. Component technologies: with regard to the target application, the reliability of the system and notably the start-up failure rate are key issues. This drives the design options that are selected for each component: The PEMFC and its auxiliaries, hydrogen tank, electrolyser, power conditioning and control system. This favours the use of passive components or processes wherever it is possible.

2. System integration: the objective of the project is to demonstrate the proper operation of the complete system, mastering the interaction between each component. A great effort is devoted to the system optimisation.

3. Manufacturing costs affordability in the market demands low costs for manufacturing, integration and implementation of the system. These costs drive also the design options.

Technical target

The main target data of the HELPS system are:

- Rated power: 5 kVA
- Autonomy: 5h
- Hydrogen storage: in Metal Hydride Tank and in conventional tank
- Oxygen storage: in conventional tank
- Start up Failure Probability in the range of 10^{-3} and 10^{-4}
- Fuel Cell: 5 kW PEMFC
- Maintenance Period: 6 months,
- low pollution: noise less than 60dBa, no gas emission.

The tests program covers 18 months and many cycles will be run to show the capabilities of the system.

Project structure

The project consortium consists of TECHNICATOME, the Centre for Renewable Energy Sources (CRES), DALKIA and the Commissariat à l'Energie Atomique (CEA). This consortium includes researchers, manufacturers, engineering industry, and operators.

CEA is the expert in Fuel Cells internal processes. It works as a support for the designers who will benefit from its many years of research.

DALKIA acts as an operator. It has defined the system requirements according to the market and will operate the system for the tests.

CRES is an applied research institute on future energies. It brings its knowledge on future energy systems and its expertise on related technologies. CRES defines and provides the electrolysis unit and H_2 and O_2 storage units.

TECHNICATOME is an engineering company in the field of energy systems. It brings its industrial view and its skills in design and development of advanced systems. It acts as the co-ordinator and is in charge of the Fuel Cell development and the system assembly. The Fuel Cell is developed and manufactured by its subsidiary HELION, the French Fuel Cell manufacturer.

Expected impact and exploitation

According to the applications, the HELPS system allows:

1. A high quality of power supply for the user in the case of critical application (hospitals, telecommunication, nuclear power plants, airports...) when used as emergency power supply. The low start-up failure rate and reliable operation is an important objective of the project. The competitiveness of HELPS system with regards to diesel generators is based on the following considerations:
   - the increase of availability: the higher initial cost is balanced by the guarantee to have a reliable service,
   - the low level of maintenance which decreases significantly the cost of operation,
   - the lower cost of infrastructures (no chimney, no noise insulation),
   - local fuel regeneration, leading to minimal refuelling cost (a few kWhs), compared to cost of purchasing and transporting diesel fuel to the site,
   - no “ ecotax “ for this clean power source.
2. The wider application of renewable energy technologies (solar photovoltaic panels, wind generators): HELPS is the appropriate storage system to supply the users even when sun and wind are not available.
3. To save energy and to avoid grid extensions by optimisation of the grid load when it is used as power peak shaving system. As a peak shav ing system, HELPS increases the cost-effectiveness of conventional electricity generation. Indeed, it allows the grid to operate at its best efficiency: load peaks are absorbed locally by HELPS which is able to store electrical energy. Thus, the distributed HELPS systems will participate in pollution reduction and the increase of the cost effectiveness of peak load generation.

Progress to date

The general design has been achieved in 2002. The Fuel Cell has been developed and is currently under test.

The electrolysis unit and storage units will be available in the last quarter of 2003.
The equipping of the test facilities is in progress. The exploitation tests of the whole system will start at the beginning of 2004 and will end in the middle of 2005.

INFORMATION

References: NNE5-1999-20025

Programme:
FP5 - Energy, Environment and Sustainable Development

Title:
Hydrogen-based Electrical energy system for Local Power Storage (HELPS)

Duration: 48 months

Partners:
- Technicatome (F)
- Centre of Renewable Energy Sources (GR)
- Dalkia (F)
- Commissariat à l’Energie Atomique (F)

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Status: Ongoing

Hybrid Fuel Cell/ Heat Pump System

FUEL-SAVE

Objectives

The overall objective of the proposed research is to develop a novel integrated fuel cell/heat pump system intended for use in buildings to provide heating, cooling and electricity generation. The proposed system could be driven by natural gas from fossil fuel reserves or from sustainable reserves such as landfill or biogas. The system will employ innovative polymer membrane fuel cell and heat pump technologies using an "environmentally friendly" working fluid.

The Intelligent Energy fuel cell system used in the Fuel Save program incorporates a pressurized fuel cell stack producing a gross stack electrical output of 3.5kW and a net thermal output of 4kW. The system utilizes pure hydrogen and operates continuously at an overall efficiency of greater than 95% (based on the lower heating value of H_2).One of the key advantages to point-of-use electricity generation is that the waste heat produced is available for exploitation, as in combined heat and power systems. By utilising a low temperature heat operated refrigeration cycle it is possible to upgrade the quality of heat and also supply both heating and cooling to a building. The ejector-compressor heat pump cycle is ideally suited to this application because it has a low capital cost, high reliability and long lifetime. Also, a wide range of working fluids can be used, such as water which has no detrimental effect on the environment.

Problems to be solved

This tri-generation system is based around two technologies that have been proven in a laboratory environment. The technical challenge is to improve and integrate these technologies. Equally important is the task of assessing the economic and social implications of this equipment. Key factors to project success include the capital and running costs, payback period, lifetime and social acceptability.

Computer modelling of the system and system components is currently underway to determine the optimum operating parameters. Optimal fuel cell electrical output for efficiency/cost saving will be determined. Heat pump modelling has identified optimal operating temperatures for a range of suitable refrigerants. Through this investigation the novel refrigerant HFE 7100 has been selected as a possible alternative to water due to its highly desirable operating conditions.

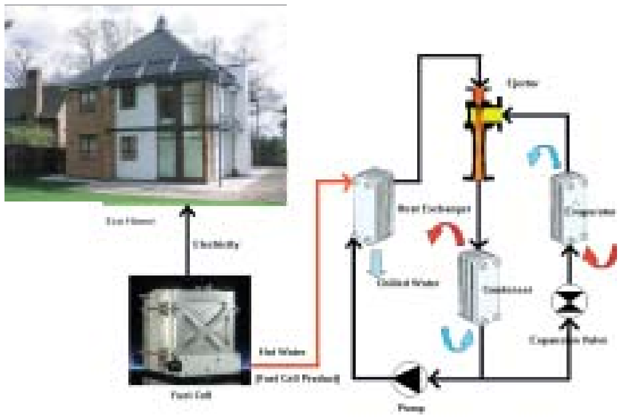
Extensive laboratory testing of the PEM fuel cell and the ejector cycle will confirm the validity of the modelling component. Later the fuel cell and the ejector cycle will be combined through an innovative heat recovery device utilising heat pipe technology. This component will allow the continued development of the system until a fully functioning prototype is ready for installation and monitoring in Nottingham University's Eco-House building.

Technical target

The integrated fuel cell/heat pump system is able to provide electricity, heating and cooling at a high overall efficiency. The system, integrated within a building's electricity and heating/hot water and cooling systems would be expected to reduce primary energy consumption and CO_2 emission. This will be determined when a fully functioning prototype is installed in a suitable building.

Project structure

The project partnership is highly complementary and multi-disciplinary as a result of its combination of expertise in manufacture (Intelligent Energy Ltd, Thermacore Ltd, Venturi Jet Pumps Ltd) energy supply (Powergen Plc), and the research expertise of the universities (Nottingham University, University of Padova). Each of the partners is utilizing their skills, experience and resources in order to satisfy the demands of this influential study.



Expected impact

The system has the potential to be a net contributor of electricity, as any excess electricity generated could be exported to the grid. If successful this investigation will improve the competitiveness of EU industry in this important sector. The market potential for the proposed system within the EU is expected to be substantial and a large demand for this type of product in the USA, Middle East, Far East and Africa is also predicted. This research will also directly benefit the energy/Heating Ventilation and Air-conditioning (HVAC) industry, and will indirectly benefit the building services industry through demand for installation of the product.

Progress to date

The project has just started.

INFORMATION

References: NNE5-2001-00232

Programme:
FP5 - Energy, Environment and Sustainable Development

Title:
Hybrid Fuel Cell/Heat Pump System (FUEL-SAVE)

Duration: 30 months

Partners:
- University of Nottingham (UK)
- University of Padova (I)
- Powergen (UK)
- Intelligent Energy (UK)
- Venturi Jet Pumps (UK)
- Thermacore Europe (UK)

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Status: Ongoing

50 kW PEM Fuel Cell Generator for CHP and UPS

50PEM-HEAP

Objectives

The recent fast development in fuel cell technology is driven largely by its potential to deliver significant energy in an environmentally safe manner. As the new technologies develop and environmental policies evolve, there is an on-going need to evaluate the future role of fuel cells for cleaner power supplies, where they appear likely to be a major player. The 50PEM-HEAP project approach is to accept the reality of today's fuels infrastructures. The stack developed requires the use of the flow of hydrogen-rich streams e.g. obtained by reforming natural gas.
The main objective is to construct and test a 50 kW PEM Fuel Cell (FC) generator with dual application possibilities (Uninterrupted Power Supply systems and Combined Heat and Power production), with dual fuel possibilities (reformed NG and LPG) and that later on can be produced at a manufacturing cost of 8,700 €/kW at pilot scale production (50-100 generator units).

Problems to be solved

Fuel cells have in combination with conventional fuels such as natural gas a large potential for energy savings and for strong reductions in CO_2 and other pollutant emissions. However, fulfillment of the promising future for fuel cells requires a substantial cost reduction not only on fuel cells but also on the related technologies, e.g. reformers. Fuel reforming not only gives hydrogen, but also carbon dioxide and carbon monoxide, and the gas clean-up needed in present day systems to bring down the level of carbon monoxide to levels of <10 ppm makes the systems complex, bulky, and very expensive. It is one of the project targets to bring the system cost below EU's short-term target for systems designed for long life (as for the present system although not in the MW-size). The system cost can be divided into the following three categories: 1) PEM FC, 2) Balance-of-Plant (BoP), excluding the fuel processor, and 3) Fuel processor. The project intends to reduce the system manufacturing cost to 8,700 €/kW (@ pilot scale production by reducing the costs of all three categories. The PEM FC cost will be reduced by optimizing the PEM MEA and replacing the costly and labour-intensive machined bipolar plates by mould in-flow plates. These two issues currently define 3/4 of the cost (Figure 1); a reduction in their contribution will therefore have a large influence on cost. Manufacturing costs are expected to be reduced by 30%, coming down to 3,000 €/kW at the end of the project. The BoP cost will be reduced by construction of a simple BoP. Experiences from other FC system projects have taught us that the PEM FC and BoP costs are almost equivalent. A cost reduction equivalent to that for the PEM FC is to be achieved by designing and constructing a simple system. The fuel processor cost will be reduced keeping a target price for the hydrocarbon reformer at 2,700 €/kW.

Technical target

The technical targets for 50 kW PEM FC generator are:

Electrical power delivered from fuel cell generator: 50 kW_e
Voltage delivered from inverter: 3 x $400V_{ac}$
Heat power delivered by fuel cell: 50 – 60 kW_{th}
Fuel: Reformed NG or LPG gas
Electrical efficiency: fuel cell stack: 55 – 60%
Electrical efficiency: generator: >35%
Heat and power efficiency, fuel cell generator system: >70%

Project structure

The project Consortium is well balanced with one Research Institution (ECN) well established in fuel cell activities and four industrial partners. Three of the industry partners are established in fuel cell and fuel-cell component production {IRD, JM, and SGL} and one in power electronics {GUTOR). The last partner is a CHP-end-user {HGC).

Expected impact

The range of potential uses of fuel cells covers a broad spectrum. Currently, the technology is proving most promising in high-demand, high-value niche markets, such as Uninterrupted Power Supply (UPS) systems. The increasing reliance on corporate networks and e-commerce by businesses around the world has necessitated a growing dependence on UPS systems.

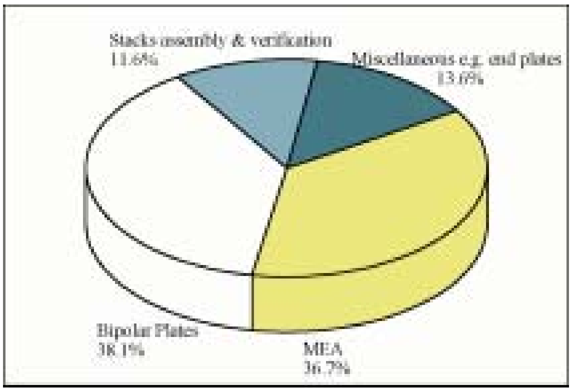

Figure 1: Cost break-down of present manufacturing costs in fabrication of PEM fuel cell stacks.

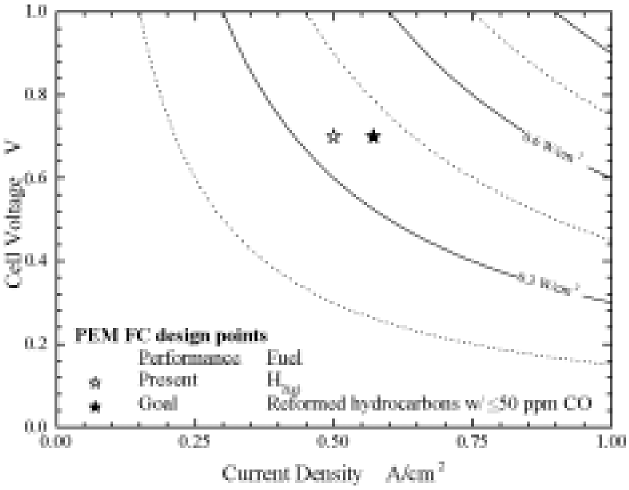

Figure 2: Present and target performance of the MEAs.

Unscheduled costs associated with network downtime can be extensive: according to Contingency Planning Research, downtime costs associated with credit card/sales authorization e-commerce average around € 2.6 million per hour. The on-site network service technician call ranges from € 300-500 an hour.

In stationary applications, there is a growing market for combined heat and power systems especially systems with a high net power output. Due to the high efficiency, low emissions, and low maintenance costs of fuel cells, this technology will be highly competitive once the cost reduction potential is fully realised. With the expected political support for CHP in Germany alone, a yearly market of about 400 MW for systems <10 MW would be secured through increased use of fuel cell technology.

The benefits of clean power and heat from fuel cells should create considerable interest, especially in regions with air-quality problems, e.g., urban areas. Many fuel cell technologies will continue to develop and mature over the next 10 years. They will eventually help power everything from industries to homes to buses to cars to computers and video recorders.

Expected results

The project is divided into "FC optimization" and "Construction and test of the 50 kW PEM FC generator". The FC-optimisation focuses on the development of new improved MEAs to give a 30% reduction in FC stack manufacturing cost. The target performance of the developed MEAs is 0.4 W/cm^2 @ 0.7 V, when the FC is fuelled with reformed NG or LPG containing up to 50 ppm CO (Figure 2). The expected CO-level at the start-up of the reformer dictates the requirement to the CO sensitivity of the MEAs. The major cost reduction will be gained by reducing the component price arising especially from increased MEA performance, and by developing graphite-based mould-in-shape bipolar plates. The optimised MEAs and bipolar plates will be used to construct the PEM FC stacks for the generator.

The "construction and test" part includes design, construction, integration, and implementation of the complete 50 kW PEM FC generator. The system will be modular to allow replacement of the individual modules, and so that larger generators can be put together.

System simplification as well as construction of a cost efficient hydrocarbon (NG and LPG) reformer will ensure a low BoP cost. The last project year is dedicated to system integration and implementation. The planned tests include UPS tests and a dynamic CHP-test over a full heating season.

INFORMATION

References: NNE5-2001-00882

Programme:
FP5 - Energy, Environment, Sustainable Development

Title:
50 kW PEM Fuel Cell Generator for CHP and UPS applications (50PEM-HEAP)

Duration: 39 months

Partners:
- IRD Fuel Cells (DK)
- Gutor Electronic (CH)
- Energieonderzoek Centrum Nederland (NL)
- Johnson Matthey Technological Centre (UK)
- SGL Technologies (D)
- HGC Hamburg Gas Consult (D)

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Status: Ongoing

Europe's first Virtual Fuel Cell Power Plant

VIRTUAL FC POWER PLANT

Objectives

Developing Fuel Cell Heating Appliances as decentralized CHP systems in multi-family houses and small industrial companies requires intensive and thoroughly executed testing in the field. As the major European manufacturer of heating appliances, Vaillant GmbH in co-operation with 9 other European project partners from academia and industry started a project for installation and testing of a Virtual Fuel Cell Power Plant in November 2001.
The objective of the project is to install and demonstrate a Virtual Fuel Cell Power Plant as an application of the innovative Fuel Cell technology, i.e. to transform laboratory technology into everyday technology. The parties expect important findings for the technical realization of the Virtual Power Plant, the definition and testing of the different load profiles and the behaviour under continuous duty of the Fuel Cell system.

Challenges

The international agreements for climatic protection, such as the Kyoto protocol, constitute major stages on the way to reduce emissions contributing to the greenhouse effect, such as CO_2, for example. However, implementing these targeted reductions also requires product development in particular on CO_2-efficient technologies. In this connection, the coupling of heat and power is becoming more and more important in the future energy mix even on the European level. If we combine Fuel Cell technology, in particular in micro-CHPs to a system of networked installations, we will be able to profit from all the advantages of decentralized energy generation with Virtual Power Plants without affecting the energy management desired by the power generators. The Virtual Power Plant is an "Internet of Energy".
The Virtual Fuel Cell Power Plant is a group of interconnected decentralized residential micro-CHPs, using Fuel Cell technology, installed in multi-family houses, small enterprises, public facilities etc., for individual heating, cooling and electricity production. Centrally controlled and grid-connected, these elements contribute to meet peaking energy demand in the public electricity grid and act as Virtual Power Plants.
The objective of the project is to install and demonstrate a Virtual Fuel Cell Power Plant as an application of innovative Fuel Cell technology, i.e. to transform laboratory technology into everyday technology.
Simultaneously this application is a fast door-opener for a broad market entrance of Fuel Cells with their environmental and economic benefits. Severe testing in different environments including requirements involving techniques, users, standards and utilities is necessary. The 40-months project is co-funded by the European Commission under the 5th R&D Framework Programme.

Project structure

Project partners are Vaillant GmbH, Europe's leading manufacturer of heating and hot water appliances. Vaillant is the Project co-ordinator and is in particular responsible for the produc-tion of the Fuel Cell Heating Appliances; Plug Power Holland, a partner of Vaillant GmbH in developing a Fuel Cell Heating Appliance; COGEN Europe, which is engaged in all aspects of co-generation, in particular data acquisition, thorough market analysis and dissemination; Instituti Superior Tecnico (IST), c/o University of Lisbon is the biggest and best known En-gineering College in Portugal; TEE, Technology of Energy Supply and Energy Systems, a department of the University of Essen, and responsible for the development of the Central Control System and measurement evaluation; DLR, Germany's Aerospace Research Centre. DLR participates in the European Solar Test Centre Plataforma Solar de Almeria, and co-ordinates the installations in the Southern European applications; Sistemas De Calor, a re-gional supplier and installer of energy-related equipment for co-generation, heating and cooling purposes, water supply, and a producer of solar collectors; N. V. Nederlandse Gasunie, one of the leading Dutch gas suppliers. Gasunie`s principal activities are producing, transporting and selling natural gas. Gasunie is responsible for the field test equipment in The Netherlands; Ruhrgas AG, the leading German gas supplier, and its local partner EAM EnergiePlus Kassel and EWR Remscheid and E.ON Energie AG and its local Partner EWE (a well established subsidiary of E.ON Energie AG).

Field Test System in Baunatal near Kassel.

Design of the Vaillant Fuel Cell Heating Appliance.

Expected impact

Developing and demonstrating the so-called Virtual Power Plants with decentralized Fuel Cell Heating Appliances is a major step on the way to the European energy market of the future. This system will play a major role in decentralizing energy management able to succeed in the future and it offers at the same time numerous synergy effects: high availability rate thanks to systems which are operated independently, the opening of new business fields, minimization of line drops even to the integration of regenerative energies. Progress expected will probably be the minimization of traditional contaminants and pollutants and in particular the reduction of greenhouse gases. Thus, Virtual Fuel Cell Power Plants significantly contribute to achieve the European target reductions set within the scope of the Kyoto protocol to combat the greenhouse effect.

Progress to date

In the first project phase at the end of 2002 and the beginning of 2003, the first 6 Fuel Cell Heating Appliances have been installed mainly in multi-family houses in Germany and The Netherlands. Overall it is planned to install several dozen appliances. In the first months of this European field test, these field test appliances developed by Vaillant GmbH and Plug-Power have proven to work really reliably and since the installation in December 2002, they have fed about 43 MWh (status: April 2003) of electric power into the public grid, generated in about 13.000 running hours.

The first field test systems are operated in multi-family houses in the Oldenburg region (part-ner E.ON and EWE), Kassel (partner Ruhrgas and EAM EnergiePlus) and Remscheid (partner Ruhrgas and EWR) as well as by Gasunie Research in the Dutch city of Groningen. In the course of the year, further systems shall be installed in Germany, The Netherlands, Spain and Portugal. The Fuel Cells are operated via a defined load profile and are heat- as well as power-controlled. Based on weather data, decentralized energy management systems will forecast the amount of energy of regenerative energy plants for the following day and will derive and set load profiles for the Virtual Power Plant. The next step will be to test the systems' behaviour with different defined load profiles. Furthermore the parties expect to get important information on the systems' behaviour under continuous duty with increasing field test duration.

INFORMATION

References: NNE5-2000-208

Programme:
FP5 - Energy, Environment and Sustainable Development

Title:
System development, build, field installation and European demonstration of a Virtual Fuel Cell Power Plant consisting of residential micro-CHPs (VIRTUAL FC POWER PLANT)

Duration: 40 months

Partners:
- Vaillant (D)
- Plug Power Holland (NL)
- CoGEN Europe (B)
- Instituto Superior Tecnico (P)
- Technology of Energy Supply and Energy Systems (D)
- Deutches Zentrum für Luft- und Raumfahrt (D)
- Sistemas de Calor (E)
- Gasunie (NL)
- Ruhrgas (D)
- EON Energie (D)

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Status: Ongoing

Multiple End-User Specified 100 kW FC Power Module

FEBUSS

Objectives

The FEBUSS project, a five year program started in 2002, targets the development of a hydrogen fuelled 100 kW PEM Fuel Cell Power Module standardised for public transport and stationary applications. It aims at achieving an optimal fit with the selected applications, through direct involvement of "end users", with safety and regulatory issues considered from the outset.

In order to ensure competitiveness in both markets, the system's design will integrate a serial production cost objective of 300€/kW. For enhanced maintainability, reliability, and performance, an innovative stack assembly and fluid distribution design, as well as newly developed auxiliaries will be implemented.

The project will conclude with a two-year test campaign of two prototype power modules, during which data on maintenance costs and system reliability will be generated. Simultaneously, an on-going cost assessment and technology benchmark will aim at ensuring that the developed design meets evolving market expectations.

Problems addressed

There has been a tendency in the past to consider the fuel cell stack as the most challenging element in a fuel cell system, with design targets reflecting solely the performance of the stack itself, but not that of the other elements required to make it function. In this project, the fuel cell power module is considered as a system to be designed as a whole according to end-user defined design objectives and constraints.

Furthermore, in order to facilitate the use of PEM fuel cell technology, despite the high initial costs, in applications where there are already strong motivations to put it in use, the project addresses the need to define a standard technical platform matching the needs of a set of urban transport and stationary applications, selected on the basis of compatibility of needs. Regarding the actual technology, development efforts will focus in particular on the optimisation of stack and system design. The objective of this is the translation to system level of the full performance potential of the membrane/electrode assembly, stack maintainability and cell defect tolerance, optimisation of the Fuel Cell system/Power Converter combination, and early stage integration of safety, regulatory and certification issues.

Project structure

The project brings together end-users, system designers, fuel cell component suppliers, and Safety/Regulations specialists, i.e. the necessary actors for effectively converting technological capabilities along with market and regulatory expertise into commercially viable products.

Axane Fuel Cell Systems, a subsidiary of *Air Liquide*, is the project coordinator and is involved principally as fuel cell module designer. *Air Liquide* is in the project as an assistant contractor to *Axane*, involved in system design and testing. Toulouse based *INPT/IMFT* laboratory develops models for a better understanding and prediction of intra-cell water transport phenomenon in the active and passive layers of the electrode membrane assembly. Schneider Electric provides its expertise of the Stationary markets, while taking responsibility for design and manufacturing of the system's power electronics and control elements. Grenoble based *INPG/LEG* laboratory provides input regarding the electrical architecture, with development of modelling tools. *Alstom Transport* is an end-user for transport applications, providing input regarding the tramways application, as well as its technical expertise with respect to vehicle power trains, hybrid electrical systems, as well as regulatory issues. *Irisbus* has expertise regarding the implementation of fuel cell technology in buses. *Johnson Matthey* develops and provides the multi-layer membrane/electrode assemblies for the fuel cell stacks (developed and manufactured by *Axane*). *SGL Technologies* develops and provides carbon composite bipolar plates for these stacks. Metallic bi-polar plate technology is also implemented, for which *INEOS Chlor* provides coating solutions. *CEA* research entity performs the tests aiming at qualifying these stack component solutions, assisted by *INTA*. Ineris, provides its expertise on safety, regulatory, and certification issues, along with *TÜV Saarland* and *INTA*.

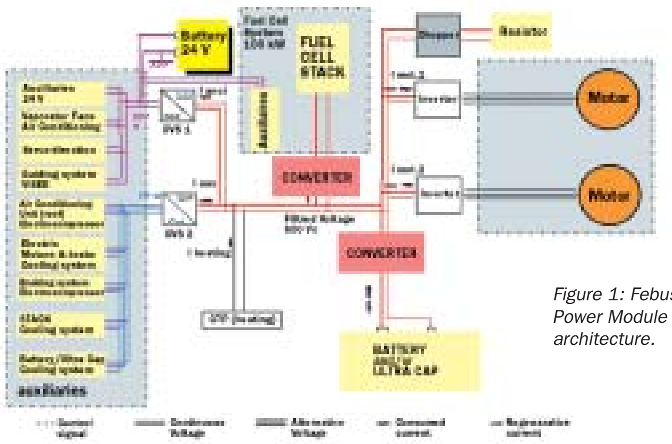

Figure 1: Febuss Power Module architecture.

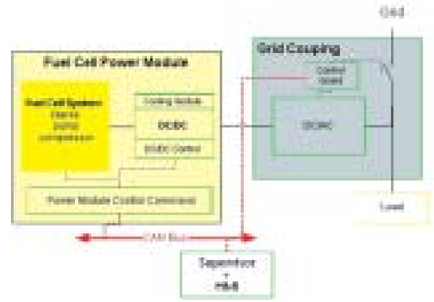

Figure 2: Bus application electrical architecture.

Expected impact and exploitation

The work carried out is expected to result in a fully qualified standard Fuel Cell power module design meeting in an optimal fashion the needs of markets where this technology is very likely to be put to use in the short term i.e. fuel cell buses and tramways, and backup power for the Service and Telecom industries.

The Febuss project is an essential stepping stone for the subsequent development of more industrially mature products for a wider range of applications. Furthermore by bringing together all the relevant actors for developing commercially viable and competitive solutions, it significantly contributes to the consolidation of a European fuel cell industry.

Progress to date

The detailed review of the needs of the urban transport and selected stationary applications has allowed the confirmation of the suitability of proposing a single technical platform for these markets. Stationary applications were analysed technically and economically in order to identify those where the fuel cell solution is the most competitive in the short term. An important issue that was solved is the identification of a single power module architecture compatible with the voltage ranges specified in the various applications.

Application architectures were studied in order to determine the mode of implementation providing the greatest benefits (Figure 1 – Bus application). The system's architecture (Figure 2) is now completely defined from the process, electrical, and control-command standpoints. It will implement six 20 kW (gross) stacks in a serial configuration, with possibilities of operation in degraded mode (one or two stacks out of service)

The models describing the electrical and thermal behaviour of the Fuel Cell system have been prepared and qualified for implementation in electrical and thermal simulations of the application architectures.

The DC/DC converter's architecture is characterised by its modularity and compactness. It implements electrical components of the latest generation for achieving high efficiency. The stack design, implementing a novel assembly solution, stands out for the ease of maintenance it entails. Its intrinsic modularity, allowing the implementation of various bi-polar plate technologies, is another advantage. Regarding the fuel cell system auxiliaries, the development of a very compact and effective solution for air humidification, is under way.

INFORMATION

References: ENK-5-CT-2001-00581

Programme:
FP5 - Energy, Environment, Sustainable Development

Title:
Fuel cell Energy systems standardised for large transport, BUSses and Stationary applications (FEBUSS)

Duration: 60 months

Partners:
- Axane Fuel Cell Systems (F)
- Institut National Polytechnique de Toulouse (F)
- Centre National de la Recherche Scientifique (F)
- Schneider Electric Industries (F)
- Irisbus (E)
- TÜV Saarland (D)
- Institut National de l'Environnement Industriel et des Risques (F)
- Instituto Nacional de Técnica Aerospacial (E)
- Institut National Polytechnique de Grenoble (F)
- Centre National de la Recherche Scientifique (F)

Assistant Contractors to Axane:
- Air Liquide (F)
- Commissariat à l'Energie Atomique (F)
- Johnson Matthey (UK)
- Ineos Chlor (UK)
- SGL Technologies (D)

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Status: Ongoing

Fuel Cell Scooter – green option for urban mobility

FRESCO

Objectives

Scooters are a very popular means of transport in major European Cities and urban areas. However, equipped with 2-stroke internal combustion engines, their use brings also serious pollution and health burdens. Powering with fuel cells would be an attractive alternative, but present fuel cell systems are hard to accomodate in the limited space available in a scooter.
The specific challenge of the FRESCO project is to prove the viability of the clean fuel cell propulsion for small vehicles, by developing a dedicated system and by integrating it in a modern mass-production type scooter.
The technological achievements comprise a compact water-cooled PEM fuel cell stack, a supercapacitor peak-power device, an innovative electric motor and traction converter allowing for regene-rative braking, and a smart system concept minimizing hardware needs for power and control electronics.

Challenges and innovations

In cities and urban area, small vehicles like scooters become more and more popular with the growing intensity of traffic and congestion. Though scooters are a convenient mode of transportation, their intensive use can result in significant environmental and health problems as known e.g. from several Asian cities. Battery scooters are no universal solution due to inherent limitations in range, recharging time and lifetime. Considering the role of hydrogen in our future society, clean fuel cell technology is an attractive alternative. The challenge of the FRESCO project is to demonstrate the technical viability of the fuel-cell option for modern scooters.

Performance and comfort requirements in present day scooters are very high; space for accommodating the drive system, however, is quite limited. An optimal matching of the drive system characteristics with the vehicle power and energy demands is therefore essential. The combination of fuel cell stack and a supercapacitor peak power device, together comprising the *electrochemical engine*, realizes this perfectly.

An innovative concept allows for the necessary power balance between fuel cell and capacitor, while minimizing their matching electronics. The concept also facilitates the absorption of regenerative braking energy, thus reducing fuel consumption significantly.

In addition to the optimal rating of the drive system components, each of these components needs to be realized at minimum volume and weight. Innovations to this end comprise (1) a compact water-cooled fuel cell stack specially shaped to fit in the available space geometry, (2) a dedicated supercapacitor module avoiding the need for balancing electronics, (3) a newly designed electric motor/generator with low current absorption and flat power characteristic, (4) a bi-directional traction controller for variable supply voltages and with low cost because of limited power transistor requirements, and (5) a light-weight hydrogen storage tank of composite material, combining high pressure for maximum capacity with very low leakage for high safety.

The electrochemical engine

The electrochemical engine being developed in the FRESCO project is a power-delivering device. As input it requires sufficient hydrogen flow at a low-pressure level. Within its specifications it delivers autonomously electric power demanded by the load, with in principle no further need for data or control communication. A main component of the electrochemical engine is the PEM fuel cell stack with its hydrogen re-circulation and humidification units and air pump. Other components are the supercapacitor module and a so-called current pump that arranges for the electrical matching between fuel cell stack and supercapacitor module. The electrochemical engine for the scooter will have a continuous power of ca. 7 kW and a peak power of 12 kW.

Project structure

The project consortium consists of the Energy Research Center of The Netherlands (ECN), Piaggio & C SpA (Italy), Selin Sistemi SpA (Italy) and Commissariat à l'Energie Atomique (France). ECN is project coordinator and in addition responsible for the development of the electrochemical engine. Piaggio & C SpA is responsible for the overall vehicle system, integration and testing. Selin Sistemi Spa develops the electric rotation machine and the traction controller. CEA is responsible

for the hydrogen tank development. Subcontractors to Piaggio & C SpA are the universities of Pisa and Florence. The project is based on preliminary developments at ECN that was partially funded by The Netherlands Ministry of Economic Affairs, and on model calculations made by Piaggio & C SpA, ECN, and the university of Pisa.

Expected impact

Today in Europe there are over 23.000.000 two-wheel vehicles on the roads. The market share of the larger type scooters is increasing and is expected to eventually reach ca. 20%. Assuming equivalence of the typical urban use with the ECE 40 drive cycle and assuming EURO II emission levels for the internal combustion engines, a moderate market penetration of fuel cell scooters of 12% at 2006 introduction would already mean the reduction 880.000 kg CO, 192.000 kg hydrocarbons and 48.000 kg Nox/year. In the longer term, when miniaturization of the technology is fully developed and small 50-cc scooters can benefit from the clean technology, reduction of at least 640.000 tons CO, 320.000 tons hydrocarbons and 8000 tons NOx in 20 years from 2006 can be realized. This means a considerable impact on the environment and on the quality of life in cities and urban areas.

Progress to date

In the first year of the FRESCO project significant efforts were related to the analysis of scooter field data, modelling of vehicle performance requirements, sizing of the various system components and modelling of the component accommodation in the scooter frame. As a result, all system components have been specified and their placing in the vehicle has been fixed. In addition, the control strategy was defined. The PEM fuel cell stack design was fixed and first single and multi cell tests confirmed the expected performances. New designs for the electric motor, the traction controller and the crank have been established. Developments of the hydrogen tank and the supercapacitor module are in progress.

INFORMATION

References: ENK6-CT2001-00565

Programme:
FP5 - Energy, Environment and Sustainable Development

Title:
European Development of a Fuel-Cell Reduced-Emission Scooter (FRESCO)

Duration: 36 months

Partners:
- Energieonderzoek Centrum Nederland (NL)
- Piaggio & C (I)
- Selin Sistemi (I)
- Commissariat à l'Energie Atomique (F)

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Status: Ongoing

The largest fuel cell bus fleet trial worldwide

C U T E

Objectives

Due to the gradual shortage and consequent increase in the cost of fossil fuel resources expected in the coming decades, it is necessary to encourage technical developments for the timely realisation of innovative and highly efficient energy systems based on regenerative/renewable resources. The aim of CUTE (Clean Urban Transport for Europe) is to develop and demonstrate a zero-emission transport system, including the accompanying energy infrastructure. The operability of a hydrogen based mobility technology will be demonstrated in 9 European cities by running 27 fuel cell powered buses in regular service for 2 years combining a number of novel systems for H2-production, storage and supply. The outcome of the project will support the public and commercial acceptance of a hydrogen fuel cell transport system, a secure energy supply, reduced overall CO_2, NO_x, SO_2 and PM emissions, improved health and living conditions in cities and better quality of life. It will strengthen European industry and greatly contribute to the Kyoto commitments.

Challenges/Problems addressed

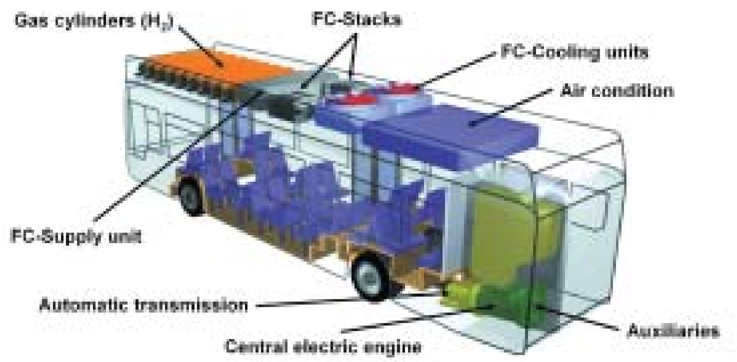
CUTE will be the first volume production test of this scale for fuel cell buses conducted anywhere in the world. The buses will be operated in cities with different climatic conditions and topographical extremes. Exchange of experiences including bus operation under differing conditions among the numerous participating companies will increase the knowledge on hydrogen and its use in transport systems. The design, construction and operation of the necessary infrastructure for hydrogen production, including the required refuelling stations, is a challenge in itself as so far only one fuelling facility exists in Europe. The collection of findings concerning the construction and operating behaviour of hydrogen production facilities for fuel cell buses will enable the future use of hydrogen in mobile applications. A wide range of pathways will be explored to produce hydrogen as a transport fuel, allowing the comparison of different methods of hydrogen production for fuelling systems. The technical and economic risk particularly lies in the use of this technology under day-to-day operating conditions, as no operational experience is available.

Technical targets

Neither the fuel cell technology nor the high-pressure filling station technologies for hydrogen are available in series production. Thus the technical targets refer to: operating fuel cell driven buses in regular service conditions for two years, operating decentralised hydrogen production facilities, getting experience in the operation of novel small scale hydrogen steam reformers and developing a 350 bar hydrogen technology for both filling station and hydrogen gas cylinders onboard.

Project structure

CUTE is organised as a *"horizontal"* and *"vertical"* cross-linked project group including 28 partners. In every city (Amsterdam, Barcelona, Hamburg, London, Luxembourg, Madrid, Porto, Stockholm and Stuttgart) a specific project group addresses the different topics (hydrogen production, hydrogen filling station, certification and homologation, operation of the buses, project management etc). The city specific organisation is vertically structured. The buses are produced by EvoBus GmbH in Germany. The bus operators in the participating cities are building the filling stations for gaseous hydrogen. Fuel producers are participating in the creation of the hydrogen infrastructure and some of these will subsequently operate the filling stations to gain experience with alternative fuels. Hydrogen is being produced through different methods in order to provide data for an efficiency comparison. A Fuel Cell Bus Club (FCBC) was founded by the CUTE & ECTOS (Ecological City Transport System) members in March 2001 to display the strong commitment of its members to support mobile fuel cell technology by developing and demonstrating an emission-free and low-noise transport system. The vision of the FCBC is to implement in the longer-term sustainable transport solutions based on renewable fuels.



Picture map of Europe and bus company logos.

Expected impact and exploitation

These 27 trial fuel cell buses will enable the cities to demonstrate that hydrogen is an efficient and environmentally friendly fuel for the future urban traffic in European cities. The buses, running on mainly locally produced and refilled hydrogen, should prove that emission-free and low-noise transport is possible today when ambitious political targets and innovative technology are combined. One of the key outcomes will be to assess and validate – in real market operation conditions – the efficiency of hydrogen production costs, and the life cycle assessment of fuel cell driven buses. Additionally a new filling technology with advanced pressure will be developed in order to fulfil a range of requirements by transport companies. The project addresses technical safety aspects (tests for the buses, filling station in city centres, production facilities close to cities, storage tanks, etc.) as well as social aspects. The CUTE project aims at creating public awareness, better public understanding and therefore acceptance of the hydrogen technology.

Progress to date

The hydrogen infrastructure and the bus maintenance facilities are being set up at all nine participating cities in order to be ready to refill and accommodate the three FC buses at each location. The first fuel cell bus will be delivered at the UITP conference in Madrid on 5th May 2003 and the other 27 buses will be delivered to the cities before the end of 2003. A general information brochure has been published and an infrastructure brochure will be made available by June 2003. Some technical information on the certification of the infrastructure and of the buses will be made available during the next months.

A Web-Site (http://www.fuel-cell-bus-club.com) is up and running with information on the CUTE project and further information on hydrogen and other fuel cell/hydrogen related projects.

INFORMATION

References: NNE5-2000-113

Programme:
FP5 - Energy, Environment and Sustainable Development

Title:
The Largest Fuel Cell Bus Fleet Trial Worldwide (CUTE)

Duration: 5 years

Partners:
Large consortium led by EvoBus, involving transport operators, hydrogen infrastructures and fuel cell developers, universities and city authorities.

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Status: Ongoing

Figure 1: Optical guidance system.

CityCell – fuel cell energy in cities

CityCell

Objectives

This project demonstrates five Fuel Cell (FC) hybrid vehicles applied in the inner-city environments of Turin, Berlin, Madrid and Paris. The vehicles for Berlin will be developed within this project, the other vehicles have been developed under national programmes. The project is aimed at demonstrating viable "zero emission energy efficient vehicles" in response to the needs of operators, EU objectives and Commission policies such as the Green Paper on Energy and the White Paper on Transport.

Innovative aspects

The CityCell project has several innovative features:

- Demonstration of one standard 12m hybrid fuel cell bus in each of the cities of Turin, Madrid and Paris. The hybrid systems applied in the Turin, Madrid and Paris buses will considerably reduce peak energy demand and thus the FC capacity required. This leads to a reduction of related investment costs.
- FC vehicle fleet comprising two vehicles on a dedicated "FC-only" route in the city of Berlin. These vehicles will have a length of 18.5 m thus allowing a high payload. The independence of the vehicles' FC-based electrical drive from an external energy supply means lower investment costs and higher flexibility in application.
- In Berlin operational efficiency is further increased through an optical guidance system (not funded by the EU project). The route selected for the operation of the FC vehicles has a length of approximately 20 kilometres and will be redesigned for the optical guidance system. The Berlin Transport Company (BVG) will install the guidance system on the vehicle and on a test section of the line. Figure 1 shows the optical guidance system mounted in a vehicle. Figure 2 shows the main feature of the lane design:

- Due to the optical guidance system the width requirements on the road can be reduced. The route will have its own lane.
- In areas with narrow bridges vehicle will have to merge with normal traffic.
- The system has the same accessibility as a low-floor tram. With its optical guidance system and the low floor throughout the vehicle the system gives passengers easy access to the vehicle from a low platform.

A safety study for the optical guidance system will be prepared (outwith the EU project).

The combination of FC technology and the optical guidance system will support the promotion of clean FC technology proving that environmental friendliness does not mean less but additional user benefit:

- higher average speed and higher passenger flow rate are possible when using optical guidance in Berlin;
- more comfortable driving behaviour;
- generous design of the inner space of the 18.5 m vehicle;
- easy vehicle access through low-floor design and pre-determined stops realized by the optical guidance system etc.;
- further increase of the positive environmental balance due to the high daily mileage of the vehicles compared to other alternative propulsion systems. The high daily mileage is gained through the usage of the increased space on the roof of the 18.5 m vehicle for hydrogen storage.

The project will have positive effects on the air quality in the inner-city areas because no regulated or unregulated pollutants are emitted through the use of hydrogen. Furthermore, no CO_2 is emitted. Thus FC technology has a significant potential to reduce the impact of transport on the greenhouse effect.

There will be careful monitoring and evaluation of the project involving

- several studies on environmental, cost benefits, energy efficiency, Life Cycle Analysis (LCA), technology implementation, socio-economic impact of applied technology, standardisation etc.;
- A direct comparison between gaseous and liquid storage of H_2 will be obtained.
- The optical guidance system in Berlin provides a further advantage to the project through lower investment costs (existing roads can be used with only small modifications, driving without guidance is possible).

Figure 2: Main characteristics of the lane design.

Project structure and technical data

Berlin Vehicle

- FC system: 140 kW Polymer Electrolyte Membrane (PEM) FC developed by Hydrocell, plus an energy storage system to provide a total power of 200 kW, low pressure, modular system with low support demand from peripheries.
- Electric architecture will be defined by an engineering study (hybrid or full power, with hybridisation rate to be defined).
- Compressed hydrogen storage system (>350 bar) to be developed by AIR LIQUIDE.
- Energy management is developed by IRISBUS.
- Vehicle: Iris Civis 18.5 metres, optically guided.

Paris Vehicle

- 12 meter CRISTALIS based vehicle.
- FC system: 75 kW PEM fuel cell developed by AXANE.
- Step-up converter and electric power-train made by ALSTOM.
- The energy storage system will be a 80 kW Ni-MH battery set planned to be developed by SAFT.
- Compressed hydrogen storage system (>350 bar) to be developed by AIR LIQUIDE.
- Energy management is developed by IRISBUS.

Turin and Madrid Vehicles

- 12 meter CRISTALIS vehicle.
- FC system: 62 kW PEM FC developed by UTCFC operating at ambient pressure.
- Step-up converter and electric drive train made by ANSALDO.
- Lead-acid battery energy storage system.
- Compressed hydrogen storage system (200 bar) in 9 cylinders developed by SAPIO.
- Energy management is developed by IRISBUS.
- The Madrid bus will be similar to the Turin vehicle except for the hydrogen storage system which should be at 350 bar with composite tanks. This storage system is under development at AIR LIQUIDE.
- The Madrid refuelling station will be used for two projects (CityCell and Cute). The IRISBUS vehicle will have a hydrogen storage system designed to be compatible with the common refueling station.

Exploitation and impact

The project will demonstrate how FC technology combined with an advanced vehicle concept can be introduced into a wider market. This will have major environmental and quality benefits on urban public transport applications.

Urban planners are constantly faced with the problem of harmonising the need for mobility with a desire to preserve and improve the air quality in our cities as well as reducing the greenhouse effect. The project will also test the installation of an integrated FC / energy storage system to obtain better energy efficiency and to keep vehicle costs low thus promoting the market introduction of this technology. An integrated propulsion system of this capacity is truly new in the public transport sector. Furthermore, implementation of FC technology in combination and without optical guidance can be compared.

Problems to be addressed

The project will start in spring 2003 and has a duration of 48 months. The work to be done includes:

- Vehicle and component manufacture -Safety, regulation, certification.
- Vehicle test, maintenance and commissioning.
- Development of compressed hydrogen tank system.
- Development and integration of the FC system, including energy storage system.
- Demonstration and evaluation and communication of results.

INFORMATION

References: NNE5-2001-00689

Programme:
FP5 - Energy, Environment and Sustainable Development

Title:
Fuel Cell Energy in Cities (CityCell)

Duration: 48 months

Partners:
- Irisbus (F)
- Berlin Senate (D)
- ATM Turin (I)
- Berliner Verkehrsbetriebe (D)
- EMT Madrid (E)
- RATP Paris (E)
- Cellpower (D)
- Air Liquide Espagna (E)
- TotalFinaElf (F)
- Ansaldo (I)
- ENEA (I)
- IDEA (E)
- Inrets (F)
- INTA (E)
- Sapio (I)
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Status: Ongoing

PEM fuel cell stack (with kind permission of NUVERA Fuel Cells Europe srl).

Proton exchange membranes for medium-temperature fuel cells

PEM-ED

Objectives

The future industrial development of electrochemical devices in the medium temperature range relies on the synthesis and production of new protonic materials stable from 80-180°C and having a conductivity preferably 10^{-3}-10^{-1} Scm^{-1}. Such ionic conducting materials, in the form of flexible, mechanically stable membranes are solid electrolytes for energy conversion devices such as fuel cells.

The objectives are the development of thermally stable protonic membranes based on sulfonated polymers and on hybrid inorganic-organic systems, that could be produced on an industrial scale, which will comply with the technical requirements necessary for a reliable system performance in a medium temperature hydrogen-air-PEM-FC stack. The project will help to strengthen the European competitiveness in the production of fuel cells for stationary and mobile applications and would establish a potential world lead for a new, and totally strategic European technology.

Problems to be solved

The solid protonic conducting materials currently known are suitable for use in temperature ranges, either below 80°C or above 800°C. This leaves a wide gap in which no protonic material retains satisfactory conduction and/or thermal stability. The only protonic electrolytes currently available for medium temperatures between 130 and 180°C are liquid e.g. in phosphoric acid fuel cells.

Technical target

The direct technological output of this project should be:

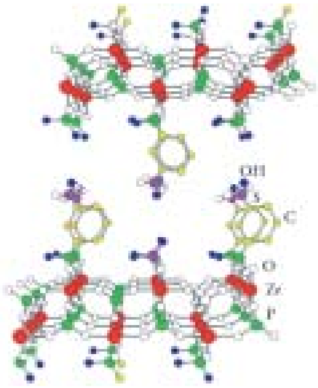
- Sulfonated thermostable polymers of conductivity > 10^{-2} Scm^{-1} appropriate for large scale production
- Thermostable polymer reinforcements with thickness < 50 micron and open area > 60%
- Hybrid inorganic-organic reinforced membranes, with dimensional swelling < 15%, conductivity > 10^{-2} Scm^{-1} at 50°C and stable to 180°C
- Optimised MEAs for fuel cells with a performance of 400 mW/cm^2 on H_2-CO/air at medium temperatures (130-150°C), max. CO content 1000 ppm
- A 1 kW fuel cell operating at temperature up to 150°C, power/weight: > 0,3 kW/kg (130-150°C)
- Hot spot and life cycle analysis of the novel membranes.

Project structure

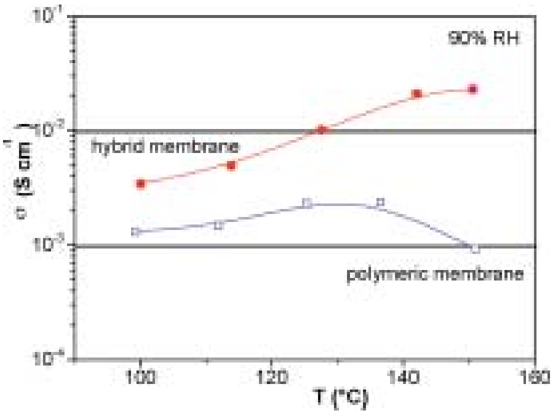
The current partnership has been developed from the consortium of a fundamental research project "Hybrid Ionomeric Membranes" (1.7.93 – 30.06.99). Scientists participated from CNRS LAMMI, who acted as co-ordinators of that project and the Universities of Perugia and Strathclyde. NUVERA and FuMA-Tech closely followed the progress of the project from its outset as endorsing industries. The results obtained to date have excited the active participation of another research centre and 3 industrial partners: CNR ITEA, specialised in the development of membrane-electrode assemblies, SEFAR, specialists in woven polymer fabrics as membrane supports, EDF, a potential end user of stationary operating fuel cell applications, IFEU, an Energy and Environmental Research Institute. The expertise of these groups completes the know-how of the previous consortium.

Expected impact

In spite of their low environmental impact, membrane fuel cells have not yet been competitive in the market segment of mobile and portable energy supply due to their high production costs (above 5,000€/kW). The automobile market is the one most usually addressed by Polymer Electrolyte Membrane Fuel Cell (PEMFC) manufacturers because of the intrinsic characteristics (high power densities) not found in the other types of cell. However this application demands very low



Schematic representation of the structure of gamma zirconium sulfophenylphosphonate, a proton conductor that can be used as a component of hybrid proton conducting membranes (with kind permission of University of Perugia).



Conductivity as a function of temperature for a sulfonated polyaromatic membrane and a hybrid membrane containing 20 wt% inorganic proton conductor (with kind permission of University of Perugia).

prices (50-70€/kW) for the whole power generator module. Auxiliary power generation systems in the range of 5-200 kW represent another market, where standard piston engine systems have a price of 1000-1500€/kW. New membrane approaches and production technologies can ease the way to acceptable fuel cell prices thus stimulating the end-user industry to invest into the new products by finding new and more accessible markets.

The project aims for the development of relatively inexpensive protonic conducting membranes characterised by high conductivity (10^{-2} S/cm) and stability up to 130-180°C, as well as the development of large-scale production capability. Fuel cell manufacturers are likely to be the main end-users of a successful product. A bench-scale fuel cell stack will be supplied and approved within the project to assure quick adaptation to stationary and mobile applications after termination of the project. Assuming that the cell stack is competitive in cost with existing technology, a new market opportunity will be created and a new manufacturing base will be required to meet the demand.

Results

The following results have been achieved till the mid-term of the project:

- Sulfonated thermostable polymers namely sPEK and sPEEK with conductivity > 10^{-2} Scm^{-1} and appropriate for large scale production are available
- Thermostable polymer reinforcements with thickness < 50 µm and open area > 60% are available
- Hybrid inorganic-organic membranes, with dimensional swelling < 15%, conductivity > 10^{-2} Scm^{-1} at 150°C, and stability up to 150°C are available
- MEAs using novel membranes and showing performance of 330 to 420 mW/cm^2 at 0.7 A/cm^2, 110°C with H_2-air, and hybrid membranes with performance of 470 mW/cm^2 at 0.7 A/cm^2 (H_2-O_2 at 100°C) are available
- Hybrid membranes having a lifetime of = 1000h at 80-90°C on H_2-O_2 have been achieved. Lifetimes of 1000h at 130°C have to be proved.

INFORMATION

References: ERK6-CT-1999-00025

Programme:
FP5 - Energy, Environment, Sustainable Development

Title:
Proton exchange membranes for applications in medium-temperature electrochemical devices (PEM-ED)

Duration: 48 months

Partners:
- Funktionelle Membranen- und AnlagenTechnologie (D)
- Centre National de la Recherche Scientifique (F)
- Consiglio Nazionale delle Ricerche (I)
- University of Strathclyde (UK)
- Università di Perugia (I)
- Electricité de France (F)
- SEFAR (CH)
- Nuvera Fuel Cells Europe (I)

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Cell laboratory fuel cell stack.

High-temperature PEMFC Stack with Methanol Reforming

AMFC

Objectives

Fuel cell systems are promising for powering vehicles with regard to increasing the energy efficiency and reducing emissions. High cost and the lack of an infrastructure for a suitable fuel block the introduction of fuel cell vehicles. There are thus many problems still to be solved before the fuel cell can be a commercial reality for vehicle applications. Several of these problems are associated with the low operating temperature (around 80°C) of the current Polymer Electrolyte Membrane (PEM) fuel cell technology.

The objective of the project is to develop an integrated Advanced Methanol Fuel Cell system, based on cost-efficient polymer membranes operating at about 200°C. The fuel cell will be thermally and physically integrated with a methanol reformer and a catalytic burner. The increased operating temperature of the fuel cell will make it possible to design a fuel cell system with improved efficiency, simultaneously reducing cost, size and complexity of the complete power system.

The feasibility of this technology as a vehicle propulsion power system will be demonstrated by dynamic tests and evaluated for commercialisation.

Challenges

In order to make the fuel cell commercially viable the cost must be dramatically reduced. Size, weight and complexity of the power system must also be reduced.

In order to reach the financial and technical goals for an automotive application a fuel cell system will be developed which is based on a temperature-resistant polymer membrane electrolyte that operates at approx. 200°C.

Traditional PEM fuel cells generally have problems when operating on reformate gas produced from hydrocarbons such as methanol, gasoline or natural gas. In the fuel processing of the hydrocarbon to hydrogen, carbon monoxide (CO) is produced as a by-product. This CO poisons the catalyst of the fuel cell. Therefore the CO has to be removed from the gas stream. Today's fuel cells cannot tolerate more than approx. 20ppm CO in the reformate stream, making the required fuel processing complex and expensive. By elevating the operating temperature of the fuel cell above 150°C this poisoning effect has little relevance. This greatly lowers the complexity of the fuel processor by removing the necessity for a multi-stage CO clean-up system. The CO clean-up system is indeed generally the most space-consuming reactor of the series required to produce the fuel cell feed gas. It is also the most expensive reactor and the most difficult to control.

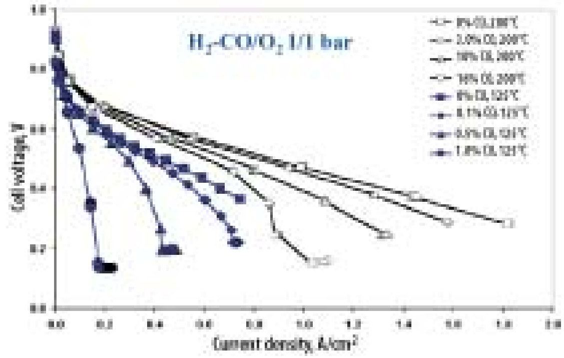
High temperature PEM fuel cell technology also makes it possible to simplify the overall power system with respect to water and thermal management. This is due to the fact that above 100°C the water management involves only a single phase (no liquid condensation), and the temperature gradient is larger for efficient cooling. Another advantage of the high operating temperature is that high value heat can be recovered.

In the project a low temperature methanol reformer will be developed. By operating the fuel cell and the reformer at temperatures close to each other it is possible to make use of the waste heat produced in the fuel cell for running the steam reforming reaction, which consumes heat. This will increase the system efficiency considerably.

Project structure

The consortium consists of six partners; three industrial partners, Volvo Technology Corporation (VTEC), Statoil ASA, Proton Motor Fuel Cell GmbH and three universities, Technical University of Denmark (DTU), Norwegian University of Science and Technology (NTNU) and University of Newcastle upon Tyne (UNEW). Volvo as co-ordinator is in charge of the fuel cell system design, simulation of fuel cell vehicle; testing and evolution of the fuel cell system. The responsibility of Statoil is to supply the methanol and design and construct the integrated methanol reformer and catalytic burner. The role of Proton Motor is to test construction material and give engineering support for design and construction of stacks and fuel cell system. DTU is responsible for fabrication of polymer membranes, catalysts and electrodes, fuel cell testing, preparing membrane electrode assembly (MEA) and for fuel cell stack design, and construction of the fuel cell system. The part of NTNU is development of electro-catalysts, testing of single cell membranes; and evaluation of construction materials and reformer and burner catalysts. The role of UNEW is design and fabrication of improved electro-catalysts.

A hydrogen fuel cell engine in the rear of a bus.



Influence of CO concentration in the fuel and the temperature on the fuel cell performance.

Technical targets

- Fuel: Methanol/Water
- Polymer thermal stability up to 200°C
- Durability over 5,000 hours for polymer
- Fuel cell catalysts for high CO-levels, 2-3%
- Fuel cell stack of 3,5 kW_{el}
- Voltage of 0,6 V per cell
- Current density of 0,5 A/cm^2
- Noble metal loading of 0,5 g/cm^2 for fuel cell
- Emissions below EURO V 2008 standards

Expected impact

Local and global environmental issues as well as the consumption and supply of energy are major challenges for the future. Fuel cells are a promising option to address these challenges. Due to the lack of an appropriate hydrogen infrastructure, a noticeable market share for vehicle applications cannot be expected before 2015. Furthermore, the fuel cell system has to fulfil severe technical and financial requirements for vehicle applications. Successfully developed high temperature PEM fuel cells with an integrated system would be a considerable step towards a commercially viable fuel cell system for automotive applications.

The main expected achievements from this project are materials and technologies for high temperature PEM fuel cells and a compact low temperature methanol reformer. The advantages of these technologies will be demonstrated as well as the benefit of combining them into an integrated system.

A positive result of this project would lead to scale up of the system to the size needed for a propulsion system.

Progress to date

New polymers have been synthesised and membranes have been produced from the polymer and polymer blends. Batches of the polymers have been made in order to increase the molecular weight to improve mechanical strength, proton conductivity and thermal stability. The performances were superior to commercial alternatives.

Gas diffusion electrodes have been prepared by tape casting, screen printing and spraying procedures. The MEA has been prepared by hot pressing of the gas diffusion electrodes to the membrane.

High power densities have been realized in laboratory cells. And high performance has been achieved with CO concentration as high as 16% in the gas feed.

More than 100 MEAs with an active area of 100 cm^2 have been prepared for single cell tests and laboratory stack test. Endurance tests have been performed in single cell and over 5000 h of operation at 150°C has been demonstrated.

A detailed design of the reformer and the catalytic burner has been carried out.

Process simulations have been performed which show that it is possible to achieve high system efficiencies with a system design of reasonable simplicity still maintaining a high level of controllability of the system.

INFORMATION

References: ENK5-CT-2000-00323

Programme:
FP5 - Energy, Environment and Sustainable Development

Title:
High-temperature PEMFC Stack with Metanol Reforming (AMFC)

Duration: 36 months

Partners:
- Volvo Technology Corporation (S)
- Danmarks Tekniske Universitet (DK)
- Statoil (NO)
- Norwegian University of Science and Technology (NO)
- University of Newcastle-Upon-Tyne (UK)
- Proton Motor Fuel Cell (D)

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Status: Ongoing

Figure 1: Forza™ power module based on PEM stack technology, by Nuvera Fuel cells.

Development of low-cost, high-efficiency PEM Fuel Cells

APOLLON

Objectives

It is generally accepted that the global demand for energy will dramatically rise in the future. Fuel cells are promising as efficient, non-polluting power sources that produces little noise and have no moving parts. The main problem is the high cost of manufacturing the devices, which has largely limited them to a handful of exotic applications.

The objective of the present project is the development and construction of Advanced Polymeric Fuel Cells, which will be able to operate under H_2 and/or methanol fuels. High thermodynamic efficiencies and power densities of the order of 0.5 W/cm^2 as well as significantly reduced manufacturing cost of the membrane electrode assembly are the main aims of this project. The accomplishment of the above is feasible either by the optimization of both the electrocatalytic performance of the electrode/electrolyte interface or the development of advanced high temperature (150°C- 200°C) polymer electrolytes with high ionic conductivity.

Challenges

The ideal fuel for the efficient operation of fuel cells is H_2, which exists, in high quantities in nature as the main constituent of water and organic substances. Conventional Polymer Electrolyte Membrane Fuel Cells (PEMFC) using Pt as a catalyst suffer irreversible damage of the electrocatalytic activity if CO (even at 100ppm) is introduced with the fuel gas. Therefore, the fuel processor should be able to supply the fuel cell with CO free H_2 and so high complexity and instability characterize the system.

In addition, overpotential losses in low temperature fuel cells are due to the *activation overpotential* developed on the electrode/electrolyte interface. These losses are essentially related to the electrocatalytic activity of the electrodes (both anode and cathode), which either oxidize H_2 or methanol or reduce O_2. This is a severe limitation for the achievement of high thermodynamic efficiency, which for the current state of the art fuel cells lies around 35%. Thus there is great room for improvement of the polarization properties of the anode and mainly the cathode materials.

In order to overcome the aforementioned constraints: (i) *new more active and cost effective electrode materials* which can be tolerant to CO poisoning even at CO concentrations 0.5-1% with applications in low temperature fuel cells (70-80°C preferably for mobile applications) and (ii) the use of *new generation high temperature cheap polymeric electrolyte membranes* which will permit the cell operation at temperatures above 150°C will be investigated. This latter medium temperature fuel cell is proposed for stationary applications. However due to the high operating temperature (above 150°C) it is quite tolerant to CO poisoning.

Apart from the improved electrocatalytic activity of the new electrode materials, they are more cost effective compared to the existing expensive Pt based electrodes because of both the cheap constituents of the active electrocatalytic phase and their ultra stable properties and long lifetime. This results in greater durability and higher electrocatalytic activity of the fuel cell.

Besides the expected significant improvement of the PEM fuel cell performance we expect that the cost of the membrane assembly will be significantly reduced since the new membrane is a factor of 10 less expensive than state of the art NAFION®. Furthermore, such medium temperature fuel cells are expected to be more cost efficient than their proposed mobile counterparts due to their higher temperature operation and the anticipated zero water drag coefficient for the membranes which result in more simplified controls.

Project structure

The project consortium consists of nine partners. Technical University of Denmark (DK) has expertise in theoretical design of catalysts. Three research organizations with expertise in synthesis and development of electrocatalysts: Max-Planck-Institut für Kohlenforschung (D), Consejo Superior de Investigaciones Cientificas (E) and Institute of Chemical Technology (CZ). The Institute of Chemical Engineering and High Temperature Processes (GR) which is also the co-ordinator of the project, has a great deal of experience in the study and physicochemical characterization of electrochemical systems and spectrochemical characterization of polymeric materials. University of Patras-Greece (GR) and Slovenian National Institute of Chemistry (SI) are

Figure 2: High temperature single cell Testing Unit.

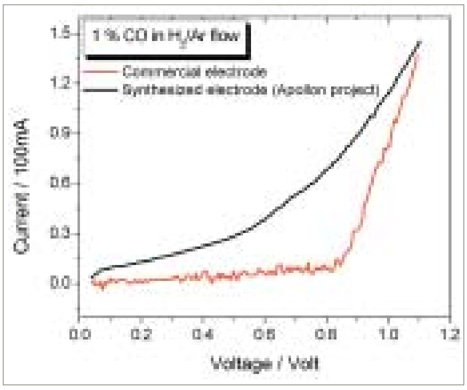

Figure 3: Commercial and synthesized electrode under 1%CO/49%Ar/50%H_2 flow, showing higher electrochemical activity at low potentials for the synthesized electrode.

responsible for the synthesis and development of novel polymeric electrolyte membranes. Finally, two industrial partners De Nora Tecnologie Elettrochimiche S.p.A. (I) and FRIGOGLASS S.A. (GR) will further develop and exploit the results achieved and market the product.

Expected impact

The successful completion of the project will allow for the production of fuel cells readily accepted by the market (simplified and more reliable fuel processors, reformate gas with marginal changes of composition, fuel cells characterised by constant performance over thousands of hours, reduced investment, more effective co-generation in the case of stationary applications but still keeping the intrinsic advantages of the membrane fuel cells, and low maintenance cost). The fuel cell system, developed as a result of the programme, will certainly increase the probability of realising the commercial forecasts for fuel cells based on a number of market surveys. Whereas the ability of the EU Industry to compete successfully in the area of the stack technology is already well established (De Nora, Siemens), the field of catalyst production and electrode manufacturing is just in the very first stage of development. For this reason, the success of this project could play a really decisive role to help EU industry to acquire a position of technical excellence in this dynamic area.

Progress to date

During the first year of the project experimental and theoretical studies were focused on pre-selection and preparation of new promising electrocatalysts, which can be used on the anode and cathode side of PEM fuel cells. A number of bi- and tri-metallic catalysts were synthesised, mainly according to theoretical predictions, and are now under investigation. The objective is to evaluate their efficiency in association with already existing and utilised materials. The results are encouraging, although a lot remains to be done, in order to refine processes and optimize results (see Figure 3).

Development and synthesis of new alternative polymer electrolytes, using various methods, are now in progress. Promising polymeric materials have been synthesised and characterised. Additionally, modification of already existing polymer blends is under study aiming to increase their ionic conductivity. Based on the above studies, formation of new polymeric membranes, which after optimisation can be tested in a single fuel cell, is underway. As a final point, the integration of the investigation results, into a single PEM fuel cell construction (see Figure 2) and testing of the assembly under real conditions, is the ultimate goal of the first part of this project.

INFORMATION

References: ENK5-CT-2001-00572

Programme:
FP5 - Energy, Environment and Sustainable Development

Title:
Development of Low-Cost, High-Efficiency PEM Fuel Cells (APOLLON)

Duration: 36 months

Partners:
- Foundation for Research and Technology Hellas (GR)
- Max-Planck-Institut für Kohlen-forschung (D)
- De Nora Tecnologie Elettrochimiche (I)
- Institute of Chemical Technology (CZ)
- Consejo Superior de Investigaciones Cientificas (E)
- Technical University of Denmark (DK)
- University of Patras (GR)
- Frigoglass (GR)
- Slovenian National Institute of Chemistry (SI)

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Status: Ongoing

High-temperature PEMFCs for industrial use

OPTIMERECELL

Objectives

Proton exchange membrane fuel cells (PEMFCs) operating at relatively high temperatures are very promising for industrial use. They have high power density, can vary their output rapidly to meet shifts in the power demand and are well suited especially for applications in the automotive industry, where quick start-up is required. Moreover, working at a high temperature could increase drastically the fuel cell CO tolerance, simplifying a reformer based fuel cell system and drastically reducing the cost.

The industrial objective of this project is to use the developed and optimised fuel cell technology for the realisation of a 10kW PEMFC stack designed and manufactured with special attention on cost reduction and working with a hydrogen and CO mixture simulating a liquid fuelled on-board reformer. Particular attention will be paid to reduction of the weight and the volume.

Challenges/Problems to be solved

PEMFC is a thin polymer sheet coated on both sides with highly dispersed metal alloy catalyst particles which allows the hydrogen ions to pass through it.

The two main R&D innovations of the project are to develop new high temperature polymers with both higher operation temperature (120°C-130°C) and higher CO tolerance (up to 200 ppm). The higher temperature reduces the problem of the thermal management of the PEMFC stack. The higher CO tolerance reduces the problems of the gas supply (generation from hydrocarbons and purification).

The novel PEMFCs with a thickness in the range of 40-100 micrometers will be developed to guarantee their most important properties associated with the dense, tough, non-porous and non-brittle dry state structure, with high ionic conductivity, and reasonable water uptake, and thermal and hydrolytic stability during their lifetime.

The PEMFCs obtained will be tested to check their capacity for generation of electrical energy. The potential and current will be measured in a membrane electrode assembly and correlated with the heat and water balance of the system. The optimum conditions of the PEMFCs manufacturing will be established during the project and will be completely focused on cost reduction and the commercialisation capacities.

Technical target

The targeted properties of the innovative optimised PEMFCs are as follows:

- Cell performance: >400 mW/cm^2
- Membrane thickness: <100 µm
- Catalyst loading (both electrodes): <0.5 mg/cm^2
- Stable work duration: 4000 hours
- Cost of energy produced
  Short term: 200-260 €/kW
  Long term: <150 €/kw

And the technical objectives (compared with current PEMFCs and conventional techniques) are:

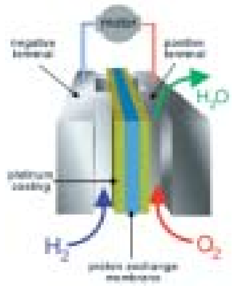
- Cost reduction-about 35-50%.
- Reduction of the weight.
- Reduction of volume.
- Increasing the CO tolerance up to 200 ppm.
- Increasing the operation temperature to 120°C-130°C.

Project structure

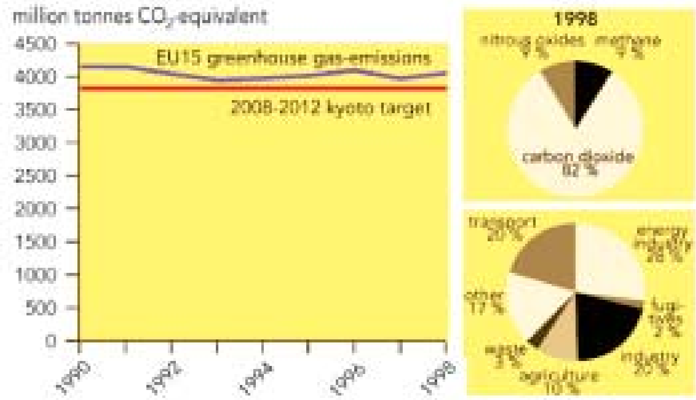
The achievement of the technical goals described calls for multi-disciplinary and complementary actions. In this respect, this project needs to associate many different competencies, which are included in the consortium e.g. Membrane, Gas Diffusion Layer, electrodes, catalyst deposition and industrial stack manufacturing.

The consortium of the project is formed by a strong European partnership. The partners sought to create a balanced structure of interests by technology providers, R&D centres and end-users. The consortium gathers 9 partners from 7 different countries (Germany, Netherlands, France, Spain, Belgium, Italy and United Kingdom).

Moreover, the impact of the project results on the industrial use of this technology will be high, since the partners of the project are major actors in their fields of activity (some partners are leaders in their respective markets) and the consortium includes an end user from the car manufacturing sector.



PEM fuel cell. Protons pass across the thin membrane as electrons flow around the circuit to drive the motor.



Total EU greenhouse gas emissions (carbon dioxide, methane, nitrous oxide, fluorinated gases).

Environmental impact: fuel cell development for vehicles

The transportation sector has a poor environmental record: it has a negative impact on local air quality and acidification and is a major emitter of CO_2. In 1999, the transportation sector was responsible for some 32% of the world's energy use, and 29% of the global CO_2 emission (Eurostat, "EU Energy and Transport figures 2001"). The enhanced greenhouse effect is considered by many as one of the most serious environmental problems. Calls for policies to reduce CO_2 emissions are growing stronger and there is a widespread demand for viable CO_2 neutral primary energy sources.

Although technological changes have reduced emissions of local pollutants, these emissions remain a serious problem in most countries of the world. Further technological development is needed to bring down these emissions to acceptable levels. Fuel cell vehicles are seen as a promising solution to these problems. Emissions of local pollutants are reduced to zero or near-zero levels, and CO_2 emissions are lower (because of the higher efficiency of fuel cells) or zero if renewable primary energy sources are used.

Economic impact: between 2-5 million cars in 2010

To be successful in the transportation sector, it is widely believed that PEMFCs will have to cost 150 €/kW or less. In fact, automakers believe that in light duty applications they will need to cost around 25-50 €/kW. This means that the current cost of about 500 €/kW will have to be reduced by another order of magnitude. To accomplish this, production volumes of the order of one million units per year are necessary.

It is clear that only technological developments driven by cost management and cost reduction could lead to results applicable on an industrial scale. In this project, special attention will be paid to the optimisation of the efficiency and the manufacturing and operational cost reduction. The presence of car manufacturers will permit the assessment of the needs and the development of solutions specifically adapted to these needs from the technical and economical points of view.

Progress to date

To date the project has achieved the objectives set for the first work package. They are as follows: Specification of the characteristics of the fuel cell membrane in relation to the fuel cell operating conditions, specification on the membrane and cell designs, definition of the catalysts to be applied and their loading, specification of the fuel cell stack design and its operating parameters, and the collection of the data available on PEMFCs in order to select the optimum process parameters. Now in the second work package, the work is focused on the development of the high temperature polymer membranes.

INFORMATION

References: ENK6-CT-2002-00646

Programme:
FP5 - Energy, Environment and Sustainable Development

Title:
High-temperature PEMFCs for Industrial Use (OPTIMERECELL)

Duration: 36 months

Partners:
- Fundacion INASMET (E)
- Commissariat à l'Energie Atomique (F)
- Nedstack Fuel Cell Technology (NL)
- Deutsches Zentrum für Luft- und Raumfahrt (D)
- Rucker Iberica (E)
- Centro Ricerche Fiat (I)
- Gencoa (UK)
- Ikarus Coatings (D)
- Solvay (B)

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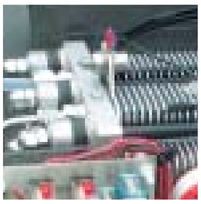
Status: Ongoing



Fuel cell Innovative Remote System for Telecom

FIRST

Objectives

Photovoltaic (PV) power systems are widely used in telecommunication applications, when AC mains are not available, for reliability and simplicity reasons or where connections to AC mains are not cost effective due to remote locations. However, availability of solar power systems depends on the amount of available solar radiation, and this varies throughout the year. This problem could be solved using fuel cells in combination with solar power systems to improve power availability.
Within the FIRST project two different solutions are being developed in this way. Showcase 1 is a hybrid system in which the fuel cell is an additional power source that enters into operation when necessary; consuming hydrogen regularly supplied to the system. Showcase 2 is a completely autonomous system with a seasonal energy storage system, including an electrolyser generating hydrogen in summer to be used in winter by the fuel cell.

Challenges

Two novel approaches for a remote power supply telecom application in the range of 150 W and an energy consumption of 3.6 kWh/day are being developed and tested:

SHOWCASE 1: PV–Fuel Cell Hybrid System. Solar energy is used, with short-term energy storage by means of batteries, during most parts of the year. Only during long periods of low solar radiation, when the state-of-charge of the batteries becomes very low, does the fuel cell start its operation as an additional system for powering the telecom equipment. Hydrogen is delivered to the system externally. The main advantage of this system is that power system availability is increased considerably because the fuel cell energy is available by maintaining fuel in the tank. Therefore with good maintenance it is possible to ensure that the telecommunication system will be properly powered. Maintenance requirements compared to conventional diesel generator powered systems will be significantly reduced.

SHOWCASE 2: PV system with additional long-term (seasonal) energy storage system. Solar energy excesses generated during long sunny periods, especially in summer, are stored by means of a hydrogen storage system based on metal hydrides, where hydrogen is initially produced by an electrolyser and consumed when required by the fuel cell. This system enables solar power systems to be used in places where operation of conventional back-up systems is not allowed. This increases the system availability while reducing the maintenance costs significantly.

In order to fulfil the strict telecommunication requirements in terms of size and reliability in these showcases it is also necessary to develop specific elements that improve the actual state-of-the-art of the components such as fuel cells, electrolyser, hydrogen storage system, energy management system and charge regulator for CIS photovoltaic modules.

Project structure

The FIRST project is being carried out by a consortium of 7 partners from 4 countries, and operates with the collaboration of a Board of Interest, formed by end user companies that have a strong interest in these technologies. The list of the partners and members of the Board of Interest is presented below along with a brief description of their role:

1. INTA (Spain): co-ordination of the project, collaboration in the design and sizing of the systems, integration and evaluation of showcase 1.
2. Air Liquide (France): PEM fuel cell system development, economics studies.
3. Fraunhofer ISE (Germany): sizing of the systems, PEM medium pressure electrolyser development, Energy Management System development.
4. CIEMAT (Spain): PEM bipolar plate design, integration and evaluation of showcase 2.
5. ICP-CSIC (Spain): Hydride metal based Hydrogen Storage System development.
6. NUVERA Fuel Cells Europe (Italy): PEM stack development.
7. WÜRTH Elektronik (Germany): CIS technology solar panels development

Board of Interest:

8. INABENSA (Spain): Interest in remote energy systems for telecom.
9. CHLORIDE BOAR (Spain): Interest in uninterrupted power supplies.
10. ISOFOTON (Spain): Interest in solar remote systems.
11. GREENCELL (Spain): Interest in fuel cell systems.

Expected results/Exploitation plan

The expected results of the two different showcases are related to improving power availability while decreasing costs and size compared with conventional solar power systems.

Exploitation plans are related to the different industrial partners:

- To analyse the reliability and the technical status of stand-alone power systems for telecom application is the main objective of companies joining the project in the Board of Interest (INABENSA, CHLORIDE BOAR, ISOFOTON and GREENCELL). This Board of Interest is still open for further participants.

- To develop power generation systems based on fuel cells for different applications is the main objective of Air Liquide and Nuvera Fuel Cells Europe.

- To develop hybrid power systems based on solar systems for different applications is the main objective of Würth Elektronik.

FIRST project tasks are focused to fulfil these different objectives of the industrial partners.

Progress to date

Presently the consortium has completed the development and commissioning phases, all the components have been developed and tested (in all the cases achieving the expected performances), and both showcases have been integrated and commissioned. In the beginning of the fourth year of the project the evaluation phase is starting at Madrid (Showcase 1 at INTA facilities and Showcase 2 at CIEMAT ones).

INFORMATION

References: ERK5-CT-1999-00018

Programme:
FP5 - Energy, Environment, Sustainable Development

Title:
Fuel cell Innovative Remote System for Telecom (FIRST)

Duration: 48 months

Partners:
- Instituto Nacional de Técnica Aerospacial (E)
- Air Liquide (F)
- Fraunhofer Gesellschaft zur Förderung der Angewandten Forschung (D)
- Centro de Investigaciones Energeticas Medioambientales y Tecnologicas (E)
- Consejo Superior de Investigaciones Cientificas (E)
- Nuvera Fuel Cell Europe (I)
- Würth (D)

Board of Interest:
- INABENSA (E)
- Chloride Board (E)
- ISOFOTON (E)
- GREENCELL (E)

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Status: Ongoing

CEA miniature fuel cell core on silicon substrate.

Hydrogen-fed miniature fuel cell for portable applications

H_2-MINIPAC

Objectives

At the moment, the further increase in functionality of portable devices is severely hindered by the limits of portable energy sources.

Fuel cells have the potential to increase the energy density of such devices by a factor of 3 to 10 compared to presently used lithium batteries. They are more user friendly since recharging is not required. They offer more flexibility for electronic designers and should result in lighter and smaller devices. They have a great potential to fulfil the requirements of "green electronics" and to lead to a better sustainability.

The "H_2-MiniPac" project aims at the feasibility demonstration of a cost-efficient and performing miniature fuel cell technology, thanks to the development and the integration of advanced micro and nano components and their associated processes.

Challenges/Problems addressed

Most of the fuel cell research activities have been up to now devoted to large power automotive and stationary applications. However, under the conditions prevailing for small communications tools, only extremely poor performances can be achieved with the "classical" technology approach used for large power fuel cell stacks. This is, apart from other parameters, due to:

- the very poor catalytic efficiency of the catalyst layer at ambient temperature,
- the large resistance drop which occurs in the "MEA" (membrane-electrode-assembly) sandwich.

Moreover, no smart solution is available to store the gaseous hydrogen used as a fuel, and the efficiency achievable with methanol as fuel, until recently was relatively poor.

In order to overcome these problems, a completely new approach is needed for micro fuel cell development. This explains why new technologies are being investigated, based on the following major breakthroughs:

- the concept of a miniaturised fuel cell core based on micro technologies
- a new electrolyte formulation
- the use of a new and highly efficient system for the in-situ production and delivery of pure gaseous hydrogen.

A complete Life Cycle Analysis (LCA) will be performed, allowing the evaluation of the social acceptability of the technology.

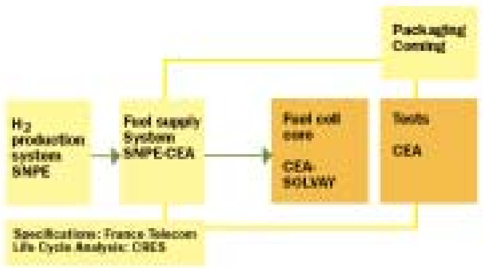
Project structure

The project combines competences and resources from research and industrial world leaders in mobile communication equipment, electrochemical energy sources, materials and components manufacturers.

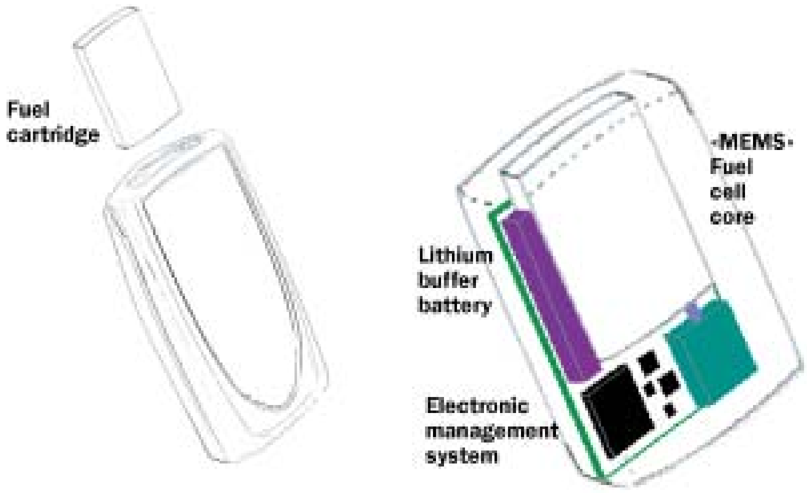
The consortium consists of CEA (fuel cell core development), SNPE (fuel production and delivery system), Solvay (membrane development), Corning (microfluidics), France Telecom (mobile devices specifications) and CRES (LCA).

Research is focusing on new materials, Micro-Electromechanical Systems (MEMS)-based concepts, and functions that take advantage of multidisciplinary interactions (chemistry and catalysis, polymer science, electronics, mechanics, etc.) combined with the use of microstructures and new nanomaterials (electrodes, catalysts).

The miniaturised lab-scale demonstration system that will be developed will prove the feasibility of an innovative and elegant solution to the new requirements related to the energy supply of mobile communication systems.



Tasks distribution synoptic.



Artist view of a portable equipment with its fuel cartridge.

Expected impact and exploitation

Wireless devices like smart phones, pagers, Personal Digital Assistants (PDAs) etc. are characterised by:

- the simultaneous multiplication of their functionalities (GPS, Internet, large colour displays, increase in data exchange rate etc.),
- new requirements of the final customer (no wire, no plug, instant charging, "always on" devices...),
- the race for miniaturisation,
- new application fields like tele-medical applications (health care smart systems), smart clothes, wearable computers, and autonomous sensors in intelligent environments.

These are some examples of products which address a huge market with hundreds of millions units per year.

Results

After 12 months, the scientific results of the “H_2-MiniPac”project are very promising: They are fully in accordance with the initial objectives (electrode power density target higher than 50 mW/cm^2 @ ambient temperature and pressure), and there is a strong hope that the feasibility of the technology will be proven.

INFORMATION

References: ENK5-CT-2001-00558

Programme:
FP5 - Energy, Environment and Sustainable Development

Title:
Hydrogen-fed miniature fuel cell for portable applications (H_2-MINIPAC)

Duration: 36 months

Partners:
- Commissariat à l'Energie Atomique (F)
- SNPE (F)
- Solvay (B)
- Corning (F)
- France Telecom (F)
- Centre for Renewable Energy Sources (GR)

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Status: Ongoing

T.E.M. analysis of the Pt catalyst developed.

Complete Direct Methanol Fuel Cell System – DREaMCAR

DREaMCAR

Objectives

The primary objective of the proposed project is to develop and demonstrate on a laboratory scale a complete Direct Methanol Fuel Cell (DMFC) System, and the necessary system components.
The use of fuel cells to power vehicles has been the subject of intense development efforts in recent years because of the significant advantages of zero emissions of pollutants and higher efficiency which these systems offer. These characteristics are of particular importance in large metropolitan areas, which suffer from intense atmospheric pollution caused by the use of automobiles.
The duration of this project is 42 months and is divided into two phases: Phase I focuses on the design, build and testing of a 1.25 kW module and Phase II concerns the design, build and testing of a 5 kW stack with optimisation of the operating parameters.

Challenges

The goal of the DREaMCAR project is to develop highly efficient, low emission automotive fuel cell propulsion systems that meet customer requirements in terms of cost and performance (better range, safety, and reliability than conventional vehicles).

The power density is the most important property of the DMFC to be improved. Indeed, the necessary active area, number of cells and stack dimensions is directly related to this property.

In order to maximise the power density, three approaches were selected:

- a higher operating temperature enhances the electrochemical reaction and so the objective is to operate at 140°C, or even higher if the innovative membranes can stand higher temperature;
- innovative membranes must be developed in order to reach a good compromise between conductivity, methanol cross-over and mechanical and thermal stability;
- new carbon supported Pt-alloy catalysts will be developed in order to increase the efficiency of the electrodes.

The target power density is at least 300 mW/cm^2 at 0.5 V for a stack operating at 140°C.

The power density could appear low compared to state of art Hydrogen Fuel Cells, but it is near double that of current state of the art DMFCs. Whilst it has a lower power density compared to a hydrogen fuel cell, the overall system is simpler, lighter, more efficient and quick starting.

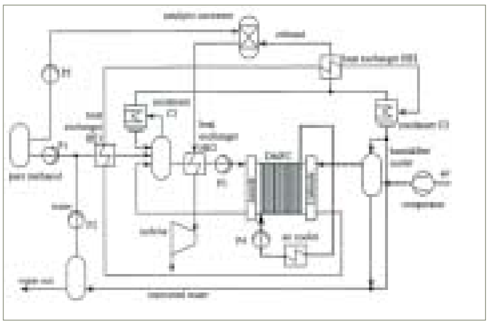
Project structure

In order to reach successfully all the targets of the project, the partnership includes one car manufacturer (Fiat, Italy) for the specification transfer, life cycle analysis and final testing; one engineering company (Thales Engineering & Consulting, France) specialised in the field of electrochemistry and project management; one chemical company (SOLVAY, Belgium) experienced in the manufacturing of polymer membranes; two research institutes (TAU RAMOT, Israel and CNR-ITAE, Italy), skilled respectively in electrocatalysts and membrane development including scaling-up of material production *and* Membrane Electrode Assembly (MEA) large-scale preparation.

Expected impact and exploitation

The interest in fuel cells is based on their potential for energy saving and cleaner energy production. It is well known that the fuel cell can reach higher efficiencies (up to 60%) than thermal engines (around 20%). Fuel cells consume between 15% and 50% less fuel than conventional generators. Fuel cells will reduce the costs associated with greenhouse gas emission. These costs, which include public health funding, are very hard to assess because all secondary effects have to be included. It could however be said that fuel cells will reduce all these costs since they lower NO_x, VOC and particulate matter emissions.

The fuel used for fuel cells could be chosen from hydrogen, natural gas, gasoline or methanol. Hydrogen fuel is the cleanest but it needs a complete change of the fuel distribution network. The other fuels, including methanol, do not necessarily need substantial changes to the distribution network.



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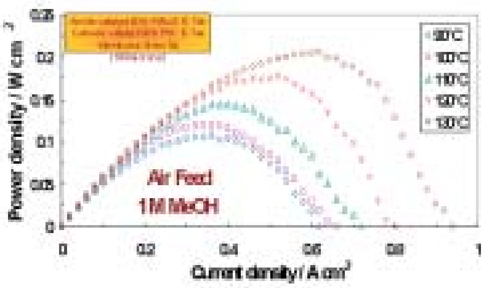

Membrane assessment.

Thus a transportation system on the basis of DMFC should be comparable to conventional systems with respect to effectiveness and user friendliness but more effective in term of energy saving and environmental aspects.

Progress to date

SOLVAY and TAU/RAMOT have been following several research routes in order to fulfil the objective of developing a membrane able to deliver a power of 250 mW/cm^2 at 130°C with air feed. The work has been split into two research areas: improve radio-chemically a grafted membrane obtained previously as well as modification of polymers by sulphonation; characterization of NP-PCM (nanoporous proton-conducting membrane) and SASA (Silica Anchored Sulphonic Acid membrane) in DMFCs and study of the performance of DMFC at high temperatures.

The recent acquisition of the Ausimont Company has given SOLVAY access to a new fluorinated polymer, which has been evaluated in the DMFC application with promising results.

The development of catalysts has concerned mainly the preparation and physico-chemical characterisation of a Pt catalyst with a lower concentration of active species on carbon supports, for the electrochemical reduction of oxygen and the electro-oxidation of methanol, respectively. Initially electrochemical characterisation was carried out on these catalysts in a DMFC, using Nafion 117 membrane as electrolyte. In a further step, the MEA was prepared using the membrane selected in the membrane development work.

Different technical protocols have been developed such as catalyst scale-up procedure, MEA preparation procedure and MEA characterisation procedure.

The cell design phase has been completed with reference to the single cell (100 cm^2 active area) and the 1.25kW module (300 cm^2 active area).

A model was developed for real-time control applications. Real-time models require a compromise between model complexity and execution speed. The DMFC model achieves a good compromise by balancing the use of physically based subsystems with look-up tables to minimise execution time.

The system model has allowed a deeper knowledge of the system, in terms of operating variables (pressure, flow, temperature etc.), and the optimum selection of components to be acquired and installed on the test bench. For each of these components a detailed technical specification file is being prepared, in order to acquire the components and assemble them on the test bench.

INFORMATION

References: ENK6-CT-2000-00315

Programme:
FP5 - Energy, Environment, Sustainable Development

Title:
Direct Methanol Fuel Cell System for Car Applications (DREaMCAR)

Duration: 42 months

Partners:
- Thales Engineering and Consulting (F)
- Centro Ricerche Fiat (I)
- Consiglio Nazionale delle Ricerche (I)
- Solvay (B)
- Ramot University for Applied Research and Industrial Development (IL)

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Status: Ongoing

State-of-the-art at the start of the project: an IRD Fuel Cells A/S 500 W DMFC stack.

A 1 kW DMFC Portable Power Generator

PORTAPOWER

Objectives

The use of portable power in Europe and worldwide has grown dramatically in recent years and continues to do so. Also, the overall increased demand for electrical power, estimated at >10%/year in the US (similar increases have been foreseen in Europe), has resulted in a corresponding increased demand for Uninterruptible Power Supply (UPS) systems. This market is currently dominated by batteries, and petrol- or diesel-fueled generators, which pollute excessively through their high emission levels and their noise. Current trends towards higher fuel prices and greater environmental awareness strongly supports a shift in consumer demands. The aim of the project is thus to design, develop, construct and test a 1 kW Direct Methanol Fuel Cell (DMFC) portable power generator capable of starting up at ambient temperature. Our starting point has been chosen at 1 kW of electrical power, which can be scaled appropriately to give an available power range from 350W to 5kW.

Problems to be solved

DMFC technology has reached a stage in its development where commercial exploitation is now seen as a reality. However, one major technological problem still requires a totally satisfactory solution – DMFC technology exploits a proton-exchange membrane as electrolyte, and this membrane still tends to permit undue METHANOL CROSSOVER. This results in lower fuel utilization, lower cell voltage, excess catalyst loading and release of methanol to the surroundings. Another problematical feature is the high cost of the state-of-the-art membrane.

A power density of 200 mW/cm^2 would make DMFC technology totally competitive in cost and performance with reformer-based pressurised PEMFC technology. The low-emission characteristics of a DMFC power supply also facilitate applications in a number of new areas, typically for indoor and low-noise applications.

A major target in achieving this is the development of a Membrane Electrode Assembly (MEA) capable of providing 200mW/cm^2. This involves developing a novel membrane in which methanol crossover has been minimized, and a novel MEA design. Both of these are to be achieved from a better understanding of methanol transport within the electrodes and the membrane. Other necessary developments are: a fuel-supply system, which controls methanol diffusion across the MEA, and a weight-optimized stack.

Technical target

First generation MEA based on Nafion®: 100 mW/cm^2

Second generation MEA based on new membrane: 200 mW/cm^2

Membrane cost: < 100 US$/$m^2$

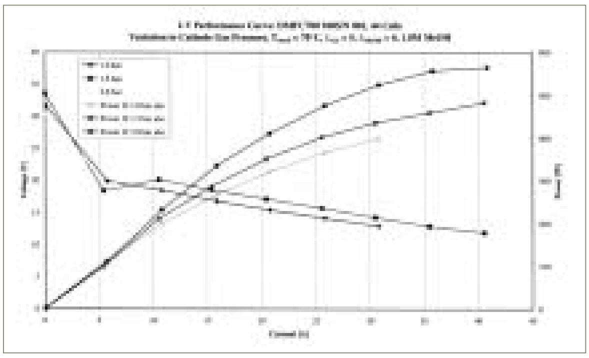
Stack power: 1kW

Specific power: < 8 kg/kW

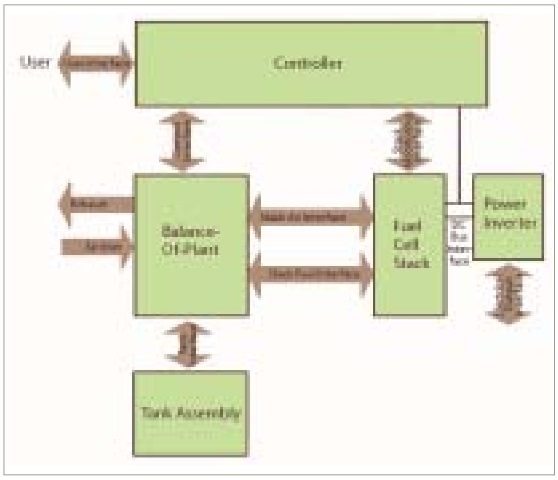
Project structure

The Project Consortium comprises: CNRS-JRU5076 together with Ecole Nationale Superieure de Chimie Montpellier (ENSCM), Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Uppsala University (UUS), American Power Conversion - Denmark (APC) and IRD Fuel Cells A/S (IRD).

The role of the CNRS-JRU5076/ENSCM partnership is to develop and prepare new fluorinated membranes for the DMFC stack; DLR are responsible for the development of MEA processing and fuel cell system development. UUS carries out membrane and MEA characterization, and is also responsible for the development of a method for measuring and modeling methanol crossover. IRD Fuel Cell A/S (Coordinator) is responsible for producing the MEA's and for developing and assembling the DMFC stack. The role of APC is system specification, and the development of the system, including the system electronics.



State-of-the-art at the start of the project: performance of an IRD Fuel Cells A/S 500 W DMFC stack. The MEA is based on Nation®, and gives a power density of 70 mW/cm^2 at 0.2 A/cm^2 and operating temperature of 70°C.



System block diagram for the DMFC generator.

Expected impact

The rapid increase in our daily use of high-technology electronic equipment lies in direct conflict with an increasing need to protect our environment both locally and globally – the increased demand for energy depletes resources and adds to pollution. Highly efficient fuel-cell generators can in this respect play an important role in achieving economically and environmentally friendly power supplies.

The result of the project will be a portable DMFC power generator that will conserve energy and reduce chemical and noise pollution on both a local and a global scale. Emerging fuel-cell technologies provide a basis for numerous applications. Success in the project will ensure reduced environmental pollution from portable power generators in Europe, and prevent health problems arising from working with such units. European Industry will also be given a new lead in portable power generators, thereby creating many new employment opportunities. Emerging fuel-cell technologies will also open up new business opportunities in the field of mobile power generators – either as add-ons to Uninterruptible Power Supply (UPS) products, or as stand-alone units for remote/mobile power generation. Applications could be: powering remote telecommunication transmission equipment and remote scientific investigation equipment, emergency AC power for hospitals, etc. Many consumer leisure applications will also emerge.

Expected results

The project will design, construct and test a portable 1 kW power generator based on the DMFC concept. It will have an integrated construction, incorporating a methanol fuel tank and supply system, a cooling system, temperature control, safety systems, and an electronic power system delivering 48 Vdc and 230 Vac. The target for the DMFC stack is a power density of 200 mW/cm^2. The achievement of these objectives will necessitate the use of many innovative approaches to: a load-driven methanol supply system which ensures maximum power capability, a novel MEA design, and membrane modification to reduce methanol crossover. The target is to develop new fluorinated membranes with high conductivity (≥ 0.1 S/cm), reduced methanol crossover (< 1%), and reduced cost (< 100 US$/m^2) compared to a state-of-the-art membrane. Product characteristics such as simple, safe, clean and convenient operation, portability (both in terms of weight and volume), fuel-tank capacity, low noise-level and a user interface are all key objectives of the project.

INFORMATION

References: ENK5-CT-2002-00669

Programme:
FP5 - Energy, Environment and Sustainable Development

Title:
A 1 kW DMFC Portable Power Generator (PORTAPOWER)

Duration: 36 months

Partners:
- APC Denmark (DK)
- IRD Fuel Cell (DK)
- Centre National de la Recherche Scientifique (F)
- Uppsala University (S)
- Deutsches Zentrum für Luft- und Raumfahrt (D)

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Status: Ongoing

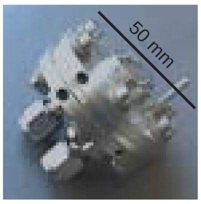

Figure 1: Fast and accurate CO sensor developed for use in a fuel processor.

On-board gasoline reforming for fuel cell vehicles

PROFUEL

Objectives

Fuel processors represent a fundamental enabling technology for the commercial success of fuel cells. By reacting readily available hydrocarbon fuels with steam, air or a combination of both, a hydrogen rich gas stream is produced which, after gas clean-up to reduce the carbon monoxide (CO) concentration to a few parts per million, can be fed to the anode of a fuel cell. Here the hydrogen combines electrochemically with the air supplied to the cathode to generate electricity.

A gasoline powered fuel cell vehicle has the potential to couple an available fuel infrastructure with the efficiency and environmental benefits of fuel cell technology. The objective of the PROFUEL project is to demonstrate such a system on a 10kWe scale. This size is small enough to have direct relevance for on-board auxiliary power units, whilst being large enough to illustrate the technical issues faced by developers of fuel processors targeted at replacing internal combustion engines.

Challenges

Developing an on-board fuel processor represents quite a challenge, and has been likened to installing a mini-oil refinery on-board a vehicle. Key issues for fuel processing systems are cost, size, weight, response time, efficiency and durability. Some of these can be addressed by identifying highly effective catalyst materials, but just as important is the development of the ancillary components such as pumps, valves, burners, sensors and control software. This dual emphasis on catalyst and component development is a key feature of PROFUEL.

Impact

Looking into the future, vehicle powertrains will have to meet increasingly more rigorous emissions regulations and efficiency standards. Fuel cell technologies offer the promise of improvements in both of these areas. The questions of how to create, deliver and store the fuel of fuel cell vehicles have been in focus for many years. Behind the apparent simplicity of direct hydrogen fuel cell vehicles lie the problems of hydrogen supply and on-board storage; these have no quick-fix solutions. The alternatives of generating hydrogen on-board from methanol, ethanol, gasoline or diesel all present their own problems ranging from fuel availability and infrastructure to toxicity and system complexity. However, it is clear that a successfully integrated on-board gasoline reformer would have many benefits in reducing the complications and capital investments needed to develop a fuel infrastructure that will support the emerging fuel cell vehicle market.

Project structure

Figure 3 shows the PROFUEL participants, and summarises their responsibilities.

Progress to date

The PROFUEL partners have had considerable success in developing long-life, low-cost catalysts for each of the fuel conversion stages. The catalyst systems in a fuel processor need to operate over a range of load demands, and remain physically robust and resistant to poisons. One of the principal poisons in gasoline is sulphur, present at levels above 10ppm even in modern low sulphur fuels. It has been dealt with in PROFUEL by developing reformer and high temperature shift catalysts that are sulphur tolerant, allowing it to be adsorbed downstream as hydrogen sulphide in a specially developed trap. (Figure 2)

The removal of CO from the reformate gas is critical to the performance of the fuel cell. This is achieved conventionally by a cascade of catalytic reactors, and such units have been developed for the PROFUEL specifications. However, additional work is underway to investigate the inclusion of a novel CO adsorber-desorber into a fuel processor system. A further key objective of the project is to develop a low-cost method to measure the residual CO. This is currently done by bulky and expensive infra-red analysers that are not suitable for integration into real systems. An accurate electrochemical based CO sensor that works rather like a mini fuel cell has been developed successfully. By measuring the effect that CO poisoning has on

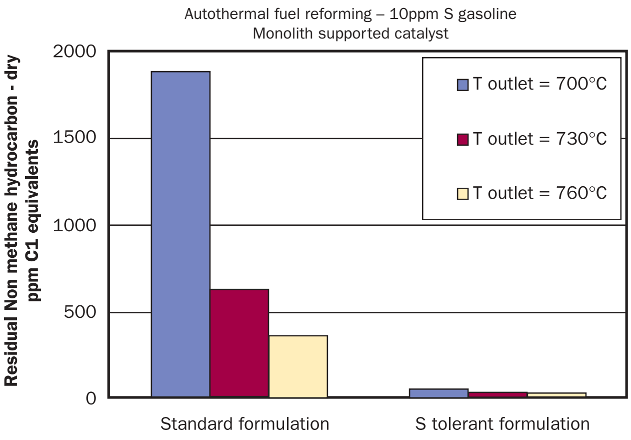

Figure 2: Performance improvement in gasoline reforming catalyst.

FEV - Motorentechnik (Germany)	Water supply Fuel supply Start-up burner
Johnson Matthey (UK)	Fuel mixing and vaporisation Autothermal reformer High temperature shift reactor
Centro Ricerche Fiat (Italy)	Sulphur trap Life cycle analysis
Politecnico di Torino (Italy)	CO oxidation and Sulphur trap materials Dynamic modelling
Ansaldo Ricerche (Italy)	Low temperature shift reactor Selective oxidation unit CO trapping
ECN (Holland)	CO sensing and O_2 dosage Component testing
Volvo (Sweden)	System modelling System integration Fuel processor testing

Figure 3: PROFUEL partners – project responsibilities.

the rate of decay of the base anode current, CO sensing is possible over the range 1-500 ppm on a millisecond timescale, with some scope for use up to 7000 ppm. This sensor will be integrated into the PROFUEL system downstream of the CO clean-up units, and used to control the units. (Figure 1)

The optimal integration of these catalytic stages is being accomplished by the use of simulations that balance the heat and mass flows around the system. Simple yet effective models of the compact heat exchangers, incorporated into the PROFUEL system as water vaporisers, are being used to predict transient response times and identify opportunities for performance enhancements. Similar outcomes are being obtained from dynamic models of the catalytic stages.

Another aspect worth highlighting is start-up and shut down of the fuel processor. The catalysts developed within PROFUEL are non-pyrophoric, allowing them to be purged with air. This is essential for materials destined for use on-board vehicles where pre-treatment and purge gases are not available. Also being developed in this project is a 7kWe start-up burner operating on gasoline. This will be used to rapidly preheat the catalytic components and heat exchangers to temperatures above which the fuel reforming reactions become self-sustaining.

The final phase of the project is to spatially and thermally integrate the sub-components and operate the unit as a complete system. The results from this, coupled with system modelling and Life Cycle Analysis, will give the partners a broad understanding of the issues involved in designing and operating complete fuel processors, as well as a view on their potential for inclusion into fuel cell vehicles. As a member of the wider FUERO cluster, the PROFUEL project will generate information that will enable valuable comparisons to be made between different fuel cell technologies.

INFORMATION

References: ENK5-CT-1999-00023

Programme:
FP5 - Energy, Environment and Sustainable Development

Title:
On-board Gasoline Reforming for Fuel Cell Vehicles (PROFUEL)

Duration: 36 months

Partners:
- FEV Motorentechnik (D)
- Johnson Matthey (UK)
- Centre Ricerche Fiat (I)
- Politecnico di Torino (I)
- Ansaldo Ricerche (I)
- Energieonderzoek Centrum Nederland (NL)
- AB Volvo (S)

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Status: Ongoing

Test rig for arc plasma reforming of gasoline; hydrogen production for car propulsion.

Plasma Reforming of Fuels and Hydrogen Purification

P M F P

Objectives

Fuel cell based propulsion systems can help effectively reduce the environmental impacts of transport. The lack of available hydrogen is one of the most important problems hampering their broad application. The project objective is to develop a new approach for on-board conversion of gasoline to hydrogen. This is based on plasma reforming techniques (arc and microwave plasma) and separation of pure hydrogen from the reformate gas obtained by a hydrogenselective membrane. This approach will reduce the system complexity and will lead to better transient response and start-up times. Compared to today's technology the cost will be lowered in high volume production.

Challenges/Problems addressed

Construction of plasma reformers (arc and microwave) avoiding use of precious metal catalysts are a big challenge for gasoline reforming because together with the membrane, the hydrogen generation and purification system will be simplified greatly. In a first step the individual components of the plasma reformers have to be designed and built based on extensive theoretical calculations and on preliminary experiments. Core components are the arc electrodes and the nozzle (microwave) for producing a stable arc torch. In addition the reformers power supply systems have to be developed.

After installation the optimum operating parameters leading to the highest yield of hydrogen possible have to be identified. The max. thermal power for both plasma reformers was fixed to 40 kW.

The composite membrane for hydrogen separation is based on a ceramic tube carrying a palladium/silver coating at the outside. The main tasks for improving the membrane comprise reducing the coating thicknes to about 5 micrometers, lowering the amount of membrane defects, increasing of the durability and improving the sealing between membrane and housing.

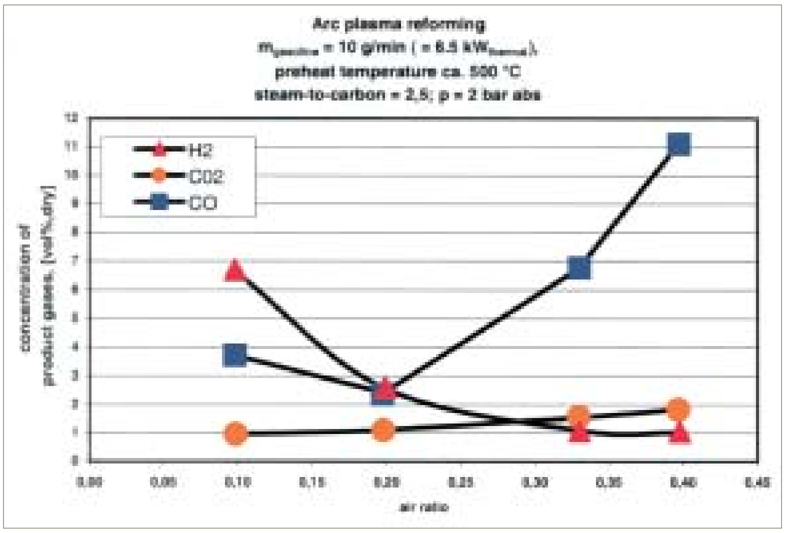
Project structure

The project consortium consits of the DaimlerChrysler AG (D), Johnson Matthey plc (UK), Mikrowellen Umwelt Technologie (D), ARMINES – Centre d'Energetique (F) and University of Madeira (UMa). The part of MUT and CENERG is the development of the microwave and the arc plasma reactor, respectively, including the power supply. UMa is supporting both centres with theoretical calculations. JM will provide the membrane and membrane modules for hydrogen separation. DCAG as the coordinator is in charge of optimising the plasma reactors at its test bench and testing of the membranes and membrane modules. DCAG and JM supply the technical centres with simulation studies concerning the fuel cell system (reformer + membrane module + FC-stack) or parts of it.

Expected impact

The problems addressed through this project are relevant for the automotive industry in Europe as a whole, both in terms of reducing environmental pollution and improving competitiveness. These problems are to be solved in an interdisciplinary approach by a consortium of five partners from four countries with excellent complementary competencies. The project is contributing to several European policies including industrial competitiveness, energy, environmental and transport sector policies as well as regional and cohesion policies and social objectives such as quality of life, health and employment.

The PMFP will be developed primarily for automotive propulsion systems with the first application probably in passenger cars. It can also be applied in any stationary or mobile fuel cell system, e. g. small mobile FC-based power supply units, or FC heat and power units for domestic application. Furthermore, the main components such as compact microwave or arc plasma gasoline reformers and hydrogen selective membranes can be used for any fuel cell application. Target users are the automotive industry, engine manufacturers and manufacturers of compact CHP systems.



Progress to date

Based on theoretical calculations the plasma refomers, particularly the electrodes for the gliding arc reactor and the nozzle for the microwave reactor were designed and built. Apart from power supply units also the devices for preheating air, water and fuel were completed.

At the monent only the gliding arc reactor has been operated with gasoline as fuel, max. thermal power is 40 kW. Experiments are under way in order to improve the hydrogen yield by varying the air stoichiometry, the steam-to-carbon ratio and the preheat temperature of the feed (gasoline, water, and air). Experiments revealed that the hydrogen concentration decreases with increasing air ratio; the maximum concentration achieved so far is 6 vol % (dry).

The microwave reactor can be operated up to a power of 52 $kW_{thermal}$. The dissipated microwave power into the plasma is close to 100%. The reactor is very flexible to changes of gas pressure and velocity. The maximum pressure achieved so far is 2 bar abs. First experiments were performed in the partial oxidation mode (POX) with propane as fuel. The hydrogen yield was in the range of 18 – 20 Vol %. Soot formation does not lower the the yield. Soot can be easily removed by operating the reactor with an excess of air.

The target thicknes of the membrane (5 microns) was achieved leading to an improved hydrogen permeation rate at the operating temperature of 400° C of approximately 35%. Efforts are being made to provide a more robust seal between the PdAg-coated tube and the housing than the currently used graphite ring device. The most favored is a design where a metal collar is brazed to the MoMn metallised open end of the tube.

INFORMATION

References: ENK-CT-2000-00346

Programme:
FP5 - Energy, Environment and Sustainable Development

Title:
Plasma Reforming of Fuels and Hydrogen Purification (PMFP)

Duration: 28 months

Partners:
- DaimlerChrysler (D)
- Johnson Matthey (UK)
- Armines – Centre d'Energétique (F)
- University of Madeira (P)

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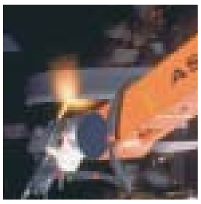
Status: Ongoing



Biodiesel processor for on-board fuel cell APU

BIOFEAT

Objectives

The overall objectives are to reduce vehicle emissions, increase fuel economy and promote the use of renewable fuels, in this case biodiesel. The concept used is the coating of suitable catalysts onto metal substrates in the form of compact plate head exchangers or monoliths. The specific technical problems are the selection of autothermal reforming or thermal cracking as the primary processing route for converting biodiesel into a hydrogen rich gas suitable for a Solid Oxide Fuel Cell (SOFC) or a Polymer Electrolyte Membrane Fuel Cell (PEMFC) with the addition of a gas clean-up system. The gas clean-up system will reduce the carbon monoxide in the primary processor exit gas to below 10ppm. After selection of the preferred primary processing route, a 10kW integrated biodiesel fuel processor complete with instrumentation and control will be designed, built and tested to meet the functional requirements specified by the end user (Figure 1). A specific modelling activity will end up with the development of a design tool.

Challenges/Problems addressed

A schematic of the basic stages of the BIOFEAT fuel processor is provided in Figure 2.

The most critical step is perhaps primary processing. For the sake of minimisation of risks in this innovative area, two processes will be developed: autothermal reforming and thermal cracking. A decision on the most promising technique will be made at the project mid-term assessment on the basis of the evaluation of $2kW_e$ demonstrators. Primary decisional parameters will be catalyst durability, process efficiency and economics, reliability and safety issues as well as reactor compactness and lightness.

In parallel, other work will consider the requirements for conditioning the biodiesel prior to entry into the primary fuel processor and the treatment of the exit gas from the primary fuel processor for a PEMFC system. The most challenging aspect of this part of the research programme will be the maximisation of heat recovery from the primary processing step and from the anode gas after-burner. Data from these activities will be used in the basic design work and the modelling task. With the possible exception of the autothermal reformer, all processing steps will use the concept of coating suitable catalysts on to metal substrates. The method for applying the catalyst will preferentially be plasma spraying (Figure 3) as it enables superior adhesion of the coating to the metal plates.

As the above underlined, the combination of compactness, lightness and efficiency is to be pursued. The prototype biodiesel fuel processor being produced by this project will demonstrate as a minimum that the following targets are achievable in production:

1. Size ≤ 0.75 litre/kW_e compatible with the available on board space;
2. Specific weight: ≤ 1 kg/kW_e (if aluminium construction is possible) or ≤ 1.5 kg/kW_e (if stainless steel construction is required);
3. Maximum start-up time: 1 min. to full-power;
4. Dynamic response: ≤ 5 sec (to sudden variations in the auxiliary power requirement);
5. Reliability > 10,000 h or 120,000 km;
6. Efficiency of biodiesel-to-hydrogen conversion: > 85%;
7. Overall efficiency of chemical-to-electric energy > 45%;
8. Cost < 10 €/kW_e (industrial mass production);
9. CO content in H_2-rich stream: < 10 ppm;
10. Unburned residues of biodiesel (HC) in the exhaust: < 5 ppm;
11. NO_x content in the exhaust gases: negligible.

Project structure

The developmental work will follow a clear and direct route starting from system specifications, to component development (feed system, primary processor, gas clean-up), basic design including instrumentation and controls followed by detailed design, construction and testing. Specific programmes are dedicated to modelling and project coordination and management.

Fundamental research on innovative catalytic materials (quite active and stable noble metal catalysts for processing biodiesel, water-gas shift reaction and CO preferential oxidation) and

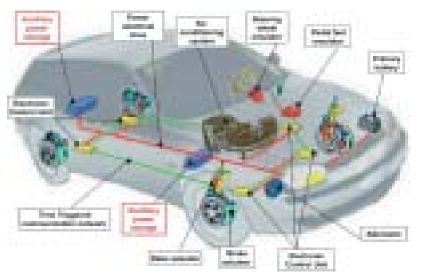


Figure 1: Future architecture using new auxiliary FC power supply for air-conditioning system, lighting systems and x-by-wire systems.

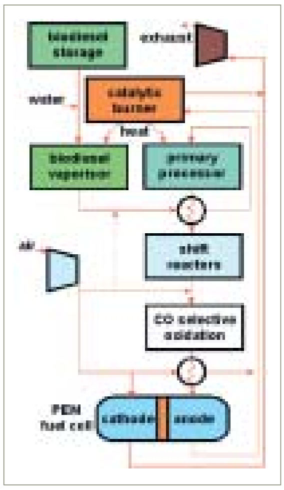


Figure 2: Flow-sheet of the BIOFEAT fuel processor.

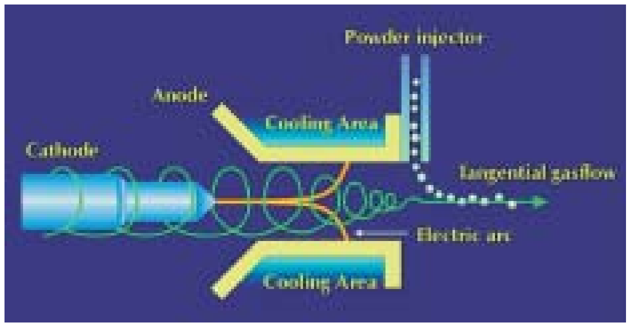


Figure 3: Basic principle and apparatus for plasma spraying.

basic industrial requirements (need of a highly efficient auxiliary power unit for decoupling on-board power generation for traction from power required for peripherals), well known by the end-user involved in the project, will be considered as starting points.

Two processes will be evaluated as part of the investigation into the primary fuel processor. These are thermal cracking in and autothermal reforming. The results of these evaluations will be used to select the preferred route for the primary processor. The catalyst development will be performed on the basis of the characterisation and assessment of the state-of-art catalysts and catalytic systems, focusing the attention on their ageing characteristics. Only a complete understanding of their chemical and physical deactivation mechanisms will allow the activity and durability of the new optimised formulations to be developed. The deposition of the best performing catalysts on designed and manufactured metal plates or other suitable substrates will benefit from the results of quick tests of structured catalyst stability.

The main output will be a $10kW_e$ biodiesel fuel processor which will be designed, manufactured and tested in real conditions, with the aim of assessing the actual durability and performance in comparison with state-of-the-art commercially available technologies.

Expected impact and exploitation

The expected major result is a fully tested modular $10kW_e$ biodiesel fuel processor for an SOFC or PEMFC auxiliary power unit for a vehicle. This will be supported by a validated design tool which will enable scale-up to different sizes for different applications. A Technical Implementation Plan will be developed to identify exploitation routes for transport, stationary and military applications. The possible adoption of the developed techniques for other feedstocks will be considered, as well. The implementation of a successful development into mass production will result in reduced emissions, enhanced fuel economy and an increase in demand for a renewable fuel, namely biodiesel. The increased efficiency achieved means that switching from even the most efficient combustion alternative to FCs will result in fuel savings of between 15% and 50%, which results in a equivalent reduction of CO_2 emissions. If this project is successful, it is anticipated that an on-board vehicle demonstration will follow according to the technology implementation plan. In this case, market penetration will likely occur before 2010.

Progress to date

The BIOFEAT project started quite recently (1/1/2003). So far, after the kick-off meeting in the middle of January, the main project activities have concerned the definition of fuel and system specifications and preliminary steps towards the development of process catalysts and catalyst deposition routes.

INFORMATION

References: ENK5-CT-2002-00612

Programme:
FP5 - Energy, Environment and Sustainable Development

Title:
Biodiesel Processor for an On-board Fuel Cell APU (BIOFEAT)

Duration: 36 months

Partners:
- Politecnico di Torino (I)
- Centro di Ricerche Fiat (I)
- Energieonderzoek Centrum Nederland (NL)
- Gerhard Mercator University Duisburg (D)
- Scandiuzzi Advanced Technologies (I)
- Bekaert VDS (B)
- Johnson Matthey (UK)

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Status: Ongoing

Figure 1: Artist impression of the evaporator structure. A channel in a silicon wafer is covered with a glass slip. The channel is filled with pillars to maximize the surface to volume ratio and hence the heat transfer coefficient.

MiRTH-e

Fuel Processor Miniaturization for Portable Power

Objectives

Fuel cells are regarded as a promising alternative for battery packs, given the much higher energy density of fuel cell systems. The breakthrough of fuel cell technology at the consumer market, however, will largely depend on the development of an easy way to deliver the fuel to the cell. Since the storage of hydrogen gas is difficult and inefficient, the *in-situ* generation of clean hydrogen from a liquid fuel like methanol offers an attractive alternative.

The main objective of this project is to develop a fuel processor system for the conversion of methanol to hydrogen to fuel a Polymer Electrolyte Membrane (PEM) fuel cell with an electrical output ranging from 20 to 100 W. Since the system is targeted to replace battery packs in portable electronic devices, the fuel-processing unit should be small and lightweight. In the development of such a unit, microreactor technology plays a key role.

Challenges

For a portable fuel processor and fuel cell system to become a viable alternative for battery packs and fuel cell systems using compressed hydrogen, it is important to minimize both the size and the complexity of the fuel processor. Challenges lie in the miniaturization of system components like reactors, heat exchangers, sensors and actuators, and also in the integration of the components in simple stand-alone devices. To be able to design and manufacture these devices, scientific advances are needed in the fields of metal- and silicon-based micromachining, the integration between metal- and silicon based micro reactors, sensors and actuators, the application of low-cost coated catalysts for microreactor systems, and the development of dedicated computer models for the design of these microsystems.

Technical target

The targeted specifications of the fuel processor system are:

power range: 20 – 100 W_e
primary fuel: methanol – water
volume FP: < 500 cc
energy density: > 800 Wh/kg
system efficiency: > 35%
emissions: < SULEV specs.
life time: > 40,000 h
cost prize: 200 – 2,000 €

Project structure

Based on an exergy analysis of the fuel processor and fuel cell system, the fuel processor was designed to consist of three integrated microstructured devices, a fuel vaporizer, a methanol reformer, which is integrated with a catalytic burner, and a selective oxidation (selox) reactor with integrated heat exchangers. All three units are fabricated using micro structuring techniques and, depending on the individual requirements, are constructed of different materials. The vaporizer is made of silicon and the reformer of aluminium, since they both require fast heat transfer, whereas the selox unit is constructed of stainless steel.

The MESA+ research institute is specialized in silicon devices and will construct the fuel vaporizer and the sensors and actuators necessary for process control. The design and modelling of the vaporizer will be conducted at the laboratory of chemical engineering science of CNRS. The Institut für Mikrotechnik Mainz will manufacture both the reformer and the selox unit, of which the design and modelling will be carried out in cooperation with the Eindhoven University of Technology. All catalysts in the project will be supplied by The Netherlands Energy Research Foundation, which focuses on applying the catalyst into micro structured channels. The industrial project partner, Shell Global Solutions, is responsible for project co-ordination.

Expected impact

The successful completion of the project and consequent production of the fuel processor will greatly enhance the applicability of small, portable fuel cell systems for itinerant use. The overall energy efficiency of the methanol-to-hydrogen fuel processing is higher than that of the alternative, hydrogen stored in metal hydrides. Also, conversion will be clean, aiming to meet the most stringent low-emission regulations. The successful development of a low power fuel processor and fuel cell system will increase the stand-alone operation time of electronic equipment by a factor of five to ten.

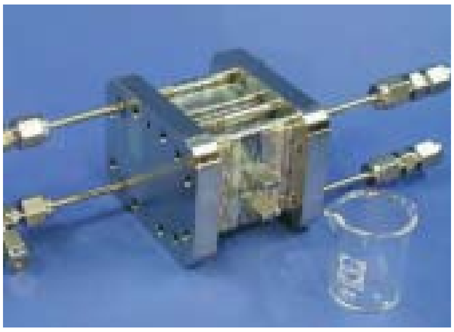

Figure 2: Selective oxidation microreactor, integrated with two heat exchangers into a stack of forty-eight, 500 µm thick microstructured plates.

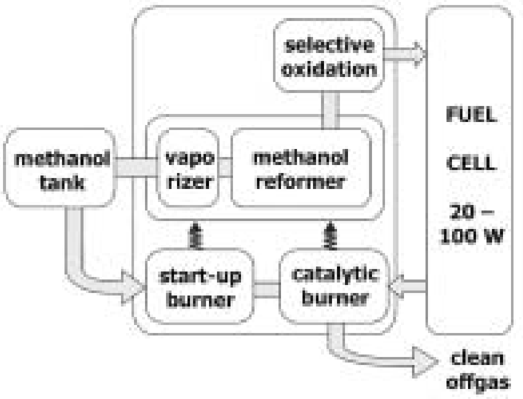

Figure 3: Fuel Cell and Processor System.

Furthermore, the practical demonstration of the designed micro chemical devices, in which chemical reactors, heat exchangers, and other process equipment are fully integrated, will provide more insight to the true possibilities of applying micro technology in the field of chemical engineering and will strengthen confidence in the emerging technology.

Progress to date

In an early stage of the project a micro reactor was designed and fabricated to facilitate the fast testing of the catalytic activity of catalysts applied as a coating on to microstructured plates. This test device has been used to improve the coating procedures. In the project several catalysts were successfully coated on to microstructured plates without significant loss in activity. These include a Pt/γ-Al_2O_3 catalytic burner catalyst, a Pt-Ru/α-Al_2O_3 selective oxidation catalyst, and a commercially available Cu/ZnO/Al_2O_3 methanol reforming catalyst.

A micro fuel evaporator was designed and constructed to convert the fuel from the liquid phase to the gaseous phase. The heat needed for this phase change is taken from the hot exit gasses from the catalytic burner. The evaporator structure is made from silicon with powder blasting as etching technique to create the channel structures. By filling the evaporator channel with small pillars (Figure 1) the high heat conductivity of silicon is used to its full potential resulting in a very high heat transfer coefficient of 3500 $Wm^{-1}K^{-1}$. The pillars in the evaporator channel also serve as nucleation points for the evaporation. It was observed that the evaporation process in channels with pillars is much more stable than evaporation in 'open' channels.

The third micro device that was designed and constructed in this project is a selective oxidation reactor, which is integrated with two counter-current heat exchangers. This device has to reduce the carbon monoxide concentration in the hydrogen rich reformate gas to below 10 ppm, as carbon monoxide is a severe poison for the fuel cell catalyst. Optimal heat recovery is achieved by constructing the selox device as a series of three counter-current heat exchangers, of which the middle one also contains a coated selox catalyst and functions as a cooled isothermal reactor. The heat exchangers and the selox reactor are integrated into a single stack of forty-eight, 500 µm thick, microstructured platelets (Figure 2), all containing flow distribution areas, gas conduits, and the actual microchannels. In spite of the large heat evolution during the CO selective oxidation, the catalyst temperature does not deviate more than 5 oK from its mean temperature and the heat recovery of the unit is about 80%.

In the final year of the project the reformer – burner reactor will be developed where focus will lie on the integration of highly endothermic and exothermic reactions.

INFORMATION

References: ENK6-CT-2000-00110

Programme:
FP5 - Energy, Environment and Sustainable Development

Title:
Fuel Processor Miniaturization for Portable Power (MiRTH-e)

Duration: 36 months

Partners:
- Shell Hydrogen (NL)
- Technische Universiteit Eindhoven (NL)
- Centre National de la Recherche Scientifique (F)
- University of Twente (NL)
- Institut für Mikrotechnik Mainz (D)
- Energieonderzoek Centrum Nederland (NL)

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Status: Ongoing

Compact microchannel 10 kW counter-flow heat exchanger (Institut für Microtechnik Mainz).

Hydrogen production from miniaturised fuel processor

MINIREF

Objectives

Fuel cell technology represents a promising alternative to conventional power trains for the automotive industry as it has a great potential for consumption and greenhouse gases emissions reduction. However, hydrogen storage issues and the lack of a distribution network make it difficult to foresee a rapid development of this new technology. Hydrogen production on-board the vehicle through a fuel processing device offers an alternative to overcome this drawback. Furthermore, using gasoline as a primary fuel takes advantage of the existing fuel distribution network and could help the introduction of fuel cell vehicles on the market more smoothly.

The primary objective of the project is therefore to develop a complete miniaturised gasoline fuel processor capable of producing 5kWe equivalent hydrogen flow. A further objective is to demonstrate its feasibility (cost and performances requirements) for on-board generation of hydrogen for fuel cells.

Challenges

The main technological innovation of the project lies in the use of microstructural catalyst support for the different reactors of the process. Various construction materials for these microstructured reactors will be assessed to ensure they are suitable in the encountered operating conditions (high temperature, corrosion…). Sealing and assembling of microchannel platelets will be studied in order to ensure reactors are leak tight. Another important issue concerning the use of catalytic microchannel reactors is the deposition of the catalytic material on the support. Several deposition techniques will be assessed to define the best operating conditions to obtain a washcoat layer with the required properties and quality.

To maximise the system efficiency, new catalytic materials for the reformer, the Water Gas Shift and the SelOx reaction stages will be developed to match the new microstructure support. These materials will be optimised with respect to specific conditions required for the intended application.Further, mechanical and thermal integration of the various reactors and all peripheral equipment will be studied to fulfil automotive requirements: improved compactness, safe operation, reduced start-up time and energy consumption, fast response time to load variation.

Project structure

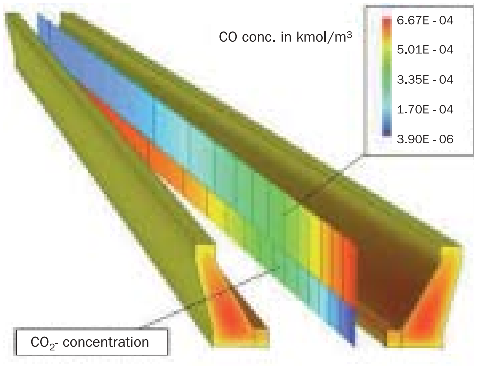
The project consortium consists of 8 different partners. IMM (D), with extensive experience in design, development and fabrication of heterogeneously catalysed gas phase micro-reactors, is responsible for reactor material selection, reactor design and engineering, system construction and single reactor testing.

Four academic partners, IRC (F), ACA Berlin (G), POLITO (I) and CIRIMAT (F), with expertise in catalytic material development, reactor design and engineering and catalyst deposition techniques on various substrates are also involved in the project. They are responsible for new catalyst development and deposition on the microstructured supports (ACA, IRC, POLITO and CIRIMAT), and for feeding system design and engineering (POLITO). Another academic partner (University of Prague, CZ), with experience in chemical reactors modelling, is in charge of steady state and dynamic modelling of single reactors and of the complete system. INFRAGAS (I), an industrial partner specialised in high technology catalytic burners will design and provide this essential part of the system. The role of PSA is to specify the system requirements, to test the final complete system and to perform an economic evaluation of the fuel processor. In addition, PSA is the project co-ordinator.

Expected impact and exploitation

Environmentally friendly fuel cells are attractive as an alternative drive system to combustion engines of vehicles. One of the automotive research objectives is to develop an integrated fuel cell system for automotive applications that will operate on common transportation fuels to take advantage of the existing distribution infrastructure.

The major benefit of the project will be the demonstration of a compact and lightweight gasoline fuel processor for automotive applications with high overall efficiency, greatly reduced emissions to the environment, and low cost.



CO and CO_2 concentration in a microchannel for the Water Gas Shift reaction (results from CFD simulation).

View of the reformer test reactor including the equipment for mounting.

Progress to date

The MINIREF project has just reached the end of its first year. Challenges faced were the following: specification and optimisation of the operating parameters to cope with automotive end-user requirements, design of the process scheme, development of new catalytic materials, design and engineering of microstructured catalytic test reactors and process modelling.

Based on previous experience of the various partners and on system requirements, a parametric study was conducted on the main operating parameters (P, T, S/C, O/C) in order to maximise hydrogen productivity of the complete process and to minimise outlet CO content. Detailed modelling of the reactors was started so as to allow efficient design of the flow scheme. A complete database was set up in order to have access to the required components properties. Attention was given to both CFD modelling (targeting optimal reactor design) and process flow modelling (targeting flow scheme design and operating procedure). This work is ongoing based on the final process flow scheme.

The process flow scheme has been worked out throughout the first year and has led to a final design recently. This flow scheme takes into account automotive requirements for operating conditions, compactness, efficiency and load following capabilities. Further heat recovery and optimised start-up procedures were integrated into the initial scheme to allow short start-up times and reduced energy consumption. The design and integration of the final complete unit will be based on this process scheme.

To maximise process efficiency, intensive catalytic material studies are taking place for all reaction stages (ATR, WGS and SelOx). Synthesised catalysts are currently being tested, characterised and different substrates and metal loading considered to define the optimal catalyst for each reactor. The most promising catalysts will be chosen before the end of the second year.

Together with this catalytic material development, innovative options for depositing these catalysts onto metallic microstructured platelets are under investigation. Three different methods are being studied and preliminary test data show promising results.

Finally, single tests reactors were designed, built and distributed to the academic partners to allow them to assess catalytic performances in real reactor configurations.

INFORMATION

References: ENK6-CT-2001-00515

Programme:
FP5 - Energy, Environment and Sustainable Development

Title:
Miniaturised Gasoline Fuel Processor for Fuel Cell Vehicle Applications (MINIREF)

Duration: 36 months

Partners:
- Centre National de la Recherche Scientifique (F)
- Institut für Mikrotechnik Mainz (D)
- Institut für Angewandte Chernie Berlin-Adlershof (D)
- Politecnico di Torino (I)
- Université Paul Sabatier (F)
- INFRAGAS (I)
- University of Prague (CZ)
- Peugeot Citroën Automobiles (F)

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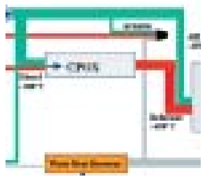
Status: Ongoing



Diesel-fed SOFC Auxiliary Power Unit

DIRECT

Objectives

While there has been significant progress in the development of fuel cells over the past ten years, two main road blocks remain to be solved: the overall system cost and the fuel issues. Unfortunately, there is a link between these two questions namely the refuelling infrastructure. This consortium addresses this problem by using diesel – an existing standard fuel – and therefore offering a faster and inexpensive introduction of the new technology. The result of the project will be a scalable compact CPOX reformer and SOFC system for vehicle auxiliary power unit (APU) application in a power range of 5kWe using the standard diesel of year 2005.

Viewing the fact that today's car needs more and more electricity either for controls or for comfort and safety features and that trucks during loading often use their idling Internal Combustion Engine or a diesel generator, the APU has a high potential for toxic emission reduction.

Challenges/Problems addressed

The main innovation in this project is the combination of a diesel reformer using Catalytic Partial Oxidation with the Solid Oxide Fuel Cell for mobile application under the condition where no other consumables e.g. additional water are needed. Since in 2005 – the most probable time of market introduction of the new system – a sulphur limit of 50 ppm is obligatory, we decided to make this our objective with regard to fuel quality. We are considering an active sulphur absorber before or after the diesel-reformer. The target is to avoid any additional maintenance for the vehicle in operation.

A further problem will be the start up time and the dynamics of the SOFC. We expect a long term target of 5 minutes to warm up the stack. Furthermore the SOFC is sensitive to thermal gradients. Load changes can be made within 5 sec. but reduce the lifetime of the stack. Thermal management and power output control (vehicle battery as buffer) are therefore considered the major challenges in order to ensure high system efficiency and customer friendly operation.

The costs of our system correspond closely to the costs of the SOFC technology at the time of market introduction. We expect our system to be competitive with existing diesel generators when the cost for SOFC are lower than 1000€ per kW.

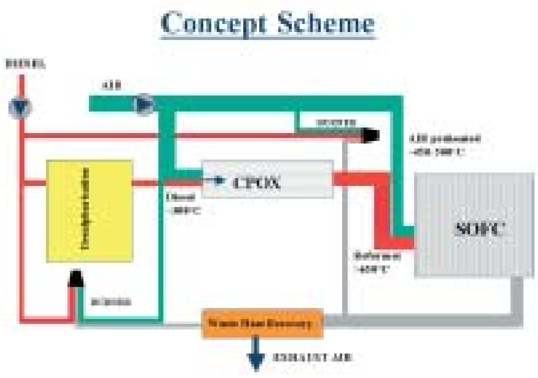
Technical target

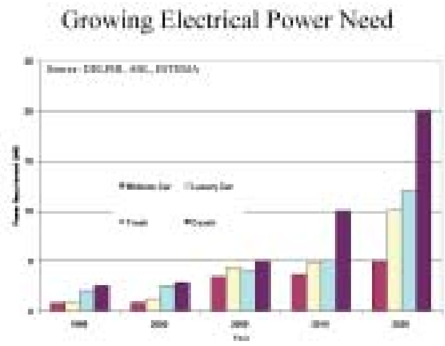
The target data of the APU at the end of the Project:

- Rated Power: 5 kW_e
- Efficiency: 40% "tank to electricity"
- Fuel: - Diesel (50 ppm sulphur tolerance)
  - Biodiesel/Synthetic Diesel
- Oxidant: Air
- GHG emissions: 0,68 kg/kWh locally
- Volume: <350 l
- Weight: <100 kg
- Costs: 2500 €/kW in 2008
- Durability: 10.000 operating hours forecast

Project structure

The project consortium consists of Arsenal Research as the Project Coordinator, ALPPS Fuel Cell Systems as the Scientific Coordinator, being also responsible for system specification, control system and mechanical integration of the system, and six further contractors: The role of Sued Chemie is the development of the desulphurisation unit as well as the catalyst for the CPOX reformer. The CPOX structure will be developed and provided by Converter Technology. Prototech is in charge of developing and supplying the SOFC stack. The system layout and thermal integration of components is simulated be Arsenal Research. C.R.F. will carry out vehicle tests with the APU. Leyland and MIRA will provide their know-how in system testing and specifications. Close co-operation between the partners is required because of the many interacting tasks.





Expected impact and exploitation

The DIRECT Project addresses the huge mobile power supply market. The first application is the future market of auxiliary power supply in road vehicles. While a market for stand by heating equipment or cooling units in heavy duty vehicles already exists, the future tendency is in the direction of separating more and more vehicle internal electrical consumption from the IC engine as source. The reason for this is the continuous effort to reduce vehicle emissions and the fact that running the engine is often forbidden during rest stops.

The first important market segment the consortium will work in is the Heavy Duty Truck market. The inclusion of a desulphurisation module opens the market even further to stationary as well as marine applications and others.

Results

The result of the project will be a prototype of a new system for auxiliary energy for vehicles consisting of an SOFC and a reformer operating on standard diesel fuel, biodiesel and synthetic diesel. The unit will have 5 kWe power, be portable for use in a vehicle, sulphur tolerant to 50 ppm and optimised regarding size, operating range, lifetime and efficiency. Major milestones consist of the desulphurisation system decision, catalyst decision and thermal management optimisation.

The process of developing the desulphurisation module will be given special importance as the relative position of this sub-process significantly influences the overall system design, e.g. the question whether the actual reformer can be made without the use of Platinum/Rhodium combinations or the absorbent capacity necessary.

INFORMATION

References: ENK6-CT-2002-00644

Programme:
FP5 - Energy, Environment, Sustainable Development

Title:
Diesel Reforming by Catalytic Technologies (DIRECT)

Duration: 36 months

Partners:
- Österreichisches Forschungs- und Prüfzentrum Arsenal (A)
- ALLPS Fuel Cell Systems (A)
- Süd-Chemie (D)
- Prototech (NO)
- Converter Technology (A)
- Centro Ricerche Fiat (I)
- Leyland Product Developments (UK)
- Motor Industry Research Association (UK)

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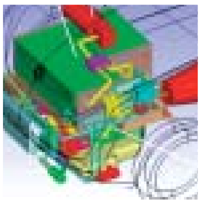
Status: Ongoing



Fuel cell for clean transport

FUERO

Objectives

Passenger and goods mobility, a mandatory need of today's society, is a major consumer in the context of the general energy use in Europe and worldwide.
It is a duty of every operator of the social system to make the energy management involvement in its relevant sector as clean and efficient as possible.
The FUERO project is aimed to identify the relevant operational requirements for the operation of fuel cell systems in vehicles, including studies of energy sources and evaluating the well to wheel efficiency. This will include the analysis of components available today with respect to their performance, production and recycling aspects.

Challenges/Problems addressed

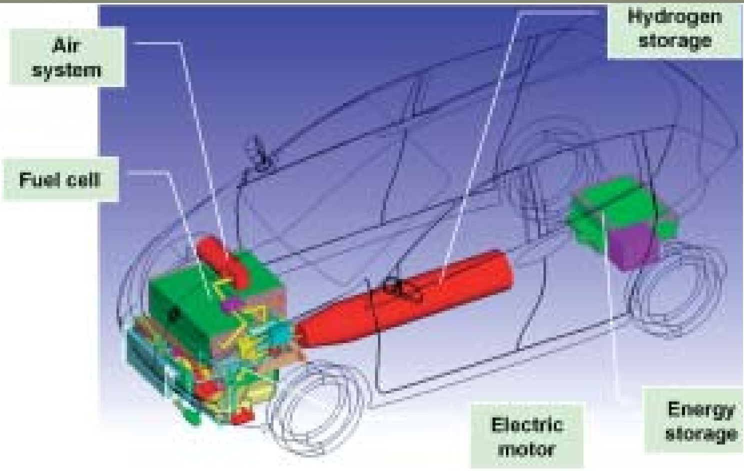
The overall problem related to the most effective management of the energy and environment protection is to identify the vehicular and infrastructure system solution which can be industrially, economically and socially sustainable within a time frame compatible with the established targets.
The final objective of the FUERO project is to make available advanced system and component technologies for fuel cell application on different categories of vehicles according to relevant operational requirements. These must be consistent with sustainable life cycle and environmental impact prerequisites, including energy sources, infrastructures, fuel availability, industrial production and recycling aspects, whose analysis is also part of the project itself. Components according to specifications, established in this project are tested and characterised in relation to system and vehicle integration. A following validation phase has been defined in the present project. The key issue of the project is focused on overall study and definition of the specifications of the components suitable for the optimised management of a FC powered vehicle, the Life Cycle Analysis (LCA), the test bench evaluation and final assessment after the demonstration phase. Study of alternative fuels, hydrogen production, specification of the mission profile and the vehicle categories, specification and testing of systems and components and an assessment of the integration of the systems on the vehicle are the target of the project.

Project structure

The first phase studies of fuel alternatives included LCA and commonly agreed component specifications are defined according to different system architectures, to be supplied to the component manufacturers for the specific developments. The second phase is dedicated to testing and characterisation of components within a view to system integration, definition of demonstrators and evaluation of the relevant overall result, to make a complete picture of the fuel cell applicability on the vehicle.
As the leading project of the cluster "Land Transport by Fuel Cells Technology" the co-ordinator together with all FUERO partners tried to add interesting and innovative projects in the field of component development for fuel cell systems to the cluster. Besides the two projects PROFUEL and BIO-H2 that were from the beginning members of the cluster, the cluster now additionally includes the DREAMCAR, AMFC, PEM-ED, ASTOR, MINIREF and ACCEPT projects.

Expected results and exploitation plans

With the work in the FUERO project the partners will bring fuel cell technology one step closer to market introduction. Fuel cell driven vehicles can be the solution for clean and high efficient propulsion and due to the development effort all over the world automakers seem to believe that the fuel cell will eventually deliver the power and performance that drivers expect. Technical challenges, high prices and infrastructural problems will probably prevent a short-term introduction of the fuel cell technology on a wide basis in the transport sector. Therefore the



efforts of five different car manufactures and two research institutes are grouped on a European level to raise the development stage of fuel cells in mobile applications. The gained knowledge and experience will strengthen the competitiveness of the European car manufactures in this promising field of technology. The results of this project will clarify the automotive industries specifications for the components of a fuel cell system to bring better understanding of the automotive industry's need to the suppliers of fuel cell technology or to establish suitable suppliers.

Progress to date

In this project a well to wheel analysis of the fuel production of different fuels for fuel cells is nearing completion. It will aid the assessment of the environmental impact of fuel cell powered cars. It covers the key production streams proceeding from oil, natural gas, coal and fuel from biomass, in this case ethanol produced from sugarbeet. This study showed the environmental balances obtained for fuel production streams based on natural gas and biomass are good compared to those obtained for coal or electricity (electrolysis). Performance requirements were identified for different classes of vehicles to provide a clear view of the demands on a fuel cell system in a car. Different system architectures to meet these requirements were studied and compared. For the system integration in a conventional car, the physical integration requirements were investigated. The whole system should be designed to fit into a conventional car.

The specifications and the performance for the key components of a fuel cell system were investigated. A simulation tool which will help to assess cycle consumption, performances and cycle pollution has been developed. It is flexible enough to simulate not only one specific architecture, but to model different system architectures with minimized effort. This accelerates the comparison and the assessment of different architectures significantly. Furthermore test procedures for the core components have been set up to guarantee the same test conditions at different test sites. The purpose is to create a common basis for the tests and performance criteria for the different components of a fuel cell system. Several state of the art components have already been tested and more will follow to create a basis for a common assessment and to provide input data for the developed simulation tool.

INFORMATION

References: ERK6-CT-1999-00024

Programme:
FP5 - Energy, Environment and Sustainable Development

Title:
Fuel Cell Systems and Components General Research for Vehicle Applications (FUERO)

Duration: 42 months

Partners:
- Institut für Kraftfahrwesen Aachen (D)
- Centro Ricerche Fiat (I)
- Institut Français du Pétrole (F)
- Peugeot Citroën Automobiles (F)
- Renault Recherche Innovation (F)
- Volvo (S)
- Volkswagen (D)

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SOFCnet

Thematic Network on Solid Oxide Fuel Cell Technology

Objectives

The objective of the thematic network SOFCnet is the support and acceleration of European research and development on Solid Oxide Fuel Cell technology. Ultimately, this should accelerate the introduction of efficient and environmentally clean conversion devices into the European energy supply. Early implementation of SOFC based system for stationary CHP and for auxiliary power for transport applications, will increases the contribution of this technology to the realisation of the EU and Kyoto objectives on reducing GHG and other polluting emissions. The network should result in a more efficient use of European and national resources and contribute to the realisation of a critical RTD mass for solving European energy related problems. The network is a first step towards the establishment of a European Research Area (ERA).

Challenges/Problems addressed

Presently the SOFC RTD activities on SOFC technology in Europe are scattered and incoherent. Each organisation autonomously defines its own development objectives and pursues its own preferred solutions. Competition and national objectives often hinder efficient international collaboration. Additionally, the mutual awareness of the needs and possibilities of the different parties in the product and development chain is considered poor. The SOFCnet links together virtually all types of stakeholders involved with the SOFC development in Europe, i.e. universities, research and development organisations, manufacturing industries and end users. The network provides a platform for the industrial developers to exert influence on the content and strategy of future European funded RTD activities and getting the focus on the issues most critical for commercial introduction.

Project structure

The network is organised in a matrix of work packages. Five of these are concerned with the main external deliverables of SOFCnet as follows 1) Informing the SOFC community on network activities and results via a web-site and other communication tools; 2) Organising technical workshops concerning the key issues for cost reduction and improved reliability of SOFC based-systems; 3) Mapping and characterising SOFC related activities within the European community and worldwide, and collaborating with other fuel cell related networks and programmes; 4) Inventorising industrial requirements for SOFC components and specification of benchmark procedures for evaluating SOFC performance. This will involve close collaboration with the FCTESTNET project which is concerned with harmonisation of fuel cell testing procedures; 5) Advising the EU and SOFCnet participants on relevant future RTD needs and the identification of barriers and opportunities for introduction of SOFC-based systems in society arising from legislation and regulation.
Four application related work packages are concerned with controlling, consulting and assisting the above described work packages. Three of these are concerned with technical and non-technical issues relevant for the technology development and commercial introduction of auxiliary power for transport applications, small scale residential CHP, and medium to large scale industrial and commercial CHP respectively. The final application work package addresses generic issues focussing on relevant RTD issues irrespective of application area. Position reports will be drawn up and updated regularly by each of the application oriented work packages.
The network presently consists of 47 member organisations covering the full development and product chain for the applications that are most relevant for SOFC technology.

Expected impact and exploitation

The SOFCnet will contribute to an improved communication, awareness, agreement and ultimately collaboration between the members on the most critical issues for further development of SOFC technology towards commercial introduction. The network facilitates access of industries to existing knowledge all over Europe. Industrial members of the network will use the results to review their current strategy and setting up new and broader collaborations. Universities and RTD organisations will better understand what research is relevant for the industrial development and also what kind of solutions are viable, e.g. do they have the perspective to fulfil essential preconditions on costs, durability and manufacturability. The SOFCnet will contribute to the establishment of the European Research Area.

Progress to date

At the moment of reporting the network has been active for three months. Together with the European Commission, SOFCnet organised the Information and Brokerage event on 'Medium to Long term Research on sustainable energy systems: Fuel Cells and their applications' in Brussels, on 13 January 2003.

The first technical workshop entitled "Operational demands to SOFC systems has been organised" in Petten, The Netherlands, on 20 March 2003.

INFORMATION

References: ENG2-CT-2002-20652

Programme:
FP5 - Energy, Environment and Sustainable Development

Title:
Thematic Network on Solid Oxide Fuel Cell Technology (SOFCnet)

Duration: 36 months

Partners:
Adelan (UK), EEA (D), HCStarck (D), Siemens (D), Univ StAndrews (UK), Alstom (UK), EMPA (CH), ICE/HT-FORTH (GR), StwDüssel (D), Univ Twente (NL), BMW (D), EnBW (D), ICSTM (UK), Sulzer Innotec (CH), ValeoCC (F), CEA (F), ENEA (I), IFP (F), Tractebel, VDI (D), CIEMAT (SP), EPFL (CH), Intema (A), TUM (D), VTT (FIN), CReeD (F), EVA (A), Prototech (NO), Univ Sherbrook (CA), Wärtsilä (FIN), Delphi (L), FHG-IKTS (D), RNL (DK), UASHH (D), Webasto (D), DLR (D), FZJ (D), Rolls-Royce (UK), Univ Aveiro (P), ECN (NL), GDF (F), RWE Fuel Cells (D), Univ Karlsruhe (D), EDF (F), GDR-ITSOFC (F), Shell Hydrogen (NL), Univ Patras (GR)

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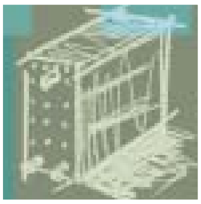
Status: Ongoing



Fuel Cell Testing and Standardisation Network

FCTESTNET

Objectives

Fuel Cell (FC) systems offer clean and highly efficient conversion of gaseous energy carriers. However, the technology needs to be further developed, since there are significant technical challenges still to be addressed. For the rating of improvements in fuel cell technology commonly agreed measures for system efficiency, power density, dynamic behaviour and durability are indispensable. This requires the definition of harmonised testing procedures for entire fuel cell systems, as well as system components, in order to track a great variety of boundary conditions. Currently no standardised test procedures exist for the assessment of FC systems against user requirements for any application.

The main objective of the FCTESTNET is to create a network of research and industrial organisations involved in development and testing of FC and FC systems. This network will produce proposals for harmonisation of test procedures at the level of FC systems down to stacks and cells. Such harmonisation is necessary to enable objective comparison of R&D results and evaluation of technological progress. It will be a valuable input for international standardisation bodies working in FC technology.

Challenges

FC is an important technology for a potentially wide variety of applications including, transportation power, auxiliary power, stationary power for buildings and other distributed generation applications, central power and micro-power.

Polymer Electrolyte Fuel Cells (PEFC), Molten Carbonate Fuel Cells (MCFC), and Solid Oxide Fuel Cells (SOFC) have been demonstrated at commercial size. Early expectations of very low emissions and relatively high efficiencies have been met with each type of FC. Fuel flexibility has been demonstrated using natural gas, propane, landfill gas, anaerobic digester gas, military logistic fuels, and coal gas, greatly expanding market opportunities. Transportation markets worldwide have shown great interest in FC; nearly every major vehicle manufacturer worldwide is supporting FC development.

However, currently no standardised test procedures for FC systems, stacks and cells exist. Similarly no standardised test procedures exist for the evaluation of the applications of FC. In practice many laboratories develop their own test protocols to meet the needs of their own or national R&D programmes. Although it is too early for formal standardisation in many FC areas, a clear need for harmonisation of test procedures and measurement methods does seem appropriate and necessary. One important motivation for establishing a network for testing and standardisation is that it will foster synergy between industry and research and will help to improving the quality of the research and quality of products at lower cost.

Project structure

Partnership

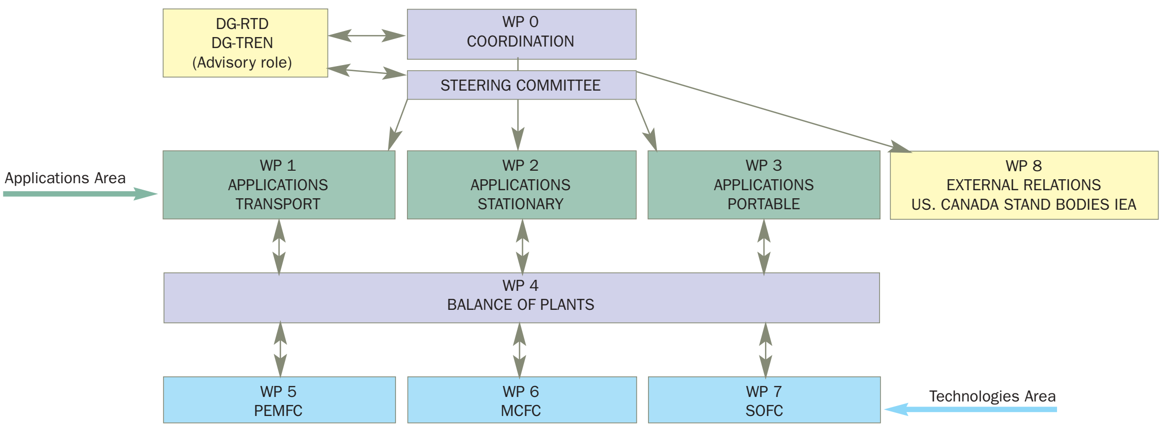
The consortium brings together 55 partners from well-known European research centres, Universities, research departments of the Industry and Small and Medium Enterprises working in the FC field. The partnership will be managed through the Project Steering Committee, with JRC-Institute for Energy in The Netherlands acting as the Scientific Project Coordinator and VDI in Germany acting as the Coordinator responsible for financial and administrative matters.

Approach

A breakthrough in FC technology will enable European manufacturers to catch up with the now dominant US industry. National funding, although underway, does not provide for sufficient R&D activity and a multinational effort is needed. This is the approach suggested with the creation of the FCTESTNET thematic network.

The approach is application and technology-oriented and ensures the necessary support and integration of the industrial interests, which is the elementary condition for harmonisation and subsequently established standardised testing procedures leading to qualified products. The increase in value of the network is to bring the industry into the position to carry out measures. The idea is to start from an analysis of applications of FC in order to define test parameters, test methods and conditions that are relevant for testing FC systems with respect to these applications. The results of that analysis at the system level can then be translated to the level of system components, stacks and single cells.

STRUCTURE OF THE FCTESTNET



Together with an inventory of test procedures, this will ultimately result in the definition of a framework for harmonising test procedures for components, stacks and cells. In this way harmonised test procedures can be derived that yield results to allow a comparison of different products and projects and that give meaningful information with respect to the progress in and applicability of different FC technologies.

The development itself of a common harmonised framework for testing of FC systems, stacks and cells is the main innovation of this project. The strength of this project is in the combination of a top-down approach, starting from an analysis of various FC applications, with a bottom-up approach, starting from an inventory of existing test methodologies at the stack, cell and component level. These two approaches will result in an integrated framework of testing procedures, in which testing methods for FC systems, stacks and cells for different application areas are based on common, harmonised methodology.

Expected impact and exploitation

Networking and benchmarking of EU and national research programmes, and mobility of human resources have been identified as key instruments to deploy the policy priorities stated in the European Research Area (ERA). In view of the EU policy to construct ERA, the co-ordination of EU and national RTD programmes and/or EU-wide networks will be promoted. FCTESTNET will contribute to the ERA concept with the element of technology mapping in the area of FC testing.

FCTESTNET aims at establishing a formal European process, providing a voice for all interested and affected parties. The network is looking to the European scientific community to implement the necessary measures. It is market-oriented in the sense of improving and reinforcing the exchange of information among developers, manufacturers and end-users to better integrate research.

The development of harmonised testing procedures will be a valuable input for all the relevant international standardisation bodies; their work will be strongly supported and promoted by the network.

Providing an international collaboration platform at a European level FCTESTNET contributes to the Energy Work Programme goals of higher efficiency and lower energy cost/kW. The project will contribute to the overall environmental targets of the EU, and can provide significant scientific and technological input to relevant activities planned by the European Commission, such as FUERO, ELEDRIVE.

An inventory (mapping) of industrial activities, institutes and consortia that work on FC development overseas, including their RTD, strategies, collaborative links, and an assessment of their specific strength, as one of the main project deliverables, will strengthen the European competitiveness.

Progress to date

FCTESTNET plenary kick-off meeting has been held 3-4 April 2003.

INFORMATION

References: ENK5-CT-2002-20657

Programme:
FP5 - Energy, Environment and Sustainable Development

Title:
Fuel Cell Testing and Standardisation Network (FCTESTNET)

Duration: 36 months

Partners:
- Joint Research Centre, Institute of Energy (NL)
- Verein Deutscher Ingenieure (D)
- TNO-Automotive (NL)
- ZSW (D)
- Catella Generics (S)
- FEV Motorentechnik (D)
- Centre de l'Energie Atomique (F)
- ECN (NL)
- ENEA (I)

In collaboration with 46 members

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Status: Ongoing

Fuel cell vehicles validation

FUEVA

Objectives

The main objective of FUEVA is to validate automotive fuel cell technologies in on board configuration and prepare for fleet tests of the most promising technologies. It is the successor of FUERO where components were evaluated on the bench. Therefore, complete systems in an automotive configuration will be validated on board of a vehicle. The fuel cell vehicles will be tested under a procedure defined and agreed upon by all the partners of the cluster project.

Challenges

The use of fuel cells for auto-motive applications is a new mar-ket. Existing vehicles are only available on a prototype status. But major automotive manufactures worldwide have announced the intention to commercialise fuel cell vehicles in the next few years. These commitments have initialised a very dynamic process of research and development on fuel cell driven vehicles and their components such as the fuel cell stack itself and the necessary auxiliaries like compressors, reformers, etc. The market share of alternative driven vehicles for the year 2005 is estimated to be about 3% and most market forecasts envisage a growth in the use of alternative drive systems. This results in about 300 000 vehicles per year in the EU, which could be potentially equipped with fuel cell drive systems.

Project approach

In order to give all interested companies the possibility to participate in the project there are two kinds of membership, active and associate members.

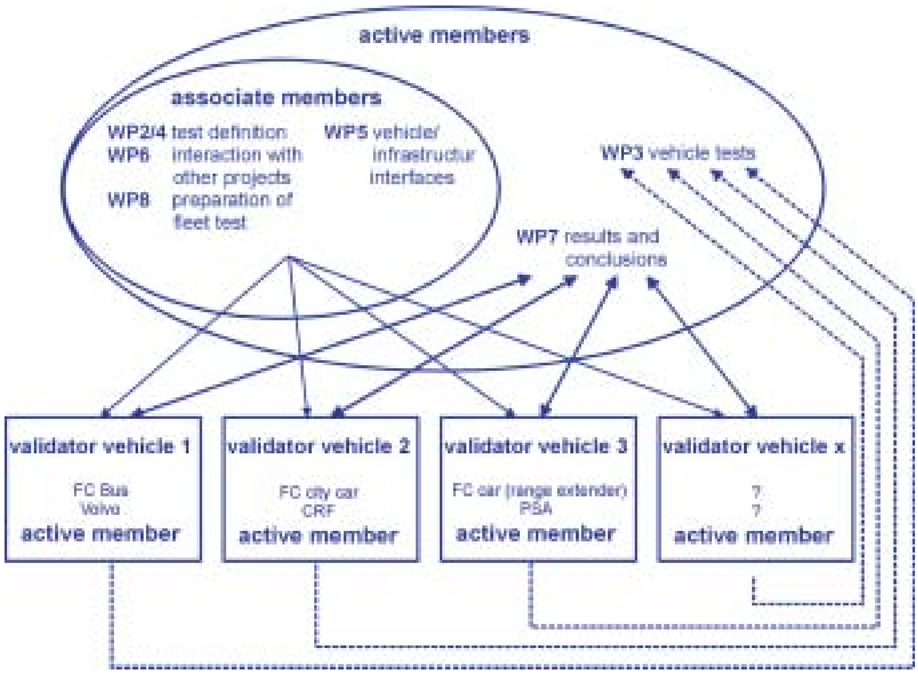
Within this project test procedures for the assessment of fuel cell vehicles performance, fuel consumption and emissions should be developed by active and associate members together. Validator vehicles contributed by the active members of the cluster project will be tested according to the developed test procedures. In order to provide the basis for later fleet testing the results of the testing and the gained experience of the actual operation of fuel cell vehicles should be shared among the active members. Apart from the development of test procedures all members should also work together in the area of hydrogen infrastructure to support and evaluate standards and common interfaces for refuelling fuel cell vehicles. The following figure shows the structure of the project with the different kind of members and the different fields of activity.

Expected impact

Fuel cell technology is an emerging and very promising technology. It can bring numerous benefits, especially in the environmental area where it is a major component in the strategy of all the automotive manufacturers in the project. All automotive partners intend to take advantage of the outcomes of this programme in their plans for the commercialisation of fuel cell vehicles.

The field operation response is a basic element in the technology development addressing the practical use of the vehicles. The outcomes of performance of the fuel cell systems tested in the practical operation in a vehicle will be used for addressing specific development lines for the supplier industries. The technical response of the components can also produce information about possible diversification of use of the fuel cell system in application sectors other than in the automotive one.

The test results in terms of energy consumption, emissions and performance of different vehicles will enable a benchmark of the technology among different manufacturers and will help to identify the state of the art and the bottle-necks of this technology in transport application. The gained experience in the designing and the operation of the vehicles will be discussed with the other active partners in the project, i.e. the partners who



test a vehicle in the project. The procedures for the tests will be developed by all the partners in the project. The assessment of technologies and products of different automotive manufacturers will take place at various test facilities.

Expected results

The outcome of FUEVA will be the following:

- Commonly agreed procedures for vehicle testing considering standards existing or under development
- Definition of common interfaces for fuel supply infrastructure
- Testing of existing fuel cell vehicles with a common procedure
- Obtaining of test results for fuel cell vehicles developed in projects clustered with this project
- General assessment for the analysis of the results, in technical and operational terms
- Preparation of fleet tests for market introduction.

INFORMATION

References: ENK6-CT-2002-00649

Programme:
FP5 - Energy, Environment, Sustainable Development

Title:
European Fuel Cell Vehicles Technologies Validation (FUEVA)

Duration: 42 months

Partners:
- Institut für Kraftfahrwesen Aachen (D)
- Centro Ricerche Fiat (I)
- Ford Forschungszentrum Aachen (D)
- Peugeot Citroën Automobiles (F)
- Renault Recherche Innovation (F)
- Volvo (S)
- Volkswagen (D)

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Status: Ongoing

www.fcship.com

Marine application of fuel cells

FCSHIP

Objectives

The project "Fuel Cell technology for SHIPs" (FCSHIP) aims to enable EU fuel cell technology providers to be more competitive in the prospective market for maritime applications, enable EU ship owners to utilise this new technology and have the competitive advantage, and assist the EU in meeting sustainable development, energy saving and air pollution reduction objectives.
The project main objectives are to define the end users' demand for the application of Fuel Cells on board ships for both main propulsion and auxiliary applications, to evaluate safety and operational demands for ships equipped with Fuel Cells, and to assess both economically and environmentally, the potentials of Fuel Cells application for waterborne transport. In short, the project objective is to provide, a roadmap for further R&D on Fuel Cell application on ships taking into account safety, operational, environmental, cost, infrastructure and market aspects.

Problems addressed

In order to put the problem areas into perspective, the technical and scientific objectives considered are:

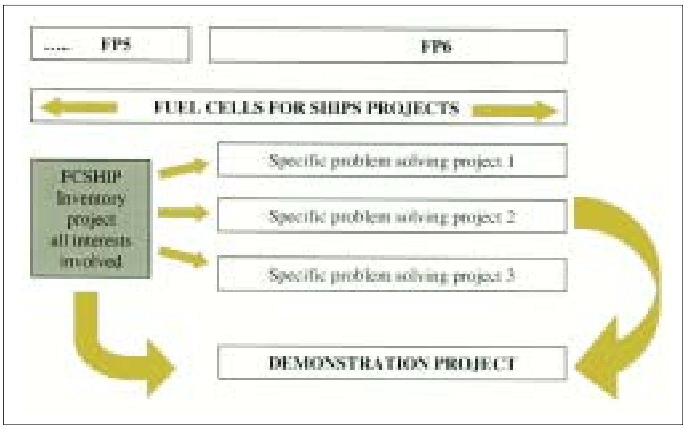
- Trade-off experience from other industrial fields to waterborne transport through the inventory and synthesis of fuel cell research and demonstration actions relevant for waterborne applications
- Development of safety and operational requirements for fuel cell application in commercial ships
- Development of end user's (ship owners) specification and functional requirements for FC application to waterborne transport
- Develop examples of FC ship conceptual designs
- Comprehensive assessment, through Life Cycle Analysis (LCA) techniques, of logistic, supply and consequence with regard to cost-effectiveness and environmental impact aspects
- Develop plans for future R&D aiming at filling the gaps towards application of FC in waterborne transportation (both inland and sea navigation).

Project structure

The FCSHIP project has a two-year duration, and the work commenced in July 2002. The project consortium consists of 21 partners headed by the Norwegian Shipowners' Association. The consortium represents the major stakeholders in the European shipping industry, including ship owners, shipyards, classification societies, universities and research institutes.

Expected impact and exploitation

In the past decade, the increasing demand for safety, efficiency and a lower environmental impact from shipping has dominated the development of the industry. The European Commission has been strategically and actively seeking solutions to meet the social and industrial requirements. The FCSHIP project will produce basic safety and operational requirements for applying fuel cells in waterborne transportation. This will provide the first guideline for the application of fuel cells on ships and contribute to the development of international legislation and standards for safe, efficient and environmentally friendly shipping. This will be further supported and materialised by the conceptual design of FC ships with an assessment of infrastructure availability and requirements in the EU leading to a final recommendation report on the application of fuel cell technology in commercial ships.
Although substantial research and development has been performed on fuel cells for use in the automotive industry and stationary power generation, limited work has been carried out on marine applications. There is presently no large-scale design and production of fuel cell systems for marine purposes, and the requirements for such systems in order to be competitive for marine applications have not been defined. Moreover, safety and operational requirements as well as industrial standards suitable for fuel cell design and application in ships are presently lacking. These presently represent major barriers towards commercial application of fuel cells in ships.
The FCSHIP project will draw a roadmap for further R&D on Fuel Cell applications on ships taking into



R&D plan to foster fuel cells application in shipping.

account safety, environment, operation, infrastructure, and market aspects. Introduction of new technology must be based on proven design, verified and approved by an independent verification body. In an early phase this will require interaction between safety requirements set by such bodies and development of new designs. For fuel cell application in ships, no such basic requirements currently exist. Such basic requirements are vital for the future implementation of the new technology, and an important element in the FCSHIP project work.

Progress to date

- Project web-site established (www.fcship.com)
- Case ships identified and mobilised for measurement of operational load profiles and other important parameters
- Ship type defined for first conceptual design and design work started
- Method of working and basic principles for definition of basic safety requirements established
- Work started to establish a framework for LCA analysis.

INFORMATION

References: G3RD-CT-2002-00823

Programme:
FP5 - Competitive and Sustainable Growth

Title:
Marine Applications of Fuel Cells (FCSHIP)

Duration: 24 months

Partners:
- Norwegian Shipowners Association (NO)
- Germanischer Lloyd (D)
- University of Applied Sciences Hamburg (D)
- University of Strathclyde (UK)
- Norwegian Marine Technology Research Institute (NO)
- MTU Motoren und Turbinen Union Friedrichshafen (D)
- Delft University of Technology (NL)
- D'Appolonia (I)
- Ludwig-Bölkow-Systemtechnik (D)
- Finantieri Cantieri Navali Italiani (I)
- Wartsila Corporation (FIN)
- Lloyd's Register of Shipping (UK)
- Det Norske Veritas (NO)
- Rina (I)
- University of Genova (I)
- Ansaldo Fuel Cells (I)
- Norsk Hydro (NO)
- Netherlands Organisation for Applied Scientific Research TNO (NL)
- Imtech Marine and Industry (NL)
- Knutsen OAS Shipping (NO)
- Color Line Marine (NO)

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Status: Ongoing

Thematic Network on fuel cell vehicles

ELEDRIVE

Objectives

The aims of the project are:

- **to create synergies at European level accelerating the development and the introduction on the market on a larger scale of fuel cell, electric and hybrid vehicles in Europe;**
- **to help to select the most promising options for prototype bench and field testing of components and /or complete vehicles thus avoiding a costly false start to the European industry;**
- **to facilitate the exchange of experience and the transfer of knowledge with the aim of enabling a global discussion ensuring a complete overview of the different problems. This will foster research and development and help to identify concrete and general solutions.**

Problems addressed

Fuel cell vehicles are very complex in design. It is therefore essential that European companies exchange their respective experience to develop synergies. This transfer of knowledge is the key to ensure a global discussion resulting in a complete overview of the different related projects and technologies.

ELEDRIVE is a thematic network aiming at fostering the exchange of information. In particular, the following aspects are regularly addressed:

- criteria for cost effective analysis of technology options which take EU policy goals into consideration
- the expectations of the various stakeholders connected with the introduction of the vehicles
- identification of gaps and future opportunities
- simulations of fuel cell hybrid drive line to predict optimal drive line architecture for given applications
- in-depth analysis of fuelling options for fuel cells, including comprehensive environmental, energy and safety audits of the complete fuel chain
- test procedures and result presentations to ensure a consistent and coherent input to technology assessment
- development of standards for vehicle equipment, installation, vehicle use and maintenance, fuelling, fuel handling, and all general operational aspects of vehicles.

A strong partnership

ELEDRIVE consists of an international and multidisciplinary partnership allowing a comprehensive approach to all facets of fuel cell and electric vehicle technology. Partners can be found in the following areas:

Industry

- Alstom Transport, France
- Centro Ricerche Fiat, Italy
- Electrabel Belgium
- Institut Français du Pétrole, France
- Peugeot-Citroën, France
- Renault, France
- Saft, France
- Volvo, Sweden
- The Automotive Consultancy Ltd, Sweden

Research

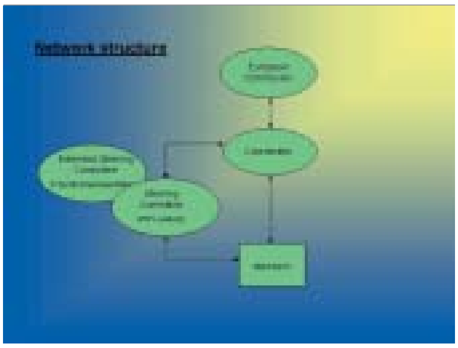
- AEA Technology, United Kingdom
- Università di Roma "La Sapienza", Italy
- Netherlands Energy Research Foundation, ECN, Netherlands
- Ecole d'ingénieurs de Canton de Vaud, Switzerland
- University of Sheffield – EMD, United Kingdom
- Ente per le Nuove tecnologie, l'Energia e l'Ambiente, ENEA , Italy
- Forschungsgesellschaft Kraftfahrwesen mbH Aachen, IKA-FKA, Germany
- Institut National de Recherche sur les Transports et leur Sécurité, INRETS, France
- RLE International, Germany
- TNO Automotive, Netherlands
- Rheinisch-Westfaelische Technische Hochschule Aachen, VKA, Germany
- Vrije Universiteit Brussel, VUB, Belgium

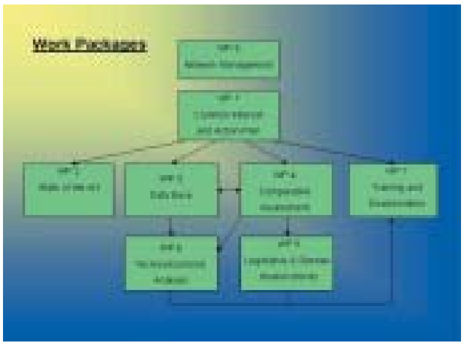
International associations

- European Association for Battery, Hybrid and Fuel Cell Electric Vehicles, AVERE
- CITELEC
- European Natural Gas Vehicle Association, ENGVA
- World Fuel Cell council

National AVERE sections

- Swedish Electric and Hybrid Vehicle Association, SWEVA, Sweden
- AVERE Dutch national section, ASNE, Netherlands
- Hellenic Institute for Electric Vehicles, HEL.I.E.V., Greece
- Portuguese Association for Electric Vehicles, APVE, Portugal





- Italian Electric Vehicles Commission, CIVES, Italy
- Swiss Association foe Electric and efficient Vehicles, E-Mobile, Switzerland
- Deutsche Gesellschaft für elektrische Strassenfahrzeuge (DGES, Germany)
- AVERE France, France
- Norwegian EV association, Norstart, Norway

Others

- Agence de l'Environnement et de la Maîtrise de l'Energie, ADEME, France
- Intema Consult, Austria
- Commissariat à l'énergie atomique, CEA, France

Approach

Protection of confidential information (experimental results, intellectual property rights, inventions...) is opposed to the need to exchange sensitive or commercially valuable information to ensure the added value of the network.

Therefore, to assure adequate supply and proper use of confidential information, ELEDRIVE has set up a process to have participants committed and responsible, according to the "give and take principle".

The process is based on:

- integrated use of the clear definition of confidentiality classes for the various exchange of information or dissemination means.
- a legal tool (Confidentiality Agreement);
- a balanced participation in the programme of work, based on the constitution of active groups for each part, determined by a Common Interest Matrix.

On this basis, exchange of information is done at workshops devoted to a well-defined topics such as:

1. General Aspects of Vehicle Technologies and Infrastructure.
2. Cost effectiveness.
3. Fuelling options.
4. Simulation and testing.
5. Vision of the future.

A final conference will ensure at the end of the project a complete and widespread dissemination of the results and recommendations for future work to an audience larger than the members of ELEDRIVE.

In order to ensure high quality discussion at these meetings, the following programme has been defined to prepare the work:

- A common interest matrix and action plan to define different classes of confidentiality, compiling a detailed common interest matrix showing who can contribute valuable inputs on what, identifying major contributors to the programme and finally defining an action plan, precise objectives for the workshops and the programme activities;
- Review of state-of-the-art and worldwide developments that is necessary to compile and analyze the detailed international state-of-the-art in the field;
- Database of results, components and testing methods that is necessary to establish a database of technical aspects of the components and parts of fuel cells and their applications to electric and hybrid vehicles and to benchmark such technologies with alternatively fuelled vehicles;
- Comparative assessment necessary to set up a set of methodologies for comparative assessment and implementation;
- Legalization and standardization trends necessary to collect information about legislation and standardization, which may be of benefit in the development and spread of the technology;
- Techo-economical analysis and recommendations for future work necessary for analyzing parts and components from a technical and economical standpoint;
- Dissemination of information and training activities.

INFORMATION

References: ENK6-CT-2000-20057

Programme:
FP5 - Energy, Environment, Sustainable Development

Title:
Thematic Network on Fuel Cell Vehicles (ELEDRIVE)

Duration: 36 months

Partners:
- ENEA (IT)
- Forschungsgesellschaft Kraftfahrwesen Aachen (D)
- Intema Consult Marketing (A)
- Association Européenne des Vehicules Electriques Routiers (F)
- Technologisch Nederlandse Onderzoek (NL)
- Università di Roma "La Sapienza" (I)
- FEV Motorentechnik (D)
- CITELEC (B)
- Rheinisch-Westfälische Technische Hochschule Aachen (D)
- University of Sheffield (UK)
- Comitato Elettrotecnico Italiano (I)
- Institut fuer Kraftfahrwesen Aachen (D)
- European Natural Gas Vehicle Association (NL)
- NORSTART (NO)
- Agence de l'Environnement et de la Maîtrise de l'Energie (F)
- AB VOLVO (S)
- SAFT (F)
- SIEMENS (D)
- Institut Français du Pétrole (F)
- ELECTRABEL (B)
- ENEL (I)
- Ecole d'ingénieurs du canton de Vaud (CH)
- Energieonderzoek Centrum Nederland (NL)
- CONNEXXION (NL)
- NOVEM (NL)
- University of Kaiserslautern (D)

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Status: Ongoing

Fuel cells systems – clean energy conversion

FCTEST

Objectives

Fuel Cells (FC) are expected to play a major role in the future energy supply and may in the long-term replace a large part of the current combustion systems in all end use sectors. In combination with conventional fuels such as natural gas, they have, in the medium and long-term, a large potential for energy savings and for strong reductions in CO_2 and pollutant emissions.

The Fuel Cells Performance Testing and Standardisation (FCTEST) action of the JRC-Institute for Energy is focusing on the following major objectives:

- **To complete the creation of the FC Testing Facility.**
- **To define, harmonise, validate and standardise test procedures for operational performance, environmental compliance, and safety of single cells, FC stacks and FC systems.**
- **To provide direct comparisons of competing FC technologies in terms of performance, operational characteristics, efficiency, safety and environmental compliance.**
- **To initiate the European Reference System for FC Testing through the co-ordination of the European Network on FC Testing and Standardisation, FCTESTNET.**
- **To provide scientific insight of the performance of FC systems by means of mathematical modelling of the complicated physical laws pertinent to FC.**

Challenges/Problems addressed

FC systems offer a clean and highly efficient way to convert energy carriers (e.g. hydrogen, natural gas…) into electricity. President Prodi, Vice-president Mrs. De Palacio and Commissioner Busquin have recently acknowledged this at the highest political level of the Commission during the launch of the High Level group on Hydrogen and FC in October 2002. According to the summary of President Prodi "This is an important choice for Europe, Hydrogen technology will not only reduce our energy dependency and gas emissions; in the long run it will also change considerably our socio- economic model and create new opportunities for developing countries".

However, the technology is not yet mature and needs to be further developed. Significant technological challenges still need to be addressed. For the rating of improvements in FC technology, commonly agreed measures for system efficiency such as power density, dynamic behaviour and durability are indispensable. This requires the definition of harmonised testing procedures both for entire FC systems and for system components. To be successful, a large variety of boundary conditions need to be tracked (e.g. different applications, different stack technologies, various types of fuel, fuel quality, etc). To date, no standardised test procedures for FC systems, stacks and cells are available. Similarly, no standardised test procedures exist for the assessment of FC systems against user requirements for stationary, portable and transport applications (e.g. homologation testing of FC vehicles). In practice many laboratories have developed their own test protocols to meet the needs of their own or national R&D programmes. In spite of the fact that FC are still in pre-commercialisation phase, the issue of harmonisation of testing procedures and measurement methods needs to be addressed now to ensure a smooth introduction of the technology.

Project structure

Structure

The FCTEST action of the Clean Energies Unit of the JRC-IE is centred on the following three major pillars:

- Creation of the Fuel Cell Testing Facility.
- Technical contribution to the European Network on FC Testing and Standardisation (FCTESTNET).
- Scientific insight of the performance of FC systems by means of mathematical modelling.

Approach

Within the **action**, technology mapping of FC testing competencies in Europe (according to ERA principles) will be realised. Generally accepted and harmonised testing procedures to qualify fuel cells, stacks and systems will be defined and developed further. Additionally, it is the purpose of **the action** to contribute to a harmonisation of quality standards, evaluation methods and test procedures for fuel cell based industrial products, for global common markets. Later on, these harmonised test procedures will be used in a comparison and benchmarking of different products and systems, to obtain information with respect to the progress in, and applicability of different FC technologies.

Mathematical modelling of transport phenomena taking place within a single fuel cell to better understand FC systems performance characteristics will be carried out as a support to the testing activities.

Expected impact and exploitation

The main goal of the action is to initiate a European Reference System for FC Testing, starting with the operation of the FCTESTNET, and in addition, supporting the creation of a European Virtual FC Testing Laboratory. In that sense, progress towards integrating European research activities in testing and standardisation in the field will be achieved. It will result in short and medium term developments that can be delivered to the industry, but that will benefit policy development as well.

JRC through the FCTESTNET Network will develop a platform to be the European counterpart in global harmonisation and standardisation in collaboration with US, Japan and Canada.

Testing and Standardisation are main issues to make FC technology acceptable. FC is a key component of the JRC Strategy for Sustainable Energy. To be in line with the JRC's mission statement, i.e. to support EU policies simultaneously enforcing the subsidiary principle, and to be in line with the other energy actions of the Institute for Energy under Environment and Sustainability, the involvement in the area of FC makes it possible to give real "integrated" S&T support to EU policies over the full range of hydrogen based energy technology.

Progress to date

The FCTEST action started at the beginning of 2003.

FC Testing Facility

The facility planning has been finished and main part of the equipment has been purchased.

Scientific insight of the performance of FC systems

A Specific Targeted Research Project proposal has been submitted for evaluation. JRC-IE is the scientific co-ordinator of a consortium focused on the detailed mathematical modelling and numerical simulation of the physico-chemical phenomena taking place **within** single cells and **FC** stacks. The long-term target is the integration of the complete FC stack model to FC systems. Three major FC technologies, namely **Polymeric Electrolyte Membrane FC** (PEMFC), Direct Methanol **FC** (DMFC) and Solid Oxide **FC** (SOFC) will be examined.

INFORMATION

References: Action 2322

Programme:
Joint Research Centre 2003 – 2006 Multi-Annual Work Programme

Title:
Fuel Cells Performance Testing and Standardisation (FCTEST)

Duration: 48 months

Partners:
- not applicable (JRC institutional activity)

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Status: Ongoing