FCTESTNET Fuel Cell Survey
by region

Edited by
Wolfgang Winkler (leader of FCTESTNET WP 8)

Part 4 Europe

Prepared by:
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4 EUROPE

The geographic region Europe comprises European Union with some views to Eastern Europe with Russia.

Different sources were used for creating databases of industrial and institutional R&D, identification of R&D focuses and partnerships, to identify the main players, major results and patents of the last five years, condense the foreseen trends for the nearer future.

While information about the work of the main players can easily be collected through the main specialized periodicals, the European Fuel Cell News, HyWeb Gazette and Newsletter of Fuel Cell Today, information about follow-ups and institutional research especially in Eastern Europe are gained through the Internet and by use of search engines.

Another possibility of defining the main players of fuel cell development is the creation of a patent survey. This survey is based on the Espacenet System with usage of the search words:

“DMFC” & “Methanol Fuel Cell”
“PEMFC”, “PEFC”, “Proton Exchange Membrane” & “Polymer Electrolyte Fuel Cell”
“PAFC” & “Phosphoric Acid Fuel Cell”
“MCFC” & “Carbonate Fuel Cell”
“SOFC” & “Solid Oxide Fuel Cell”
in the worldwide databases and is going back to 1998. Although patents do not provide the security that the related invention is an important or just useful step in development, they do show the overall endeavours of the applicant.

The results of most of the work can be found in the annex. A database of a number of European Organizations participating in the Fuel Cell Research is listed there. The Organizations are sorted by region, type of Fuel Cell and research topics and, if available, the name of a contact person is added. In addition the joint work of project partners is marked in many cases. An electronic version of these data can be obtained from the authors.

Information sources have been:
ILC-021-04, ILC-023-04; UK - Energy White Paper 2003
SUSTAINABLE ENERGY TECHNOLOGY ROUTE MAPS 1 FUEL CELLS,
4.1 Main players
(industry, researchers of Universities and research centres etc.)

The survey of the European main players and leading projects has shown that the main development in Western Europe today is based on integrated projects with industrial and institutional partners with very strong industrial players. The activities comprise all project phases from fundamental research to pre-commercialization and marketing activities. In contrast the Eastern Europe development seems to be more the work of research centres and universities. Thus the development can be seen in an earlier stage.

The following Table 4.1-1 through 4.1-4 show the main developers sorted by a sample of published and patented results and by the fuel cell type as far as identified.

4.1.1 PEFC and DMFC Development

Table 4.1-1 provides just a brief overview of the main PEFC developers.

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<td>6 / 3</td>
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<td>Degussa/DMC2/OMG AG; now Umicore</td>
<td>Manufacturer</td>
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<td>Research lab</td>
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<td>2</td>
</tr>
<tr>
<td>Fraunhofer ISE / Masterflex (DE)</td>
<td>Research lab / Manufacturer</td>
<td>5</td>
<td>4 / 1</td>
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<td>FZ Juelich (DE)</td>
<td>Research lab</td>
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<td>Intech Thueringen GmbH (DE)</td>
<td>Manufacturer</td>
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<td>4 / 3</td>
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<td>Johnson Matthey PLC (GB)</td>
<td>Manufacturer</td>
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<td>5 / 2</td>
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<td>Nedstack (NL)</td>
<td>Manufacturer</td>
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<td>6 / 2</td>
</tr>
<tr>
<td>Proton Motor Fuel Cell GmbH / MH Scientists (DE/US)</td>
<td>Manufacturer</td>
<td>2</td>
<td>4 / 4</td>
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<td>Siemens AG (DE)</td>
<td>Manufacturer</td>
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<td>20 / 6</td>
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<td>Voller Energy (GB)</td>
<td>Manufacturer</td>
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<td></td>
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<tr>
<td>Zentrum fuer Solarenergie &amp; Wasserkraft Forschung (ZSW) (DE)</td>
<td>Research lab</td>
<td>4</td>
<td>4 / 2</td>
</tr>
</tbody>
</table>

Table 4.1-1 Main players in the field of PEFC in Europe
Because only PEFC are commercially available, today a number of industries is adapting this technology for their developments. The different institutions are listed below in their alphabetic order. The addresses can be found in the Annex.

**Airbus**
The European aircraft manufacturer Airbus investigates PEFC systems for specific onboard power.

**AVL List GmbH (AVL)**
AVL is the world’s largest privately owned and independent company for the development of power train systems including PEFC implementation in automotive application.
http://www.avl.com/wo/webobsession.servlet.go/encoded/YXBwPWtiYXNlJnBhZ2U9Y29udGVudC1tYW5hZ2VuZdW50L3ZpZXcmaWQ9NDAwMDM4ODgy.html#
http://www.avl.com/

**Ballard Power Systems Inc.**
The German subsidiary of the Canadian Ballard Power Systems Inc., has recently been bought by DaimlerChrysler AG and Ford Motor Company.
www.ballard.com

**Buderus AG**
The German Buderus AG has three business segments: heating products, castings, and specialty steel and co-operates currently with the US company UTC Fuel Cells for its PEFC development of a residential PEFC heat appliance.
www.heiztechnik.buderus.de

**Catella Generics AB**
Catella Generics AB provides independent analysis and testing world-wide in the areas of battery & power sources systems technology.
http://www.genericsgroup.com/group1-detail.asp

**CEA (French Atomic Energy Commission)**
Since 1987, the CEA has developed a know-how in the PEFC (Proton Exchange Membrane Fuel Cell) field.
http://www.cea.fr/gb/

**CESI**
CESI, a private company belonging to the ENEL Group (Italy’s largest electricity supplier), is actually testing a Nuvera 5 kW PEFC stack coupled with a hydrogen storage system based on metal hydrides.
http://www.cesi.it/default_e.asp
CIEMAT - Centro de Investigaciones Energéticas, Medio Ambientales y Tecnológicas

CIEMAT is a Public Organism for Research and Technological Development supported by the Spanish Ministry of Science and Technology researching in low temperature fuel cells (PEFC) for application in transport and stationary power sources.
http://www.ciemat.es/eng/index.html
http://www.ciemat.es/eng/actividad/programas/p_cg_pilascombust.html

CNR-ITAE (Institute for Advanced Energy Technologies of the National Council of Research in Italy already Institute for Transformation and Storage of Energy)

The CNR-ITAE has actively investigated PEFC, and DMFC in the different applications.

CRES Centre for Renewable Energy Sources

The Centre for Renewable Energy Sources (CRES) is the Hellenic national centre involved in the PEFC research field.
http://www.cres.gr/kape/present/labs/hydro_2 uk.htm
http://www.cres.gr/kape/default uk.htm

CRF Centro Ricerche FIAT

Centro Ricerche Fiat (CRF) developed the Seicento Elettra Fuel Cell Phase II, representing an evolution of the model
http://www.crf.it/uk/2 do.htm
www.fiat.com
www.nuvera.com

CSIC Council of Scientific Research

Instituto de Catálisis y Petroleoquímica, Consejo Superior de Investigaciones Científicas
The Spanish Council of Scientific Research (CSIC) is researching in low temperature fuel cells (proton-exchange membrane fuel cell, PEFC), for application in transport and stationary low power sources.
http://www.csic.es/wi/index.jsp
http://www.icp.csic.es/aplicada.en.html

DaimlerChrysler

The German carmaker, as OEM building a variety of PEFC driven vehicles like urban busses, small delivery vans as well as small passenger cars.
www.evobus.de
www.daimlerchrysler.com

DLR - German Aerospace Research Centre

The German Aerospace Research Centre (DLR) is conducting PEFC research and system integration in automotive applications.
www.dlr.de
http://www.dlr.de/fk
DuPont
The developer of the NAFION membrane, DuPont (USA), is working in the office in Switzerland on MEAs and Conductive Plates and might be a partner for interregional projects.
www.dupont.com/fuelcells/products/nafion.html

ECHEM Austrian Research Centres GmbH – ARC
ECHEM is conducting R&D on PEFC systems and new materials for PEFC and DMFC.
http://www.echem.at/

ECN Energy Centrum Netherlands
ECN has eight years experience in PEFC-development, covering all aspects of cell, stack and system design and optimization and develops materials, components, stacks and BoP-components for both automotive and stationary applications.
http://www.ecn.nl/en/h2sf/

efc European Fuel Cell
EFC a German subsidiary of the British Baxi Group develops and produces residential PEFC-CHP heat appliances.
http://www.europeanfuelcell.de/

ENEA
ENEA is a scientific research and technology development organization that developed a low-pressure PEFC stack and manufactured it by desktop milling and MEGA technologies.
http://www.enea.it/com/ingl/default.htm

Forschungszentrum Juelich in Germany (FZJ)
A broad research program for the development and feasibility of Direct Methanol and Solid Oxide Fuel cells (DMFC and SOFC, respectively) is an essential part of energy technology and energy research, one of the focal research areas in the FZJ mission.
www.fz-juelich.de

Fraunhofer ISE
The German research institute Fraunhofer ISE Energy Technology a flat fuel cell for laptop applications called banded structure membrane fuel cell.
www.ise.fhg.de

Germanischer Lloyd (GL)
Germanischer Lloyd (GL) is an independent international non-profit organization for ship classification, safety and quality control and is involved in the approval of FC-Systems for use under special conditions in submarines.
http://www.gl-group.com/maritime/research/3644.htm
GKSS
GKSS is developing metal hydrides for hydrogen storage purposes and membranes for PEM and DMFC fuel cells.
http://www.gkss.de/index_e_js.html

Helion
The French Helion is developing PEFC systems for propulsion of submarines both as “pure hydrogen-oxygen” and “reformed hydrogen-air” systems.
www.helion-fuelcells.com

HOWALDTSWERKE-DEUTSCHE WERFT AG
The German shipyard Howaldtswerke-Deutsche Werft AG delivered the first commercial PEFC product by the hydrogen-oxygen supplied PEFC propulsion system of its new submarine class 212/214.
http://www.hdw.de/index_en.php?
http://www.hdw.de/hfcs/englisch/index.htm

INEGI
INEGI was created in 1986, as a not-for-profit r&d organisation..
http://www.inegi.up.pt/

INTA Institute for Aerospatial Technologies
The Spanish Institute for Aerospatial Technologies (INTA) is experienced in electricity generation on board vehicles with PEFC.
http://www.inta.es/index.asp

Intelligent Energy Limited
Intelligent Energy Limited is a relatively new company (incorporated in 2000) that was formed developing simplified PEFC systems. The company claims a higher cost efficiency and reliability an a better cold start performance.
http://www.intelligent-energy.com/

Intech Thueringen GmbH
The German Intech Thueringen GmbH, German branch of Intech EDM, part of the Agie Charmille Group, deals with electrode development.
www.intechedm.com

IRD Fuel Cells A/S
The Danish company IRD Fuel Cells A/S develops PEFC stacks and systems for stationary and automotive applications and serves as a development partner for industry and scientific institutes.
www.ird.dk
Johnson Matthey PLC

The British company Johnson Matthey PLC (GB) is a player in the field of catalysts and precious metals, providing PEM MEAs as well as their brand HiSPEC® catalysts.
www.jmfuelcells.com

MAN Nutzfahrzeuge AG

MAN Nutzfahrzeuge AG, GER, started the operation of two hydrogen busses in 2005. The fuel cell model is equipped with a 70 kW Ballard stack only, while the hybrid technology provides the energy necessary for acceleration.
http://www.brennstoffzellenbus.de/bus2004/bsz04-2gb.htm
www.man-mn.com

Masterflex

Based on its experience Masterflex has a cooperation with Fraunhofer ISE to build portable PEFC systems.
http://www.masterflex.de/com/index.html

Michelin

The French tire manufacturer Michelin developed together with the Swiss Paul Scherrer Institut (PSI) an experimental PEFC hybrid car (see also at “Paul Scherrer Institut”).
http://ecl.web.psi.ch/supercap/

NedStack

The Dutch NedStack develops, builds and sells PEFC stacks with a rating up to 5 kW.
www.nedstack.com

NuCellSys

NuCellSys owned by DaimlerChrysler and Ford will continue developing and manufacturing fuel cell systems for automotive applications.
www.nucellsys.com

Nuvera Fuel Cells

(Italy/USA) was formed in April 2000 from a merger between De Nora Fuel Cells and Epyx with the focus on PEFC development.
www.nuvera.com

Opel

The German carmaker Opel provides PEFC based FC car development for the whole US owner company General Motor Corporation
http://www.gm.com/company/gmability/adv_tech/400_fcv/fc_milestones.html
www.opel.de

**Paul Scherrer Institute (PSI)**
The Swiss Paul Scherrer Institute (PSI) is involved e.g. in the development of mobile FC applications like the hybrid vehicle HY.POWER.
www.psi.ch

**PEMEAS GmbH**
The German PEMEAS GmbH, a subsidiary of Celanese, currently develops high temperature PEFC MEAs, capable of operating temperatures well above 100°C.
www.pemeas.de

**Proton Motor Fuel Cell GmbH**
The German Proton Motor Fuel Cell GmbH and the US MH Scientists develops up to 150 kW PEFC systems as well as hybrid systems.
www.proton-motor.de

**Smart Fuel Cells**
The German Smart Fuel Cells is delivering DMFC systems for portable applications.
www.smartfuelcells.de

**Still**
The German company Still a producer of forklifts is a subsidiary of the Linde Group. Linde is one of the leading hydrogen suppliers and has a great experience in hydrogen technology. Still is developing a hybrid fuel cell powered forklift and co-operates with Proton Motor.
http://www.still.de/414.0.43.html

**TNO-AUTOMOTIVE**
TNO Automotive is strongly involved in the development of new test methods and procedures for conventional vehicles and vehicles with advanced power trains including PEFC.
http://www.automotive.tno.nl/

**Umicore**
The German Umicore is active in the fields catalysts and precious metals, providing materials for the fuel cell industry.
www.umicore.de

**Vaillant**
The German manufacturer of heating devices Vaillant uses the PEFC technology provided by the US manufacturer Plug Power for its product development.
www.vaillant.com
Viessmann

Viessmann is developing PEM fuel cell technology with German partners for domestic heating applications.
http://www.fuelcellmarkets.com/member_view.fcm?articleid=2473&subsite=1
http://www.viessmann.com/

Vito (Flemish Institute for Technological Research)

Vito (Vlaamse Instelling voor Technologisch Onderzoek) is a research institute in Flanders analyzing the technology status of the PEFC mainly with testing.
http://www.vito.be/english/

Voller Energy

The UK Voller Energy offers commercially three models from Portapack a 1000, 100 and 10 watt PEFC system.
www.voller.com

Volkswagen

The German car manufacturer Volkswagen is involved in various FC developments. The latest development is the Touran HyMotion.

Zentrum fuer Solarenergie & Wasserstoff Forschung (ZSW)

The German research centre Zentrum fuer Solarenergie & Wasserstoff Forschung (ZSW) is engaged in the development of PEMFC and DMFC and system engineering.
www.zsw-bw.de

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Number of research or prototype related articles or references</th>
<th>Number of patents</th>
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<td>Ballard Power Systems AG (DE)</td>
<td>Manufacturer</td>
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<td>Daimler Chrysler AG (DE)</td>
<td>Manufacturer</td>
<td>4</td>
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</tr>
<tr>
<td>DBB Fuel Cell Systems (DE)</td>
<td>Manufacturer</td>
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<tr>
<td>FZ Juelich (DE)</td>
<td>Research lab</td>
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<tr>
<td>Siemens AG (DE)</td>
<td>Manufacturer</td>
<td></td>
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</tr>
<tr>
<td>Smart Fuel Cell (DE)</td>
<td>Manufacturer</td>
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</tr>
<tr>
<td>XCELLSIS GmbH (DE)</td>
<td>Manufacturer</td>
<td></td>
<td>3</td>
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Table 4.1-2  Main players in the field of DMFC in Europe since 1998

The European contribution to the research activities worldwide in the field of the Direct Methanol Fuel Cell is very high compared with the development of the other Fuel
Cell types. With more than 30% of the patents world-wide (110 of 345) the companies and institutions involved seem to gather a high share. One reason should be the long and profound knowledge of the PEFC technology in theory and practice.

Most activities published are related to prototype testing, the more technical publications are related to methanol crossover, the relatively low efficiency and the need of material research.

4.1.2 MCFC Development

The European research in the molten carbonate fuel cell technology is strongly dominated by two industrial players, the German company MTU CFC Solutions and the Italian Ansaldo Fuel Cells. Since ECN skipped its MCFC development ENEA is the only one of European big research centres conducting MCFC research.

Ansaldo Fuel Cells (AFCo)
The Italian Ansaldo Fuel Cells (AFCo) was de-merged from Ansaldo Ricerche in 2001 (and EnerTAD and Fincantieri joined AFCo’s-equity in 2004 MW). It is developing MCFC systems.

CESI
Established in 1956, CESI, is a private company belonging to the ENEL Group. It is operating and investigating a 100 kW MCFC plant.
http://www.cesi.it/default_e.asp

CIEMAT - Centro de Investigaciones Energéticas, Medio Ambientales y Tecnológicas
CIEMAT is a Public Organism for Research and Technological Development supported by the Spanish Ministry of Science and Technology with a research program for MCFC.
http://www.ciemat.es/eng/actividad/programas/p_cg_pilascombust.html

CNR-ITAE (Institute for Advanced Energy Technologies of the National Council of Research in Italy already Institute for Transformation and Storage of Energy)
The CNR-ITAE is investigating fields MCFC behavior and performance as the base of industrial developments.

CSIC Council of Scientific Research
Instituto de Catálisis y Petroleoquímica, Consejo Superior de Investigaciones Científicas
The Spanish Council of Scientific Research (CSIC) is the biggest public institutions for scientific research of Spain conducting MCFC research.
http://www.icp.csic.es/aplicada.en.html
**ENEA**

ENEA is a scientific research and technology development organization with vast, internationally recognized experience in conducting advanced research programs on MCFC.

http://www.enea.it/com/ingl/default.htm

http://www.bfcnet.info/downloads/Hydrogen%20and%20FC%20project%20ENEA.pdf

**LECA: Laboratoire d'Electrochimie et de Chimie Analytique- ENSCP/CNRS**

This French laboratory is conducting research for the understanding and optimization of MCFC.

http://www.enscp.fr/en_recherche_index.html

**MTU CFC Solutions**

MTU CFC Solutions has successfully developed MCFC systems "Hot Module", in cooperation with the US FCE/ERC.


http://www.mtu-online.com/cfc/de/cfcs/cfcs.htm

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<th>Name</th>
<th>Type</th>
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<td>Motoren Turbinen Union MTU (DE)</td>
<td>Manufacturer</td>
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<td>Stichting Energie (NL)</td>
<td>Manufacturer</td>
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<td>4</td>
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</tbody>
</table>

Table 4.1-3 Main players in the field of MCFC in Europe since 1998.

**4.1.3 SOFC Development**

European companies, institutions and inventors obtained about 15 % (18 % in 1998/99, 15 % in 2000/01 and 13 % in 2002/03) of the worldwide SOFC related patents.

**Adelan Ltd. / University of Birmingham**

The UK Adelan Ltd. is a start-up enterprise of Prof. K. Kendall of the University of Birmingham.

http://www.adelan.co.uk/company.htm

**Airbus**

The European aircraft manufacturer Airbus investigates SOFC systems for onboard power supply.

www.airbus.com
Alp²s
The Austrian company Alp²s describes its business:
“Our fuel cells feature outstanding thermal cyclability and have already proven to last over some thousands load cycles. To the best of our knowledge this forms a world record for solid oxide fuel cells. Our cells are suitable for all applications - stationary as well as mobile - where high efficiency is required.”
http://www.alpps.at/en/brennsys.html#nr02

AVL List GmbH (AVL)
The Austrian AVL is the world’s largest privately owned and independent company for the development of power train systems its R&D activities include PEFC and SOFC implementation in automotive application.
http://www.avl.com/

BMW AG
The German carmaker BMW AG is to be mentioned in the field of system integration with their SOFC APU. [no direct sources to be found at “BMW” itself, but various on reporting portals for fuel cells]
http://www.bmw.com/

CEA (French Atomic Energy Commission)
CEA (French Atomic Energy Commission) is a research state agency for nuclear energy, employing a staff of 16000 people. The R&D projects on SOFC are focused on a 5 kW CHP system as a first prototype.

Ceres Power
The UK company Ceres Power has been founded in 2001 to commercialize a within Imperial College new developed SOFC concept. Ceres site near Gatwick has integrated product development, testing and pilot production capabilities.
www.cerespower.com

CNR-ITAE (Institute for Advanced Energy Technologies of the National Council of Research in Italy already Institute for Transformation and Storage of Energy)
The CNR-ITAE (Institute for Advanced Energy Technologies of the National Council of Research in Italy already Institute for Transformation and Storage of Energy) conducting SOFC research is located in Messina.

CSIC Council of Scientific Research- Instituto de Catálisis y Petroleoquímica, Consejo Superior de Investigaciones Científicas
The Spanish Council of Scientific Research (CSIC) is the biggest public institutions for scientific research of Spain studying the components used in MCFC and SOFC.
http://www.icp.csic.es/aplicada.en.html

DELPHI AUTOMOTIVE SYSTEMS
Fully independent from any OEM, Delphi Automotive Systems is a public company since May 1999. Closer information about its technology see Part 1 North America.
The German Aerospace Research Centre (DLR) is the largest engineering research organization in Germany and has about 4500 employees. The specialty of DLR is the development of thermal spraying processes for SOFC production.

http://www.dlr.de/tt

ECN Energy Centrum Netherlands

The Dutch ECN is a private research organization for the development of products and processes in the frame of energy conversion and innovation focusing on anode supported planar SOFC development.

http://www.ecn.nl/

EMPA

The R&D activities on SOFC at the Swiss EMPA division of High Performance Ceramics include material and component development for an efficient SOFC operation with fossil fuels as e.g. natural gas.

http://www.empa.ch/plugin/template/empa/614/7643/-/-/l=1

Fraunhofer-IKTS Dresden

The institute of the German Fraunhofer society IKTS in Dresden is developing planar SOFC.


FZJ -Forschungszentrum Juelich

A broad research programme for the development and feasibility of planar SOFC is an essential part of energy technology and energy research, one of the focal research areas in the German FZJ mission.


Haldor Topsoe

The Danish company Haldor Topsoe started SOFC development based on the results of the research centre Risoe.


H.C. Starck GmbH

H.C. Stark is a subsidiary of the German Bayer group and is specialized on fine ceramics. It has agreed a joint APU development with the Webasto AG and formed recently with them the new company Staxera.


InDEC b.v.

InDEC B.V. (Innovative Dutch Electroceramics), Petten, Netherlands, was founded in 1999 as a spin-off company for the pilot production of specially developed fuel cell components by ECN.

**LECA: Laboratoire d'Electrochimie et de Chimie Analytique- ENSCP/CNRS**
This French laboratory is conducting a SOFC program to lower the SOFC temperature for APU and stationary applications.
http://www.enscp.fr/en_recherche_index.html

**RISOE NATIONAL LABORATORY**
The Danish National Laboratory at Risoe is conducting a broad SOFC development program.
http://www.risoe.dk/afm/sofc/activities/activities_uk.htm

**Rolls-Royce Fuel Cell Systems Ltd**
The UK company Rolls Royce Fuel Cell Systems Ltd is a subsidiary of Rolls Royce and is developing SOFC since the early 1990s.

**SIEMENS**
The German SIEMENS company developed a planar SOFC until it bought Westinghouse. Thus the development of SIEMENS based on the former Westinghouse company is considered as a US activity.

**Staxera**
The German Staxera GmbH is a joint venture between Webasto AG and H. C. Starck GmbH for the industrialization of SOFC.
http://www.staxerafuelcells.de/

**Sulzer Hexis AG**
The Swiss Sulzer Hexis developed a SOFC residential CHP system and is in a restructuring phase now, continuing work as Hexis AG.
http://www.hexis.ch/

**Wärtsilä,**
Wärtsilä, the Finnish manufacturer of heavy duty engines started an SOFC development program for marine and industrial application.
http://www.wartsila.com/

**Webasto**
The German automotive supplier Webasto AG is developing a SOFC based APU for trucks and leisure vehicles (caravans and boats) using logistic fuels.
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<thead>
<tr>
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<th>Type</th>
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Table 4.1-4 Main players in the field of SOFC in Europe since 1998.
4.2 Research Targets and Strategies

In most European countries hydrogen is considered as the most promising energy carrier for a clean energy future and fuel cells being the ideal device to convert hydrogen into electricity (& heat). There are national research programs in most of the European countries. Harmonization of European efforts is currently built up through the framework programs of the European Community and networks of excellence. The following overview about H₂ & FC-activities in the EU and in European (Member) countries is (mostly) derived from the web-site www.hy-co-era.net. Hy-Co is a co-ordinated action supported by the European Commission to establish a “Hydrogen & FC European Research Area – Net”. Hy-Co aims to:

- Strengthen the European Research Area (ERA);
- Create a network of harmonized national and regional R&D programs in the field of hydrogen and;
- To implement respective transnational joint R&D activities.

The main identified strategies of the member states and the associated states of the European Union and the European Union itself are listed below.

THE EUROPEAN UNION

Within all Framework Programs since 1985 organizations from two or more European countries have to co-operate. The Fifth RTD Framework Program (1998 – 2002) was completed and the Sixth RTD Framework Program is in operation (2002-2006). Hydrogen and fuel cells have been taken into consideration in the Key Action “Energy” in thematic program 4 “Energy, Environment and Sustainable Development”. In the area of Hydrogen RTD the European Commission supports at present 20 projects with a financial support of 71.97 M€ (14.36 M€ annually). In the area of fuel cell technology 11 projects are supported with M€ 32.0 (6.58 M€ annually). An overview of “European Hydrogen & Fuel Cell projects” under the “Sixth Framework Program” was published with number EUR 21241 (ISBN 92-894-8003-3) by the “Office for Official Publications of the European Communities” in Luxembourg (see: www.publications.eu.int.).

See also for information on energy research in the EU:

www.europa.eu.int/comm/research/energy/index_en.htm
www.cordis.lu/sustdev/energy

In 2004 there were several calls for H₂ & FC technologies which may further increase the interest and participation of the European Commission. Also the EC’s Joint Research Centres conducted several studies in the field of “Sustainable Energy Technologies Reference & Information System (SETRIS)”. The EC is supported by a “H₂ & FC Technology Platform” to outline a “Strategic Research Agenda (SRA)” and a “Deployment Strategy (DS)”. See for the “H₂ & FC Technology Platform”: www.hfpeurope.org. The SRA has six working groups to outline:
• A research strategy for 2005 – 2015 (targeted);
• Mid-term perspective to 2030;
• Long-term outlook to 2050 (qualitative);

to be based upon a “broad-based consultation”. The reference SRA has been adopted by mid 2005. The DS concerns the technical, socioeconomic and political challenges and the possible strategies to address them and confronting Europe to the pathways for future hydrogen and FCs based energy systems. The basic approach selected is to:

• Describe intermediate scenario (snapshot 2020);
• Continue technical, strategic, socio-economic and market assessment of H₂ & FC’s of the main barriers and gaps;
• Outline steps required to pursue the Snapshot 2020 in terms of goals and milestones including recommendations for large-scale demonstration projects, market introduction, establishment of RC&S and development of political/policy framework. A “reference” DS is to be adopted by mid 2005.

In 2004 the EC initiated the "Quick-Start" program to stimulate public/private partnerships to achieve critical mass (first call under the FP6 in December 2004). The “Hydrogen Quickstart” is a 10-years program (total effort – all resources included to be estimated at 2.8 billion €):

• Hypogen: Large facility generating H₂ and electricity from fossil fuels with CO₂-capture and sequestration;
• Hycom: Realization of hydrogen communities/competence centres demonstrating the generation and utilisation of H₂ in stationary (CHP) and vehicle applications.

The FP7 will run for the period 2006-2010 (possibly 2013) with a proposed substantial increase in budget (double FP6?). One of the objectives is to create a “European Joint Technological Initiatives (JTI’s). The first calls to be expected in late 2006. Characteristics of JTI’s are:

• Large-scale public-private partnerships;
• Scale of the challenge and ambition of the SRA (and DS) require the mobilisation of very high public and private investments;
• New dimension to integrate EU RTD needs;
• Industry-led: industry committed to provide sustained high levels of resources (financial, human, prototypes…);
• Legal, technical and managerial frameworks need to be identified – new legal structures likely.

http://europa.eu.int/comm/research/future/index_en.html is a source for the plans about FP7.

The national organizations are additionally supporting hydrogen and fuel cell activities within EU. These identified national activities are described below.
AUSTRIA

A new Austrian Hydrogen and Fuel Cell Initiative (AHFI) has been established. The AHFI program has a funding budget of 15 M€ for the years 2005 and 2006. The program concentrates on mobile FCs and H₂ deployment taking the strong position of the Austrian automotive supply industry into account and its potential threat by a sudden change in the propulsion system. It focuses on hydrogen production out of renewable sources according to the Austrian environmental policy and aims to establish interesting niches for Austria and includes because of this reason also R&D activities beyond the actual main stream (Alkaline FC, FC with circulating electrolytes, hydrogen carriers like ammonia and other options). The program priorities:

- Development of a high efficient electric power-train as important element of an efficient overall system;
- Propulsion systems using hydrogen from renewable sources;
- Development of a fuel cell as auxiliary power unit.

Contact for further information:
Mr. Theodor Zillner of the Federal Ministry of Transport, Innovation and Technology (BMVIT), e-mail: theodor.zillner@bmvit.gv.at.

BELGIUM

Flemish Region:
At the moment there is no dedicated program for hydrogen and fuel cell research and development. Strategic funding for hydrogen and fuel cell technology is attributed to the Flemish Institute for Technological Research (VITO) through its yearly budgetary allocation, which is managed by the Science and Innovation Administration. Other actions have been started among which the most important: a thematic innovation network entitled VSB (Vlaams Samenwerkingsverband Brandstofcellen – Flemish Cooperation Network Fuel Cells), in which a number of companies and research institutes have joined forces in order to stimulate information dissemination and innovation in the field of hydrogen and fuel cell technology. The network defines currently research projects with a common strategy and vision. In total, funding for hydrogen and fuel cell technology research in the Flemish region can be estimated at about 1.0 M€ per year.

Contact for further information: Mr. Bart Laethem, “Ministerie van de Vlaamse Gemeenschap (MVG-AWI)”, e-mail: bart.laethem@wim.vlaanderen.be.

Walloon Region:
The Ministry of the Walloon Region, General Directorate for Technologies, Research and Energy (DGTRE), has launched calls for proposals on research topics, in which research related to hydrogen and fuel cells were eligible. Since 1999, the amount of energy research investments in hydrogen and fuel cells is around 1 M€ every year. The mains topics are production of hydrogen (from CH₄ by partial oxidation, from CH₄, LPG, alcohol and Bio-gas by catalytic process, production from biomass by a selection of bacteria and by gasification of wood) for fuel cells and meanwhile for industry: storage by Carbon nanotubes; design of PEMFC-membranes; fuel cell dem-
onstration (Ballard 100 kW power PEMFC, and mini SOFC). The DGTRE is prepared to continue to fund an annual research program of roughly 1M€ per year.

Contact for further information: Mr. Alain Stéphenne, Ministry of the Walloon Region (MRW-DGTRE), e-mail: a.stephenne@mrw.wallonie.be.

CZECH REPUBLIC

The Czech Republic (CR) executes no specific program for H₂ & FC support. Some programs partially cover subjects in this area like the “National R&D policy of the CR” including the following subjects e.g.: innovative materials & technologies, clean coal technologies and alternative use of biomass. The Czech Energy Agency (CEA) executes a state-funded program for the promotion of the rational use of energy among which the funding of pilot projects on fuel cells and an awareness campaign for H₂ & FC technologies. The CR “Transport Policy” of the Ministry of Transport supports R&D on alternative engines. Furthermore the CR participates in “Nordic Energy Research (NER)” of a description follows below.

Contact for further information: Mr. Josef Bubenik of the Czech Energy Agency (CEA-CZ), e-mail address: bubenik@ceacr.cz.

DENMARK

The Danish Energy Authority (DEA) is a public authority responsible for financing or managing of most of the research activities within the energy area. The Danish Energy Authority is responsible for funding 5 M€ per annum in research for fuel cells and hydrogen. Research on the development of Danish fuel cell technology totals 20 M€ per year. Denmark has a formulated specific strategy and a roadmap for development of Danish fuel cell technology.

Contact for further information: Mr. Aksel Mortensgard of the Danish Energy Authority (DEA), email: amo@ens.dk.

See also for further information (partly in the Danish language): www.ens.dk and for the Danish fuel cell strategy: www.energiforskning.dk

FINLAND

Tekes, the National Technology Agency, has launched in the beginning of 2003 a national research and technology development program (DENSY) in the field of distributed energy systems. The program will last five years and its estimated budged is about 60 M€ of which Tekes share is about 25 M€, the rest is covered by Finnish industry. The definition of distributed energy systems in the programs is “local, small scale energy transform, production and storage technologies including services”. The systems can produce electricity, heat or cold and vary from household size up to multi-megawatt size. The scope of the programs is on business concepts, component integration, customer integration, industrial manufacturing, information and communication technology and demonstration of technologies. Fuel cell and hydrogen systems are included in the many technologies included in the program. Spending on H₂
& FC technologies by Tekes was in 2004 2.4 M€ (total 4.8 M€) and the estimation for 2005 is 2.1 (and total 3.3 M€).

Contact for further information: Mr. H Kotila of the “National Technology Agency”, e-mail address: heikki.kotila@tekes.fi

and see for further information about the „Densy“-program at: www.tekes.fi/programs/densy.

FRANCE

The „French Ministry for Research and New Technologies (MRNT)“ initiated in cooperation with other ministries the PACo (French Fuel Cell Research and Innovation Network) funding program in June 1999 to contribute to the French energy policy for the development of new energy sources. The purpose of PACo is to bridge the gap between French industries and public laboratories by funding collaborative projects. PACo is to be a public funding program but also a network that gathers companies, government, universities and research institutes involved in fuel cells and hydrogen in France. PACo aims at fostering the creativity and invention needed for fuel cells commercial development and accelerating the progress of technology from lab to market. The budget is 10 M€/year to fund projects on fuel cells (portable, stationary and transportation applications), hydrogen (reforming, storage and others). More than 50 projects were funded by PACo. PACo is being managed and coordinated by „ADEME (L’Agence de l’Environnement et de la Maîtrise de l’Energie) and CEA (Commissariat à l’Energie Atomique)“.

Contact for further information Mrs. F. Hacque of CEA at francoise.hacque@cea.fr


GERMANY

In the 4th Program on Energy Research and Technologies, fuel cell R&D and testing efforts have been concentrated on new materials, improved components and system integration. The objectives of the program are the development of high-temperature fuel cells and fuel cell systems for stationary applications (house applications and CHP plants). Annually, the public funding through the Federal Ministry of Economics and Labor (BMWA) amounts to 8 – 10 M€. Fuel cells and hydrogen technologies are additionally funded by the “Program on Investment into the Future”, in which demonstration plays a major role. This program for 2001-2005 had a volume of about 120 M€ and concentrates on demonstration of CHP plants, fuel cells for house applications, and auxiliary power units. In addition, education, technical training, further development of components for automotive applications, norms and standards, on-board reforming of fuels and demonstration of fuel cell busses are part of the program. The programs are coordinated and managed by PTJ, Project Management Organization Juelich. In the Federal States of North-Rhine-Westphalia, Baden Wuerttemberg and Bavaria, substantial State (Bundeslaender) programs on hydrogen re-
search are in place. Additionally there are hydrogen and fuel cell related programs in other Federal States like in Hesse, Lower Saxony, Mecklenburg-West Pomerania and Saarland. The overall annual budget of the Federal and Federal States programs is estimated to about 50 to 60 M€ per annum of public support. Projects are cost-shared with the private sector and industry spends considerably more on R&D for both stationary and transport application of hydrogen and fuel cell technologies.

A market entry strategy was prepared by the "German Fuel Cell Alliance" (Brennstoffzellen-Bündnis Deutschland), see: www.hy-co-era.net/datapool/page/28/05Tillmetz_1.pdf."

On 9th February 2005, the final draft of the „Strategy Report on Research Needs in the Field of Hydrogen Energy Technology“ was published (see www.hy-co-era.net/datapool/page/40/SKH2_eng.pdf). The report was prepared by the "Hydrogen Strategy Group" of the German Federal Ministry of Economics and Labour (BMWA).

Contact for further information Mr. E. Seitz at e.seitz@fz-juelich.de or Mr. H.J. Neef at h.j.neef@fz-juelich.de of the „Forschungszentrum Jülich GmbH (FZJ)“.

GREECE

Hydrogen and fuel cells research in Greece has its share in the national program in the following specific areas: “Enhancement of excellence in Technological Research and Technology”, “Co-operatives for research and technological development in sectors of national priority”, and the “Development of human resources through training networks of research organizations and enterprises”. The program includes ongoing research activities in 8 academic organizations (4 universities and 4 research centres) running during four years. The total research budget involved for the last 5 years is about 8 M€. The participating institutions will actively seek to participate in open calls for the national program involving “Hydrogen and Fuel Cells“.

Contact for further information: Mr. Vasalos of the „General Secretariat for Research and Technology of the Greek Ministry for Development (GSRT/CERTH)“, e-mail: vasalos@certh.gr.

ITALY

Since the early 1980s, Italy invested in hydrogen and fuel cell technology development. Early R&D activities concentrated on the development of fuel cell technologies, while a moderate R&D commitment was addressed towards the production of hydrogen as sustainable energy carrier, in particular for the production of hydrogen from renewable and its utilization in internal combustion engines (ICE). A national R&D program on "Hydrogen and Fuel Cells", supported by Ministry of Research and University and Ministry of the Environment, was outlined in the framework of the National Research Plan (PNR) in 2003. The program covers three years, with an overall funding of around 90 M€. The following areas have been identified as priorities for hydrogen as a sustainable energy carrier, with a funding of 51.1 M€:
• Development of technologies, components and innovative systems for hydrogen production from renewable sources or from fossil fuels and hydrogen/CO₂ separation;
• Development of systems for hydrogen storage;
• Study of CO₂ sequestration in geological sites and development of related technologies;
• Development of technologies, components and systems for use of hydrogen in transport sector and for energy distributed generation.

The R&D priority areas related to fuel cells technologies, whose funding is 38.7 M€, are:

• Improvement of performances and cost reduction through the development of innovative materials, components and cell design;
• Development and demonstration of fuel cell systems for transportation, stationary power generation and portable units;
• Plant demonstration, monitoring and verification of operative behaviour of cells using different fuels.

The selected proposals are cost-shared with the private sector, to result in an overall budget of about 130 M€, corresponding to a yearly budget of 43 M€/a.

Contact for further information: Prof. Dr. Vellone of the "Ministry of Education, University and Research (MIUR)", and e-mail address: vellone@cassacia.enea.it.

NORDIC ENERGY RESEARCH

Nordic Energy Research (NER) is responsible for program in the whole value chain in the field of hydrogen and fuel cell (from production to use). The programs involve central and considerable partners from the Nordic countries and the East Sea region: industry, scientific community, public authorities. The financing from Nordic Energy Research into the energy programs in the period 2003-2006 is approximately 14 M€, of which hydrogen and fuel cells account for 25 % (3.5 M€ annually). Projects are cost-shared with the private sector and therefore this corresponds to an overall budget of 16 – 18 M€. In the following, some key areas are given like:

• Foresight projects with scope: To develop socio-technical visions for a future hydrogen economy and explore roadmaps to commercialization of hydrogen production, distribution, storage and utilization and to contribute as decision support for companies, research institutes and public authorities in order to prioritize R&D and to develop effective framework policies;
• Storage projects with scope: To develop new metal hydrides for hydrogen storage satisfying the IEA goal and the integration of advanced hydrogen storage materials and systems into the hydrogen society;
• Production projects with scope: Electrolysis, CO₂-capture and Storage, Demonstrate, and further improve, significant production of renewable bio-hydrogen using both photo-biological and fermentative pathways;
• Fuel Cell (applications) with scope to strengthen research and development on applied fuel cell technology within the Nordic and the East Sea region.
Contact for further information: Mr. M. Forss at mikael.forss@nordicenergy.net or Mr. T. Gartner at trond.gartner@nordicenergy.net of the Nordic Energy Research (NER).

NORWAY

Because of the existence of Norway's huge natural gas resources, hydrogen production from natural gas with CO₂ capture and storage are now of high priority in Norway. In addition to its gas resources, Norway has access to large areas suitable for CO₂ sequestration in the North Sea. The Norwegian government has established a Hydrogen Commission, with representatives from industry, R&D, governmental institutions and NGOs. The Commission's objectives are to:

- Define national targets to develop hydrogen as energy carrier;
- Identify means and instruments for added value and better environment;
- Identify necessary participation from government and framework conditions;
- Propose organization, responsibility and necessary funding for a national hydrogen program.

There is no specific hydrogen program in Norway at present; however the R&D activities are organized within the major energy program in the Research Council - Renergi. The Renergi program period is from 2004 to 2013. The funding for hydrogen related R&D projects in year 2003 was roughly 3 M€ supplied by the Research Council. Additional funding for demonstration projects by other governmental bodies, support from industry, and projects run by industry themselves, adds all together up to around 7 M€. Demonstration activities have recently started, with some funding from the energy agency ENOVA. The major demonstration project in Norway – the Utsira project – is primarily financed by the company Norsk Hydro. The portfolio of hydrogen projects is the following: 16 projects on hydrogen production and hydrogen storage and two projects on hydrogen combustion (total contribution from government is 4 M€).

Contact for further information: Mr. T. Moengen of „The Research Council of Norway (RCN)“, email address tm@interenergi.no.

POLAND

Under the umbrella of the „Polish Hydrogen & FC Technology Platform“ the following working groups are active: „Processes for hydrogen from coal“, „Processes for hydrogen from natural gas“, FCs (high- & low-temperature FCs), „Hydrogen technology development strategy in power engineering and industry“, and the „production of hydrogen on industrial scale and its transmission“. The following lists of priorities are defined for FCs by the working groups aiming at the National Framework program (NFP): FCs as a source of clean energy and as chemical reactors and their use“, „Developing and optimizing materials for FCs including construction of prototypes (type IT-SOFC) to be used in dispersed energy systems. For low-temperature FCs: hydrogen fuelled PEFC and fuelled by methanol (DMFC).

Contact person: Mr. Jacek Kijenski of INMAT [jacek.kijenski@ichp.pl]
PORTUGAL

Although Portugal has no specific program on hydrogen and fuel cells, the Government supports research on hydrogen through students that are funded by FCT, the Science and Technology Foundation ("Fundação para a Ciência e a Tecnologia"). In 2002 FCT had an overall budget of 194.6 M€. In 2002, funding specifically in the field of energy represented an overall value of 2.5 M€ from which 0.3 M€ were allocated to direct funding of Energy Research Centres, 1.7 M€ to research energy projects, and 0.5 M€ to PhD fellowships in the field of energy.

Contact for further information Mr. R. Fernandes of The Science and Technology Foundation (FCT), e-mail address: reifernandes@navier.ist.utl.pt.

ROMANIA

The Ministry of Education & Research executes three programs: „National R&D & Innovation Plan (2001-2005), the Nucleus Program (2003-2005) and the R&D-Sector Plan (2004-2005). The budget for H2 & FC R&D projects in the Nucleus Program for 2005 is 0.14 M€. In 2004 the “R&D Sector Plan” was launched including a project: „Developing an H2 & FCs Integrated R&D Platform in Romania (2004-2005). The ministerial support for this project is M€ 0.25 (total budget M€ 0.325). Its objectives are to ascertain the scientific and technological capabilities of the partners involved, determine future developments in line with the European strategy and to increase the national H2 & FC platform scientifically and technologically. The Romanian Hydrogen and Fuel Cells Platform is a network organization of nine R&D organizations to further develop the Romanian capabilities in this field. Topics: PEMFC & SOFC, H2 production via reforming and storage in metal hydrides, H2-purification and bio-fuels. Also: The „Alliance on Hydrogen and Fuel Cells (H2FC-RO). This non-governmental organization has among its objectives: „To strengthen the Romanian researchers‘ relations with the European H2 & FC Technology Platform“ through the „promotion of energy efficient technologies and standardization in the field of H2 & FCs."

Contact persons: Mrs. Elena Enescu, ICPE-CA and Mr. Vasile Staciu of ICSI.

SLOVENIA

Total research activities in the period 1997-2004 could be summarized to the equivalent of 0.6 – 0.7 M€ /year, although probably many activities could not be included in this review. The most prominent projects and programs in the research in the field of “H2 and Fuel Cells” are financed nationally by the Ministry of Education, Science and Sport of the Republic of Slovenia. Some funds (approximately 0.6 M€) were attributed also by the Ministry of Environment, Spatial Planning and Energy, by the Ministry of the Economy and by the industry (also from outside Slovenia):

- Projects on hydrogen production and fuel cells at the National Institute of Chemistry, Ljubljana;
- Projects on hydrogen production and fuel cells at the “Jožef Stefan” Institute, Ljubljana;
- Projects on hydrogen production and fuel cells at the “Faculty of Chemistry and Chemical Technology, University of Ljubljana;
• Projects on hydrogen production and fuel cells at the Institute for electronic and vacuum techniques.

Contact for further information: Mr. A. Gnamus of the Ministry of Education, Science and Sport (MESS), e-mail address: ales.gnamus@gov.si.

**SPAIN**

The Spanish National R&D Plan is managed by the Spanish Ministry of Science and Technology. Several National R&D Programs are included in this program among which the Energy National Program (ENP). At present the ENP is arranged in three thematic groups: conventional energy, renewable energies and fusion energy. The ENP has three calls for proposal every year, one for universities and research centres, the second for technology centres and the third for the remainder. The annual budget (10 M€ in 2003 for the ENP) is defined by the government and its distribution between the programs decided by the Ministry (2.9% for the ENP in 2004). H₂ & FCs are part of the Energy National program (2004-2007). The overall goals for H₂ are: Production, storage (compressed through nano-structures), distribution & supply, strategies, regulations, specifications, standardization, safety and quality. For FCs: Development of alternative fuels, materials, manufacture procedures, simulation models for PEMFC, high-temperature FCs (MCFC & SOFC), pilot- and demonstration plants. In 2003 21 H₂ & FC projects were approved and supported with 1.92 M€ by the Ministry of Education and Science.

Contact for further information Mr. M. Montes Ponce De Leon of the Spanish Ministry of Education and Science (MCYT), e-mail: manuel.montes@mcyt.es.

**SWEDEN**

Sweden has several R&D programs related to hydrogen and fuel cells technologies:

• A large research program on Artificial Photosynthesis engages groups in Lund, Stockholm and Uppsala. This program also supports research on hydrogen production by blue-green algae. Program period: 2002-2005. Program budget: 5.4 M€ or 1.35 M€ annually;

• The Alternative Motor Fuels program has its main focus on fuels made by gasification of biomass, but it also includes projects on hydrogen. Program period: 2003-2006. Program budget: 6.1 M€ or 1.5 M€ annually;

• The program on Stationary Fuel Cells includes both research and development activities. Program period: 2002-2005. Program budget: 3.9 M€ or 1 M€ annually;

• The program Energy Systems of Road Vehicles support projects on various technologies relating to the drive line of vehicles, fuel cells being one of them. Program period: 2004-2006. Program budget: 11.4 M€ or 3.8 M€ annually.

Contact for further information Mr. L Vallender of the „Swedish Energy Agency (STEM)“, e-mail address: lars.vallender@stem.se.
SWITZERLAND

In Switzerland several R&D-activities are executed in the production, storage and transformation of hydrogen. The scientific strengths are in solar thermal and photo-electrical water splitting. There is a considerable potential to develop functional materials for electrodes and membranes. The Swiss researchers and industry are networking within the framework of the Swiss Hydrogen Association “Hydropole” (www.hydropole.ch). The Swiss fuel cell activities are focused on PEMFC and SOFC technologies. Numerous research groups have international approved competencies from basic research like material and theoretical modeling up to systems integration. Several companies are involved in the R&D process however no industrial breakthrough is achieved. The strategic objective is to mobilize industry through further realization of niche market products. The total funding budget from federal through the cantons resources are estimated to be 5.5 MCHF (3.6 M€) annually for hydrogen and for fuel cells and at 10.0 MCHF (6.5 M€) annually for the period 2005 – 2007.

Head of the hydrogen and fuel cell programs at the Swiss Federal Office of Energy (www.energie.schweiz.ch) is Dr. Alphans Hintermann.

THE NETHERLANDS

The combined public-private investment in hydrogen and fuel cells is currently over 30 M€ annually. The public part is approximately 8-10 M€ annually. The subjects addressed include R&D and demonstration for production, storage, infrastructure and application of hydrogen, etc. SenterNovem (formerly Novem) manages various energy programs like GAVE (Non-pollutant Energy Carriers), DEN (Renewable Energy Netherlands), the Environment and Technology Program (ETP), the Ecology, Economy and Technology program (EET) (together with Senter) and the newly initiated program „Hydrogen Networking“. These programs offer extensive opportunities to hydrogen projects. New programs are under development, including the development of demonstration projects. The sister organization of Novem was Senter, also functioning as an agency for the Ministry of Economic Affairs. Senter managed several innovation programs on behalf of the government and employs approximately 700 people. Novem and Senter merged to SenterNovem, stimulated by the Ministry of Economic Affairs. Recently, a program had started for the academia called “Sustainable Hydrogen”, which is managed by NWO (Netherlands Organization for Scientific Research) directly related to the Ministry of Education.

Contact for further information Dr. H. Barten of SenterNovem with e-mail address: h.barten@senternovem.nl.

TURKEY

In Turkey there is no focussed program on energy RD&D. Turkey has recently announced the national Research & Technology Foresight Program (vision 2023). It includes the following priority fields: H₂ & FC technologies (FCs for transport applications, stationary applications, and for portable applications), renewable energy technologies and clean & efficient combustion & gasification technologies. The vision aims at increasing the RD&D program expenditures as percentage of the GDP (from 0.67% in 2003 to 2% in 2010).
Contact person Dr. F. Akgun of the “Tubitak National Research Centre”; e-mail address: fehmi.akgun@mam.gov.tr.

UK

In the UK - Supergen – is a directed program to address sustainable power generation and supply with nine themes (including hydrogen). UKSHEC – the UK sustainable Hydrogen Energy Consortium – works with a budget of M£ 3.5 for 4 years (1.3 M€ annually). The new “DTI”-technology program supports co-operative R&D projects for priorities identified by the “Technology Strategic Board” with the expectation that hydrogen features in future calls. With respect to fuel cells the major objective is the development of an industry. Views on fuel cell technology are presented by “Fuel Cells UK”, “UK Fuel Cell vision”, “UK Fuel Cells Roadmap”, the "Fuel Cell Forum", and the “Low Carbon and FC Vehicle Centre of Excellence”. In the UK a policy framework for hydrogen energy activities is being developed, a fuel cell industry is beginning to develop and there is strong interest at regional level.

Contact for further information Mr. R. Eaton of the Department of Trade and Industry, 1 Victoria Street, London SW1H 0ET, UK and e-mail address: ray.eaton@dti.gsi.gov.uk.

The following table has been derived for the above given data. Only those countries are included which presented specific data on their hydrogen and fuel cell technologies effort. The interpretation of the table has to be treated with some caution. For example the last calls for tender in 2004 within the Sixth Framework Program of the European Commission aren't included nor their spending through the Joint Research Centres on hydrogen and Fuel Cell technologies. Another example: the annual spending of 17 M€ by the Netherlands is caused by the start of contracts for projects in the framework of the "Renewable Hydrogen Program" in 2003. Blank entries in the cells in this table mean that no further data were published in the above presented overview.
### Public expenditures in Europe on Hydrogen & Fuel Cell technologies (M Euros annually)

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<td>Denmark</td>
<td>Danish Energy Agency</td>
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<td>Finland</td>
<td>Tekes &quot;Densy&quot;</td>
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<td>France</td>
<td>MRNT: PACo</td>
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<td>Germany</td>
<td>BMWT (research):</td>
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<td>Progr. on Investm. into the Future (demonstrations):</td>
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<td>Support by German States:</td>
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<td>Nord. Energy Research</td>
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<td>3.50</td>
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<td>Norway</td>
<td>Research Council: Renergi</td>
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<td>The Netherlands</td>
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**Total: 171.67**

Table 4.2-1  Funding overview
4.3 Major results of the last 5 years  
(hardware, patents, research results, etc.)

4.3.1 PEFC and DMFC Development

European companies, institutions and inventors file about 14 % (16 % in 1998/99, 17 % in 2000/01 and 12 % in 2002/03) of the worldwide PEFC related patents. In total there are 149 patents from European countries. 9 of them concern applications, 13 control systems, 9 the gas diffusion layer, 19 the electrodes, 5 the MEA, 15 membranes, 9 stacks, 17 the water management and 53 general patents and patents concerning systems, see Fig. 4.1.

From 345 world-wide patents on DMFC or DMFC Systems 111 (32%) were filed by European Companies. 6 of them concern Applications, the most (23) concern Control Systems, 5 of them concern the gas diffusion layer, 8 electrodes, 10 MEA, 13 membranes, 9 the internal fuel preparation, 1 sealing, 12 stacks, 1 the water management, 23 general and system patents, see Fig. 4.3-0.

![Figure 4.3-0 Patents of Low Temperature Fuel Cells and relevant items](image)

The following companies and institutions have significant activities published.
AIRBUS

The European aircraft manufacturer Airbus investigates PEFC systems for specific onboard power supply. Currently Airbus is involved as a coordinator in various projects dealing with different approaches of the implementation of both low and high temperature fuel cells onboard aircraft. The EU funded project CELINA covers a broad area of technologies it is an “Investigation of the technical capabilities and behaviour of an existing fuel cell system under aircraft operating conditions by means of a simulation model”


AVL LIST GMBH (AVL)

AVL is the world’s largest privately owned and independent company for the development of power train systems with internal combustion engines as well as instrumentation and test systems. AVL has about 1300 employees in Graz (over 500 graduated engineers) and a worldwide network of 45 representations and affiliates resulting in total 2100 employees worldwide. The AVL Advanced Simulation Technologies division develops and markets the simulation methods necessary for the power train development work including simulation of electric vehicles with fuel cell stacks as well as detailed flow simulation in single cells. The Instrumentation and Test Systems division is an established manufacturer and provider of instruments and systems for engine and vehicle testing. The activities include PEFC and SOFC implementation in automotive application.

http://www.avl.com/wo/webobsession.servlet.go/encoded/YXBwPWtiYXNlJnBhZ2U9Y29udGVudC1tYW5hZ2VtZW50L3ZpZXcmaWQ9NDAwMDM4ODgy.html#
http://www.avl.com/

BALLARD POWER SYSTEMS INC.,

The German subsidiary of the Canadian Ballard Power Systems Inc., strongly involved in PEFC development for automotive applications, has recently been bought by DaimlerChrysler AG and Ford Motor Company and resulted in the Joint Venture NuCellSys GmbH, settled in Nabern, GER. The acquisition of the fuel cell system business is a major step in the realignment of the Fuel Cell Alliance between Ballard, DaimlerChrysler and Ford towards the market introduction of fuel cell engines. The acquisition agreement signed on June 23, 2005, establishes the framework for the further collaboration of the Alliance partners and defines the details of the transaction. Ballard’s shareholders approved the acquisition on August 29th, 2005.

www.ballard.com

BUDERUS AG

The German Buderus AG has three business segments: heating products, castings, and specialty steel. Its Buderus Heiztechnik subsidiary is a European market leader for heating products and manufactures boilers, storage tanks, radiators, oil burners, solar energy panels and co-generation units. In March 2001 Buderus Heiztechnik announced that it plans to work with UTC Fuel Cells to develop and market fuel cell
systems for residential applications. Under the terms of the agreement, Buderus will sell in Europe the UTC PEFC system now being developed for homes and light commercial buildings. Initial European tests of prototype units were scheduled for 2003. A second prototype (beta unit) was developed in 2003 together with Toshiba International Fuel Cells. The German Buderus AG became a part of the German Bosch-Group, and co-operates currently with the US company UTC Fuel Cells. Recently BBT Thermotechnik GmbH joint RWE Fuel Cells and IdaTech for the development of a commercial 5-kW combined heat and power fuel cell system. The aim of this cooperation is to develop a fuel cell heating system for multi-unit housing and small businesses. Fig 4.3-1 presents the current unit.

![Buderus CHP system, 4.6 kWe rated output](www.heiztechnik.buderus.de)

**Fig. 4.3-1**   Buderus CHP system, 4.6 kWe rated output

[www.heiztechnik.buderus.de](http://www.heiztechnik.buderus.de)

**CATELLA GENERICS AB**

Catella Generics AB provides independent analysis and testing world-wide in the areas of battery & power sources systems technology. Catella Generics is mainly interested in developing methods for and to carry out tests on new power sources, promoting their development and in this way contributing to the introduction of new products in the marketplace. Fuel cells and their application to replace batteries are interesting activities for the company. Catella Generics operated until 1999 the secretariat of the IEC standardization committee TC69 and chaired the working group for batteries and also coordinator for EV battery standardization between IEC, SAE and JEVA (Japan).

CEA (French Atomic Energy Commission)

CEA (French Atomic Energy Commission) is a research state agency originally founded for nuclear energy research, and employs a staff of 16000 people. It is now running a major hydrogen and fuel cell program since 1996. One of the main topics is dealing with fuel cells, both PEFC and SOFC. More than 60 persons are now involved in these studies, of whom 20 are currently working in the Hydrogen and Fuel Cell laboratory (LHPAC previously Electrochemical Storage of Energy Laboratory). The main objective are to meet industrial requirements through materials research and development, electrochemical expertise, manufacturing of demonstration object, modeling and system studies and also recycling process studies. Since 1987, the CEA has developed a know-how in the PEFC (Proton Exchange Membrane Fuel Cell) field. At present, the Hydrogen and Fuel Cell laboratory is known for its studies in fields of modeling, comprehension and design of PEFC. The mission of this new group consists in the development and the co-ordination of the whole activities of research of CEA in the field of the Fuel Cell. Those activities are carried out in collaboration and for the benefit of the industrials. The topics studied are: materials, phenomena comprehension and modeling, technology and design, hydrogen storage.

http://www.cea.fr/gb/

CESI

Established in 1956, CESI, a private company belonging to the ENEL Group (Italy's largest electricity supplier), is a market leader in testing, certification of electromechanical equipment and electrical power system studies. CESI offers the services of its well renowned technicians to electrical utilities, electro-mechanical industry, electronics manufacturers and large-scale electricity users. The CESI structure is based upon 6 units (Power Generation Processes, Transmission and Distribution Networks, Industrial Applications, Renewable Energies and Final Uses of Energy, Environment, Tests and Components, Certification). CESI shareholders include the Italian Independent System Operator (GRTN), electrical utilities (ENEL, Edison, Sondel, Milan and Turin municipal utilities), leading European electromechanical groups (ABB, Alstom, Pirelli, Schneider, Ansaldo, Siemens, etc) and industrial users. Customers include: Electrical Utilities (production, transmission and distribution), Independent System Operators (ISO), Regulating Authorities, Electromechanical and Electronic Manufacturers, Industrial Users, Public Authorities, International Financial Institutions. CESI is focusing a significant part of its research activities on the promising technologies for distributed power generation with special emphasis on fuel cells. The ongoing fuel cell projects include the testing of a Nuvera 5 kW PEFC stack coupled with a hydrogen storage system based on metal hydrides.

http://www.cesi.it/default_e.asp

CIEMAT - Centro de Investigaciones Energéticas, Medio Ambientales y Tecnológicas

CIEMAT is a Public Organism for Research and Technological Development supported by the Spanish Ministry of Science and Technology, which has as main objectives to find solutions to improve the use of resources and energy generation sys-
tems and to develop alternative energy sources. At CIEMAT, the Fuel Cell Group is aimed at the design and development of fuel cell prototypes as energy generation systems able to compete with the conventional methods, considering aspects such as electric efficiency, environmental impact, flexibility and modularity. Since 1995 the group has been involved in two major research areas: low temperature fuel cells (PEFC) for application in transport and stationary power sources, and high temperature fuel cells (MCFC) for stationary electrical power generation applications. The available facilities include two automated stations to test PEFC single-cell and stacks (<1 kW) and three small-scale stations (8 cm²) that allow for the study of components used in MCFCs. Moreover, several fuel cell components (cathodes, anodes, bipolar plates...) can be manufactured and electrochemically characterized by impedance spectroscopy and cyclic voltametry techniques.

http://www.ciemat.es/eng/index.html
http://www.ciemat.es/eng/actividad/programas/p_cg_pilascombust.html

CNR-ITAE (Institute for Advanced Energy Technologies of the National Council of Research in Italy already Institute for Transformation and Storage of Energy)

The CNR-ITAE (Institute for Advanced Energy Technologies of the National Council of Research in Italy already Institute for Transformation and Storage of Energy) is located in Messina. It has a long a proven experience in all categories of fuel cells having contributed to the penetration of this technology into Europe since the early 80’s. The fields of PEFC, DMFC, MCFC and SOFC have been actively investigated with the participation to EC and National programs. Recently, the Georgia Technology Policy & Assessment Centre has classified the CNR-ITAE in the first six world most prolific affiliations operating in the field of fuel cells in the last twenty years. The activity has been focused on the development of components (anode and cathode catalysts, electrodes, membranes, electrolytes) technologies for the preparation of cells and stacks, studies on utilization in the different applications (automotive, stationary, portable), optimization of integration with different technologies.


CRES Centre for Renewable Energy Sources

The Centre for Renewable Energy Sources (CRES) is the Hellenic national centre for Renewable Energy Sources (RES), Rational Use of Energy (RUE) and Energy Saving (ES). The Division of Applied Research and Technology Development (DARTD) of CRES is composed by the following departments: Wind energy, Biomass, Geothermal energy, Passive solar, Active solar, Photovoltaics and Hybrid Systems, Rational Use and Energy Saving. DARTD employs 40 scientists and engineers, focusing its activities on the design, support and execution of European and national RTD&D programs for the development of economically viable and environmentally friendly RES/RUE/ES technologies. Over the years DARTD has been successfully involved on more than 100 European projects in the areas of its expertise (JOULE, THERMIE, AIR, FAIR etc.). The role of CRES in the thematic network will be to provide specifications and information on the operating conditions of energy producing devices (Fuel Cell systems) and components in various application areas and contribute to the definition of testing procedures. CRES is the focal point for Greece in order to contact and disseminate information to various groups involved in the fuel cell field.
“CRES developed a hydrogen technologies based UPS comprising: a 2,5 kW alkaline electrolyser capable of producing up to 0,5 Nm3/h of hydrogen at 17 bar, with a purity of 99,98%, innovative metal hydride storage tanks with a total capacity of 40 Nm3, oxygen storage tank with a capacity of 10 Nm3, a 5 kW PEFC, and control and data recording system. The unit was developed in the context of the EC funded HELPS project in co-operation with other partners including Technicatome, France (fuel cell and control system).”
http://www.cres.gr/kape/present/labs/hydro_2_uk.htm
http://www.cres.gr/kape/default_uk.htm

CRF Centro Ricerche FIAT

The Italian Fiat Group is a manufacturer of automobiles, buses, commercial vehicles, machinery etc. Centro Ricerche Fiat (CRF) is an Engineering Centre providing R&D services to each of the different companies within the FIAT Group. In 2002, the research centre and Fiat Auto division developed the Seicento Elettra Fuel Cell Phase II, representing an evolution of the model introduced in 2001, which was developed with Danish fuel cell company IRD. In 2003, Fiat introduced two new prototype small cars using fuel cells which were jointly developed with Nuvera. The Fiat 600 and the Fiat Panda are the third generation of prototype fuel cell vehicles Fiat has produced. Together with Fiat’s subsidiary Iveco, Ansaldo and De Nora (Nuvera), the company has also presented a 30kW PEFC bus in 1998. One of the latest achievements is the development of a “Seicento”, powered by Nuvera’s Andromeda FC module, which also took part in Monte Carlo’s
http://www.crf.it/uk/2_do.htm
www.fiat.com
www.nuvera.com

CSIC Council of Scientific Research

Instituto de Catálisis y Petroleoquímica, Consejo Superior de Investigaciones Científicas

The Spanish Council of Scientific Research (CSIC) is the biggest public institutions for scientific research of Spain. About six thousand people are permanent employees in some of the one hundred institutes in the CSIC. In particular, the Institute of Catalysis and Petroleum chemistry (ICP), with more than twenty fives years experience in research activities, has a great amount of expertise in subjects such as chemistry at surfaces, development of catalysts, new materials application, combustion and green processes, etc. The ICP-CSIC has ten years experience in fuel cell prototypes as well in control and monitoring systems. These activities have been carried out with the financial support from many competitive programs of R&D. The main objective of the Fuel Cells Group is the design and development of components and prototype fuel cells. The objective is pursued following two complementary research activities: experimental and modeling and numerical simulation. The group is involved in two research areas: low temperature fuel cells (proton-exchange membrane fuel cell, PEFC), for application in transport and stationary low power sources, and high temperature ones (molten carbonate fuel cell, MCFC, and solid oxide fuel cell, SOFC) for stationary electrical power generation applications. The available installations include several automated stations to test PEFC single-cell and stack, and for the study of
components used in MCFC and SOFC cells. Fuel cell components can be manufactured and characterized by electrochemical and physicochemical techniques.

http://www.csic.es/wi/index.jsp
http://www.icp.csic.es/aplicada.en.html

DaimlerChrysler

The German carmaker, as OEM building a variety of PEFC driven vehicles like urban busses, small delivery vans as well as small passenger cars. Latest development is a B-Class FC model with a range of about 300 km (see Fig. 4.3-2). Beside these important steps and strong engagement, a time range of 20-30 years has been mentioned until fuel cell cars, supplied by an appropriate infrastructure, will be a regular sight on our roads. DaimlerChrysler and Ford founded their joint company NuCellSys to develop Fuel Cell power trains based on Ballard technology.

Fig. 4.3-2 DaimlerChrysler’s FC-B-Class, unveiled early 2005

Through its subsidiary Evobus DaimlerChrysler is the supplier of the vehicles of the CUTE project. The project will be combined with the European project HyFleet and will last at least one more year.

www.evobus.de
www.daimlerchrysler.com
http://www.daimlerchrysler.com/dccom/0,,0-5-7179-1-460443-1-0-0-0-0-0-243-7165-0-0-0-0-0-0-0,00.html

DLR - German Aerospace Research Centre

The German Aerospace Research Centre (DLR) is the largest engineering research organization in Germany and has about 4500 employees. DLR undertakes applied research and development in the divisions space flight, aeronautics, energy and transport. Research on fuel cell technologies is done in the divisions energy and transport. The DLR Institute of Technical Thermodynamics (DLR-TT) in Stuttgart is
active in the field of renewable energy research and technology development for efficient and low emission energy conversion and utilization. A staff of about 90 is working in the divisions Electrochemical Energy, Solarthermal Energy and System Analysis. In Electrochemical Energy with a staff of about 45 the institute focuses on polymer membrane fuel cells for hydrogen and methanol (PEFC, DMFC), on solid oxide fuel cells with planar and tubular design (SOFC) and on fuel cell systems for stationary, portable and mobile applications. Major achievements in polymer membrane technology:

- Low cost, dry rolling technique for membrane-electrode production
- Novel measurement of current density with high local resolution
- Low cost, robust portable PEFC fuel cell system to replace batteries

DLR has a definite competence in current density measurement with high local resolution. A patented method has been licensed which is a valuable tool for stack testing e.g. in a production line. DLR is permanently improving and extending these high resolution techniques aimed at establishing a reliable basis for comparing fuel cell components and systems.

The Institute of Vehicle Concepts of DLR works on fuel cell systems for mobile and automotive applications, mainly based on PEFCs. The Institute of Vehicle Concepts is working in projects to develop systems and components of the sub systems in collaboration with car manufacturers and automotive suppliers. Currently the Institute of Vehicle Concepts is coordinating a three-year-project of eight German car suppliers to demonstrate innovative technologies for the fuel supply sub system, the air supply sub system, the heat and water management and the control sub system. The Institute of Vehicle Concepts is responsible for the overall system design of the fuel cell system and its integration into a light weight car. Therefore the Institute operates test benches for systems and components of sub systems. System development and integration is supported by modeling activities from vehicle/system to component level.

www.dlr.de
http://www.dlr.de/fk
http://www.dlr.de/tt

DuPont

The developer of the NAFION membrane, DuPont (USA), is working in the office in Switzerland on MEAs and Conductive Plates and might be a partner for interregional projects. Example for integration of Nafion membrane see Fig. 4.3-3.
ECHEM Austrian Research Centres GmbH – ARC

With more than 700 employees at different sites the ARC constitutes Austria’s largest contract research centre. Founded in 1956 it defines its role as potent service provider in the field of applied-oriented research and development – with a broad interdisciplinary catalogue of skills and specialized know-how. ECHEM (Kompetenzzentrum fuer Angewandte Elektrochemie GmbH) a new R&D company supported by the Austrian government and the state of Lower Austria. More than 30 internationally well known companies and six Austrian research institutions collaborate in this Centre of Competence for Applied Electrochemistry in Wiener Neustadt. ECHEM combines basic- and applied research with industrial know how and experience by focusing on the areas of surface technology, environmental technology and electrochemical energy storage and conversion systems. The latter area is conducting R&D on PEFC systems and new materials for PEFC and DMFC. ECHEM provides a variety of highly sophisticated spectroscopic and electrochemical equipment for materials and system investigations and testing. ECHEM is the Austrian contracting party of the IEA Implementing Agreement for Hybrid and Electric Vehicle Technologies and Programs.
http://www.echem.at/

ECN Energy Centrum Netherlands

ECN is a private research organization for the development of products and processes in the frame of energy conversion and innovation. The ECN mission is to contribute to a clean and reliable energy supply for a viable world. Major points of activity are technological research on energy consumption, energy conversion and related environmental and materials problems. ECN is the main national research institute in the field of fuel cells. ECN has eight years experience in PEFC-development, covering all aspects of cell, stack and system design and optimization and develops materials, components, stacks and BoP-components for both automotive and stationary applications. Fuel processing for fuel cells as well as for other applications is also one of the core activities of ECN. A separate group deals with the integration of components into practical fuel cell system and the demonstration of those systems under realistic operating conditions. In Fig. 4.3-4, the current 5-kW-stack is shown. More-
over, ECN deals with the development of supercapacitors and fuel processing as well.

![ECN's 5-kW-Stack](http://www.ecn.nl/en/h2sf/)  
[www.ecn.nl](http://www.ecn.nl)

**efc European Fuel Cell**

EFC, a German subsidiary of the British Baxi Group develops and produces residential PEFC-CHP heat appliances. The company’s natural gas powered, 1.5kW beta unit is to be field tested with plans for 100 installations. The company has signed a co-operation agreement with IRD Fuel Cell for development and production of fuel cells and system components. In July 2003, EFC has opened a new 23 million Euro research facility for the development of fuel cell heating appliances in Hamburg, Germany. The company has built up a great experience in BoP components and system testing and optimization. The company’s system is optimized for a one-family house and combines a 1.5 kW electrical output with an 2.9 kW thermal output. Currently, the CHP-unit (see Fig. 4.3-5) is reported to be tested under continuous operating conditions.
ENEA

ENEA is a scientific research and technology development organization with vast, internationally recognized experience in conducting advanced research programs and implementing complex projects in the fields of research and innovation for the sustainable development and environment safeguard. Among its main scopes, there is the research, development and promotion of environmentally safe and energy saving technologies. In this field many programs on fuel cells are underway, also in cooperation with industry, academic institutions and research organizations at national and international level. Since mid-80's ENEA is conducting R&D Programs on various FC technologies (mainly, PEFC and MCFC) for mobile and stationary applications. In such activities, basic research on materials, components, auxiliaries and related technologies (batteries, drivelines, reformers, balance of plant) is continuously carried out. One qualifying aspect has been the creation of a variety of test facilities for components and complete systems and test procedures. ENEA developed a low-pressure PEFC stack and manufactured it by desktop milling and MEGA technologies with following specialties:

- cathodic open-channeling useful for insight into water management phenomena
- positive preliminary tests
- computer equipment adequate for fuel cell applications
- further design and improvement for higher current density and temperature

http://www.enea.it/com/ingl/default.htm
Forschungszentrum Juelich in Germany (FZJ)

A broad research program for the development and feasibility of Direct Methanol and Solid Oxide Fuel cells (DMFC and SOFC, respectively) is an essential part of energy technology and energy research, one of the focal research areas in the FZJ mission. FZJ was one of the first research organizations to start with DMFC development several years ago and in the meantime the department of Energy Process Engineering has become known world-wide as developer of DMFC fuel cell stack technology not only for small applications but also for high power outputs. The institute has realized 50 and 500 W stacks on DMFC technology that were presented in public at the occasion of the Hanover Fairs 2000 and 2001. Several test benches exist for stack and single cell tests, where a broad range of expertise has been gathered during the last years.

Works conducted at FZJ include:

- development and production of materials and components
- study of electrical, electrochemical, catalytic, mechanical, micro structural and chemical properties of materials and components
- assembling and stack testing
- development of peripheral components where needed
- system modeling ranging from elementary reactions to BOP-design

The actual research for DMFC and PEFC is described at their website as:

"In order to solve these key problems, work is devoted to the development of new membrane electrode assemblies. At the Institute, both the single components and different manufacturing processes are being examined. This work will be supported by simulation calculations. Furthermore, improved power densities are to be achieved by optimizing the process technology. Within the framework of stack development different cell and stack structures are examined and adequate optimum operating conditions determined. These activities are also accompanied by simulation calculations. For the planning and evaluation of energy conversion systems with fuel cells it is necessary to develop and analyse process concepts. This is the task of process analysis."

www.fz-juelich.de

Fraunhofer ISE

The German research institute Fraunhofer ISE (Fraunhofer Institute for Solar Energy Systems) is a member of the Fraunhofer Society, a non-profit organisation, which occupies a mediating position between the basic research of universities and industrial practice. Fraunhofer ISE develops systems, components, materials and processes in the areas of thermal use of solar energy, photovoltaics, solar architecture, fuel cells, electrical power supplies, chemical energy conversion and rational use of energy. The institute comprises 4 scientific departments, namely „Thermal and Optical Systems“, „Solar Cells – Materials and Technologies“, „Electrical Energy Systems“, and „Energy Technology“. The last department is involved in this project with its group “Micro Energy Technology“. Fraunhofer ISE developed in 1999 a flat fuel cell for laptop applications called banded structure membrane fuel cell. In 2000 Fraunhofer ISE presented another fuel cell for laptop application with an integrated
DC-DC-converter and a micro fuel cell with an active area of 1 cm². Fraunhofer ISE initiated the Fraunhofer-Initiative Miniature Fuel Cells, which developed a miniature fuel cell system for a commercial camcorder. About 280 people are presently employed at the Fraunhofer Institute for Solar Energy Systems ISE. ISE and the German company Masterflex are active in the fields of Hydrogen generation as well as in the development of fuel cells. Fig. 4.3-6 presents a 3.3-kW test bench, while Fig. 4.3-7 shows a reforming test bench, a micro electrolyzer as well as a measurement of the temperature distribution in a cell as further fields of activity.

![Test bench of a 3.3-kW-el-Stack](image)

Fig. 4.3-6 Test bench of a 3.3-kW-el-Stack

![Kerosene reformer for a solid oxide fuel cell (SOFC) with a power of 25 kW and integrated de-sulphurisation.](image)
![Hydrogen production in a miniature electrolyzer.](image)
![Temperature distribution in a miniature PEM fuel cell during start-up.](image)

Fig. 4.3-7 Examples for current activities within Fraunhofer-ISE

www.ise.fhg.de

**Germanischer Lloyd (GL)**

Germanischer Lloyd (GL), established in 1867, is an independent international non-profit organization for ship classification, safety and quality control. GL establishes standards, guidelines and rules for the design, construction and survey of ships flying any flag and other marine structures such as mobile offshore units. The Research, Development and Engineering Division currently has a permanent staff of about 70 employees in five departments concerned with 1) hydrodynamics and reliability, 2) strength and vibration analysis, 3) application of information technology in ship de-
sign, 4) mechanical engineering, and 5) experimental investigations. Since more than 10 years GL is involved in the approval of FC-Systems for use under special conditions in submarines. These approvals, which were performed for different navies and yards were not restricted to the FC-Module only. An important task was the examination of the fuel storage, supply and piping system with respect to safety aspects and availability. Ex. in 2000 GL examined and certified the first civil marine FC-application on a pleasure boat and certified a reformer plant for a marine FC application. Beginning with the first part of the EC funded Euro Quebec Hydro Hydrogen Project (EQHHPP) at the end of the eighties GL was a major partner in a number of national and European R&D projects related to storage and transport of fuel cell supply media and has got a lot of experience in this field (cryogenic gases, liquefied gas storage and transport etc.).

http://www.gl-group.com/start_ns.htm
http://www.gl-group.com/maritime/research/3644.htm

GKSS

The GKSS Forschungszentrum Geesthacht GmbH (GKSS) is one of 16 national research facilities belonging to the Hermann von Helmholtz Association (HGF). GKSS is situated at Geesthacht near Hamburg and has a branch in Teltow near Berlin with a total staff of approximately 750 employees, including about 480 scientists, engineers and technicians. The three main GKSS research areas cover materials science, environmental research, and separation processes using membrane technologies. The Institute for Materials Research at GKSS has about 120 persons and concentrates on light materials for traffic and energy technology. GKSS has more than 5 years research experience in hydrogen storage in form of nanocrystalline light metal hydrides for mobile applications and was involved in international projects and cooperations in this field. The membrane group at GKSS has about 100 persons covering from basic research, membrane development to module design and engineering aspects of membrane separation processes and applications. The largest group (12 researchers) in the membrane development department is working in the field of polyelectrolyte development for the direct methanol fuel cell. In addition, an independent power generation and supply plant was built for demonstration of hydrogen technology, including solar heat and photovoltaic collectors, electrolysis and a metal hydride tank for hydrogen storage, as well as a 720 W PEFC for energy conversion. GKSS is developing metal hydrides for hydrogen storage purposes and membranes for PEM and DMFC fuel cells.

http://www.gkss.de/index_e_js.html

Helion

The French Helion is developing PEFC systems for propulsion of submarines both as “pure hydrogen-oxygen” and “reformed hydrogen-air” systems. The company describes its first product on its website: “HELPS (Hydrogen based Emergency Local Power Source) is the first 5 kWe French fuel cell system based on PEM technology. It is designed to meet the requirements of emergency power systems, offering high reliability and availability levels and low maintenance. The HELPS system relies on innovative technologies:

> a PEM-type (Proton Exchange Membrane) fuel cell,
> a water alkaline electrolyser generating pressurized pure hydrogen and oxygen,
> a hydrogen storage system in metal hydride form (significant reduction of storage volumes),
> a pressurized oxygen storage system,
> a conditioning device for the electric energy.


The second available product, an integrated fuel cell emergency power system, is described as:

“SYSPAC is an integrated fuel cell emergency power system, with power outputs ranging from 20 to 50 kWe. It is designed to be connected to a standard industrial Uninterruptible Power Supply (UPS). Modular, the SYSPAC fuel cell system is equipped with fuel cell stacks relying on PEM (Proton Exchange Membrane) technology. SYSPAC provides an unlimited autonomy (subject to gas supply), high reliability levels and requires reduced maintenance (especially thanks to using super capacitors). At last, SYSPAC is an environment-friendly system. It benefits from the fuel cell advantages:

> pollution-free: it does not release greenhouse gases and water is the only effluent.”


www.helion-fuelcells.com

Howaldtswerke-Deutsche Werft AG

The German shipyard Howaldtswerke-Deutsche Werft AG delivered the first commercial PEFC product by the hydrogen-oxygen supplied PEFC propulsion system of its new submarine class 212/214. The stacks have been specially developed and built for this specific application by the Siemens. The main benefit of this design is the most silent and most difficult to detect power generation system known. The hydrogen is stored within metallic hydride tanks and the oxygen in pressure vessels. The first boat of four was delivered to the German navy in 2004. Fig. 4.3-8 gives an overview.

Fig. 4.3-8 Overview of the 214 class submarine with PEFC propulsion system developed by Howaldtswerke-Deutsche Werft AG and Siemens
Currently a demonstration system has been developed comprising a 160 kw el PEM system installed in a standard container to be placed onboard a ship to study the influence of a maritime environment on the fuel cell’s operation. (Fig. 4.3-9)

Fig. 4.3-9 Schematic of the demonstration unit

http://www.hdw.de/index_en.php?
http://www.hdw.de/hfcs/englisch/index.htm

INEGI

INEGI was created in 1986, as a not-for-profit r&d organisation. Its founders are: Universidade do Porto, through the “Departamento de Engenharia Mecânica e Gestão Industrial – DEMEGI”, (department of mechanical engineering and industrial management), Associação de Antigos Alunos do DEMec - ADEMEC, (society of the alumni of the department of mechanical engineering), Associação Portuguesa de Gestão e Engenharia Industrial - APGEI, (Portuguese society of industrial management and engineering), Associação dos Industriais Metalúrgicos e Metalomecânicos do Norte - AIMIT, (association of metallurgical and mechanical industries of northern Portugal). In 1990, with the support of PEDIP I - the first 'specific programme for the development of the Portuguese industry' - a certain number of new technological units were created. CETERM – Energy and Environment Centre is an unit directly involved in R&D projects and training programmes in the field of Thermal Engineering, Aerialics, Fluid Mechanics, Heat and Mass Transfer, Combustion, Renewable Energy Sources, Rational Use of Energy, Air Pollution Measurements, Traditional Cogeneration, cogeneration with cold production and with Fuel Cell Systems. In addition to its own personnel and equipment, CETERM draws on human and material resources from the Heat Transfer and Fluid Mechanics Section of the Department of Mechanical and Industrial Management of the Faculty of Engineering of the University of Porto.
http://www.inegi.up.pt/

INTA Institute for Aerospatial Technologies

The Spanish Institute for Aerospatial Technologies (INTA) is a public organisation for the research and technological development in the fields of aeronautics and space
science and technology. The Department of Energy of INTA started its activities in energy generation and storage following the needs of energy management in space, for both manned and unmanned missions. Three main groups were formed: photovoltaics, batteries and fuel cells and hydrogen energy. Fuel cells and hydrogen energy activities started in INTA in 1991, requested by the European Space Agency, in order to get experience in regenerative fuel cell systems, for participating in the definition and design of the European space shuttle (HERMES project). Following, it has gained experience in electricity generation by means of low temperature fuel cells (AFC), hydrogen production from solar electricity by means of electrolysis, and hydrogen storage (hydrides and compressed). The decision to postpone the HERMES project, forced a reorientation of the activities to other applications like energy management in remote renewable equipment, distributed electricity generation with low and medium temperature fuel cells, or electricity generation on board vehicles with PEFC. The Department of Energy at INTA has a wide range of experience in the characterisation of fuel cell prototypes in a wide power range (up to 10 kW), and in installation and monitoring of demonstrations of renewable energy systems. These activities have been carried out with financial support of INTA itself, the Regional Government of Andalucia, the Spanish National Plan for R&D, and the European Framework Programmes.

http://www.inta.es/index.asp

Intelligent Energy Limited

Intelligent Energy Limited is a relatively new company (incorporated in 2000) that was formed by bringing together two teams with technical and commercial skills. It currently has 30 employees. The technology team is built around a fuel cell R&D company, Advanced Power Sources Limited (incorporated in 1995). The team, authors of over 100 academic publications and more than 30 international patents, includes engineers and electrochemists with broad based experience in fuel cells and related technologies.

Fig. 4.3-10 Comparison of the technology of Intelligent Energy with competitive designs
The company has usual PEFC designs simplified as shown in Fig 4.3-10. The company claims a higher cost efficiency and reliability and a better cold start performance.

The company describes its PEFC technology on its website:
“Broad portfolio Our PEM stack technologies span the power range - from a few tens of watts through a few kilowatts to more than 100kW. In application terms - from laptop and personal power to combined heat and power through to distributed generation and even large automotive.
We've designed and developed a number of system platforms using our world leading stack technologies as a foundation, including:

- generator unit
- motive engine
- CHP unit
- personal power pack
- motor cycle power train.”

http://www.intelligent-energy.com/

**Intech Thueringen GmbH**

The German Intech Thueringen GmbH, German branch of Intech EDM, part of the Agie Charmille Group, deals with electrode development.
www.intechedm.com

**IRD Fuel Cells A/S**

The Danish company IRD Fuel Cells A/S develops PEFC stacks and systems for stationary and automotive applications and serves as a development partner for industry and scientific institutes. Fig 4.3-11 and Fig 4.3-12 present some examples of IRD’s products. Moreover, IRD is the provider of the FC unit in the Utsira project.

Fig. 4.3-11 IRD’s PEMFC P01 stack, rated output 1.25 kW
Fig. 4.3-12  IRD’s 2.5 kW Power Generator, rated at 2.5 kW el output (left) and stationary 50 kW el system, comprising 20 stacks @ 2.5 kW each (right)

http://www.ird.dk/index.php?id=84,0,0,1,0,0
www.ird.dk

**Johnson Matthey PLC**

The British company **Johnson Matthey PLC** (GB) is a player in the field of catalysts and precious metals, providing PEM MEAs as well as their brand HiSPEC® catalysts. These are dedicated to allow an ultra high CO tolerance, utilising a PtMo-PtRu bilayer concept. The company presents its products on the website:

“Johnson Matthey Fuel Cells is addressing key catalytic components in fuel cell stacks and systems. We achieve this through our product offerings including: membrane electrode assemblies (MEAs), gas diffusion substrates, anode and cathode electrocatalysts, fuel processor catalysts and coated components (reforming, water gas shift (WGS), CO removal (PrOx) and anode off-gas oxidation catalyst).

- PEM Fuel Cell MEA Datasheet
- HiSPEC® Catalyst Datasheet
- HiSPEC® Catalyst Products Listing
- Fuel Processor Catalyst Datasheet”

www.jmfuelcells.com

**MAN Nutzfahrzeuge AG**

MAN Nutzfahrzeuge AG, GER, started the operation of two hydrogen busses in 2005. A main target is to compare results between one ICE powered and one hybrid fuel cell bus. The fuel cell model is equipped with a 70 kW Ballard stack only, while
the hybrid technology provides the energy necessary for acceleration. Fig. 4.3-13 presents the model 2005 fuel cell bus.

![Fig. 4.3-13 MAN’s fuel cell bus](image)

The company presents its fuel cell program at its website:

“The innovative PEM fuel-cell technology is growing in importance in the attempts to safeguard tomorrow’s mobility by using hydrogen as a fuel. Vehicles with fuel-cell drive permit emission-free transport of goods and persons, which makes them particularly suitable for use in urban areas. MAN presented the first bus with this technology in the year 2000. It was then tested in scheduled services. May 2004 saw presentation of the second fuel-cell bus. Whereas the first bus drew all its power from the fuel cell, the second bus has a hybrid driveline. The bus is equipped with a fuel-cell system and an electronic energy storage unit. The drive output necessary for operation is covered jointly by the fuel-cell system and the energy storage unit. With this electrical storage unit it is possible to make use of the brake energy, which thus leads to a reduction in fuel consumption. This hybrid solution in the city bus makes synergy between car and commercial-vehicle drive systems possible. As operation under real-life conditions supplies important information for further development, this bus too will be fully integrated in an operator's fleet and driven and fuelled by the operator's personnel.

http://www.brennstoffzellenbus.de/bus2004/bsz04-2gb.htm
www.man-mn.com

Masterflex

“The core competence is focussed on developing and producing the highly versatile polyurethane (abbreviated to PUR). During the last years, this material has been very successful because of his definite advantages against traditional materials such as PVC, rubber and even steel. One of Masterflex's corporate business goals is to research the manifold applications of polyurethane and convert them into innovative products. More than fifteen years of success are based on the experienced Masterflex research & development team as well as on mastering the entire production chain from the materials procurement via the processes technology up to the own distribution. With this expertise Masterflex AG focuses on three business units with attractive future potential: High Tech Hose Systems, Medical Technology and Fuel Cell Technology.” Reports Masterflex on its Company profile on its website.
Based on this experience Masterflex has a cooperation with Fraunhofer ISE to build portable PEFC systems. The size of the units has a range of 50 W (portable application) to 250 W (bicycle power supply).

Michelin

The French tire manufacturer Michelin developed together with the Swiss Paul Scherrer Institut (PSI) an experimental PEFC hybrid car (see also at “Paul Scherrer Institut”).

![Hybrid car with PEFC](https://www.hfpeurope.org/hfp/hfp-annual-event_17mar2005)

It is supplied with compressed hydrogen and oxygen. A super-capacitor is used as the electrical storage device. A 30kW PEFC is combined with a supplementary 32 – 45 kW super capacitors. The four seated 850 kg car has a top speed of 130 km/h and uses compressed hydrogen and pure oxygen as fuel and has a range of 400 km (at a constant speed of 80 km/h). Fig. 4.3-14 shows the car.

MTU Friedrichshafen GmbH

The German MTU Friedrichshafen GmbH was engaged in PEFC systems for onboard generation but it closed the PEFC business in late 2004.
**NedStack**

The Dutch NedStack develops, builds and sells PEFC stacks with a rating up to 5 kW. In 2004, the development of a 50 MW plant (200 MW peak) has been launched in collaboration with Akzo Nobel Chemical Plant with very ambitious targets in terms of lifetime.

![NedStack’s P01-30-stack](www.nedstack.com)

**NuCellSys**

NuCellSys will continue developing and manufacturing fuel cell systems for automotive applications that control and supply the fuel cell stack with conditioned gases under dynamic load changes and automotive specific requirements. Ballard will focus on the development of fuel cell stacks. DaimlerChrysler and Ford will assemble the complete fuel cell drive train including the inverter, electric engine and hydrogen storage and integrate it in their vehicles. The new operating model will allow for each Alliance Partner to concentrate on their respective core competencies. 235 predominantly highly specialized employees at the Nabern facility will be responsible for system development and design, component and software development, and system assembly and qualification.

www.nucellsys.com
Nuvera Fuel Cells (Italy/USA) was formed in April 2000 from a merger between De Nora Fuel Cells and Epyx. De Nora Fuel Cells was at the forefront of fuel cell development in Italy for many years, working on bus and car concepts with international partners such as AirLiquide, CEA, Renault etc. Nuvera Fuel Cells is now part of the De Nora Group. Working on PEFC, the company manufactures stacks and fuel processors for residential and automotive applications (1kW-75kW+). Nuvera is designing and manufacturing 5 kW units that can provide primary and/or auxiliary backup power to residential homes. These units are being developed and tested for manufacturers of home power generators and backup power equipment. Nuvera has distribution and joint-venture agreements with Best Water Technology, Mitsui, RWE and Verizon Communications. Additionally, the company is developing a 4 kW natural gas system (branded the Avanti). Nuvera also revealed that it is planning to integrate a PEFC with a small turbine, producing an innovative cogeneration product, branded the DuAlto. Field tests of prototypes are expected from 2005. Nuvera is also working on PEFC to power vehicles. Together with Fiat, the company has presented two PEFC cars in 2003. Other activities include the development of a 7 kW PEFC stack with Fiamm for material handling vehicles (forklift trucks, etc.); the participation in the Milan-Bicocca Project with Ansaldo, BMW, ENEA, SOL and others; and an agreement with Total to optimise hydrocarbon fuels for PEFC. Latest news is the announcement of a next-generation automotive fuel cell system Andromeda II. Major achievements are as follows.

- 1.6 kWe/liter power density at high pressure, 1.3 kWe/liter at low pressure
- Low pressure (< 1.6 Bar) operation
- No external humidification for fuel or air
- Repeatable freeze start from -30°C reaching 50% power in 30 seconds
- Greater than 1,500 hours steady-state operation with a 10 microvolts/hour/cell decay rate
- 100,000 cycles during operation with no measurable decay
- Non-coated stainless steel bipolar plate construction for low cost

Products for stationary CHP production as well as a 5-kW-heavy duty unit round up the offer.
www.nuvera.com

Opel

The German carmaker Opel provides PEFC based FC car development for the whole US owner company General Motor Corporation. Currently, the “HydroGen3”-Model (Fig. 4.3-16) is the most recent fuel cell model build by OPEL, which has been the winner of the first “Rally Monte Carlo Fuel Cell and Hybrids”. It comprises a 200-cell-stack with a rated output of 94 kW at a power density of 1,6 kW/l and 0,94 kW/kg. It powers a 60-kW-e-motor, resulting in an acceleration from 0 – 100 km/h in 16 s and a traveling distance of 400 km. The Opel fuel cell development is a part of the General Motors fuel cell and innovative propulsion strategy.
http://www.gm.com/company/gmability/adv_tech/400_fcv/fc_milestones.html
Paul Scherrer Institute (PSI)

The Swiss Paul Scherrer Institute (PSI) is involved e. g. in the development of mobile FC applications like the hybrid vehicle HY.POWER. In collaboration with montena SA (Supercapacitors), ETH Zurich (Fuel Cells), VW (Car, el. drive, car control), FEV Motorentechnik (fuel cell charging and humidification) this study has first been presented in 2002 and is under ongoing improvement (Fig. 4.3-17). Today's vehicle is the study “HY-LIGHT”. Together with Michelin, PSI developed a hybrid fuel cell car with four seats and a weight of just 850 kg (Fig. 4.3-18). Other fields of activity concern supercapacitors and virtually all aspects in PEM development.
ulate operation well above 100°C with no need of extra humidification and high CO tolerance, targeting automotive, stationary and portable systems. Fig. 4.3-19 shows the core of PEMEAS’ development. Most recently PEMEAS announced to combine their and De Nora’s fuel cell activities. De Nora will bring their fuel cell business E-TEK (situated in Somerset, New Jersey, US) into PEMEAS and will account a part of the enlarged PEMEAS.

**PEMEAS GmbH**

The German PEMEAS GmbH, a subsidiary of Celanese, currently develops high temperature PEFC MEAs, capable of operating temperatures well above 100°C with no need of extra humidification and high CO tolerance, targeting automotive, stationary and portable systems. Fig. 4.3-19 shows the core of PEMEAS’ development. Most recently PEMEAS announced to combine their and De Nora’s fuel cell activities. De Nora will bring their fuel cell business E-TEK (situated in Somerset, New Jersey, US) into PEMEAS and will account a part of the enlarged PEMEAS.

![PEMEAS High Temperature MEA](image)
Proton Motor Fuel Cell GmbH

The German Proton Motor Fuel Cell GmbH and the US MH Scientists develops up to 150 kW PEFC systems as well as hybrid systems. Current applications are forklifters (Fig. 4.3-20) and small busses in collaborations with Magnet Motor, a sister company of Proton Motor.

![Proton Motor's concept of replacing a forklifter’s battery by an integrated 18 kW fuel cell module](image)

Fig. 4.3-20 Proton Motor’s concept of replacing a forklifter’s battery by an integrated 18 kW fuel cell module

The development partner of Proton Motors is the German Company Still a subsidiary of the Linde Group.

www.proton-motor.de

Smart Fuel Cells

The German Smart Fuel Cells is delivering DMFC systems for portable applications. The module C20 provides continuous 20 W (36 W peak) out of a 2-kg-system (see Fig. 4.3-21), while the A50 module provides 50 W at a system weight of 8 kg (see Fig. 4.3-22)
Still

The German company Still a producer of forklifts is a subsidiary of the Linde Group. Linde is one of the leading hydrogen suppliers and has a great experience in hydrogen technology. Still is developing a hybrid fuel cell powered forklift and co-operates with Proton Motor.

http://www.still.de/414.0.43.html
TNO-Automotive

TNO is a fully independent R&D organization, established by law in 1932. It has a staff of approximately 5,000, employed in a number of institutes and laboratories throughout the Netherlands. Its research covers a variety of fields such as product- and process innovation, environment and energy, human factors, transport, building and construction, health, nutrition, defense, and information technology. TNO Automotive concentrates on vehicle dynamics, power trains, crash safety, advanced transport systems, and homologations. The Power Trains department of the institute performs a wide range of fundamental and applied research, development work and contract engineering on internal combustion engines and advanced power trains for road vehicles. Products and services include feasibility studies, engine optimization, engine and vehicle testing, environmental studies and development of engine management systems, fuel supply systems, exhaust after treatment equipment and hybrid-electric power trains. In cooperation with TNO Environment, Energy and Process Innovation battery development and battery and fuel cell testing is carried out. Through research and consulting activities TNO Automotive is strongly involved in the development of new test methods and procedures for conventional vehicles and vehicles with advanced power trains.
http://www.automotive.tno.nl/

Umicore

The German Umicore is active in the fields catalysts and precious metals, providing materials for the fuel cell industry.
www.umicore.de

Vaillant

The German manufacturer of heating devices Vaillant uses the PEFC technology provided by the US manufacturer Plug Power for its product development. Fig. 4.3-23 shows the current 4.5-kW-el system for residential use. This year, the generations "EURO 1" and "EURO 2" are being reported to have reached a total of 800,000 kWh produced electricity with 60 units installed and 280,000 operation hours.

The German manufacturer of heating devices Vaillant presents the latest generation of a domestic Fuel Cell Heating Appliance FCHA designed together with Plug Power for European multi-family homes and small business applications. The third generation systems are being tested in German, Dutch and Austrian applications since December 2002 and will demonstrate reliability in domestic and small business CHP installations. Furthermore, Vaillant and Plug Power are supplying 4.6 kW units as part of the European Union 'Virtual Power Plant' project, which tests and connects 31 CHP units in Germany, the Netherlands, Portugal and Spain.
Viessmann

“Viessmann produces heating equipment in ten factories, both in Germany and abroad. Our sales organisation comprises a total of 106 sales offices based in Germany and in 33 other countries, through which it maintains close partnerships with customers. Viessmann is developing PEM fuel cell technology with German partners for domestic heating applications. The product range comprises boilers for operation with oil, gas and solid fuels ranging from 4 to 15,000 kW output, as well as all modular components designed for this product range.

- Domestic Heating - a wide range of high efficiency condensing boilers, cylinders and heating towers.
- Commercial Heating - with boiler outputs from 40kW to 15,000kW.
- Renewable Energy Solutions - from solar panels to heat pumps and heat recovery.
- Control Systems - including optional weather compensation, these are designed for flexibility and efficiency”

http://www.fuelcellmarkets.com/member_view.fcm?articleid=2473&subsite=1
http://www.viessmann.com/

Vito (Flemish Institute for Technological Research)

Vito (Vlaamse Instelling voor Technologisch Onderzoek) is a research institute in Flanders and implements client-driven research projects and develops innovative products and processes. The activities of the 482 researchers are implemented in 8 Centres of Expertise’, dealing with energy, new materials and environmental protection and innovation. Regarding fuel cells the centres of expertise ‘Energy Technology’, ‘Process Technology’ and ‘Materials Technology’ are of most interest.

In the past a substantial program was executed in Belgium in the field of the development and application of alkaline fuel cells at low temperature and atmospheric
pressure (Elenco). During that time people of SCK-CEN (Nuclear Research Centre in Mol, Belgium) and later of Vito were directly involved in these fuel cell projects: fuel cell units in the range of 0.5 kW up to 140 kW were realized and tested in the field as stand-alone or traction energy sources within or without a hybrid configuration. At the moment Vito is analyzing the technology status of the PEFC and is making a test-and measure infrastructure operational for PEFC. Part of the tests is focused on the characterization of PEFC under different conditions. Specific attention will be paid to rapid load variation, as we expect this will be a more critical condition, both in terms of system performance and emissions. These integrated design concepts can be tested on two test benches, actual present at Vito. For stationary applications dynamic tests of fuel cell based energy systems at different water temperatures (between 6°C and 95 °C) can be performed in TTL (thermo-technical laboratory). In case of automotive applications the drive train test bench (E²TRAC) can be used to analyze the performances of design configurations.

Voller Energy

Voller Energy is a UK private company. Commercially available are three models from Portapack by Voller Energy (GB), a 1000, 100 and 10 watt PEFC system resp. Hydrogen supply is maintained by metal hydride storages. Fig. 4.1-21 shows the medium model VE100 with 100 W nominal output, 9 kg weight.

Volkswagen

The German car manufacturer Volkswagen is involved in various FC developments. The latest development is the Touran HyMotion, who is now running in it's 3rd generation. Equipped with an 80 kW fuel cell, it accelerates within 14 s from 0 to 100 km/h and reaches 140 km/h top. A hybrid system incorporating a NiMH battery rounds up the approach.
The German car manufacturer Volkswagen unveiled its first fuel cell car, the Bora HyMotion, together with Swiss Paul Scherer Institute (PSI) in November 2000 (Figure 4.3-26). Fuelled by liquid hydrogen it has a top speed of 140 km/h and a range of about 350 km. Volkswagen has also been involved with the European Union funded CAPRI project to produce a methanol fuel cell vehicle. In April 2004, VW presented a people carrier equipped with a PEFC auxiliary power unit (APU).

Zentrum fuer Solarenergie & Wasserstoff Forschung (ZSW)

The German research centre Zentrum fuer Solarenergie & Wasserstoff Forschung (ZSW) is engaged in the development of PEMFC and DMFC as well as in system engineering and the development of test rigs and test procedures of fuel cells. ZSW was established in 1988 as a non-profit foundation under the civil code. The goal of the foundation is: to conduct and promote research and development in the field of solar energy and hydrogen technology in co-operation with university and non-university research and by transferring the results into industrial application. According to its fields of expertise, ZSW is structured into the following departments, each with their specialized technical staff and laboratories: System Analysis, Photovoltaic Materials Research, Photovoltaic Modules, Systems and Applications, Renewable Fuels and Processes, Electrochemical Materials Development, Electrochemical Accumulators, Electrochemical Hydrogen Technology, Electrochemical Processes and Simulations. In these departments materials, meth-
ods and technologies for photovoltaic conversion of solar energy, for battery and fuel cell technology and for the production of renewable fuels are developed. In the field of fuel cells ZSW is active in the field of Polymer Electrolyte Membrane Fuel Cells (PEFC) and Direct Methanol Fuel Cells (DMFC). PEFC stack technology up to a power of 10 KW has been developed recently in co-operation with industrial partners. Furthermore, development projects for the use of PEFC in stationary and portable applications are currently carried out. Currently, ZSW is establishing a test facility for PEFC stacks and systems. A total of 6 fully automated test benches up to a power level of 10-kW are in operation. A test bench for full sized automotive stacks up to a power of 100 kW is available.

www.zsw-bw.de

4.3.2 MCFC Development

The European research in the molten carbonate fuel cell technology is strongly dominated by two industrial players, the German company MTU CFC Solutions and the Italian Ansaldo Fuel Cells. Since ECN skipped its MCFC development ENEA is the only one of the European big research organization conducting MCFC research. 16% of the 240 patents related to MCFC or MCFC Systems announced within the years 1998-2003 were filed by European Countries. 3 concern applications, 1 control systems, 3 electrodes, 7 electrolytes, 1 interconnectors, 4 current collectors, 1 the sealing, 2 stacks and 16 of them are general or system patents, see Fig. 4.3-27.

![Patents related to High Temperature Fuel Cells since 1998](image)

Fig. 4.3-27  Patents of High Temperature Fuel Cells and relevant items

Ansaldo Fuel Cells (AFCo)

The Italian Ansaldo Fuel Cells (AFCo) was de-merged from Ansaldo Ricerche in 2001 (and EnerTAD and Fincantieri joined AFCo’s-equity in 2004). AFCo defined a program in co-operation with many Italian and European partners, to manufacture a
full European technology which will target the market of low- and medium-sized power plants (from some kW to a few MW). AFCo tested a 100 kW MCFC proof-of-concept in 1999 at ENEL in Milan, Italy. Next a newly designed rectangular MCFC-stack was tested. This stack will be the core of the program with the “Series 2TW (500 kWe when fuelled by natural gas)” to be applied as a building block for bigger plants. In 2004 a new production facility was opened and investments continue in the developments of stacks, process- and balance-of-plant components. Ansaldo Fuel Cells SpA (AFCo) will in move to commercialization and will up-grade its present factory in Terni, Italy their next phase (to start in 2006). The present production capacity in Terni is 3 MW/yr to be up-graded to 15 MW/yr. The Company has launched a program, in cooperation with other Italian and European partners, for developing a fully European technology, targeting the market of low-medium size power plants (from some kW to a few MW). Within this program a new concept of a rectangular stack has been conceived and tested. It will be the core of the “Series 2TW”, a powerplant with a nominal power of 500 kW if fed by Natural gas, that will be the building block for bigger plants. Figure 4.6 presents the TWINSTACK® configuration of the “Series 2TW” development, allowing for integration of a gas turbine for increased efficiency and providing an approach with standardized stack and BoP components.

Fig. 4.3-28 Ansaldo Fuel Cell’s “Series 2TW”,


CESI

Established in 1956, CESI, a private company belonging to the ENEL Group (Italy’s largest electricity supplier), is a market leader in testing, certification of electromechanical equipment and electrical power system studies. CESI is actually focusing a significant part of its research activities on the promising technologies for distributed power generation with special emphasis on fuel cells. The ongoing fuel cell projects include the repowering of the 100 kW MCFC plant with a new 125 kW Ansaldo Ricerche MCFC stack and a gas microturbine, laboratory activities on bench scale MCFC cells and on component characterization, the modeling of high temperature fuel cell plants for CO₂ concentration and removal, the modeling of combined MCFC – microturbine plants, studies of the distributed power generation impact on the distribution network and on the environment.
CIEMAT - Centro de Investigaciones Energéticas, Medio Ambientales y Tecnológicas

CIEMAT is a Public Organism for Research and Technological Development supported by the Spanish Ministry of Science and Technology, which has as main objectives to find solutions to improve the use of resources and energy generation systems and to develop alternative energy sources. At CIEMAT, the Fuel Cell Group is aimed at the design and development of fuel cell prototypes as energy generation systems able to compete with the conventional methods, considering aspects such as electric efficiency, environmental impact, flexibility and modularity. Since 1995 the group has been involved in the major research area of MCFC for stationary electrical power generation applications. The available facilities include three small-scale stations (8 cm²) that allow for the study of components used in MCFCs. Moreover, several fuel cell components (cathodes, anodes, bipolar plates…) can be manufactured and electrochemically characterized by impedance spectroscopy and cyclic voltametry techniques.

http://www.ciemat.es/eng/index.html
http://www.ciemat.es/eng/actividad/programas/p_cg_pilascombust.html

CNR-ITAE (Institute for Advanced Energy Technologies of the National Council of Research in Italy already Institute for Transformation and Storage of Energy)

The CNR-ITAE (Institute for Advanced Energy Technologies of the National Council of Research in Italy already Institute for Transformation and Storage of Energy) is located in Messina. It has a long and proven experience in all categories of fuel cells having contributed to the penetration of this technology into Europe since the early 80’s. The fields MCFC has been actively investigated with the participation to EC and National programs. Recently, the Georgia Technology Policy & Assessment Centre has classified the CNR-ITAE in the first six world most prolific affiliations operating in the field of fuel cells in the last twenty years. The activity has been focused on the development of components (anode and cathode catalysts, electrodes, membranes, electrolytes) technologies for the preparation of cells and stacks, studies on utilization in the different applications, optimization of integration with different technologies.


CSIC Council of Scientific Research Instituto de Catálisis y Petroquímica, Consejo Superior de Investigaciones Científicas

The Spanish Council of Scientific Research (CSIC) is the biggest public institutions for scientific research of Spain. About six thousand people are permanent employees in some of the one hundred institutes in the CSIC. In particular, the Institute of Catalysis and Petroleum chemistry (ICP), with more than twenty five years experience in research activities, has a great amount of expertise in subjects such as chemistry at surfaces, development of catalysts, new materials application, combustion and green processes, etc. The ICP.CSIC has ten years experience in fuel cell prototypes as well in control and monitoring systems. The main objective of the Fuel Cells Group is the design and development of components and prototype fuel cells. The objective is pursued following two complementary research activities: experimental and model-
ing and numerical simulation. The group is involved in high temperature fuel cells (molten carbonate fuel cell, MCFC, and solid oxide fuel cell, SOFC) for stationary electrical power generation applications. The available installations include several automated stations for the study of components used in MCFC and SOFC cells. Fuel cell components can be manufactured and characterized by electrochemical and physicochemical techniques.
http://www.csic.es/wi/index.jsp
http://www.icp.csic.es/aplicada.en.html

**ENEA**

ENEA is a scientific research and technology development organization with vast, internationally recognized experience in conducting advanced research programs and implementing complex projects in the fields of research and innovation for the sustainable development and environment safeguard. ENEA fields of competence include engineering, materials science, chemistry, physics, geology, mathematics, agriculture, oceanography, information science and technology, meteorology, biology and many others. ENEA works with Italian Ministries on designing and conducting projects involving the European Union, and other international organizations such as the United Nations and the OECD, representing Italy in various IEA Implementing Agreements, including those on Advanced Fuels Cells and Electric/Hybrid Vehicles. Among its main scopes, there is the research, development and promotion of environmentally safe and energy saving technologies. In this field many programs on fuel cells are underway, also in co-operation with industry, academic institutions and research organizations at national and international level. Since mid-80’s ENEA is conducting R&D Programs on various FC technologies (mainly, PEFC and MCFC) for mobile and stationary applications. In such activities, basic research on materials, components, auxiliaries and related technologies (batteries, drivelines, reformers, balance of plant) is continuously carried out. One qualifying aspect has been the creation of a variety of test facilities for components and complete systems and test procedures.
http://www.enea.it/com/ingl/default.htm
http://www.bfcnet.info/downloads/Hydrogen%20and%20FC%20project%20ENEA.pdf

**LECA: Laboratoire d’Electrochimie et de Chimie Analytique- ENSCP/CNRS**

This laboratory (about 30 permanent investigators and 25 Ph.D students) associated to the National Centre of Scientific Research in France (CNRS), is dedicated to fundamental research in electrochemistry, separation techniques, modeling and melt chemistry with a view to technical and industrial applications. It has a large experience, in different fields:

- Fundamental and applied research in fuel cells: MCFC and SOFC.
- Molten salts (carbonates, chlorides, hydroxides, fluorides and chloroaluminates) applied to extractive metallurgy, fuel cells, corrosion by molten phases and catalytic applications.
- Semiconductor electrochemistry and photo electrochemistry, associated to thin films technology.
- Electrode modification related to catalytic effects in electrochemistry.
• Capillary electrophoresis.
• Molecular modeling and simulation of electrochemical processes.

The main objective is the understanding and optimization of MCFC, in particular in what concerns the corrosion effect of the electrolyte towards the electrodes and bipolar plates. Studies on new cathodic materials and bipolar plates protective coatings are developed since 1988. Thermodynamic predictions and electrode reaction mechanisms are also studied in the laboratory. Recently it is developing different thin layers deposition techniques: electro deposition, sputtering and Atomic Layer Deposition.

http://www.enscp.fr/en_recherche_index.html

**MTU CFC Solutions**

The German MTU Motoren- und Turbinen-Union Friedrichshafen has developed molten carbonate fuel cell technology including internal reforming in cooperation with the US company FCE/ERC. The most important system development in that area is the integrated carbonate fuel cell system "Hot Module", which offers significant efficiency and cost advantages. It has demonstrated the design at the 250 kW scale and has experience with natural gas and synthesis gas (coal gas) feedstocks. 16 Hot Module systems had been delivered up to now. MTU CFC Solutions was founded in 2003 with 74.9% of the shares owned by MTU Friedrichshafen and 25.1% by RWE Fuel Cells. MTU CFC Solutions schedules the setting-up of series production in 2006. At the end of 2004 a new production building in Munich/Ottobrunn was taken into service with an area covering 7,400 m², 85 employees are jointly engaged in development and production. The utilization of waste gases is expected to become a future market.

Fig. 4.3-29 Assembling of a Hot Module

MTU is involved in research and lifetime testing of conventional and advanced fuel cell technologies. This includes component, cell and stack tests in laboratory scale up to tests in 250 kWel field trial units. Further on MTU performs out of cell tests for catalysts and material stability.

http://www.mtu-online.com/cfc/de/cfcs/cfcs.htm

4.3.3 **SOFC Development**

14% of the 535 world-wide patents (1998-2003) related to SOFC or SOFC systems were filed by European companies. 7 of them concern applications, 4 control sys-
tems, 13 electrodes, 6 electrolytes, 6 interconnectors, 5 current collectors, 2 sealing, 8 stacks, and there are 26 general and system patents, see Fig. 4.7.

![Patents related to High Temperature Fuel Cells since 1998](image)

Fig. 4.3-30 Patents of High Temperature Fuel Cells and relevant items

European companies, institutions and inventors obtained about 15 % (18 % in 1998/99, 15 % in 2000/01 and 13 % in 2002/03) of the worldwide SOFC related patents.

**Adelan Ltd. / University of Birmingham**

The UK Adelan Ltd. is a start-up enterprise of Prof. K. Kendall of the University of Birmingham. Adelan Ltd. delivers the first world-wide development of the microtubular SOFC technology. The design of the microtubular SOFC as already reported in 1994. The ~2 mm SOFC tube is electrolyte supported and produced by extrusion. The current collector is a wire, see figure 4.3-31. Experimental devices had been built up to 1000 tubes within a natural gas fired unit.
Airbus

The European aircraft manufacturer Airbus investigates SOFC systems for onboard power supply.
www.airbus.com

Alp²s

The Austrian company Alp²s describes its business:
“Our fuel cells feature outstanding thermal cyclability and have already proven to last over some thousands load cycles. To the best of our knowledge this forms a world record for solid oxide fuel cells. Our cells are suitable for all applications - stationary as well as mobile - where high efficiency is required.”
http://www.alpps.at/en/brennsys.html#nr02

AVL List GmbH (AVL)

The Austrian AVL is the world’s largest privately owned and independent company for the development of power train systems with internal combustion engines as well as instrumentation and test systems. AVL has about 1300 employees in Graz (over 500 graduated engineers) and a worldwide network of 45 representations and affiliates resulting in total 2100 employees worldwide. The AVL Advanced Simulation Technologies division develops and markets the simulation methods necessary the power train development work including simulation of electric vehicles with fuel cell stacks as well as detailed flow simulation in single cells. The Instrumentation and Test Systems division is an established manufacturer and provider of instruments and systems for engine and vehicle testing. The activities include PEFC and SOFC implementation in automotive application.
http://www.avl.com/wo/webobsession.servlet.go/encoded/YXBwPWhCiYXNlJnBlY29udGVudC1tYW5hZ2VtZW50L3ZpZXcmaWQ9NDAwMDM4ODgy.html#
http://www.avl.com/
BMW AG

The German carmaker BMW AG is to be mentioned in the field of system integration with their SOFC APU. [no direct sources to be found at “BMW” itself, but various on reporting portals for fuel cells]
http://www.bmw.com/

CEA (French Atomic Energy Commission)

CEA (French Atomic Energy Commission) is a research state agency for nuclear energy, employing a staff of 16000 people. The Research & Technologies Division (DRT), one of the 4 operating division, whose policy is to meet the needs of partners both in the CEA and in the industry, has two main activities: the first one is to develop electronic applications, while the other one is to work on new Technologies for Energy. In order to support industrial developments in the field of renewable energy, an ambitious research program on electrochemical energy storage has been set since 1996. One of the main topics is dealing with fuel cells, both PEFC and SOFC. More than 60 persons are now involved in these studies, of whom 20 are currently working in the Hydrogen and Fuel Cell laboratory (LHPAC previously Electrochemical Storage of Energy Laboratory). The main objective are to meet industrial requirements through materials research and development, electrochemical expertise, manufacturing of demonstration object, modeling and system studies and also recycling process studies. The mission of this new group consists in the development and the co-ordination of the whole activities of research of CEA in the field of the Fuel Cell. Those activities are carried out in collaboration and for the benefit of the industrials. The topics studied are: materials, phenomena comprehension and modeling, technology and design, hydrogen storage. The R&D projects on SOFC cover

- New materials to decrease operating temperature
- New design to reliable and temperature cycling SOFC
- Coupling Biomass gases and SOFC (Biostar, Greenfuelcell)
- Efficient reformer multi fuel without catalyst (N’GHY)

The research partners of CEA are CNRS and universities with the industrial partners Saint Gobain, EDF, GDF, Dalkia. The first targeted product is a 5 kW prototype SOFC for Cogeneration applications in 2008: Gecopac Project (6 M€). It is targeting a new design and is using natural gas as a fuel.

http://www.cea.fr/fr/presse/dossiers/Gecopac.pdf

Ceres Power

The UK company Ceres Power has been founded in 2001 to commercialize a within Imperial College new developed SOFC concept. Ceres site near Gatwick has integrated product development, testing and pilot production capabilities. The proprietary technology is a metal-supported SOFC operating at an intermediate temperature, see fig. 4.3-32. It is designed for fast and can be operated by a range of fuels, includ-
ing LPG, natural gas, methanol, hydrogen and logistic liquid fuels. Ceres is developing small scale distributed power generation systems using intermediate temperature solid oxide fuel cells. The targeted size is between 1 kW and 25 kW electric power generation.

Fig. 4.3-32  Ceres Power SOFC technology
http://www.electricalreview.co.uk/news/article.asp?articleid=3922
www.cerespower.com

CNR-ITAE (Institute for Advanced Energy Technologies of the National Council of Research in Italy already Institute for Transformation and Storage of Energy)

The CNR-ITAE (Institute for Advanced Energy Technologies of the National Council of Research in Italy already Institute for Transformation and Storage of Energy) is located in Messina. It has a long a proven experience in all categories of fuel cells having contributed to the penetration of this technology into Europe since the early 80’s. The fields of PEFC, DMFC, MCFC and SOFC have been actively investigated with the participation to EC and National programs. Recently, the Georgia Technology Policy & Assessment Centre has classified the CNR-ITAE in the first six world most prolific affiliations operating in the field of fuel cells in the last twenty years. The activity has been focused on the development of components (anode and cathode catalysts, electrodes, membranes, electrolytes) technologies for the preparation of cells and stacks, studies on utilization in the different applications (automotive, stationary, portable), optimization of integration with different technologies. http://www.itae.cnr.it/Engl/index-en.html

CSIC Council of Scientific Research Instituto de Catálisis y Petroleoquímica, Consejo Superior de Investigaciones Científicas

The Spanish Council of Scientific Research (CSIC) is the biggest public institutions for scientific research of Spain. About six thousand people are permanent employees in some of the one hundred institutes in the CSIC. The ICP.CSIC has ten years experience in fuel cell prototypes as well in control and monitoring systems. These activities have been carried out with the financial support from many competitive programs of R&D. The main objective of the Fuel Cells Group is the design and development of components and prototype fuel cells. The objective is pursued following two complementary research activities: experimental and modeling and numerical
simulation. The group is involved in high temperature FC (MCFC, SOFC) for stationary electrical power generation applications. The available installations include several automated stations to study the components used in MCFC and SOFC cells. Fuel cell components can be manufactured and characterized by electrochemical and physicochemical techniques.

http://www.csic.es/wi/index.jsp
http://www.icp.csic.es/aplicada.en.html

DELPHI AUTOMOTIVE SYSTEMS

Fully independent from any OEM, Delphi Automotive Systems is a public company since May 1999. Delphi is the largest and most diversified supplier of automotive components, systems and modules. In Europe, Delphi employs over 48000 people in 71 manufacturing sites, 8 joint ventures, 8 technical centres. European turnover 4.6 billion Euro. Closer information about its technology see Part 1 North America.
http://delphi.com/

DLR - German Aerospace Research Centre

The German Aerospace Research Centre (DLR) is the largest engineering research organization in Germany and has about 4500 employees. The DLR Institute of Technical Thermodynamics (DLR-TT) in Stuttgart is active in the field of renewable energy research and technology development for efficient and low emission energy conversion and utilization. on solid oxide fuel cells with planar and tubular design (SOFC) and on fuel cell systems. DLR is developing its own type of anode supported planar SOFC. Major achievements are:

- Thin layer SOFC cell in planar design for operation at lower than 800 °C
- Successful development of coatings of SOFC bipolar plates with vacuum plasma spraying

The specialty of DLR is the development of thermal spraying processes for SOFC production.
http://www.dlr.de/tt

ECN Energy Centrum Netherlands

The Dutch ECN is a private research organization for the development of products and processes in the frame of energy conversion and innovation. The ECN mission is to contribute to a clean and reliable energy supply for a viable world. Major points of activity are technological research on energy consumption, energy conversion and related environmental and materials problems. ECN is the main national research institute in the field of fuel cells. ECN has been involved in SOFC development since 1991, working closely with Siemens (D) and Sulzer (CH). ECN has a pre-pilot cell-manufacturing unit for SOFC cells. A commercial venture, InDEC b.v., has been instigated, as a spin-off from ECN for manufacture of the SOFC cells on a commercial basis. Fuel processing for fuel cells as well as for other applications is also one of the core activities of ECN. A separate group deals with the integration of components
into practical fuel cell system and the demonstration of those systems under realistic operating conditions. ECN focuses on anode supported planar SOFC. http://www.ecn.nl/

**EMPA**

The Swiss research institution EMPA has its root in the Swiss federal material testing institute. The R&D activities on SOFC at its division of High Performance Ceramics include material and component development for an efficient SOFC operation with fossil fuels as e.g. natural gas. “Current research topics in this area include the development of functional oxide ceramics and metal-ceramic composites that allow for the efficient conversion of gaseous fuel and air in the porous electrodes. Together with our partners from industry and research, we work in the area of materials synthesis, electrode/electrolyte processing and component. We develop anode (fuel electrode) substrates as the supporting element of a Solid Oxide Fuel Cell and the synthesis of perovskite materials for the air electrode.”

http://www.empa.ch/plugin/template/empa/614/7643/---/l=1
http://www.empa.ch/plugin/template/empa/124/6581/---/l=2
www.empa.ch

**Fraunhofer-IKTS Dresden**

The institute of the German Fraunhofer society IKTS in Dresden is developing planar SOFC. A major partner in co-operation is STAXERA targeted on the application for automotive APU originally started by the German car supplier Webasto one of the owners of Staxera.

http://www.ikts.fraunhofer.de/index_en.html

**FZJ -Forschungszentrum Juelich**

A broad research programme for the development and feasibility of SOFC is an essential part of energy technology and energy research, one of the focal research areas in the FZJ mission. Investigations on SOFC started in 1990, dealing with fundamental aspects in materials science and electrochemistry. In 1995, a first 10-cell stack was tested successfully. Intense work has been done on refinement of the technology since then. Recently, cost reducing raw materials, processing techniques and stack designs have been evaluated. Works conducted at FZJ include:

- development and production of materials and components
- study of electrical, electrochemical, catalytic, mechanical, micro structural and chemical properties of materials and components
- assembling and stack testing
- development of peripheral components where needed
- system modeling ranging from elementary reactions to BOP-design

FZJ is developing a planar anode supported SOFC. The research centre describes its SOFC work principles on its website: “Solid oxide fuel cells (SOFCs) are of the
first type and are of major interest for stationary electricity and heat generation in power plants or buildings. Scientists in Jülich are working on advanced SOFCs with planar cells and thin electrolytes. It was recently possible to increase the performance of an SOFC stack consisting of 40 single cells to a record value of 9.2 kilowatts in operation with hydrogen."

**Haldor Topsoe**

The Danish company Haldor Topsoe started SOFC development based on the results of the research centre Risoe. The technology is an anode supported planar SOFC. The company describes its business plan on its website.

"Topsoe Fuel Cell A/S (TOFC) was formed in 2004 and is a fully owned subsidiary of Haldor Topsøe A/S (HTAS). Prior to this company formation, solid oxide fuel cell (SOFC) technology was pursued under a research project fully integrated within the R&D Division of HTAS. TOFC was established to create a leaner, more focused and independent frame for enhancing commercialisation efforts and creating a visible basis for collaboration and strategic partnerships. .... Topsoe Fuel Cell has a large network of partners with whom it leverages its research and development effort. Partners include major European and American research institutions, the most important being Risø National Laboratory, and private companies both up and downstream the production of cells and stacks.

The commercialisation effect of TOFC focuses on the substantial reductions in production costs, improvement in robustness and reliability and an increased presence in the pre-market through suitable channel-to-market relationships. Topsoe Fuel Cell has carefully chosen manufacturing methods already well proven in other ceramic industries in order to utilize present experience and achieve the highest degree of reliability.

Presently, cell production takes place at co-owned and co-operated manufacturing facilities at the Risoe National Laboratory, while stack production takes place at dedicated facilities at TOFC, but TOFC is currently working on combining and up-scaling the manufacturing in order to meet the growing market needs. It is the ambition to complete the combined, up-scaled in-house cell and stack facility before the end of 2007."

http://www.topsoe.com/

**H.C. Starck GmbH**

H.C. Stark is a subsidiary of the German Bayer group and is specialized on fine ceramics. It has agreed a joint APU development with the Webasto AG and formed recently with them the new company Staxera. H.C. Stark has bought from the Dutch research centre ECN its subsidiary InDEC b.v. H.C. Stark describes its SOFC activities on the product website as:

"H.C. Starck’s scientists are developing materials and components for high-temperature Solid Oxide Fuel Cells (SOFC) that generate not just electricity, but also heat that can be harnessed for domestic use. This process is also possible on the
basis of natural gas. These electrochemical power plants require highly complex ceramic-metal composites that are manufactured from fine-grained powders.”


InDEC b.v.

The introduction of InDEC can be found on the website of H.C. Starck: “InDEC B.V. (Innovative Dutch Electroceramics), Petten, Netherlands, was founded in 1999 as a spin-off company for the pilot production of specially developed fuel cell components. It all began with ECN (Stichting Energieonderzoek Centrum Nederland), also located in Petten. With its electroceramic expertise, ECN developed components for solid oxide fuel cells (SOFC). When it was realized that these components have a market potential, the production was separated from the research activities into a special entity, which was the initial basis for the later InDEC. In early 2003 H.C. Starck acquired a majority holding in InDEC.”


LECA: Laboratoire d'Electrochimie et de Chimie Analytique- ENSCP/CNRS

This laboratory (about 30 permanent investigators and 25 PhD students) associated to the National Centre of Scientific Research in France (CNRS), is dedicated to fundamental research in electrochemistry, separation techniques, modeling and melt chemistry with a view to technical and industrial applications. It has a large experience, in different fields:

- Fundamental and applied research in fuel cells: MCFC and SOFC.
- Molten salts (carbonates, chlorides, hydroxides, fluorides and chloroaluminates) applied to extractive metallurgy, fuel cells, corrosion by molten phases and catalytic applications.
- Electrode modification related to catalytic effects in electrochemistry.
- Capillary electrophoresis.
- Molecular modeling and simulation of electrochemical processes.

The main objective of its SOFC program is to lower the SOFC temperature for APU and stationary applications, mainly by decreasing the thickness of the electrolyte layer (YSZ) or by using bi or multi-layered systems (YSZ, CGO).

http://www.enscp.fr/en_recherche_index.html

RISOE NATIONAL LABORATORY

The Danish National Laboratory at Risoe is conducting a broad SOFC development program. http://www.risoe.dk/afm/sofc/activities/activities_uk.htm

The targeted research topics are as follows:

- Cell Development
- Cell Manufacture
- Stack Development
- Testing
The Danish company Haldor Topsoe is the industrial partner of Risoe. A cell of the 2nd generation, an anode supported one is shown in fig. 4.3-33. The last generation is the third generation, described as: “The 3G or metal supported cell is at a more experimental stage. Here the anode support is replaced by a porous layer of ferritic stainless steel (approx. 78% iron and 22% chromium). The expected advantages are a significant decrease in cost and an increased robustness in case of fuel supply failure or operating stop (redox and temperature cycles). At the same time the operating temperature is reduced to 550-650 °C which have been shown to be an optimal temperature range. In addition to the completely new support, all active components will be improved. The cathode will be that used for the 2.5G cell.”

http://www.risoe.dk/afm/sofc/activities/celldev_uk.htm

Fig. 4.3-33 2G cell produced at Risø. The active area (the dark region) is 12 cm×12 cm. The thickness is less than 1 mm.
http://www.risoe.dk/afm/sofc/activities/celldev_uk.htm

A pilot manufacturing plant has been erected. The cells are used partly for testing purposes at Risø, partly for the stack development at Haldor Topsoe A/S. The experiences from the pre-pilot plant will play a central role when an industrial production facility is established.
http://www.risoe.dk/

**Rolls-Royce Fuel Cell Systems Ltd**

The UK company Rolls Royce Fuel Cell Systems Ltd is a subsidiary of Rolls Royce and is developing SOFC since the early 1990s. The concept is unique it was the first successful attempt to combine the benefits of tubular and planar SOFC in one design: the flat tube concept or also called integrated planar concept with a number of integrated cascaded and serial connected SOFC strips. The concept is shown in fig. 4.3-34.
The company is planning to entrance the market with SOFC hybrid systems with a capacity up to 1 MW. Fig. 4.3-35 gives an overview of its architecture.


SIEMENS

The German SIEMENS company developed a planar SOFC until it bought Westinghouse. SIEMENS integrated the tubular Westinghouse technology in its corporate strategy and stopped the planar development. Due to its global strategy the SOFC business of SIEMENS is now located in the US however some research activities remained or have been even newly started in the corporate research department in Germany. Thus the development of SIEMENS based on the former Westinghouse company is considered as a US activity and not included in Table 4.4. Westinghouse as an US company applies all patents of the tubular technology even if invented after 1999, the year of the fusion of the companies.
Staxera

The German Staxera introduces itself on its website: “Staxera GmbH is a joint venture between Webasto AG and H. C. Starck GmbH for the industrialization of high temperature fuel cells. We consider solid oxide fuel cell (SOFC) technology as the perfect method to generate electricity from a wide range of liquid and gaseous fuels with high efficiency and ultra low emissions. Fuels can be either from fossil fuels or renewables available in a certain region.” Staxera shall become an independent deliverer of stacks for different system integrators as e.g. Webasto itself.
http://www.staxerafuelcells.de/en/?Home
http://www.staxerafuelcells.de/

Sulzer Hexis AG

Knowledge of the practical behavior in the electrical net is today gained by the manufacturer Sulzer of Switzerland. Latest news: By the end of 2005, Sulzer closed its subsidiary Sulzer Hexis AG. But it has been reported that a core of the crew has been shifted to a rescue company to secure the knowledge, while a continuation of the work can not be seen up to now.
http://www.hexis.ch/

Wärtsilä

Wärtsilä, the Finish manufacturer of heavy duty engines started an SOFC development program. The best available description of Wärtsilä’s business is given by the website www.fuelcellmarkets.com:

The present R&D work of Wärtsilä focuses on SOFC systems for commercial and industrial applications. The company is currently developing a 20 kW SOFC power unit as a prototype. Wärtsilä plans to introduce its first commercial demonstration of WFC50 units in the 50 kW range in the next years, looking into pre-commercial niche market applications later on. Fig. 4.3-36 gives an overview of the technology.

Fig. 4.3-36 Wärtsilä’s first SOFC power generator prototype
Wärtsilä plans to commercialize the units in a number of marine and stationary applications. The former includes marine auxiliary power generation uses, and the latter commercial buildings like hotels, supermarkets, service stations, data centres, etc.

"Wärtsilä is focusing on natural gas and methanol as the most potential fuels for the SOFC-units. However, there are also a number of other fuels suitable for SOFC-systems, such as diesel, biogases, landfill gas, coal bed methane and waste gases, as well as ethanol and other alcohols. Wärtsilä is committed to providing its customers with highly efficient and environmentally sustainable power generation solutions and developing new energy generation technologies of the future, such as fuel cells. The fuel cell program supports Wärtsilä’s long-term strategy for sustainable development."

http://www.wartsila.com/

**Webasto**

The German automotive supplier Webasto AG founded together with H. C. Starck GmbH, controlled by Bayer, Staxera for the joint SOFC development. This new cooperation continues its work together with Fraunhofer-IKTS Dresden. Latest development, publications and patents are focused on stacking components and anode materials. Webasto is now focusing only the system development itself. "The first applications for the Webasto APU are planned for 2008 in trucks and leisure vehicles (caravans and boats). Until then, the 25-strong Webasto development team based in Neubrandenburg, Germany, will be working on tweaking the system to achieve a few more optimisations such as quicker start-up times, improved power-to-weight ratio and cost reductions."


In Russia an alliance of nation-wide operating companies are promoting and working on SOFC. Partners are Minaton, ISTC, Gazprom, Norilsk Nickel Company, Russian Academy of Science and the Russian Federal Nuclear Centre - All-Russia Scientific Research Institute of Experimental Physics (VNIIEF). Two SOFC designs are manufactured and tested by the consortium.
4.4 Organization of research
(funding procedures, funding organizations, project management, interface product development - research, interaction and competition of different research groups, etc.)

The research organization on hydrogen technologies and fuel cells in Europe is quite complex because of the variety of different programs and countries. Research is done in universities and public research centres as well as in industry. Within the EU programs and most of the regional programs a lot of research groups are collaborating. Most of them demand the participation of public research institutes as well as industrial partners.

An overview on currently funded projects can be found in the following paper published by the commission:

A valuable database from the European Hydrogen and Fuel Cell Technology Platform, focused on hydrogen and fuel cell related projects, can be found under http://www.infotools.hfpeurope.org/hfp_pro/pro_start.html.

The activities of the European Commission are discussed below to illustrate the development in Europe. Because these activities has an increasing impact on the national strategies and organizations they can be considered as representative.

GENERAL OVERVIEW

A “Joint Technology Initiative” (JTI) has been established to promote the market entrance of Hydrogen and Fuel Cell products, providing an EU wide coordination of activities in policy, industry and science. JTI is supposed to provide funding within a 7 years program as a first step to secure the investments necessary. The overall funding period shall be much longer, > 15 years are being reported.

Figure 4.4-1 through 4.4-7, taken from a presentation by the EC held in Berlin on 08.09.2005, outline the program. Here just an overview is being given; for the whole program please refer to.

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**EU Support for Hydrogen and Fuel Cells**

- Support in the R&D Framework Programme
- Towards the 7th R&D Framework Programme
- Hydrogen/Fuel Cell R&D structures
- JTIs, Lighthouse projects

Figure 4.4-1 Current EU’s targets for Hydrogen and Fuel Cell support

source: Angel Perez Sainz
Figure 4.8 shows the structure of the European Union’s support activities by the instruments framework program FP, R&D structures, Joint Technology Initiatives and Lighthouse Projects.

The funding supplied by the European Union for FC and H2 technologies increased during the development of the framework programs from 8 M€ in FP 2 to 250 M€ in FP 6 as shown in Figure 4.9.

Figure 4.4-2 Development of funding for Hydrogen and Fuel Cell related projects during the recent framework programs 2 to 6 source: Angel Perez Sainz

However this increase is remarkable the public funding in the EU is about 160 M€/year compared to about 300 M€ in the US and Japan. An other important benefit of the US and Japan is a clear unified strategy while the European effort is fragmented. The US has furthermore the benefit of a big defense research program concerning fuel cells for troops. Figure 4.10 gives the details.

Figure 4.4-3 Assessment of the current funding policy within the EU source: Angel Perez Sainz
The FP 7 initiative shall improve this situation by a higher amount of funding and a better strategic harmonization, see Figure 4.11.

Figure 4.4-4 Proposed time schedule of FP7
source: Angel Perez Sainz

Figure 4.4-5 Main EC DGs with responsibilities on Hydrogen and Fuel Cells Projects, source: Angel Perez Sainz

The entities within the EC that are concerned with hydrogen and fuel cell technology are the DG TERN (Transport and Energy), the DG RTD (Research) and the Joint Research Centre. The proposed priority areas of FP 7 are related to H2 and fuel cell technology in the following fields:

- Hydrogen and fuel cells
- Energy savings and energy efficiency
- Clean coal technologies
The total view of the priority areas is given in Fig. 4.14.

![Diagram of priority areas](image)

**Fig. 4.4-6** Proposed Priority Topics in Energy within FP7, source: Angel PEREZ SAINZ

**European Hydrogen and Fuel Cell Technology Platform (HFP)**

“The main goal of the European Hydrogen and Fuel Cell Technology Platform (HFP) is to facilitate and accelerate the development and deployment of cost-competitive, world class European hydrogen and fuel cell based energy systems and component technologies for applications in transport, stationary and portable power. The platform is steered by a high level Advisory Council. The establishment of the HFP has been facilitated by the European Commission.”


“The European Hydrogen and Fuel Cell Technology Platform aims at accelerating the development and deployment of these key technologies in Europe. The platform assists in the efficient co-ordination of European, national, regional and local research, development and deployment programs and initiatives and ensures a balanced and active participation of the major stakeholders (i.e. industry, scientific community, public authorities, users, civil society). It helps to develop awareness of fuel cell and hydrogen market opportunities and energy scenarios and fosters future co-operation, both within the EU and at global scale.”


**Fig. 4.4-7** gives an overview of the implemented structure.
"The technology platform is instrumental in structuring socio-economic and technical research on hydrogen and fuel cells at European level, as well as in stimulating increased public and private investment in research and development. The platform also helps to identify and to promote deployment opportunities both for energy infrastructure and services. The platform is built up from ongoing and new projects, clusters and networks in the European Commission’s Framework Program and in Member States, and includes a number of specific steering panels and initiative groups as may be necessary to optimize its functioning and realize the platform’s overall goals. These activities are complemented by new initiatives for public-private partnerships and linked to industry projects, when appropriate.

The results of activities, including research and demonstration projects, undertaken under the auspices of the platform are widely disseminated and communicated to the appropriate policy making bodies. These bodies themselves are represented in the platform governance structure and play a crucial role in target setting and assessment. Regular annual or bi-annual meetings of platform participants ensure shared ownership and a common vision. The technology platform and all its activities contribute to an integrated strategy to accelerate the realization of a sustainable hydrogen economy in Europe, a concept endorsed by the European Commission on 10 September 2003.

Participants in the TP represent a balance of expert knowledge and stakeholder interests and include:

- Research community - public and private; technical and socio-economic;
- Industry (incl. SMEs) - embracing the whole production and supply chain;
• Public authorities - European, national, regional, local;
• Financial community - banks, venture capital, insurance, ...;
• Users and consumers - to ensure markets for products;
• Civil society - to enhance public awareness.

The technology platform is steered by an Advisory Council, whose mission is to take forward and consolidate the “vision” of the former high level group and to facilitate the smooth and efficient running of the platform, ensuring its strategic relevance within a global context and that its direction is consistent with European Union policy. The European Hydrogen and Fuel Cell Technology Platform was established on recommendation by the European Commission’s High Level Group (HLG) on Hydrogen and Fuel Cells. The HLG was formally launched in Brussels on 10th October 2002 by the Vice-President of the European Commission Mrs Loyola de Palacio, responsible for Energy and Transport, and Research Commissioner Philippe Busquin. It brought together top-level stakeholders from across Europe representing a broad cross section of interests, with the aim of formulating an integrated EU vision on the possible role that hydrogen and fuel cells could play in achieving sustainable energy.”


A report "Hydrogen Energy and Fuel Cells - A vision of our future" has been prepared by nominated representatives from the organizations of the HLG members.

NETWORKS

The formation of networks has been developed as a measure to form a European Research Area and Community. This strategy has been already implemented successfully in H2 and fuel cell research as well. Recently two fuel cell related networks has been finished SOFCNET for SOFC and FCTESTNET for testing and standardization of fuel cell technology. FCTESTNET will be continued in a new starting network FCTESQA.

FCTESTNET

FCTESTNET (Fuel Cell Testing and Standardization Network) is a now finished European network project within framework program 5. It is a three-year project that commenced 2003, with 55 partners from European research centres, universities, and industry, working in the fuel cell field.

Fig. 4.4-8  FCTESTNET-Logo

“The main objective of FCTESTNET is to promote the harmonization of testing procedures and methodologies within the European Union. The lack of standardized test
methods for fuel cell technology is a fact. The development of standardized test methods is very important for the commercialization of the fuel cell technology. Standardized test methods are one of the most important instruments in the quality management work of any industrial process. The players that have a common interest to promote and develop harmonized test methods for fuel cell technology are

- Standardization bodies (IEC and ISO)
- Fuel cell manufacturing industry (type testing and routine testing)
- OEMs (acceptance testing)
- Research institutes and universities (R&D)

The current work presents one of the core results from the FCTESTNET project, namely a proposal of a harmonized testing format for fuel cell technology. The harmonized testing format has been developed based on a testing model that was proposed in the initial phase of FCTESTNET.

The testing model describes the common process steps in testing and has been a valuable tool to communicate testing activities and develop test format within the network. The testing model describes testing in general and fuel cell testing in particular. It is a three-step model. The first step is the planning step and comprises the listing of standardized test methods and other references that are required for the execution of any specific testing activity. The second step of the testing model is the testing execution, which is where the actual testing is carried out. The result of the testing execution is here referred to as test output data or test output. The test output is analysed and compared with input data from the planning step and finally reported in the third step, that is the **evaluation step**.

Some examples of specific test inputs, in the context of fuel cell testing, are temperature, vibration, fuel flow, rain, etc. Examples of specific test outputs are current, voltage, gas emissions, heat, degradation, etc. In professional testing, the internal function of the test object is of secondary importance. The object is to be treated as a “black box”. It is the test output and the test result that are of primary importance.

Based on terminology originating from the testing model, such as test object, test inputs, test outputs, etc, a harmonized testing format has been developed and proposed. The key terms in the harmonized testing format are **test program** and **test module**. The test program is defined as a program comprising two or more test modules. A test module is a test method defined as the variation of one single test input, for example the testing of power output as function of ambient temperature. Furthermore, a test module comprises the objectives, the scope, the test input varied, the test outputs tested, test object class (fuel cell, fuel cell stack or fuel cell system), test procedure, test report, etc.

Some further information can be found at:
www.jrc.nl/fctestnet,
europa.eu.int/comm/research/energy/pdf/efchp_fuelcell37.pdf

The project summary, presented by the FCTESTNET-Group itself, is shown in the following paragraph.
Problems to be solved

Currently no standardized test procedures for Fuel Cell (FC) systems, stacks and cells are available. Similarly no standardized test procedures exist for the evaluation of the applications of FC (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 programs. Although it is too early for formal Standardization in many areas related to FC, a clear need for harmonization of test procedures and measurement methods does seem appropriate and necessary.

One important motivation for establishing a network for testing and Standardization is that it will foster synergy between industry and research and will help to improving the quality of the research and the quality of products at lower cost. The creation of a FC testing network will bring together the best expertise on a European level with a common aim to improving the quality of harmonization process, and in addition to both supporting and complementing the work of IEC TC 105 and IEA.

FC testing and harmonization requires multidisciplinary R&T&D involving technological competencies which are widely dispersed in Europe. A European fuel cell network is the most efficient way of bringing these competencies and disciplines together, thus avoiding overlaps and allowing an efficient use of available resources.

Scientific objectives and approach

The main objective of the FCTESTNET is to create a network of research and industrial organizations involved in development and testing of fuel cells, fuel cell systems and fuel cell applications. This network will produce proposals for harmonization of test procedures at the level of fuel cell systems down to stacks and cells. Such harmonization is necessary to enable objective comparison of R&D results and evaluation of technological progress in this field, and it will be a valuable tool / input for international standardization bodies working in the fuel cell technology field.

The aims of the project are distributed to eight Work Packages (WPs) each consisting of several tasks to allow a smooth co-ordination. WP 0, Co-ordination & Project management, is devoted to the planning and scheduling of the resources. WP 1, Applications-Transport, will define a general set of tests and the associated test parameters that are necessary to characterize the suitability for different transport applications of various kinds of fuel cell systems, containing different types of fuel cells. It is the goal of WP 2, Applications-Stationary, to defining a general set of tests and the associated parameters for stationary applications. WP 3, Applications-Portable, will define and harmonize test methods for portable fuel cells. WP 4, Balance of Plants, in a first step will analyze the state-of-the-art balance-of-plant concepts, will identify the major system components and define the representative systems concepts representing the wide variety of specific concepts. In a second step representative requirements and boundary conditions for all major system components defined in step 1, based on the fuel cell system test parameters and test procedures defined in WP 1, 2, 3, and taking the interaction between the balance-of-plant components into account, will be defined. In a third step the target of WP 4 will be the development of boundary conditions for all system components with the aim of testing entire fuel cell systems under defined boundary conditions. WPs 4, 5, 6, PEMFC, MCFC, SOFC respectively, have to define the main parameters determining
the performance of a fuel cell system and to establishing common test procedures and methodologies for evaluation of cell and system components among the fuel cell community, both for comparison purpose and for identification of criteria and guidelines for future standardization. Finally, WP 8, External relations, will concentrate on the exchange and collaboration with other relevant European and overseas networks and institutions.

The approach is application and technology-oriented and ensures the necessary support and integration of the industrial interests, which is the elementary condition for harmonization and subsequently established standardized 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 FC applications to define test parameters, test methods and conditions that are relevant for testing fuel cell 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. Together with an inventory of test procedures already in use, this will ultimately result in the definition of a framework for harmonizing test procedures for components, stacks and cells. In this way harmonized test procedures can be derived that yield results that allow a comparison of different products and projects and that give meaningful information with respect to the progress in and applicability of different fuel cell technologies.

Expected impacts
A number of milestones have been set; these are:
- Definitive frameworks for oriented testing of fuel cell systems for applications;
- Representative system concepts; Standard system testing procedures;
- Definition of representative requirements and boundary conditions for components;
- Description of testing conditions of the components, single cells, stacks;
- Recommendations and Specification and external workshop;
- Agreement on, and harmonization of approaches and measuring criteria.

The expected results will be as follows:

A technology mapping of industrial activities, institutes and consortia that work on fuel cell development and testing, including their RTD, demonstration and commercialization targets and strategies, collaborative links, and an assessment of their specific strength National programs; Integration of National programs on testing at European level; Agreement on, and harmonization of approaches and measuring criteria; Establishment of links between European and US R&D organizations and standardization bodies in the frame of harmonizing procedures; Perform an advisory role to the European Commission.”

EU’S FRAMEWORK PROGRAMS 7 THROUGH 4

FP 7 2007-2013
Looking towards the Seventh Framework Program of the EU
The final preparation of FP 7 is still ongoing. The main outlines of the concepts up to date are collected below.

“At the beginning of 2005, the European Commission will present its proposal for the European Union’s Seventh Framework Program for Research (2006-2010). Along with specific information about the financial support schemes and implementation instruments, it will include the Commission’s proposals for thematic research priorities. The Commission has made strengthening European research a major objective in its Communication on the future financial framework of the Union2, proposing to increase the European Union’s research budget significantly. At the Barcelona European Council of March 2002, the EU set itself the objective of increasing the European research effort to 3% of the European Union’s GDP by 2010, two-thirds coming from private investment and one-third from the public sector. In order to increase the impact of the European Union’s action, it is proposed to organise FP7 around six major objectives:

**Objective 1.** Creating *European centres of excellence* through collaboration between laboratories. Programs to support transnational collaboration between research centres, universities and companies will be implemented using the FP6-type instruments, such as the Networks of Excellence and Integrated Projects.

**Objective 2.** Launching European technological initiatives. Technology platforms are being set up to bring together different stakeholders to define a common research agenda which should mobilise a critical mass of public and private resources. This approach has been adopted in areas such as the hydrogen economy, with the creation of the European Hydrogen and Fuel Cell Technology Platform. Often it will be possible to implement the research agenda by means of Integrated Projects. In a limited number of cases, a ‘pan-European’ approach appears appropriate, involving the implementation of large-scale ‘joint technology initiatives’. An appropriate framework for their implementation is that of structures based on Article 171 of the Treaty3, including possible joint undertakings.

**Objective 3.** Stimulating the creativity of basic research through competition between teams at European level. Open competition between individual research teams and support for them at European level would boost the dynamism, creativity and excellence of European research whilst increasing its visibility. The Commission suggests the creation of a support mechanism (e.g. a European Research Council) for research projects conducted by individual teams which are in competition with each other at European level.

**Objective 4.** Making Europe more attractive to the best researchers. The European Union’s objective is to promote the development of European scientific careers while, at the same time, helping to make sure that researchers stay in Europe and attracting the best researchers to Europe. Against the background of growing competition at world level, it is necessary to strengthen the ‘Marie Curie’ actions which are being conducted for this purpose.

**Objective 5.** Developing research infrastructure of European interest. With the creation of the ESFRI Forum, an important step has been taken in the field of research infrastructures in Europe. It is proposed to strengthen this action through the introduction of support for the construction and operation of new research infrastructures of European interest.

**Objective 6.** Improving the coordination of national research programs. Efforts have successfully been made to improve the coordination of national research programs in the context of FP6 – such efforts must be strengthened. This involves increasing the
resources allocated to ERA-NET activities for the networking of national programs, extending the financial support they offer to research activities, and an increased effort towards the mutual opening-up of programs."


Comment of Commissioner Potocnik to reduced FP 7 budget:
[Date: 2005-12-19]

"With the European Council reaching a compromise on the EU's Financial Perspectives that falls short of the proposed doubling of the Seventh Framework Program (FP7) budget, Science and Research Commissioner Janez Potocnik has called for a prioritisation of resources on those areas with the greatest added value. Speaking to an audience of industrial participants in European Technology Platforms (ETPs) in Brussels on 16 December, Mr Potocnik correctly predicted that the Council would not provide all the funds for FP7 originally requested by the Commission. Therefore, he said, 'we will have to prioritise and focus our resources on those topics that have the greatest added value, both in terms of the European dimension and in terms of transforming knowledge into growth.' Having already helped to shape the FP7 proposals through their strategic research agendas, ETPs will be close partners in the process of drafting the specific work programs, he added.

Given the lower than hoped for budget for FP7, Commissioner Potocnik also stressed the importance of finding opportunities within the Structural Funds to invest in research and innovation. 'I believe that Technology Platforms could usefully draw attention to opportunities for investment in this sector,' he said.

Despite expressing high hopes for the role that ETPs can play in the EU's Growth and Jobs strategy, the Commissioner warned that two factors will be crucial to their future success. First, platforms must demonstrate openness and transparency to avoid being perceived as closed shops representing narrow industry interests. 'The second factor is to avoid dilution [... with] a technology platform for every subject or lobby under the sun,' he added.

Mr Potocnik concluded: 'We want to invest in you, because we strongly believe that your action can yield interesting dividends. We are not opportunistic investors. We invest for the long haul, but of course we want to see results. I trust that you will do what you can to optimise the shareholder value that we would expect.'"

http://icadc.cordis.lu/fep-cgi/srchidadb?CALLER=FP6_NEWS&ACTION=D&RCN=24950

**FP 6 2002-2006**

Main targets within FP 6, Sustainable Energy Systems, Medium to Long Term (DG RTD), Fuel Cells, including their Applications, are as follows:

"Energy: Long to Medium-term Research (DG Research)
Research is needed to reduce the cost and improve the performance and durability of fuel cell systems for stationary, transport, and portable applications, to enable them to compete with conventional combustion technologies. This will include the optimization and simplification of fuel cell subsystems and components as well as testing and characterization protocols. The long-term target is to achieve an attractive return on investment by 2020 for many applications. For fuel cells, the strategically important areas in which research should be concentrated are: the development of competitive fuel cell and related technologies for stationary and transport applications (covering both low temperature fuel cell sys-
tems, including stacks, fuel processors, etc. and related technologies such as reversible fuel-cell/ electrolyzers and high temperature fuel cell systems. The emphasis for RTD will be on materials, processes and component level development, aimed at improving performance and durability, whilst also reducing costs.) and fuel cell systems applications (research will concentrate on systems and integration for various applications, exploiting, where appropriate, synergies between applications, e.g. technologies for multi-fuel capability. Research will include system simplification, simulation and modelling, optimisation and cost reduction of auxiliary components and balance of plant. The types of application concerned are: small and medium size, mainly low temperature, fuel cells, power generation in the range of 0.5 - 5 MW, development of portable power systems and Auxiliary Power Units, fuel cell systems for small road vehicles and fuel cell systems for heavy duty road, marine and railway transportation.)

New instruments, having been integrated in FP6, are Networks of Excellence (NoE) and Integrated Projects (IP). Together with Specific Targeted Research Projects (STREP), Co-ordination Actions (CA) and Specific Support Actions (SSA) these instruments form the frame for spending an overall budget of 890 MEUR within SES (Sustainable Energy Systems)

http://www.cordis.lu/sustdev/energy/ml-term/home.html#

FP 5 1998-2002
The major innovation of the Fifth Framework Program was the concept of “Key Actions”. Key actions are problem-oriented and clearly defined on the basis of a common set of criteria. They are specifically targeted to the objectives of each program and to the desired results, taking into account the views of users. They will have a clear European focus. The "key action" is regarded as a cluster of small and large, applied, generic and, as appropriate, basic research projects directed towards a common European challenge or problem, not excluding global issues.

Key actions as in GROWTH were

- Innovative products, processes and organization
- Sustainable mobility and intermodality
- Land transport and marine technologies
- New perspectives in aeronautics,

comprising an overall funding of 2705 mio EUR (covering all GROWTH activities).

An overview on projects, funded within FP5 GROWTH, as well as links to more detailed information can be found in:

http://cordis.europa.eu.int/fp5/

FP 4 1994-1998
Non-Nuclear Energy - R&D Component (JOULE III)
NNE-JOULE was the research and development component of the specific program for Non-Nuclear Energy (NNE) within the European Union's Fourth Framework Program for Research and Technological Development. NNE-JOULE dealt with research and development in the field of innovative energy technologies, whereas THERMIE -
the other component of NNE program- focused on the demonstration of these energy technologies. The NNE Program had a total budget of ECU 1030 million, of which around 460 million was allocated for NNE-JOULE. It aimed to address three central issues:

- improving security of energy supply;
- protecting the environment;
- encouraging the rational use of energy.

NNE-JOULE provided financial support (up to 50%) to RTD projects in four different areas:

- energy RTD strategy;
- rational use of energy;
- renewable energy sources;
- fossil fuels.

JOULE also provided support for concerted actions, technology stimulation measures, and training grants. Within JOULE III, 18 projects in the field of fuel cells have been funded, an overview is presented in the listed overview below.

http://www.cordis.lu/data/PROJ_JOULE/QF_EP_SPF_AeqJOULECat0203dIndUSR_SORTeqEP_RPG_ACHARASC.htm

Overview on projects in the field of fuel cell research within JOULE III

1. Development and evaluation of an integrated methanol reformer and catalytic gas clean-up system for a spfc electric vehicle Project Reference: JOE3950002 Project Acronym: MERCATOX Status: Completed Duration: 42 months

2. Improving durability of SOFC stacks Project Reference: JOE3950005 Status: Completed Duration: 36 months

3. Evaluation and scale-up of intermediate temperature (700 C) SOFC technology (IT-SOFC technology Project Reference: JOE3950008 Project Acronym: IT-SOFC TECHNOLOGY Status: Completed Duration: 36 months

4. Second generation PEM fuel cell working with hydrogen stored at high pressure for the electric vehicle Project Reference: JOE3950013 Project Acronym: HYDROGEN Status: Completed Duration: 63 months

5. Development of 50kw class SOFC system and components Project Reference: JOE3950015 Status: Completed Duration: 48 months

6. Selection and development of materials for high-endurance MCFC bipolar plate Project Reference: JOE3950024 Status: Completed Duration: 30 months

7. Direct methanol fuel cell : system development and a stack construction Project Reference: JOE3950025 Status: Completed Duration: 48 months
8. Development of industrially relevant MCFC stacks Project Reference: JOE3950026 Status: Completed Duration: 42 months

9. Second generation SPFC; Development of commercially viable stacks Project Reference: JOE3950027 Status: Completed Duration: 48 months

10. Advanced DIR-MCFC development Project Reference: JOE3950033 Status: Completed Duration: 36 months

11. Compact methanol reformer test-design construction and operation of a 25 kW unit Project Reference: JOE3950038 Status: Completed Duration: 36 months

12. Design and engineering of the electrical power supply quality electronic measurement Project Reference: JOE3961004 Status: Completed Duration: 6 months

13. Advanced solid polymer fuel cells for operation at temperatures up to 200 °C Project Reference: JOE3970045 Status: Completed Duration: 30 months

14. Development on low temperature fuel cells with methanol as a fuel option Project Reference: JOE3970049 Status: Completed Duration: 42 months

15. Development of a novel partial oxidation reactor for natural gas and integration into a micro CHP SOFC system Project Reference: JOE3970060 Status: Completed Duration: 24 months

16. Conception and realization of a new low cost direct methanol fuel cell Project Reference: JOE3970063 Status: Completed Duration: 48 months

17. Feasibility study of an urban fuel cell network with coal gasifier Project Reference: JOE3970071 Status: Completed Duration: 24 months

18. High temperature fuel cells use for the next ten years Project Reference: JOE3980097 Status: Completed Duration: 24 months
4.5 **Quality assurance of research**

*(review of proposals, review of results, exchange of results, networks, etc.)*

However different member states have different strategies but there is a more or less common approach of a mixture of basic funding and financing by research contracts from public funding agencies or industries. The successful organizing of external funding is generally seen as one parameter for evaluating quality.

Public research institutes and universities have usually a basic funding by the government. Depending on their strategy the percentage of public funding may differ between the different entities and member states. Their publication lists, the number of citations and successful proposals for external funding are important items here for such evaluations of quality. External reviewers are usually used for reviewing results and performance.

Generally research groups have to apply for additional funding of specific projects. For this purpose they have to submit proposals for projects. Such proposals are reviewed. Groups with the best proposals and experience in the subject are favored. Usually there is additionally a midterm evaluation for ongoing projects. In 2005 a review event of the funded projects has been organized by the European Commission for the first time. The benefit of this sort of approach is a better transparency of research and results.

The procedures developed by FCTESTNET will be used for a better comparison of research results of different groups.

Denmark, European Commission, Netherlands, Norway, Sweden and U.K. are members of CADDET Energy Efficiency, Centre for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET), along with other member countries: Australia, Canada, Korea, Japan and U.S.A. Fundamental to the operation of CADDET Energy Efficiency are the CADDET National Teams from these member states. Made up of experts from government agencies or energy industries, every National Team is well placed to obtain information on the latest energy-saving technologies used in their own country. This information is pooled, analyzed and used to make various products. By offering an information service, National Teams play a vital role in distributing these products among the member countries.

The strategy of networking within the EU funding strategy was described in 4.4.
4.6 Standardization activities  
(regional activities, philosophy, IEC TC 105 co-operation)

In Europe there exist in parallel national (like DIN or AFNOR) as well as European bodies for Standardization. European bodies are the European Commission for Standardization (CEN) and the European Commission for Electrotechnical Standardization (CENELEC).

Furthermore Germany, France, Italy, Finland, Norway, Sweden, Switzerland, United Kingdom and The Netherlands are participating countries concerning the Advanced Fuel Cells technology agreement of the IEA. The objectives of the Implementing Agreement on Advanced Fuel Cells are to advance the state of understanding of Participants in the field of advanced fuel cells through co-operative research, technology development and system analysis on Molten Carbonate, Solid Oxide and Polymer Electrolyte Fuel Cell systems. There is a strong emphasis on information exchange through meetings, workshops and reports.

The main areas of activity are aimed at reducing the cost and improving the performance of molten carbonate, solid oxide and polymer electrolyte fuel cells and examining ways in which fuel cells and systems can be optimised for stationary and transport applications, taking into account users’ requirements.

The main achievements to date have been the establishment of expert networks and the initial exchanges of information on cell, stack and system performance, testing methods and application requirements. The formation of experts groups and the exchange of information between them have strengthened national capabilities and are expected to lead to the achievement of significant technical objectives.

Denmark, Finland, France, Germany, Italy, the Netherlands, Spain, Switzerland and the United Kingdom are P members of the IEC TC 105 „Fuel Cell Technologies“. Austria, Belgium, Norway, Poland, Portugal and Sweden are O members of the IEC TC 105.

Albania, Austria, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Denmark, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland are members of the ISO technical committee – TC 197 – „Hydrogen Technologies systems and devices involved in producing, storing, transporting, measuring and using hydrogen“.

In Germany the association of the German automotive industry VDA also has standardization activities in the field of hydrogen technology. The group of experts, which previously drew up the first standards for electric road vehicles within the framework of the ISO, has now included the fuel cell vehicle in its program of work. The aim of its activities is to draw up the first generally applicable basic rules for vehicles with fuel cell drive systems. Under German lead and maintaining a watching brief on developments, the group intends to define the following subjects for international standards:
Requirements for the functional and electrical safety of vehicles with fuel cell drive systems,

Protection against the dangers of hydrogen,

The integration of fuel cell drive systems in vehicles and

 Procedures for measuring the consumption and mileages of fuel cell powered vehicles.

Even at this early stage, work on Standardization is valuable, in that it effectively defines the development activities of the manufacturers and provides for technical diversity, for example in the form of modularity.
4.7 Testing activities
(test benches, test programs, testing standards, etc.)

Within the European Commission, the Joint Research Centre Petten, Institute for Energy (JRC IE) is supposed to play a major role in testing fuel cell components and applications.

Overall, IE carries out research in the fields of clean and sustainable energy spanning both nuclear and non-nuclear domains. Typical activities encompass: nuclear safety in the enlarged EU, including support to TACIS (technical assistance for the Commonwealth of Independent States) and PHARE (Poland, Hungary aid for the reconstruction of the economy); new nuclear energy systems; thermal treatment of waste and biomass/biofuel; waste incineration; emission mitigation; and clean energy sources. All activities are linked to large networking activities in line with the European Research Area (ERA).

In particular, through standardized tests and test conditions, JRC-IE will provide with comparative data on the performance, operational characteristics, and durability of fuel cells. The capabilities of the facility will include:

- Short and long-term load testing of fuel cell systems
- Thermal testing of fuel cell heat recovery systems
- Vibration Test System
- Temperature / Humidity Environmental Testing equipment
- Accurate simulation of flow transients
- Supervisory data acquisition and process control system

Fig. 4.7-1 Energy Commissioner Andris Piebalgs visiting the climate and vibration test chamber at JRC in Petten on 20.01.2006, G. Tsotridis presenting the facility http://ie.jrc.cec.eu.int/
Annex 4.1 Addresses of European Stakeholders

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http://www.enea.it/com/ingl/default.htm
http://www.bfcnet.info/downloads/Hydrogen%20and%20FC%20project%20ENEA.pdf

Forschungszentrum Juelich in Germany (FZJ)
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Tel.: +49-2461-61-5124
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www.fz-juelich.de

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Fraunhofer ISE
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D - 79110 Freiburg, Germany
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www.ise.fhg.de

Germanischer Lloyd (GL)
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D - 20459 Hamburg, Germany
Tel.: +49 (0)40-36149-621
Fax: +49 (0)40-36149-7320
http://www.gl-group.com/maritime/research/3644.htm

GKSS
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D – 21502 Geesthach, Germany
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Fax: +49-4152-87-2444
http://www.gkss.de/index_e-js.html

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H.C. Starck GmbH
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Helion
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www.helion-fuelcells.com

Howaldtswerke-Deutsche Werft AG
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Fax: +49 (0) 431 700-2312
http://www.hdw.de/index_en.php
http://www.hdw.de/hfc/englisch/index.htm

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Intelligent Energy Limited
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Fax: +44 (0)1509 223911
http://www.intelligent-energy.com/
Intech Thueringen GmbH
P.O. Box 4325
NL-5944 ZL Arcen/Lomm, The Netherlands
Tel.: +31 (0)77-473 82 00
Fax: +31 (0)77-473 21 75
www.intechedm.com

IRD Fuel Cells A/S
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DK - 5700 Svendborg, Danmark
Tel.: +45 6280 0008
Fax: +45 6280 0009
www.ird.dk

Johnson Matthey PLC
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Fax: +44 (0) 1793 755800
www.jmfuelcells.com

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http://ie.jrc.cec.eu.int/

LECA: Laboratoire d'Electrochimie et de Chimie Analytique- ENSCP/CNRS
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Fax: +33 (0) 1 44 27 67 50
http://www.enscp.fr/en_recherche_index.html

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Fax: +49 (0)89 1580-912485
http://www.brennstoffzellenbus.de/bus2004/bsz04-2gb.htm
www.man-mn.com

Masterflex
http://www.masterflex.de/com/index.html

Michelin
Place des Carmes-Déchaux
F - 63040 CLERMONT-FERRAND CEDEX 9, France
Service Tel.: +33 (0) 820 20 63 63
http://ecl.web.psi.ch/supercap/

**MTU CFC SOLUTIONS**  
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Tel.: +49 7541 90 -0  
Fax: +49 7541 90 -1  
http://www.mtu-online.com/cfc/de/cfcs/cfcs.htm

**NedStack**  
Westvoorsedijk 73  
NL - 6802 Arnhem, The Netherlands  
Tel.: +31 26 366 4278  
Fax: +31 26 366 5129  
www.nedstack.com

**NuCellSys**  
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4.7.4  D - 73230 Kirchheim/Teck – Nabern, Germany  
Tel.: +49 (0) 7021 89-3927  
www.nucellsys.com

**Nuvera Fuel Cells**  
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Milan, Italy  
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Fax: +39 (02) 21.29.24.03  
www.nuvera.com

**Adam Opel GmbH**  
Adam Opel Haus  
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http://www.gm.com/company/gmability/adv_tech/400_fcv/fc_milestones.html  
www.opel.de

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Fax: +41 (0) 56 3102199  
www.psi.ch

**PEMEAS GmbH**  
Industriepark Höchst, G 865  
D - 65926 Frankfurt am Main, Germany  
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Fax: 49 (0) 69/305-36784  
www.pemeas.de
Proton Motor Fuel Cell GmbH
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Fax: +49 (0)8151 26864-18
www.proton-motor.de

Risoe National Laboratory
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DK-4000 Roskilde, Denmark
http://www.risoe.dk
http://www.risoe.dk/afm/sofc/activities/activities_uk.htm

Rolls-Royce Fuel Cell Systems Ltd
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Derby DE24 8BJ, UK
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Still GmbH
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http://www.still.de/414.0.43.html

Smart Fuel Cells
Eugen Saenger Strasse
Gebaeude 53.0
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Fax: +49 (0)89 45469
www.smartfuelcells.de

Staxera
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Fax: +49-3512554400
http://www.staxerafuelcells.de/
Sulzer Hexis AG  
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CH - 8401 Winterthur, Switzerland  
Tel.: +41 52 262 11 22  
Fax: +41 52 262 01 01  
http://www.hexis.ch/

TNO-Automotive  
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2628 VK Delft  
Postbus 6000  
NL - 2600 JA Delft, The Netherlands  
Tel.: +31 (0)15 269 69 00  
Fax: +31 (0)15 261 24 03  
http://www.automotive.tno.nl/

Umicore  
Rodenbacher Chaussee 4  
D-63403 - Hanau-Wolfgang  
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Fax: +49 61 81 59 4204  
www.umicore.de

Vaillant  
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D - 42859 Remscheid, Germany  
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Fax: +49 (0) 21 91/18-28 10  
www.vaillant.com

Viessmann  
Viessmannstraße 1  
D - 35107 Allendorf, Germany  
Tel.: +49 (0) 6452 / 70-0  
Fax: +49 (0) 6452 / 70-2780  
http://www.fuelcellmarkets.com/member_view.fcm?articleid=2473&subsite=1  
http://www.viessmann.com/

Vito (Flemish Institute for Technological Research)  
Boeretang 200  
B - 2400 Mol, Belgium  
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Fax: + 32 14 33 55 99  
http://www.vito.be/english/

Volkswagen  
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Fax: +358 20 722 7048  
http://www.vtt.fi

**Wärtsilä**
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Tel.: +358 10 709 0000  
Fax: +358 10 709 5700  
http://www.wartsila.com/

**Webasto AG**
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**Zentrum fuer Solarenergie & Wasserstoff Forschung (ZSW)**
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Annex 4.2 Universities involved in FCTESTNET

Ecole des Mines /ARMINES

The Centre d’Énergétique (CENERG) is one of the 18 Research Centres of Ecole des Mines de Paris. It is composed of about 80 people distributed on two sites: Paris and Sophia Antipolis. Generally speaking CENERG activities concern both the elaboration of tools for designing and optimising complex energy systems and the development of highly efficient innovative products with low environmental impacts. Activities on fuel cell and hydrogen production and storage were launched about ten years ago within this lab. A research team called EM&P has been dedicated to their study. It was deeply involved in the FEVER project (JOU-CT93-0301) for which it built a dedicated laboratory capable of testing fuel cells up to 15 kW. System analysis and modelling was carried out in the frame of this project and in the end a real demonstrator, a Renault Laguna was tested successfully. It is also involved in research concerning materials for supercapacitors as well as for hydrogen storage and works about hydrogen production through reforming processes. An important topic concerns hybridisation of PV systems with fuel cells. This research is carried out within the European contract PVFCSYS. key persons involved:

Ecole Polytechnique Fédérale de Lausanne - EPFL

Ecole Polytechnique Fédérale de Lausanne, Lausanne, Switzerland, is the French-language campus of the Swiss Federal Institute of Technology, which also includes the German language campus ETHZ, Zürich, the national research centres EMPA, PSI etc. Within EPFL, the Laboratory for Photonics and Interfaces (LPI), Department of Chemistry, specialises in electrochemistry for energy, for example electrochemical photovoltaics, batteries, and of course fuel cell, both SOFC and PEMFC. With a total of 40 personnel, it has been engaged in fuel cell R&D since 1989. In addition to original research in materials and processes in SOFC and PEMFC, LPI under contract to the Swiss Federal Office of Energy (OFEN - Office Fédéral de l'Energie) was the launching Operating Agent for the International Energy Agency annex on SOFC in 1989. Since than that IEA programme has had the continuous support of the LPI research group, most recently for the Jan. 2001 Workshop on SOFC Materials & Mechanisms. Within the national fuel cell programme LPI acquired the resources for fuel cell component testing, including microstructural and electrochemical characterisation, in addition to cell fabrication facilities. PEMFC research, including fuels other than hydrogen, is carried on in cooperation with Paul Scherrer Institute, the Swiss specialist energy research centre. As a University, the primary role is obviously education and training to doctoral level in materials and fuel cell processes, and as such it is currently involved in a European Training and Mobility of Researchers action (HiTProton). However the LPI resources have permitted a vigorous support to industry over more than 10 years, including the testing and validation services mentioned.

Hamburg University of Applied Sciences

The research group “fuel cells and rational use of energy” is located in the Faculty of Mechanical Engineering. The research work covers theoretical and experimental work with the main topics fuel cell system design and fuel cell stack design. The research group has experience in the thermodynamics and system integration of combined fuel cell cycles including the fuel processing, the design studies for the product development of stationary and mobile SOFC-GT systems and the stack design. However the research is mainly based on the SOFC technology but there are also PEFC studies on the way. The modelling of cycles is done by self-developed software. The available test facilities include: Three high temperature test rigs
(up to 1100 °C and 2 bar) including measuring equipment and a cold flow measurement test rig for model investigation. The experience includes planar and tubular designs as well.

**Imperial College of Science, Technology and Medicine (ICSTM)**

Imperial College of Science, Technology and Medicine (ICSTM) has a world-class reputation in the field of Science and Engineering. ICSTM has around 10,000 students, of whom some 3000 are at the postgraduate level. ICSTM has a long tradition of work in the fuel cell arena, with over 20 years experience in the field. Presently around 60 staff and students are active in the area, with work addressing both polymer and solid oxide fuel cells. This represents a highly multidisciplinary grouping, with staff from the Departments of Materials, Chemistry, Chemical Engineering, Mechanical Engineering, Electrical Engineering, and Environmental Science and Technology all active in the field. In the network, ICSTM will provide data to the PEMFC component testing and SOFC component testing work packages.

**IST**

Instituto Superior Técnico was funded by the Minister of Development in 1911, on the basis of the model of the Leading Schools of Engineering in Europe. IST has become the biggest and the best-known Engineering College in Portugal. Since the end of the 60's, work was done to promote scientific research and allow for the technological development of the IST, firstly by setting up Centres of INIC. Two groups of IST are involved in this proposal as mentioned in the next paragraphs. The research group on sustainable energy has 7 PhD researchers belonging to the Thermofluids and Energy Section (STE). The group participated in projects related to fuel cell applications. Two projects were carried out on dimensioning steam reformers for integration in fuel cell systems for both stationary and mobile applications. The group is also involved in the demonstration of fuel cell buses in both Lisbon and Porto and on the demonstration of a domestic small cogeneration fuel cell plant. The group has a combustion laboratory with 120m² and offices for staff members and about 20 scholarship fellows. The Electrical Machines and Power Electronics Section (SMEEP) has 9 PhD members working in the scientific areas of power electronics and motion control. The installations of the SMEEP include an office area with 240 m² corresponding to a power electronics and electrical machinery experimental laboratory and a service area (100 m²) divided into secretariat, meetings/seminars rooms, library and workshops. R&D activities in the Electrical Machines and Power Electronics Section come under the headings of "Control of Electrical Drives" and the "Intelligent Motion Control". Through a significant number of scientific publications and international R&D projects, the unit has acquired experience and international competence in these fields.

**Kungliga Tekniska Högskolan (Royal Institute of Technology), KTH**

Kungliga Tekniska Högskolan (Royal Institute of Technology), KTH, in Stockholm, Sweden is a technical university with education and research. It provides one-third of Sweden’s capacity for engineering studies and technical research at post-secondary level. KTH has about 11 600 students and 3 000 employees and there are about 1 900 active post-graduate students. Applied Electrochemistry is part of the Department of Chemical Engineering and Technology, KTH. The department consists of seven divisions and a total of 180 employees. The research at Applied Electrochemistry, involving about 20 persons, is directed towards electrolytic processes and electrochemical power sources within the field of electrochemical engineering. At present the following research projects are running: The molten carbonate fuel cell (MCFC), the polymer electrolyte fuel cell (PEFC), the direct methanol fuel cell (DMFC), lithium-polymer batteries, electrochemical treatment of cancer. A common theme in different research projects is the development and application of porous electrode theories for
battery electrodes and gas diffusion fuel cells electrodes. Experimental studies of electrode kinetics and mass transfer to electrode surfaces are other important and frequent activities in the research programme. The work on molten carbonate fuel cells at Applied electrochemistry started in 1989. The present work on molten carbonate fuel cells involves three researchers and two doctorate students. The doctorate students are working on performance and modelling of cathodes, anodes and cells. The group is well equipped with modern instruments for electrochemical experiments. There is a special MCFC laboratory equipped with two complete laboratory fuel cells of 3 cm² geometric area and four ovens available for half cell experiments etc. The group has been involved in two projects funded by the European Commission (Joule II and III) where materials for use in molten carbonate fuel cells have been investigated. The group has also participated in an international co-operation on MCFC research between eight universities (three in Japan, one in USA and four in Europe) funded by NEDO, Japan. The project was focused on the modelling and characterisation of the porous gas diffusion electrodes in the MCFC. The group has a scientific collaboration with Ecole Nationale Superieure de Chimie de Paris, France since several years. A co-operation on cathode materials and cell modelling with ENEA, Italy has recently started.

Lehrstuhl für Verbrennungskraftmaschinen Aachen (VKA)

The Lehrstuhl für Verbrennungskraftmaschinen Aachen (VKA) (Institute for Combustion Engines) is placed in the faculty for mechanical engineering of the Aachen University of Technology (RWTH Aachen). VKA employs about 33 engineers at this time who intend to complete their thesis in regard of reaching a 'Dr.-Ing.' degree. Furthermore many non-scientific employees work in laboratory, computer, mechanical shop, administration, and organisation areas. Student workers are employed, too. The total number of employees at the institute is about 145. VKA has 23 fully equipped engine test benches, one chassis dynamometer and a highly dynamic transient test cell which is qualified for acoustic investigations. Beyond that test cells for engine components are available. In addition, VKA is provided with high-class exhaust gas analysers, particle size analysers, acoustic measurement and evaluation systems and computer tools. Single cylinder transparent engines for diesel and gasoline combustion research are available as well as full size engines equipped with future technologies. Basic research and application-oriented research projects are conducted at VKA in regard of advanced powertrains. The main goals are the reduction of fuel consumption and environment pollution. Research activities concentrate on investigations of mixture formation and combustion processes, reduction of toxic agents and exhaust gas aftertreatment by catalysts and particulate traps. Furthermore alternative fuels as methanol and hydrogen are investigated for a potential application in vehicles. In addition, investigations on friction and acoustic behaviour of engines are done. Additionally, VKA deals with the fuel cell system research for powertrain applications. With a view to international cooperation VKA is involved in collaborative projects, which are financed by the European Community and European automotive companies. In this connection several universities and research institutes from all over Europe collaborate intensively.

RWTH Aachen Institut für Kraftfahrwesen Aachen (ika)

The Institut für Kraftfahrwesen Aachen (ika) is part of Aachen University of Technology (RWTH Aachen) and deals mainly with automotive applications in both teaching and research, i.e. with passenger cars, trucks, buses and motorcycles, as well as related overlapping themes. Aachen University of Technology is recognised as one of the leading universities world-wide and as one the most important concerning automobile engineering, with experience in thermodynamics, plastics application, production engineering and electronics. Modern institutes increasingly link to research projects with development tasks that have to be fi-
nanced by third party funding. Therefore ika’s equipment allows in principle the kind of work done in the automotive and supplier industry. Public funding, industrial sponsoring as well as a great deal of personal effort on behalf of the institute’s staff have helped to make this equipment accessible. Correct and punctual realisation of research and development tasks is therefore achieved. IKA’s activities are tailored to industrial demands and comprise the departments chassis, body, drivetrain, acoustics, electronics and traffic. Vehicle concepts are developed in overlapping projects starting from the idea to the concept, simulation, design, prototyping, and testing. IKA has its own facilities available, such as CAD, CAE, latest software and hardware, mechanical and automobile workshops, all necessary test-benches, a test-track for driving experiments and a crash-test-facility for total-vehicle-examination. IKA has contacts with vehicle and supplier industry world-wide, and co-operates in many different projects. In particular, ika has more than 25 years experience in hybrid and electric vehicles, e.g. different kinds of prototype hybrid vehicles have been developed in state funded projects and in co-operation with the automobile industry. Besides different running projects on electric, hybrid and fuel cell vehicles with the automotive industry the ika is currently involved in the following European funded projects: SUVA (Growth), FUERO (EESD) and ELMAS (EESD). Furthermore various European funded projects have already been carried out with participation of ika: INMOVE (Brite/Euram), FLYTECH (Brite/Euram), MATADOR (Joule) and Electric vehicle fleet demonstration with advanced batteries (Thermie).

**Universität Karlsruhe (TH), Institut für Werkstoffe der Elektrotechnik IWE,**

The IWE is an institute within the faculty of electrical engineering and information technology of the Universität Karlsruhe (TH). The SOFC related research activities at the IWE are based on the experiences collected during different fuel cell projects conducted at Siemens Central Research and Development in Munich (1989-1996). In cooperation with national and international partners from industry, research centres and universities, the IWE is developing electrode- and electrolyte- materials / structures and new types of single cells with respect to improved performance, efficiency, long term stability and system costs. There is a wide experience in the area of electrical testing of SOFCs under realistic operating conditions. Several testing setups for planar single cells and short-stacks are in use. Testing of small planar single cells (1 to 16 cm² electrode area) is possible in a wide range of operating conditions (different types of gas compositions: air, O₂/N₂-mixtures / H₂, H₂O, CO, CO₂, CH₄, natural gas; temperature 500 ... 1000 °C, up to 20 A, in-situ impedance spectroscopy, in-situ mass spectrometry), including an automated entire monitoring of the cell and individual electrode properties for operating times up to some 1000 h. Impedance spectroscopy is used to characterize single cells under varying operating conditions and to record the extent of individual loss mechanisms. Additional setups for single electrode characterization in oxidizing and reducing atmospheres are available. Further research activities in the field of power electronics for fuel cells are carried out at the IWE. Next to the experimental work different types of modeling are performed to simulate the behavior of fuel cells. Conventional methods (FEM-modeling using tools like Maxwell, Ansys and Fluent) and new approaches (system identification, black box modeling) are used for a model supported material- and cell-development.

**University of Perugia**
The Department of Industrial Engineering (former Institute of Energy) of the University of Perugia is active in the research of advanced power plants, such as gas turbine combined cycles, cogeneration systems, renewable energy sources with particular attention to thermal use of solid urban wastes, biomass and biogas, fuel cells and their integration with gasification systems and gas turbines. Among the experimental activities in the field of power plants, the energy systems research group has studied the cogeneration system of the University of Pe-
rugia where an on-line monitoring and diagnostic system based on artificial intelligence techniques has been set up, and the application of fuel cells to low heating values gases. In this second activity a molten carbonate fuel cells test rig has been set up with the aim of studying MCFC performance when fed by a mixture of gases simulating the composition of landfill or biomass gasification gases. The Department has several national and international research contracts with private and public enterprises.