SOFC[1)] in Jülich

Fuel Cells

Initial Position

Materials and systems for combined heat and power generation in industry and households

- ▶ Improved overall efficiency
- ▶ Environmentally friendly: no pollution
- ▶ Scalability for utilization in several applications

Challenges on the way to implementation

- ▶ Multi-disciplinary R&D tasks:
  - Optimization of thermo-mechanical behaviour w.r.t. stable sealing and operation of stacks
  - Understanding and resolving degradation effects w.r.t. longevity of 20,000 – 50,000 h
  - Reduction of operation temperatures to 600 – 700 °C
  - Accelerated testing methods
  - Process, stack, system integration and upscaling to > 50 kW

20 kW system with integrated modules

1) SOFC: Solid Oxide Fuel Cell

SOFC in Jülich

JÜLICH FORSCHUNGSZENTRUM

Research

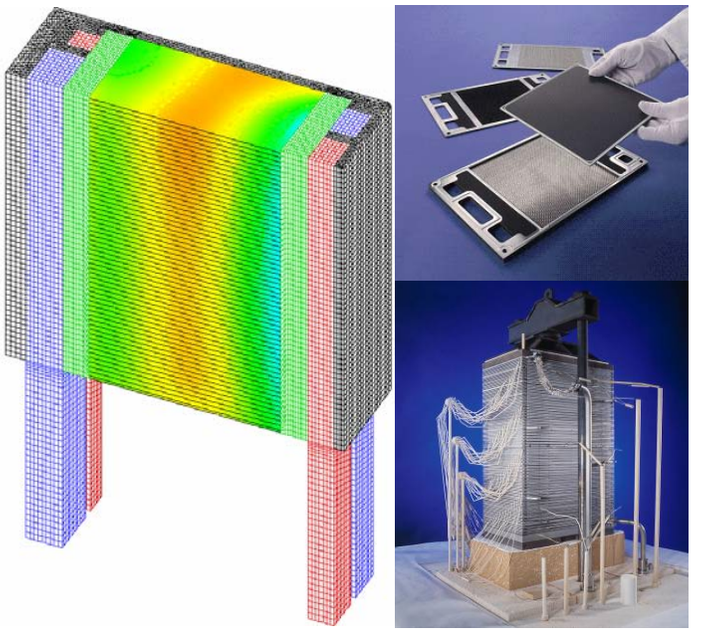
Cells with reduced operating temperatures and increased lifetime
- ▶ Cost-effective production of cells with novel materials and processes
- ▶ Cell operation on reformate @ 400 – 600 °C for > 10,000 h

High performance and robust kW-class stack technology
- ▶ Advanced steel, protective coatings and sealing
- ▶ Resolution of thermo-mechanical and degradation effects
- ▶ Accelerated testing and computational design

System technology with thermal integrated stack modules
- ▶ Advanced modelling and simulation of BoP[2)] components and systems
- ▶ Design & testing of BoP[2)] components, integrated modules and system

Milestones
- ▶ 2011: 3rd generation 2 kW stack @ 5,000 h @ u_F[3)] > 60 %
- ▶ 2012: Thin film cells with 16 cm² delivering 0.5 W/cm² @ 600 °C
- ▶ 2014: Concept of integrated sub-module for systems of 20 – 250 kW

Cooperations
- ▶ Universities: Aachen, Imp. College, Karlsruhe, Lausanne, Patras
- ▶ Research institutes: CEA, ECN, KIER, KIST, Risø DTU, VTT



Cell components (top right), 60-cell stack (bottom right) and computer-simulated temperature distribution in operation (left)

2) BoP: Balance of Plant
3) μF: Fuel Utilization

SOFC in Jülich

JÜLICH FORSCHUNGSZENTRUM

Results

Cells

- ▶ Max. power density 1.38 W/cm² @ 700 °C
- ▶ Operating temperatures 600 – 800 °C

Stacks

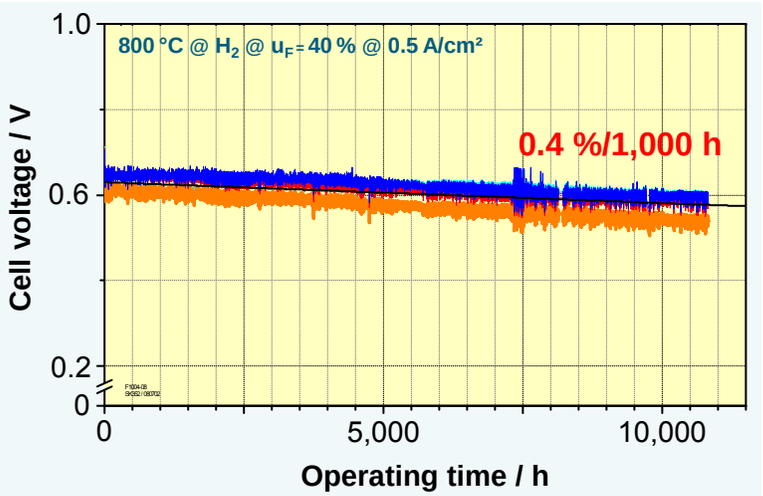
- ▶ Interconnector coating APS[4)] perovskite coating
- ▶ Degradation rate 0.4 %/1,000 h @ > 10,000 h

System

- ▶ Integrated module stack/afterburner/pre-heater/pre-reformer
  4 modules of 5 kW each (projected)
- ▶ Nominal load 20 kW (projected)

Industry cooperations

CeramTec – THE CERAMIC EXPERTS, SAINT-GOBAIN, plansee GROUP, elringklinger



Extrapolated operating time

- ▶ 25,000 h @ 10 % power loss

Voltage loss behaviour of a stack with coated interconnector

4) APS: Atmospheric Plasma Spraying

DMFC for light traction

Fuel Cells

Initial Position

New energy supply system for light traction with electric drive

- ▶ Extended operation time and range
- ▶ Enhanced functionality
- ▶ Easy handling and quick refuelling
- ▶ Evironmentally friendly
- ▶ Improved economy: reduced cost for personnel, space & investments

DMFC[2)] forklift truck

Challenges on the way to implementation

- ▶ Competition with hydrogen PEFC[1)] systems
- ▶ Use of methanol as fuel
- ▶ Multi-disciplinary R&D tasks:
  - Longevity of 5,000 h
  - Cost reduction
  - Hybridization w.r.t. peak load and break energy recovery
  - Water autonomy (≤ 35 °C) and improved total systems efficiency (30 %)
  - Prototype development

1) PEFC: Polymer Electrolyte Fuel Cell

2) DMFC: Direct Methanol Fuel Cell

DMFC for light traction

JÜLICH FORSCHUNGSZENTRUM

Research

Analytics of operating mechanisms

- ▶ Degradation mechanisms
- ▶ MEA[3)] structure-activity relationship
- ▶ Characteristic field of operation
- ▶ 2-phase flow modelling

Reliable systems

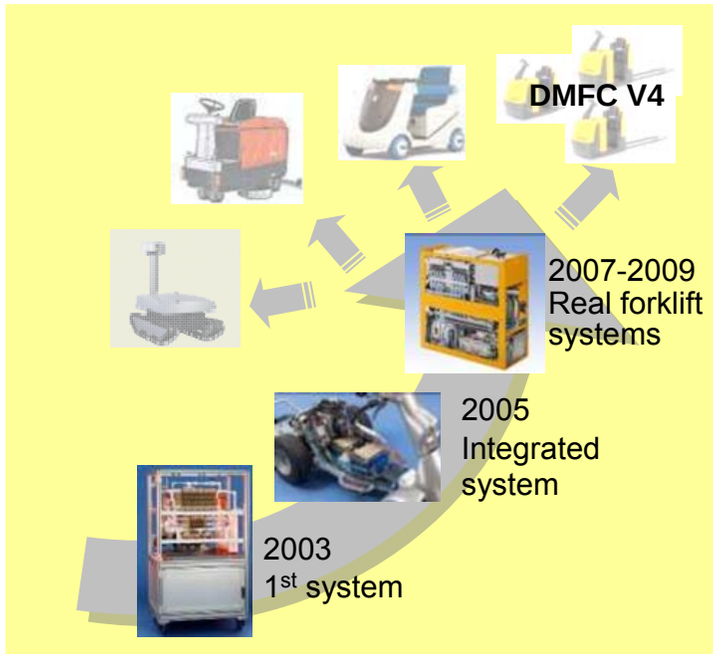
- ▶ 2 – 5 kW stacks and systems
- ▶ Automated manufacture
- ▶ MEA[3)] components and stacks: 100 mW/cm² @ 500 mV

Milestones

- ▶ 2010: Automated fabrication of stack components
- ▶ 2014: DMFC[2)] system for light traction
  (lifetime ≥ 5,000 h; overall efficiency ≥ 30 %)

Cooperations

- ▶ Universities: Aachen, Bochum
- ▶ Research institutes: GKSS, HZB, KIER, NRC



DMFC[2)] systems development in Jülich

2) DMFC: Direct Methanol Fuel Cell

3) MEA: Membrane Electrode Assembly

DMFC for light traction

JÜLICH FORSCHUNGSZENTRUM

Results

MEA

- ▶ Power density 75 mW/cm² @ 450 mV
- ▶ Catalyst loading 4.5 mg Pt/PtRu[4)]/cm²/cell

Stack

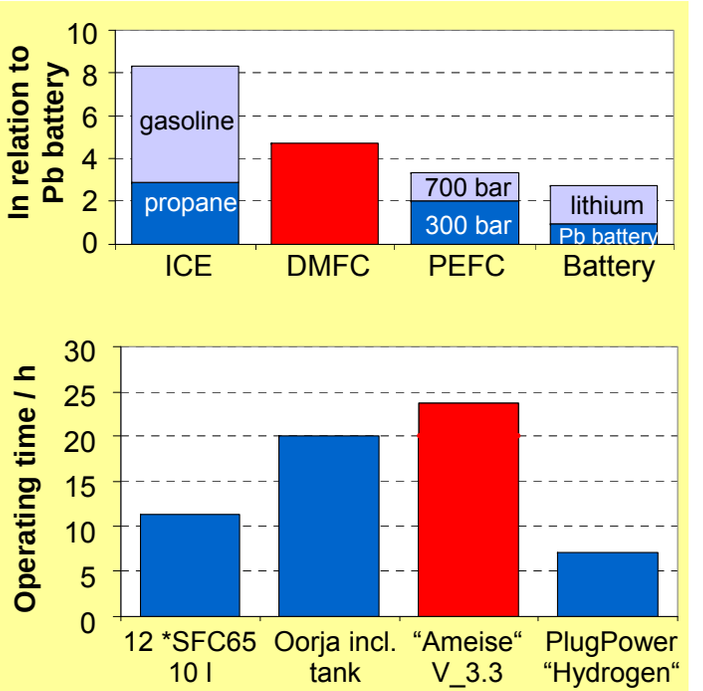
- ▶ Nominal power 1.3 kW
- ▶ Pressure loss 2 mbar (cathode)
- ▶ Air ratio 3
- ▶ Lifetime target dyn. 3,000 h

Drive module

- ▶ Peak power 7 kW (fuel cell battery hybrid system)
- ▶ Water autonomy 35 °C

Research consortium

AKG, RITTER Elektronik Mechatronik, JUNGHEINRICH, ebmpapst



Operating range (top) and systems characteristics (bottom)

4) Pt: Platinum
PtRu: Platinum-Ruthenium Alloy

Reformer Fuel Cell System For Bioethanol

Fuel Cells

Contact:
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Freiburg, Germany
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ulf.groos@ise.fraunhofer.de
www.ise.fraunhofer.de

Initial Position

Researchers at the Fraunhofer Institute for Solar Energy Systems ISE in Freiburg developed an automated ethanol reformer fuel cell system in cooperation with eight partners from industry and one institute. The system is fueled by denatured bioethanol. This fuel is inexpensive, non-toxic and commercially available to users throughout the world. One of the various applications envisioned is the off-grid power supply for medical equipment in emerging and developing countries.

Complete system with the four modules (ethanol tank, reformer, fuel cell, and electronics).

Reformer Fuel Cell System For Bioethanol

Research

The core pieces of the system are a PEM fuel cell with 300 Watt electric power output and an ethanol reformer, which constitute two of the four modules. The fuel tank and the electronics are integrated in the remaining two modules. The modular design allows modules to be removed separately, for instance to refill the tanks or to transport the system more easily. The system can be operated at temperatures ranging form -10 to +40 degrees Celsius. The electric power is available upon system start-up.

Reformer module for processing ethanol to hydrogen.

Reformer Fuel Cell System For Bioethanol

Results

The project partners are in the position to offer the developed technology to interested manufacturers for commercialisation in series production. The system can be scaled up to ca. 2 kW electric power.

We gratefully acknowledge our partners E.G.O., HSG-IMIT, INTRATEC, ELBAU, DMT, LIFEBRIDGE, MAGNUM, and UMICORE. The development of the reformer fuel cell system was funded by the Federal Ministry of Economics and Technology.

From left to right: Fuel cell module, reformer module and ethanol tank.

HT-PEFC with fuel processing for on-board power supply

Initial Position

Auxiliary power units (APUs) using middle distillates with fuel cells

- ▶ Bridging technology: fuel cell use with conventional liquid fuels
- ▶ Environmentally friendly w.r.t. pollution release and biofuel use
- ▶ Enhanced functionality
- ▶ Improved overall efficiency

Challenges on the way to implementation

- ▶ Multi-disciplinary R&D tasks – fuel processing:
  - Fuel flexibility
  - Longevity during dynamic operation
  - Power density
- ▶ Multi-disciplinary R&D tasks – HT-PEFC[1)]:
  - Cathodic overpotential
  - Sealing (≥ 160 °C)
  - Longevity
- ▶ Multi-disciplinary R&D tasks – APU:
  - Cost reduction
  - System integration
  - Prototype development

Efficient and environmentally friendly on-board power supply for the mobile sector

1) HT-PEFC: High-temperature Polymer Electrolyte Fuel Cell

HT-PEFC with fuel processing for on-board power supply

Research

Analysis and enhancement of the process performance

- ▶ CFD modelling on supercomputers and computational design
- ▶ Process optimization: reforming and desulfurization
- ▶ Electrode and MEA research: cathodic overpotential

Reliable systems

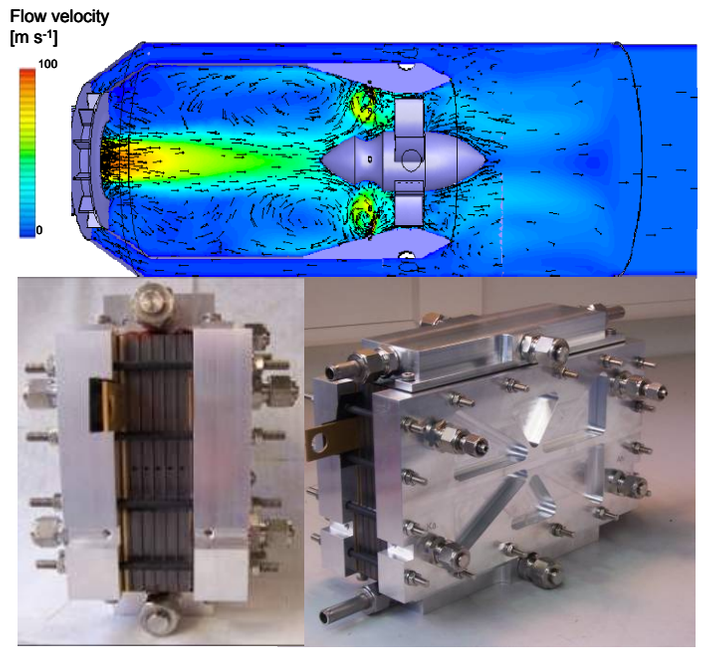
- ▶ Reformer development: 5 – 50 kW @ 5,000 h @ 99,99 %
- ▶ Stack development for APUs: 1 – 10 kW @ < 1 % CO
- ▶ 5 – 50 kW HT-PEFC[1)] systems

Milestone

- ▶ 2012: Integrated system with fuel processing and 5-kW HT-PEFC[1)]

Cooperations

- ▶ Universities: Bayreuth, Düsseldorf, Karlsruhe, Ulm
- ▶ Research institutes: NRC



Advanced reformer design (top) and 0.5-kW HT-PEFC[1)] stack (bottom)

1) HT-PEFC: High-temperature Polymer Electrolyte Fuel Cell

HT-PEFC with fuel processing for on-board power supply

JÜLICH FORSCHUNGSZENTRUM

Results

Autothermal reformer and water-gas shift reactor

- ▶ Thermal load 10 kW
- ▶ Fuel conversion > 99,7 % @ < 2,000 h
- ▶ Reformate CO[2)] concentration < 1 % CO[2)]

HT-PEFC stack

- ▶ Nominal power 0.6 kW @ 0.6 V
- ▶ Air ratio 2
- ▶ Voltage loss 60 µV/h @ H_2[3)]; 70 µV/h @ reformate

Brassboard system

- ▶ Electrical peak power 5 kW
- ▶ Operating conditions Fuel processing/HT-PEFC[1)]/APU test bed

5-kW brassboard system for flexible operation conditions with up to 3 stacks

Industry cooperations

AIRBUS, umicore materials for a better life, fumatech, BASF The Chemical Company

1) HT-PEFC: High-temperature Polymer Electrolyte Fuel Cell

2) CO: Carbon Monoxide

3) H_2: Hydrogen

Callux, Practical Tests for Fuel Cells in a Domestic Setting

Initial Position

The German Ministry for Transport, Construction and Urban Development (BMVBS), launched together with nine partners from industry Germany's biggest practical test for fuel cell heating systems for domestic use under the project name Callux.

Fuel cell heaters provide environmentally friendly heat and power at a domestic level. The benefits of the system lie-in the decentralized production of energy, which is achieved with comparatively high efficiency levels.

In addition, fuel cell heaters also produce thermal energy, which can be used to heat living spaces. Minister Wolfgang Tiefensee is convinced: „Fuel cells are an important option for sustainable, economical energy supply in a domestic setting. The ‚Callux Light House' project marks the start of a collaboration with partners from industry in producing an exemplary initiative that is immensely practical in nature - this constitutes one of the world's largest practical tests for the use of fuel cells in buildings."

Press conference at the public launching of the lighthouse project Callux. The Federal Minister and project partners in Berlin

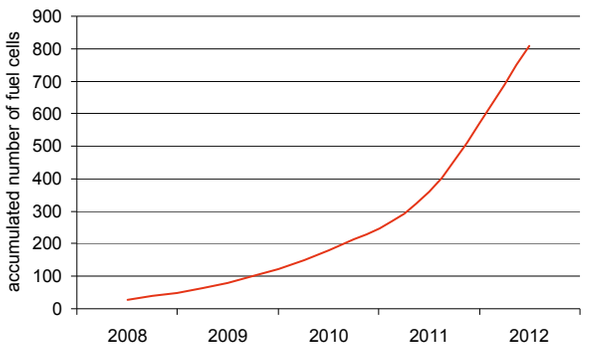
Callux, Practical Tests for Fuel Cells in a Domestic Setting

Research

Callux is a field test for about 800 German households, using fuel cells for residential combined heat and power generation. Different fuel cell systems running on natural gas will be installed throughout the country.

Besides concept demonstration and the further development of the systems to achieve reliable and marketable products, the project aims to improve public awareness, educate craftsmen and designers, validate customer and market requirements and develop concepts to integrate fuel cells into the energy infrastructure.

At project level, the Callux project is coordinated by the ZSW and the ZSW provides scientific monitoring for the syndicate.



Cumulative installations of fuel cell heaters in the Callux project

Callux, Practical Tests for Fuel Cells in a Domestic Setting

Results

In October 2009 more than 40 units installed in 4 regions of Germany and first assessment of installed units being realized presently.

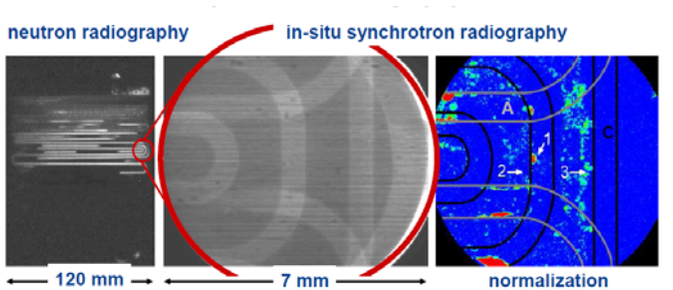
The development of qualification tools for craftsmen started and first qualification tool will be published in March 2010.
The supporting market research started. And bids invited from third parties to develop a standardized communication interface for residential applications.

The members of the Callux project

Imaging of Fuel Cells

Initial Position

Fuel Cells should be ready to be operated over a wide temperature range. This requirement results in a strong variations of humidification degrees within the cell. Both too humid as well as too dry conditions may ameliorate the power output of a fuel cell.
The investigation and improvement of the water household of PEM fuel cells has a central importance for the further development of the technology.
In this context, the visualization of water distribution in fuel cells is of high importance for the further development.
The new developed methods of neutron- and synchrotron tomography and -radiography provide a tool which allows an insight into the water household of fuel cells, including running systems.
In several projects, the water household of fuel cells is presently investigated, and detailed information on the water household of fuel cell components like gas distribution field, GDL and the electrode is obtained.



[I. Manke et al., Applied Physics Letters 90, 174105 (2007)]

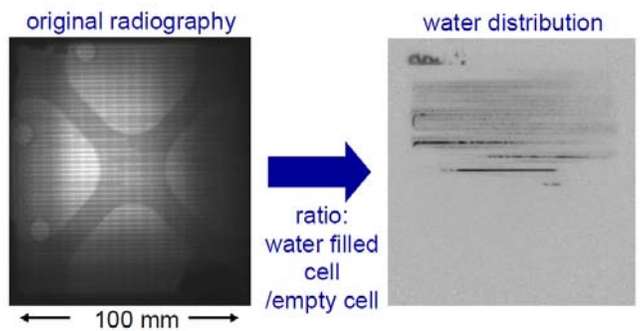
Survey on Neutron- and Synchrotron Imageing for a PEM Fuel Cell

Imaging of Fuel Cells

Research

Neutron imaging
provides information on water distribution in the scale of square cm up to full cell scale. The resolution of this method is high enough (50 to 100 µm) to provide reliable information on water distribution within a flow field and also for global information on the water content in the GDL. Under investigation are e.g. the influence of flow field geometry on water removal capability and the influence of ageing on the water hosehold of GDLs.

Synchrotron imaging
provides information on water distribution in the scale of square mm up to several cm square. The resolution of this method is much higher (3 to 5 µm) than for neutron imaging and the method provides reliable information on water distribution within a GDL (including water distribution in pores) and in the membrane. Under investigation are e.g. the influence of operating conditions on GDL water content, including he influence of ageing.



Neutrons can visualize water in flow field channels (dark areas (right side) = liquid water)

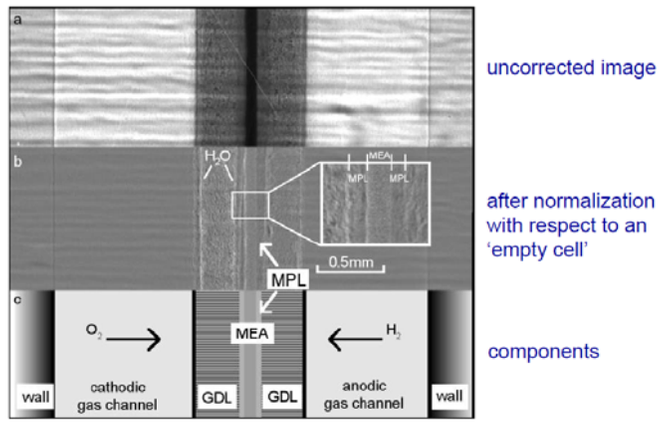
Imaging of Fuel Cells

Results

The performed work on neutron imaging provides information on necessary operating parameters for condensate removal and promotes the development of improved flow fields.

The performed work on synchrotron imaging provides information on GDL water distribution for new and aged GDLs and is helping to improve mass transport models of the GDL. In general, synchrotron imaging of fuel cells allow to detect the cell regions with water layers which hinder the gas transport. Selective measures can then be taken to improve cell design and performance.

The presented research is done within the project RuNPEM.



[Ch. Hartnig, I. Manke et. al, APL **92** (2008) 134106]

Cross sectional synchrotron image of a fuel cell (cathode gas distribution field-GDL-electrode-membrane-electrode-GDL-anode gas distribution field). The bright parts in the middle of the picture show regions of high water content.

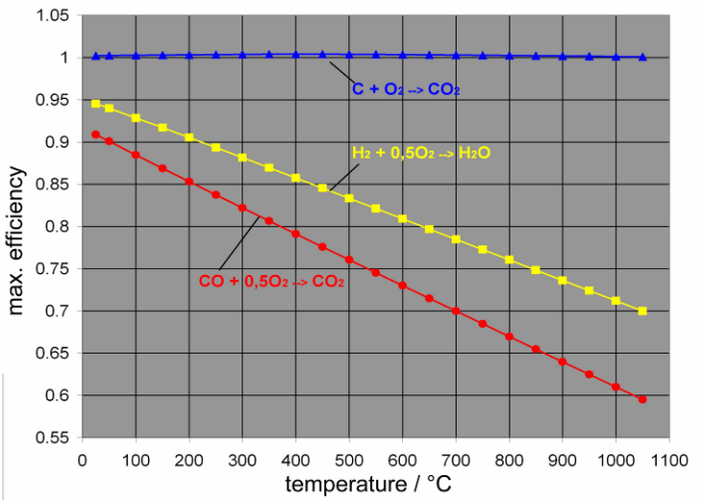
Direct Carbon Fuel Cell

ZAE BAYERN

Initial Position

In times of worldwide growing demand for electrical energy and decreasing fossil resources, the long term focus should be on renewable energies. But in the near future also new and improved concepts are required in order to use the limited fossil energy carriers in a more efficient way. Coal will play an important role, because its resources are abundant and regionally dispersed.

In this context, the direct carbon fuel cell (DCFC) is a promising development, which directly converts the chemical energy of carbon containing materials into electricity with an efficiency exceeding those of thermal conversion systems. Thermodynamically direct carbon conversion shows a maximum electric efficiency of about 100 %!



Thermodynamic efficiency for different fuel cell processes as function of temperature. Direct carbon conversion shows nearly 100 % efficiency even at high temperatures.

Direct Carbon Fuel Cell

Research

At the ZAE Bayern a DCFC concept is developed based on the well known solid ceramic electrolyte material YSZ, which has been used over several years for the gaseous fueled high temperature fuel cell SOFC.

Though a standard cathode can be used (for the conversion of oxygen), the anode side (for the conversion of carbon) has to be optimized according to the novel demands of a solid fuel regarding geometrical structure (e.g. porosity) and catalytic activity.

For the fuel supply carbon pellets are formed offering both sufficient electronic conductivity for current collection and adequate porosity for the disposal of the reaction products.

The influence of carbon fuel morphology and operating temperature has been studied in detail.

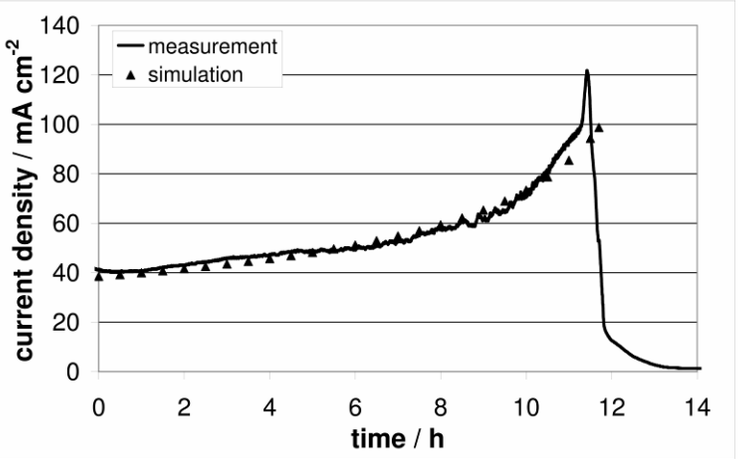
Carbon pellet contacting the anode side of a DC-SOFC

Direct Carbon Fuel Cell

Results

Direct carbon conversion to electricity on a solid oxide electrolyte based on YSZ gives power densities in the range of 100 mW/cm^2 for operating temperatures of about 800 °C.

Long term tests with purified coal show no decrease in performance nor instabilities due to ash formation or debris of impurities. The system works without any obvious degradation over more than 10 hours. Breakdown occurs only when the carbon pellet is totally consumed.



Long term test of a Direct Carbon Fuel Cell. The increase in current density can be directly correlated to the decrease of the ohmic resistance of the pellet during consumption.

Fuel cell systems for aircraft applications

DLR Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

Initial Position

Future aircraft generations have to face enhanced requirements concerning productivity, environmental compatibility and higher operational availability.
Fuel cell systems represent a promising solution regarding the enhancement of the energy efficiency especially for on-ground operation. The development is supplemented by optimization of complex electrical architectures which will lead to an overall improvement of energy efficiency. The conventional air and hydraulic systems will be replaced by electrical components. New avionic systems may accelerate this tendency. The multifunctional approach to fuel cell systems (see research) may lead to further modifications in various aircraft systems for efficient energy use on board. The goal of Airbus and DLR is to conceive innovative electrical architectures in which the multifunctional fuel cell system is a key component to ascertain a technology leadership for efficient future aircrafts.
An important milestone in the development effort was the test of an emergency power fuel cell systems during flight in the research aircraft D-ATRA (A320).

DLR research aircraft D-ATRA and the flight tested emergency power fuel cell system from Michelin

Fuel cell systems for aircraft application

DLR Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

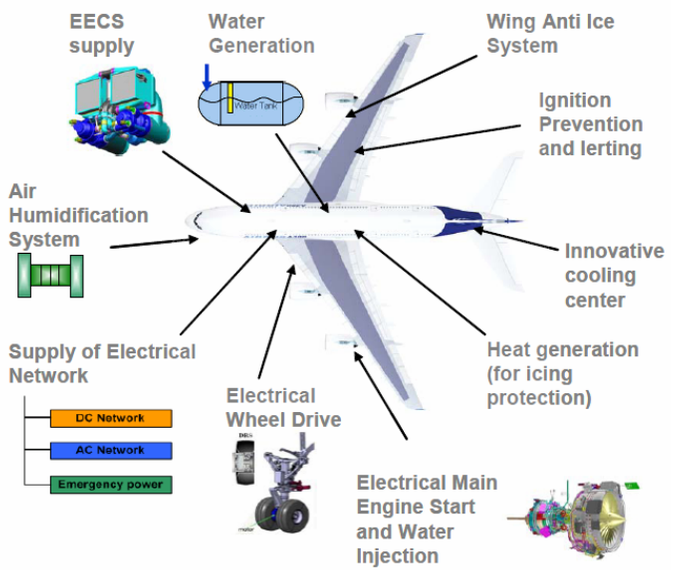
Research

A strategic cooperation between Airbus and DLR in the context of ecologically friendly aircraft systems has resulted in the first results for development of fuel cell systems for future aircraft.

The activities of DLR focus on:

- Identification of best fuel cell configurations for aircrafts
- Modeling of possible system designs
- Experimental aircraft-relevant investigations
- Qualification of airworthy fuel cell systems
- Set up and full scale testing of fuel cell systems for applications in research aircrafts

In cooperation with Airbus a multifunctional fuel cell design with multiple benefits has been identified. The provision of inert gas for the jet fuel (kerosene) tank and electrical cabin power supply including water regeneration represent the most promising application fields. The numerous functions that a fuel cell system can provide for aircraft is represented in the figure.



Scope of application for a multifunctional fuel cell system in a wide-bodied aircraft

Fuel cell systems for aircraft application

DLR Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

Results

DLR has worked on system modeling and simulation to identify beneficial system designs and multiple functions. It has demonstrated together with Airbus and Michelin the first fuel cell system for emergency power on an A320. An airworthy test platform for flexible investigations of the multiple function and application is being developed. This platform will be used for flight test and rapid change of components. The platform will be
tested in-flight in the A320 in spring of 2010. Furthermore emission free ground operation with an electrical noise wheel drive is being developed and demonstrated.
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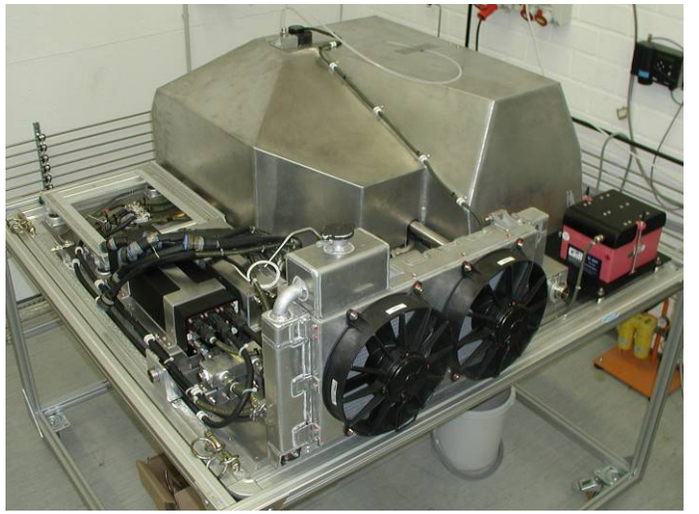


Airworthy fuel cell system platform with 12,5 kW fuel cell

Fuel cell systems for aircraft application

Results

Arising from the need to perform inexpensive and flexible fuel cell system tests in the realistic environment the testing bed Antares DLR-H2 has been developed in cooperation with Lange Aviation. The Antares was presented on 7th of July 2009 at Hamburg Airport as the world wide first pilot driven, fully autonomous fuel cell powered airplane (able to start and take off with just fuel cell power). The flight of the Antares is a CO_2 emission free flight with obviously lower noise in relation to comparable motor gliders. It demonstrated a 42 % efficiency from chemical energy to propulsion.

Antares motor glider DLR-H2, fully autonomous fuel cell powered aircraft

Fuel Cell Systems for Portable Applications

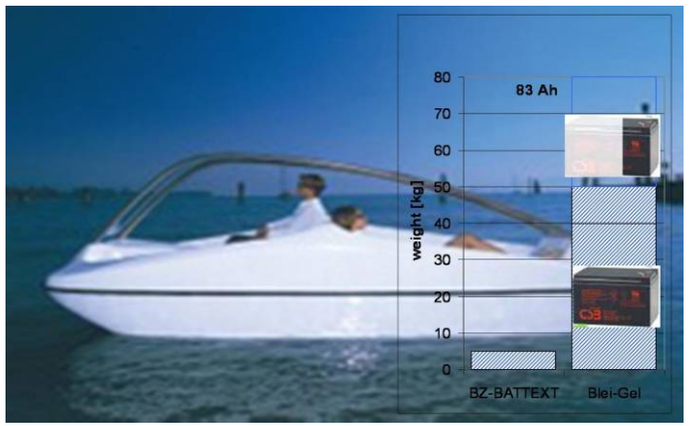
DLR Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

Initial Position

The Institute is developing portable fuel cell systems (PEFC, DMFC) in the power range of few hundred watts to few kilowatts. The target is to realize compact and robust systems with high energy density by using commercially available components. One focus is to realize a modular concept which can be easily adapted to all power ranges and special requirements of the application. The power output can be easily changed by addition of power modules. Ongoing projects are respectively DMFC battery extender (100 W) for solar boat, hybrid PEM battery loading system (0.3 -1 kW) for industrial application and a hybrid PEM system for portable use.

The applications are:

- decentralized energy systems for e.g. data acquisition, safety and observation
- mobile power systems for construction sites and traffic information systems
- auxiliary power units for automotive applications
- power units for recreation vehicles, camping and summer houses
- power supply for industrial applications



Solar boat with batteries and battery range extender

Fuel Cell Systems for Portable Applications

DLR Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

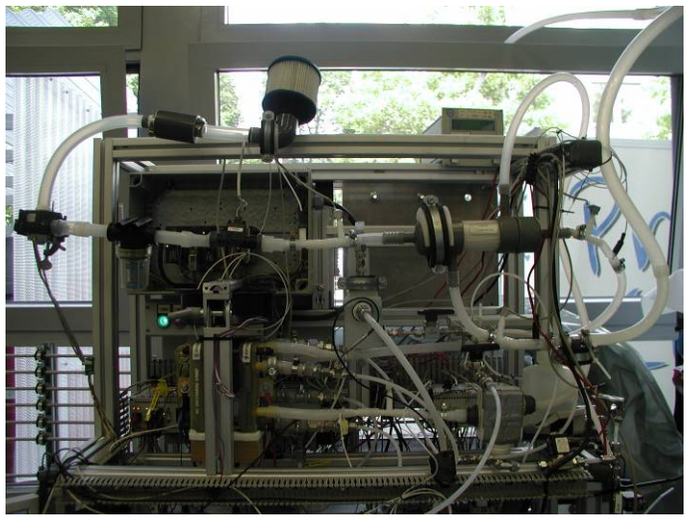
Research

The work in this field at DLR ranges from fundamental to system aspects. This means development of membrane electrode assemblies (MEA), flow field development to realize advantageous stack concepts and system design. In general, the development is performed with industrial partners. Therefore the system development effort comprised component research, subsystem development, test and evaluation, integration of controls and power electronic, safety aspects, packaging ….

The MEAs developed at DLR by dry spraying have demonstrated high performance for DMFC at moderate catalyst loading (140 $mWcm^{-2}$ and 1 bar, 75°C, 4 mg_{Pt} cm^{-2}), which enables the production of components at low costs.

The DLR has also developed flow fields for use in commercial stacks at ambient pressure with low pressure drop.

The focus of the work is presently the development of hybrid fuel cell and battery systems for portable applications.



Test bench DMFC fuel cell system

Fuel Cell Systems for Portable Applications

DLR Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

Results

1. In a recent project commercial MEAs with high power density for DMFC are available. Bipolar plates with flow fields developed at DLR with low pressure drop are integrated in a 25 W DMFC short stack and a 100 W DMFC full stack in collaboration with industrial partners (Shunk Group). For the manufacturing of the stacks a production line for PEM stacks can be used. Furthermore a 100 W DMFC as battery range extender is available as laboratory and as compact stand alone systems.

2. In collaboration with industrial partners a portable 300 W PEM system has been developed as a portable stand alone system in a prototype version. A hybrid version in combination with a Li-Ion battery offers a peak power of up to 1.5 kW. The system has been developed in respect to high efficiency, robustness, low weight, high performance and flexible use for different applications.

Short stack, stack and portable fuel cell system

SOFC Cell and System Development at the German Aerospace Center (DLR)

DLR Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

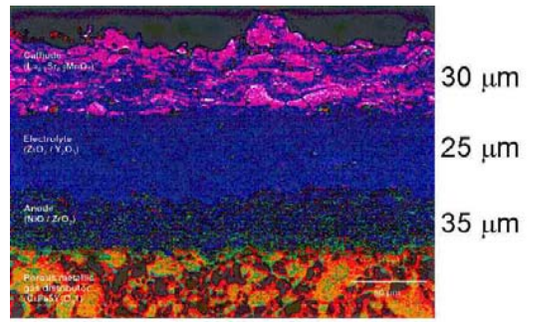
Initial Position

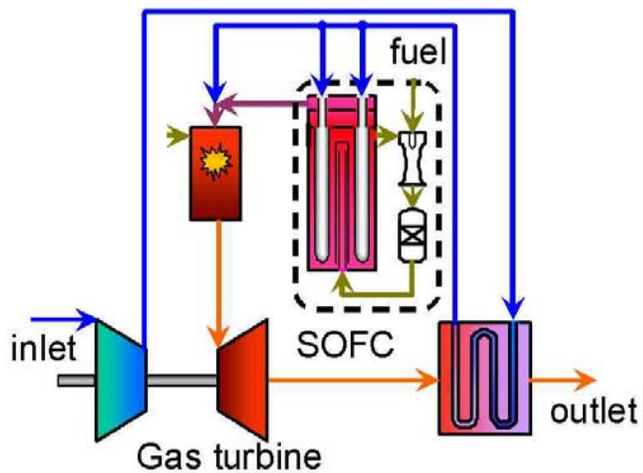
DLR focuses on selected SOFC research and development topics which high innovation potential:

1. Development of metal-supported cells with the potential of improved thermal conductivity, high mechanical stability and strength, superior redox-stability and cost advantages

2. Pressurized SOFC as a requisite for hybrid power plants, consisting of a pressurized SOFC system combined with gas turbines.

Advantages consist in a high system efficiency and very low emissions. In order to design the system and to derive the control system it is necessary to determine the behavior of pressurized SOFCs.





SOFC Cell and System Development at DLR: Metal-supported Cells

DLR Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

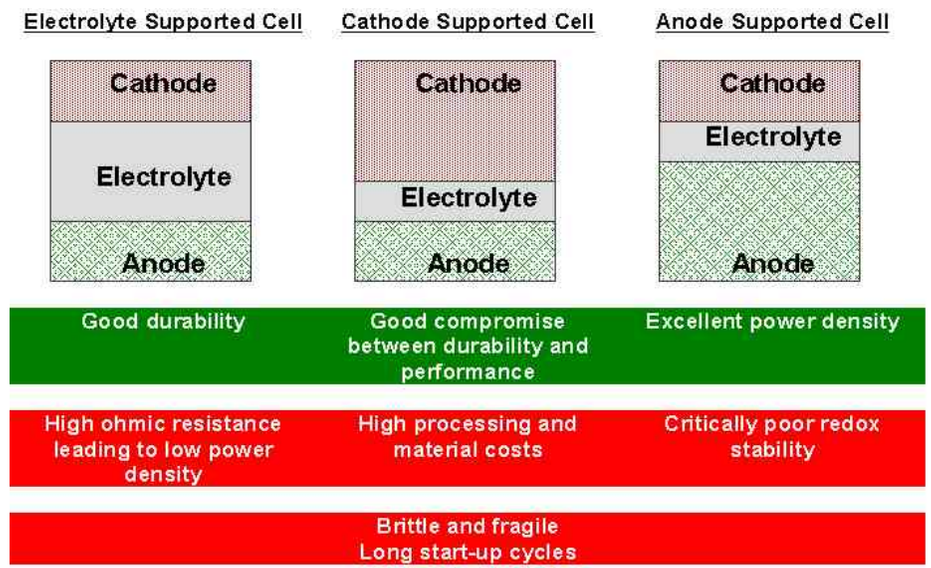
Research

1. Develop light weight metal supported SOFC cells and stacks for auxiliary power units (APU) in automobiles.

2. Enhance the power density for cells and stack above 500 mW/cm².

3. Increase the durability up to 3000 hrs with degradation below 2% kh^{-1}.

4. Demonstrate redox and thermal cycling stability.



SOFC Cell and System Development at DLR: Metal-supported Cells

DLR Deutsches Zentrum für Luft- und Raumfahrt e.V.
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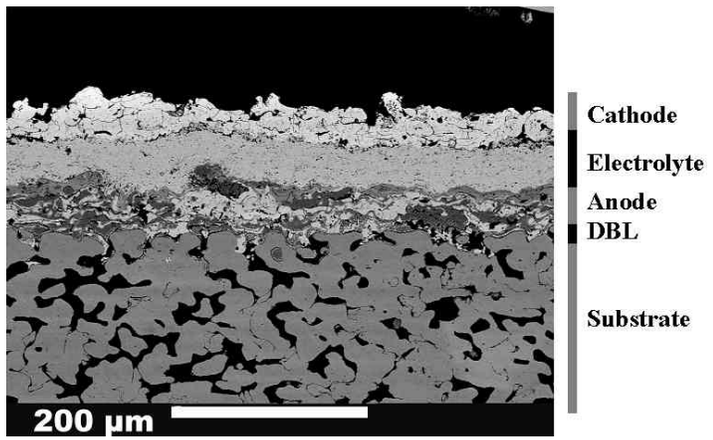
Research

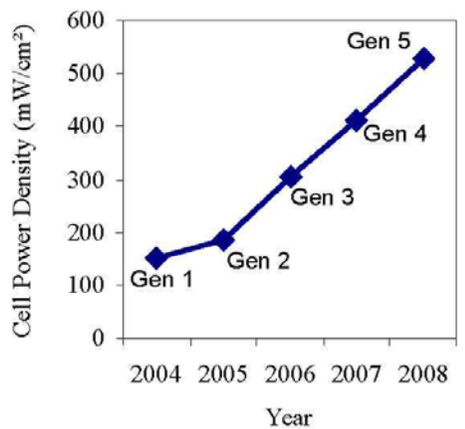
1. Advanced plasma spray processing for functional layers was developed. 100 cm² cell processing needs 32 seconds.

2. Strain tolerant nano – micro hybrid electrodes were introduced. Consequently polarization resistance was reduced and stability under redox and thermal cycling is enhanced.

3. Diffusion barrier layers (DBL) between anode-substrate were investigated. Interdiffusion between substrate and anode species was suppressed enhancing the durability of the cell above 2000 hrs.

4. Stack design is evolved to reduce the losses due to gas transport, ohmic polarization and thermal gradients.





SOFC Cell and System Development at DLR: Metal-supported Cells

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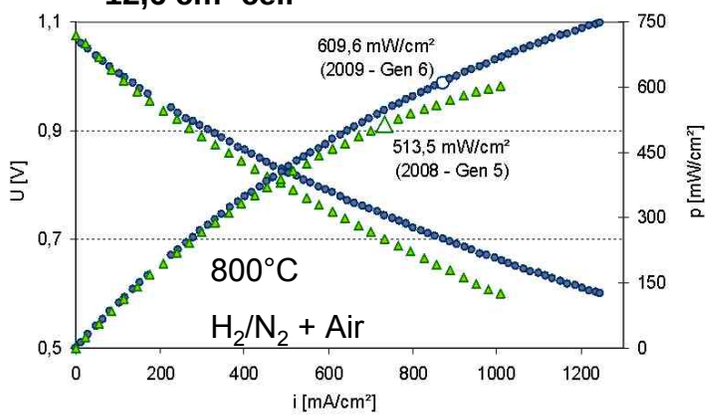
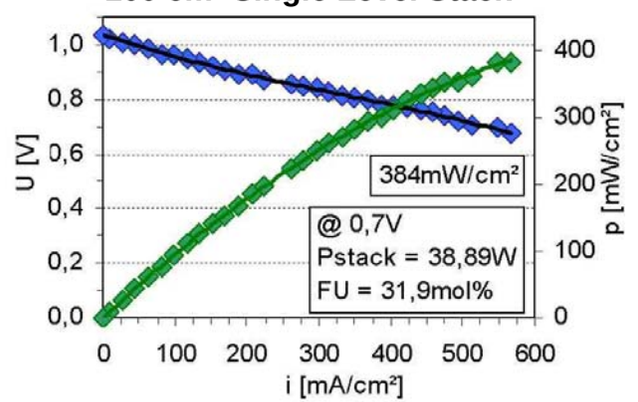
Results

1. 609 mW/cm² power density is reached for 12.6 cm² cells.
2. 384 mW/cm² power density is reached for 100 cm² single level stack. Lower power density is associated to higher ohmic losses in stack.
3. 20 full redox cycles with less than 2.3% degradation is demonstrated.
4. 2000 hrs of operation with 1.1% kh^{-1} degradation is achieved.

12,6 cm² cell



100 cm² Single Level Stack



SOFC Cell and System Development at DLR: Hybrid Power Plant

DLR Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

Results

Pressurized SOFC
2008/2009 a test rig for characterization of SOFC at elevated pressures up to 8 bars has been designed and built. Due to a complex and precise pressure control, pressure differences anode/cathode/surroundings from 500 down to 10 mbar can be regulated. First results with pressurized operation of planar stacks are being obtained.

The pressurized measurements are combined with an in-house cell model which is experimentally validated. It is based on elementary kinetics and flexible regarding cell concepts. Simulation possibilities include U(i) curves, impedance spectra and detailed analysis of losses. Pressure dependent overvoltages are shown in the diagram.

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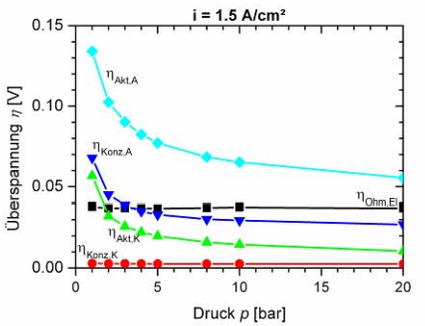
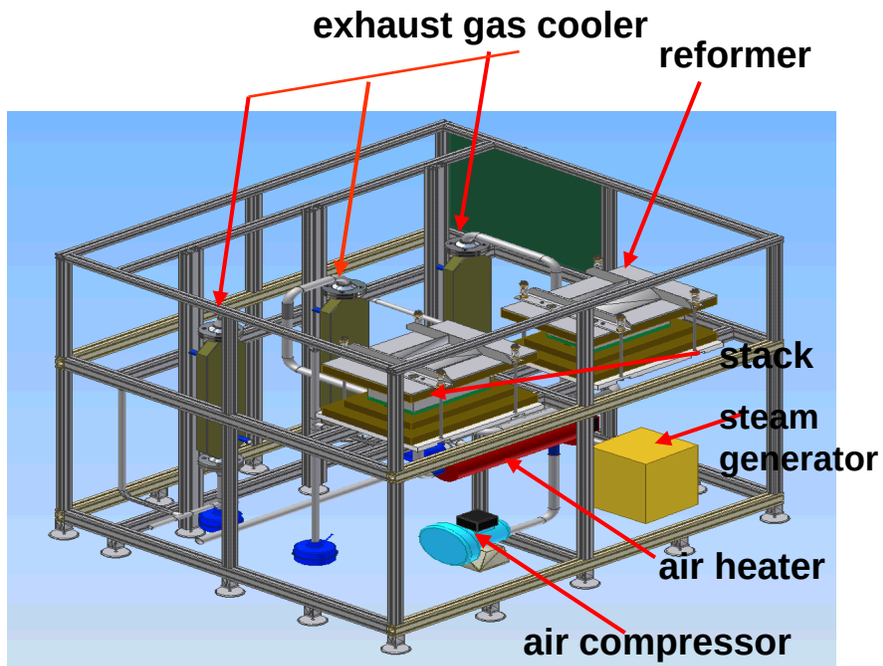
DLR-Institute for Technical Thermodynamics



Pilot operation of a high temperature fuel cell (SOFC) with coal mine gas

Initial Position

Apart from natural gas there is another important natural source of methane. The so-called coal mine gas is a by-product of the geochemical process of the carbonisation of sediments from marsh woods of the Earth's Carboniferous Period. Methane evaporates from the coal and has to be removed out of the active mines where it represents one of the main safety risks. Methane also evaporates in abandoned coal mines. In the federal state Saarland in Germany exists above ground a more than 110 km pipeline for the drained coal mine gas from twelve different sources. The content of methane varies between 25 and 90%, the oxygen content (from air) is in the range up to 10%. This wide range or variation, respectively, of fuel and oxygen content cause a lot of problems for the use in conventional engines. Therefore the company Evonik New Energies GmbH is interested in using SOFC with coal mine gas as efficient as possible to produce electric power. For that purpose at Research Centre Jülich the available SOFC technology was adapted to the use with coal mine gas and a test facility was designed to operate a SOFC stack (app. 2 kW electrical power output) together with a pre-reformer.



Design of the test facility

Pilot operation of a high temperature fuel cell (SOFC) with coal mine gas

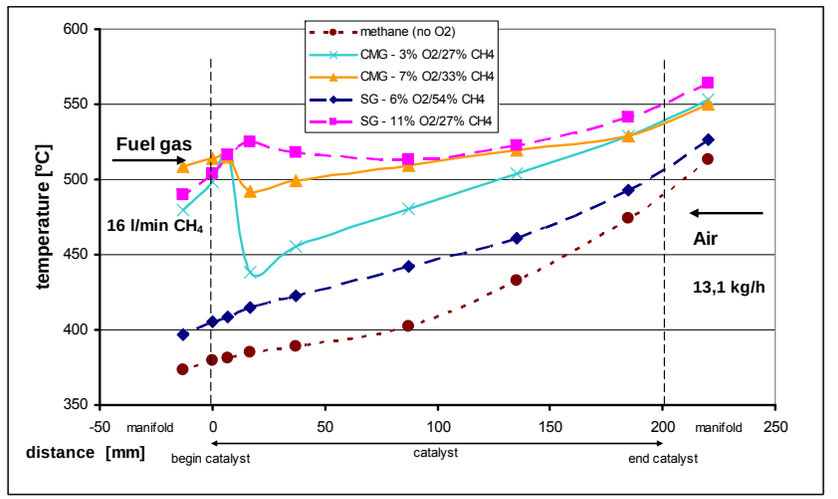
izes gGmbH
Institut für ZukunftsEnergieSysteme

Research

After integration of the reformer in the test facility in Luisenthal intensive testing was started.

First measurements showed a reforming behaviour comparable to the laboratory tests performed at the research centre Jülich as shown in the Figure on the right. But as can be seen also in the Figure on the right the temperature profile for the oal mine gas in Luisenthal showed a more pronounced decrease after the first increase because of the reaction with the contained oxygen. Probably this difference was caused by the deviating methane content in the real coal mine gas compared to the assumed simulated compositions used for pre-testing.

During the approximately 2.000 overall operating hours of the pre-reformer the quality of the reforming process decreased exponential. The rapid degrease of the performance of the pre-reformer was caused by the growth of the leakage between the anode and cathode gas rooms.



Temperature profile inside the reformer using different coal mine-gas compositions in Luisenthal as well as synthetic gas compositions in Jülich

Pilot operation of a high temperature fuel cell (SOFC) with coal mine gas

Results

The stack was mounted in the test facility next to the reformer unit. During heating to operating temperature the anode compartment of the stack was flushed with 4% hydrogen in argon mixture to prevent the Ni in the anode from re-oxidation. Already during this phase several cells in the stack showed a much too low OCV, indicating leakages. Nevertheless coal mine gas was supplied to the stack for a few hours during which current was drawn from the stack as well.

At the time of the test the methane content of the coal mine gas was about 46 Vol.%. The average stack temperature was about 840 °C. At a current of 66 A the stack voltage was still 8,1 V, giving a power of 0,53 kW, even with several cells having a cell voltage close to zero. The operation of the stack had to be aborted after a few hours, because the temperature in the fuel exhaust line of the stack reached values above the safety limits.

For further test series a fuel cell stack with an optimised design and a new sealing concept will be installed mid November 2009 into the test facility.

Contact person: Dr. Bodo Groß, gross@izes.de

The project was funded by the federal ministry of economy and technology. It was realised in cooperation with Evonik New Energies GmbH and the research center Juelich (FZJ).

Reformer within the test facility