

Roads2HyCom

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REVIEW OF HYDROGEN COMMUNITY R&D AGENDAS

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The European Commission is supporting the Coordination Action "HyLights" and the Integrated Project "Roads2HyCom" in the field of Hydrogen and Fuel Cells. The two projects support the Commission in the monitoring and coordination of ongoing activities of the HFP, and provide input to the HFP for the planning and preparation of future research and demonstration activities within an integrated EU strategy.

The two projects are complementary and are working in close coordination. HyLights focuses on the preparation of the large scale demonstration for transport applications, while Roads2HyCom focuses on identifying opportunities for research activities relative to the needs of industrial stakeholders and Hydrogen Communities that could contribute to the early adoption of hydrogen as a universal energy vector.

Further information on the projects and their partners is available on the project web-sites www.roads2hy.com and www.hylights.org



REVIEW OF HYDROGEN COMMUNITY R&D AGENDAS

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REVIEW OF HYDROGEN COMMUNITY R&D AGENDAS

1. Introduction

Roads2HyCom (R2H) is a project to assess and monitor Hydrogen and Fuel Cell technologies for stationary and mobile energy application against current and future infrastructures, and the needs of communities which may be early adopters of the technology, in order to support the Commission and stakeholders in planning future activities.

The objective of Work Task 6.1.1 is to review national and regional R&D agendas in terms of their coverage of issues related to hydrogen energy research, putting emphasis on the development of technologies and socio-economic schemes for the creation of “hydrogen communities”. As this task is not focusing on R&D activities, which are covered in the context of WP1, more emphasis was given in reviewing international R&D agendas and funding schemes for the development of hydrogen communities.

The review conducted in the framework of Task 6.1.1 has not found R&D agendas with a specific focus on creating “hydrogen communities”, with the exception of Australia and Canada; but there are national programmes and/or R&D agendas targeting in the development and implementation of hydrogen energy technologies, including fuel cells, in a significant number of countries.

The best part of these R&D agendas are technologically driven, since they set specific targets for the involvement of each particular country in the research, development and demonstration of different technologies related to hydrogen and fuel cells. Moreover, an important target of the majority of national R&D agendas is most usually the implementation of large-scale demonstration projects in the field of hydrogen energy, either in stationary applications or in the transport sector. Short descriptions of significant large-scale demonstration projects realized all over the world are being also presented in the following sections.



2. Austria

Austria is one of the pioneers of the development of fuel cells in Europe. As early as the 1970s, Professor K. Kordesch of the University of Graz constructed a vehicle equipped with an alkaline fuel cell supplied with pressurised hydrogen. Austrian H₂ and FC work has primarily been “horizontal” across a number of broader R&D activities [1]. During the 1990s the Austrian R&D activities concentrated on the following main activities: Alkaline fuel cell R&D; basic R&D on DMFC; demonstration exercises of 200 kW_{el} / 230 kW_{th} PAFC ONSI power plants; and material developments of low and high temperature fuel cell systems. This work was mainly driven by industrial developments and yielded achievements such as a stationary H₂ engine-based combined heat and power plant for (commercial viable) industrial applications, and the development of H₂ storage materials (MeH) and liquid storage tank systems.

More recently, R&D activities involving AFC and PAFC have been largely discontinued, shifting now to work on PEFC, DMFC, SOFC and MCFC systems. Despite having no “specific” fuel cell and hydrogen programs, 50 ongoing H₂ and fuel cell projects are being conducted in Austria. In total, up to 40 Austrian organisations are carrying out hydrogen and fuel cell R&D activities. A key area of the country’s R&D programme includes deploying and demonstrating residential fuel cell systems (PEM and SOFC) in the near-term. Experience has also been gained with the demonstration of 230 kW PAFC power plants. Additionally, the Austrian gas industry has an initiative for testing fuel cell heating systems for residential applications using five residential fuel cell systems from Sulzer Hexis AG (Switzerland) and Vaillant (Germany). Depending on the results of these demonstration projects and the capabilities of the fuel cell system providers, major market deployment / implementation activities are expected.

The Austrian R&D is mainly driven by third party funds (i) from the Austrian R&D public and/or private funds, and (ii) from EU framework programme budgets. In total it is estimated that 7,5 Million Euro in 2003 and 7,5 Million Euro in 2004 was spent in the hydrogen and fuel cell fields. The R&D framework programs of EU, with over 20 projects, are dominating the Austrian ongoing and future activities [2].

2.1 Priorities and targets

In 2001/2002 a fuel cell strategy both for stationary and mobile/portable applications was formulated. The key recommendations of this strategy were:

For stationary/portable applications:

- Participation in International programs like the IEA Implementing Agreement on Advanced Fuel Cells,
- Increased supportive activities for the participation of Austrian R&D entities in EU-Programmes (like the RTD Framework Programmes),
- Initiation of world-class competitive Austrian R&D activities by increased usage of Austrian existing R&D instruments,



- Creation of Austrian Fuel Cell Cluster fostering public/private R&D activities/initiatives.

For mobile applications:

- Taking advantage of Austria's excellent position in mechanical engineering through the development of suitable balance-of-plant components and adequate production technologies,
- Further improvement of the strong position in the field of electromotive drive units,
- Establishing "centres of excellence" concentrating on PEM, fuel cells with circulating electrolytes and SOFC,
- Research in the field of APUs,
- Development of novel vehicles architectures and concepts.

The Federal Ministry of Transportation, Innovation and Technology (BMVIT) has now implemented strategy elements in two new R&D programme lines: (i) Austrian Advanced Automotive Applications (A3 Programme), and (ii) Energy Systems of the Future. Concerning hydrogen as an energy carrier Austria developed a new strategy at the end of 2004.

Austria, which has been a leader in developing bio-fuels for transportation, has two demonstration plants and several pilot projects dedicated to gasification, conversion and purification of biomass for hydrogen production. Additionally, research on photo-biological work, focusing on anaerobic digestion of different substrates and purification systems, has been reported. Concerning hydrogen pathways Austrian research institutions mainly focus on hydrogen production from renewable energy sources (from biogas, biomass and PV/electrolysis). Extensive modelling activities concerning the prospects of a hydrogen economy (incl. fuel cells) in the future energy system are being carried out by the International Institute for Applied Systems Analysis (IIASA).

2.2 Programme activities

Key areas of Austrian R&D activities may be summarized as follows:

- Reformer / component development of fuel cell systems fuelled by RES (mainly biogas, solid biomass, and PV),
- Demonstration projects deploying residential fuel cell systems (PEFC and SOFC),
- R&D activities for liquid hydrogen storage systems and storage hydride materials,
- H₂ gas engines already deployed in stationary industrial applications (Austria has developed a 1 kW SOFC based on natural gas),



- New private/public start-ups of DMFC research activities for portable and mobile applications, and
- APU (PEFC, SOFC) and transportation applications.
- Concerning standards, Austria developed in 2002 a pre-standard for fuel cell residential CHP systems with a heat load of up to 70 kW (OENORM M 7454; August 2002-08-02).

2.3 Budget

Austria presently uses a mix of different public/private R&D instruments to support H₂ and fuel cell activities. In total up to 50 ongoing/future activities were identified by E.V.A.* analysis ("Hydrogen and Fuel Cell R&D in Austria: Country Picture", September 2003) involving more than 40 Austrian institutions/companies. For 2003 and 2004 the total spent R&D budget for these R&D fields was estimated to be €7.5M for each year respectively.

2.4 Key players

- Federal Ministry of Transportation, Innovation and Technology (BMVIT)
- Institute for Chemical Technology of the Technical University of Graz (hosting also the CD Laboratory for Fuel Cells). Here, development of advanced electrodes for the fuel cell is in progress. This Institute also makes the fuel cell stacks and assembles the stacks with accessory equipment. Five prototype Apollo™ Fuel Cells have been made. Advanced storage systems and cycles are also part of the research activities.
- ECHEM – the Austrian electrochemical competence centre in Wiener Neustadt - is active in advanced electrode developments (incl. Catalyst research) and in high power short stack manufacturing and testing.
- Plansee AG is developing chrome-based alloys for SOFC fuel cell bipolar plates deployed in residential applications.

2.5 Other Activities

- GE Jenbacher is producing gas engines for stationary applications using process gases with high hydrogen contents for industrial applications in a power range between 100 kW_{el} and several MW_{el}. The engines achieve electrical efficiencies up to 40 % (LHV) and total efficiencies up to 90 % (LHV). The LEANOX patent guarantees NO_x emissions from these engines as low as < 5 ppm.
- Magna Steyr is developing innovative and cost competitive liquid storage tanks. The research activities concentrate in the short term on high pressure vessels and cryogen storage vessels and in the medium to long term on novel solid storage materials.

* E.V.A. is short for the Austrian Energy Agency.



- Treibacher Industrie AG is developing metal hydrides with a view to improving and optimising their H₂ storage properties for effective use in stationary and mobile energy systems.
- Austrian company, Fronius, is developing hydrogen production systems from PV via electrolysis.
- In 1997 the US company Apollo Energy Systems, Inc. started its advanced Alkaline Fuel Cell programme at the Technical University of Graz (TU Graz). The programme was directed by Dr. Karl Kordesch, who has worked on Alkaline Fuel Cells since the 1960s. The Alkaline Fuel Cell programme at TU Graz made significant improvements to the Apollo™ Fuel Cell. New electrodes were developed with over 100% more power than the previous ones. In addition, a new ammonia-based "Propulsion Fuel" was developed together with an Ammonia Cracker. This Propulsion Fuel is fed into the Cracker where it is broken down into hydrogen for the fuel cell and nitrogen. On completion of this research programme at TU Graz, Apollo Energy Systems moved the work to their technical centre in Florida, US [3].
- The Austrian gas utility companies Energie AG Oberösterreich, Wienstrom, ESTAG and SAFE are testing PEFC and SOFC residential fuel cell power plants from Sulzer Hexis and Vaillant companies.
- IIASA – the International Institute for Applied Systems Analysis is carrying-out extensive modelling efforts of a future hydrogen economy (incl. fuel cells).
- AVL is the world's largest privately owned and independent company for the development of powertrain systems. AVL is partner in a regional initiative in Styria to foster the application of Hydrogen together with partners from industry and Universities. AVL is coordinator of the FP5 project NFCCPP, member of the FCTestNet, sub-project leader in the FP6 Integrated Project FELICITAS, and a key task leader in Roads2HyCom.

2.6 Useful links

<http://www.bmvit.gv.at/>

<http://www.eva.ac.at/>

<http://www.jenbacher.com/>

<http://www.iiasa.ac.at/>

<http://www.echem.at/>

<http://www.energieaq.at/>



3. Belgium

Although there is no specific national R&D programme, Belgium is working on a number of individual projects to explore the potential of hydrogen and fuel cells, including 7 individual field projects on fuel cells. The Walloon region is particularly active in supporting a number of projects around fuel cells and related technologies including hydrogen. Belgium is also a participant in several of the EU programs. Notably, Belgium has practical experience in the area of hydrogen transport and distribution. It is home of part of the Air Liquide Industries hydrogen grid covering Belgium, the North of France and the South of the Netherlands which connects to chemical industries and oil refineries.

3.1 Priorities and Targets

A recent Belgian coalition agreement stated: “Research and development of renewable energy, decentralized cogeneration, fuel cell technology and energy-efficient technologies, will be supported, in cooperation with the regions.”

3.2 Programme activities [2]

- ProCoCo: Miniaturization and integration of a hydrogen generator with a fuel cell, supported by Walloon government - €380,000
- HYDROGEN: Hydrogen generation from natural gas and alcohols supported by Walloon government - €850,000
- GAZOPILE: Study on fuel cell feeding from wood gas generator supported by Walloon government - €500,000
- BIO-H2-FC: Biological production of hydrogen for fuel cells from organic residues, supported by Walloon government - €420,000
- SYNATEC: synthesis of multi-wall and single-wall carbon nanotubes, supported by Walloon government - €1,300,000
- Carbon Sequestration:
 - Study on the potential of CO₂ storage in the ‘Kempen’-Flanders, supported by Flemish government - €150,000;
 - Study on the influence of super critical CO₂ on reservoir rocks (PhD) - €250,000;
 - Participation to the European project RECOPOL for the enhanced coal bed methane extraction, aiming besides to identify the barriers to such developments in the Walloon Region - €150,000.
- Policy Studies:
 - Trends in vehicle and fuel technologies: for European Science and Technology Observatory - €23,000;
 - Sustainability evaluation of technologies and modes in the transport sector in Belgium - €228,000;



- Scientific judgment of the use of hydrogen as fuel for buses (esp. on environmental impact), for Flemish government - €37,000;
- HySociety: inventory and evaluation of non-technical barriers for hydrogen society, including meta-study of environmental studies, codes, policy provisions supported by EU (BE is one of 13 participating countries) - €262,000.
- NANOCELL: Nanocompounds application to design of fuel cell membranes, supported by Walloon government - €800,000.
- Set up of a fuel cell laboratory for PEM, supported by Flemish government in collaboration with JRC-Petten - €520,000.
- Methylal: research project on direct methylal fuel cell, supported by Walloon government - €400,000.
- PEMFC: Design optimization of fuel cell, supported by Walloon government - €800,000.
- Stuart Tilman Project: Establishment of Ballard stationary fuel cell, PEM of 220 kW, funded by Walloon Government and industry - €4,000,000. (demonstration).
- The Green Family: Mini fuel cell for combined energy production in domestic use, supported by Walloon government - €390,000.
- Accept: PEM stack fuelled by ammonia (via a reformer) for automotive supported by the EU (BE is one of 6 countries) - €325,000.
- ELEDRIIVE: Thematic European network on fuel cells and their applications for electric & hybrid vehicles, supported by EU - €700,000.
- Mini-UAV: Design of a Mini-UAV (Unmanned Aerial Vehicle) using a Fuel Cell Propulsion System - €100,000.
- Development of a knowledge centre on FC technology, supported by the Flemish government in collaboration with IEA - €224,000.

3.3 Budget

Belgium has allocated roughly €3.4M and €4.2M for R&D to hydrogen and fuel cell work, respectively.

3.4 Key players

- Research on fuel cells (systems) is done by the University of Liège and by Flemish Institute for Technological Research (Vito, Mol).
- Promocell is a company on field projects with fuel cells and is involved in research projects in Wallonia.



3.5 The Belgian Fuel Cells Industry

A collaboration between industrial players and research organizations was set up to enhance the innovative research on fuel cells within the Flemish region. This partnership is financed with public and private funds and started in June 2003 with 12 companies.

3.6 Other Activities

- In October 2003, Fuel Cell Technologies Ltd. (Canada) announced that it had signed a contract to manufacture and supply one of its Second Generation Series SOFC 5 kW units to the University of Liège in Belgium. By October 25, 2003, FCT's First Generation Series of 5 kW SOFC units had generated a total of over 34 Megawatt-hours of electricity [4].
- College d'Europe is among the leading centres of excellence for the analysis, discussion and study of European affairs. The newly established 'Toyota Chair for Industry and Sustainability', situated within the Department of Economics in Bruges, has the objective of integrating environmental and business issues within the European context. A particular focus is on the creation of markets for sustainable technologies and eco-efficient services, including Fuel Cells and the "Hydrogen Economy".



4. Denmark

4.1 Overview

Denmark has a strong and well consolidated R&D community, engaged in national, Nordic and European R&D activities related to hydrogen and fuel cells. The NORDIC HYDROGEN ENERGY FORESIGHT, composed of all 5 Nordic countries, was established in 2005. Energy research on hydrogen and fuel cells has, in the last five years, been supported by the National Energy Research Programme (EFP), the Public Service Obligation Funds for R&D within environment and electricity (PSO), the Research Councils, and, the short-lived, Hydrogen Programme (1999-2001).

The National Energy Research Programme has historically supported R&D projects on SOFC, while the Hydrogen Programme has supported both hydrogen and fuel cell R&D activities. A total of 34 projects with a total budget of 22.13 million euro have been approved in the period 1998-2002 – some of which have been completed while others are still running [2]. Of this total, the Hydrogen Programme was launched in 1999 in order to give priority to pre-competitive research and demonstration projects in hydrogen technologies and development and application of PEM fuel cells for both stationary and mobile applications. Also, Denmark reports the development of MCFC, primarily for stationary central or distributed power generation. More than 14 projects with a total budget of 4.8 million euro have received support from the programme. Based on these past R&D activities, a national research strategy has recently been made for fuel cells covering both SOFC and PEM. A national research strategy for hydrogen is yet to be made by the funding agencies in close cooperation with key stakeholders from industry, academia and the energy companies. So far no strategy has been made for hydrogen, but the Danish Energy Agency is currently preparing a Danish hydrogen R&D strategy together with key stakeholders.

4.2 Priorities and targets

In 2003 the Danish Energy Agency, Elkraft and Eltra published strategies for four priority fields for Danish energy research:

- Wind energy
- Biomass
- Photovoltaic
- Fuel cell (divided into two sections, one on SOFC and one on PEM fuel cells)

The Danish national research strategy for developing fuel cells concentrates on SOFC and PEM technologies and includes the following objectives:

- To maintain and develop Danish R&D at highest international position.
- To involve Danish industry in this development.
- To assure internationally competitive Danish products in terms of price, durability, environmental and technical feasibilities.
- To bring the products to the market.



- To orient R&D on fuel cells towards possible applications in Denmark and elsewhere.
- To educate researchers, technicians, engineers in the field.
- To maintain and build Danish know-how, i.e. through active patenting.

Prospects up to 2005 (based on the Strategy Energy):

- 20% reduction of Denmark's CO₂ emissions 1988-2005
- Share of renewable energy to grow to 12-14% of energy supply
- Liberalization of the electricity sector, including introduction of market for electricity trade, a special market for electricity based on renewable energy and quotas for large electricity producers
- Focus on energy savings through new comprehensive legislation, including e.g. labelling, savings in the public sector, more stringent building codes, and research & development.

The Danish fuel cell strategy is oriented towards smaller stationary power systems, i.e. 1 – 500 kW. The two types of technologies have slightly divergent application focus: SOFC technology is appropriate to larger systems with high, uninterrupted utilization whereas the PEM technology is more suitable in smaller systems. Furthermore, it is expected that the technologies can deliver rapid regulation services to the grid. The PEM technology is also expected on a longer term to be widely used in the transport sector, though this is closely related to the building of a hydrogen infrastructure. There is also some interest in using SOFC in other application areas as for example Auxiliary Power Units APU.

4.3 Selected project activities [5]

- The PSO-Eltra project: Establishment of a Pre-pilot SOFC cell production plant. As a link to the future commercialization of fuel cell technology the Materials Research Department has in collaboration with Haldor Topsøe A/S established a pilot production plant to manufacture anode supported flat plate cells at Risø. The purpose of the plant is to scale-up existing laboratory production methods, build up the necessary know-how for establishing industrial production, and to better reproduction possibilities, as well as, to analyse and develop non-destructive methods for production control. Furthermore, a high production level will enable a number of cells to be used to develop and optimise Danish cells for external recognition within fuel cell production. The participants of this project are Risø and Haldor Topsøe A/S. The project (January 2001 – March 2003) was financed by Eltra.
- The PSO-Elkraft Project: Establishment of fuel cell testing facilities. The 2-year project ended in 2002. The project was based upon Danish developed Solid Oxide Fuel Cells (DK-SOFC). The PSO-Elkraft project focuses on the following subjects:



- Development of test facilities for the long term testing of single solid oxide fuel cells
 - Long term testing of fuel cells for scale-up production
 - Improvement of reproducibility of cell manufacturing
 - Evaluation of lifetime limiting factors of fuel cells
 - Development of a test facility for the testing of fuel cell stacks fuelled with methane
 - Development of stacking techniques
 - Corrosion protection of interconnect materials
- The CORE-SOFC Project: Consortium to improve the durability of SOFC systems. The consortium of this project plans to improve the durability of planar SOFC systems to a level acceptable for commercial operation. For this purpose, identically fabricated cells will be used with dimensions applicable for commercial use and tests lasting thousands of hours. The work will focus mainly on materials selection for interconnects, contact layers and protective coatings to minimize corrosion between metallic and ceramic parts to achieve reliable and thermally cyclable SOFCs. Degradation mechanisms will be identified and solutions will be developed and tested. In addition to typical operational conditions, the limits of performance under high power density and during thermal cycling will be investigated. Especially for the anode compartment, the use of different fuel gases and fuel utilization will be of special concern by observing resulting corrosion effects on the interconnect surface under these operating conditions. In all work packages, cells and stacks will be analysed by advanced chemical and ceramographic methods.
 - The MF-SOFC Project: Scale up of a multi-functional solid oxide fuel cell to multi-tens of kilowatt levels. This programme aims to develop a new generation of affordable indigenous European Multi-Functional Solid Oxide Fuel Cells (MF-SOFCs), built from a universal MF-SOFC module fabricated by cheap processes. It serves both sub-MW standalone combined heat and power, and multi-MW combined SOFC/gas turbine cycle systems. Scale up is proposed both in rating and production volume. Addressing the challenges that this poses: reliability, durability and performance under commercial operating conditions. To solve these problems further research is required at Community level. The project ran from 2000–2003 and comprised a vertically integrated team from Rolls-Royce (UK), Risø National Laboratory (DK), Imperial College (UK), Advanced Ceramics Limited (UK), and Gaz de France (FR).
 - The EFP Project: Long term SOFC development. The purpose of the Danish fuel cell programme is to develop a technology for energy efficient and environmentally friendly electricity production. On the background of the results reached at this point by the Danish SOFC programme, together with the interest shown by Danish industry, a strategy has been developed for the commercialisation of SOFC technology. The Danish SOFC project is dealt into two parts. The first part involves a PSO financed project aimed at solving the short-term problems, which occur in the experimental development and demonstrations of Danish fuel cell and stack technology. The second part of



the project (EFP) represents a five-year plan aimed at establishing a long-term development path, leading to the reduction of the operating temperature of a fuel cell, without increasing area specific resistance. Furthermore, the project aims to better the robustness of cells, material structures and components, and partly to understand the operational relevant mechanisms, which have a special importance for the forthcoming technological breakthrough. An important part of the project is to build up 'know how' by establishing patents, which can secure a leading position for future industrial co-operation. The projects industrial partners are IRD A/S and Haldor Topsøe A/S. Academic partners are the Chemical Institute, Odense University and the Institute for Chemistry at the Danish Technical University.

- The Hydrogen Project: Hydrogen vehicle based on a Danish produced PEM fuel cell made by IRD fuel Cells A/S. The objectives of the project are to finalize the construction and thereafter to demonstrate the fuel cell driven electrical hybrid car. The car is intended for demonstrating hydrogen as a fuel in the transport sector. The project is a continuation of a previous project. The hybrid car functions as a laboratory where components and modules in the future can be upgraded with improved versions. Danish industry gets in this way an opportunity to develop and test products for the future car technology. Two hybrid cars are made, one for Fiat and one for IRD. The car is tested in the laboratory and demonstrated on a test track. Other partners are Centro Ricerche Fiat (IT) and the Folkecenter for Renewable Energy (DK).
- The EU Project: High temperature PEMFC Stack with Methanol Reforming aims at developing an integrated Advanced Methanol Fuel Cell system, based on a cost-efficient polymer membranes operating at about 200°C. The fuel cell will be thermally and physically integrated with a methanol reformer and a catalytic burner. The increased operating temperature of the fuel cell will make it possible to design a fuel cell system with improved efficiency, simultaneously reducing cost, size and complexity of the complete power system. Project partners are Volvo (SW), Technical University of Denmark (DK), Statoil (NL), NTNU (NO), University of Newcastle-Upon-Tyne (UK), and Proton Motor Fuel Cell (DE).

4.4 Budget

Total budget for realizing the strategy comes from various public support schemes:

- The National Technical and Natural Science Research Council. The annual budget managed by the Council is app. €20 million
- National Energy Research Programme (EFP) has an annual budget of app. €23 million
- Public Service Obligation Funds (PSO) has an annual budget of app. €13.5 million.
- International research programme as EU Framework programme and Nordic Energy Research.



- The annual investment in 2003 in fuel cell R&D projects was approximately €18 million, more specifically €11 million to SOFC and €7 million to PEM fuel cells. This indicates a very strong increase in R&D in fuel cells compared to the previous 20 Danish projects launched in 1998-2002 with a total budget of €14.50 million.

The venture capital market has demonstrated interest in hydrogen and fuel cell technologies. The Danish manufacturing company Danfoss A/S has recently joined the Conduit Ventures Limited ("CVL") the first European based venture capital company which focuses purely upon fuel cells and related hydrogen technologies. Danfoss A/S has added 5 million US\$ to the fund. The target group for investments is unquoted growth companies in the post seed to pre-IPO stages that develop and market different H₂/FC technologies.

4.5 EU programs

Danish research communities are well represented in European research and demonstration projects in the area of fuel cells. In the period 1999–2002, 43 projects were supported by the EU's Fifth Framework programme on Energy Environment and Sustainable Development (EESP). Danish partners were represented in 9 fuel cell projects:

- Scale-up of the IP-SOFC to multi-tens of kW Level (MF-SOFC) (Rolls-Royce Fuel Cell Systems (UK), Risø National Laboratory (DK), Imperial College of Science, Technology and Medicine (UK), Gaz de France (FR), Advanced Ceramics (FR)).
- Component reliability in SOFC Systems for Commercial Operation (CORE-SOFC) (Forschungszentrum Jülich (DE), Risø National Laboratory (DK), Energieonderzoek Centrum Nederland (NL), Haldor Topsøe (DK), Rolls-Royce (UK)).
- Pressurized IP-SOFC (PIP-SOFC) (University of Genova (IT), Rolls-Royce Fuel Cells (UK), Morgan Matroc (UK), Gaz de France (FR), Risø National Laboratory (DK)).
- Integrated Researches on Materials, Technologies and Processes to enhance MCFC (Ansaldo Fuel Cells (IT), Fraunhofer Institute for Environment, Safety and Energy Technologies (DE), Balcke-Dürr (DE), Tubitak – Marmara Research Centre (TR), Centro National de la Recherche Scientifique (FR), ENEA (IT), Consejo Superior de Investigaciones científicas (ES), KTH Tekniska Högskola (SW), Centro elettrotecnico Sperimentale Italiano (IT), EniTechnologie (IT), Electric Power Systems (IT), Technip/KTI (IT), University of Genova (IT), Rich Müller (DK)).
- 50 kW PEM fuel cell generator for CHP and UPS applications (50PEM-HEAP) (IRD Fuel Cells (DK), Gutor Electronic (CH), Energieonderzoek Centrum Nederland (NL), Johnson Matthey Technological Centre (UK), SGL Technologies (DE), HGC Hamburg Gas Consult (DE)).



- High-temperature PEMFC Stack with Methanol Reforming (AMFC) (Volvo (SW), Technical University of Denmark (DK), Statoil (NL), NTNU (NO), University of Newcastle-Upon-Tyne (UK), Proton Motor Fuel Cell (DE)).
- Development of Low-cost, High-efficient PEMFC (APOLLON) (Foundation for Research and Technology Hellas (GR), Max-Planck-Institut für Kohlenforschung (DE), De Nora Technologie Elettrochimiche (IT), Institute of Chemical Technology (CZ), Consejo superior de Investigaciones Científicas (ES), University of Patras (GR), Technical University of Denmark (DK), Frigoglass (GR), Slovenian National Institute (SL)).
- A 1kW DMFC Portable Power Generator (PORTAPOWER) (APC Denmark (DK), IRD Fuel cells (DK), Centre National de la Recherche Scientifique (FR), Uppsala University (SW), Deutsches Zentrum für Luft- und Raumfahrt (DE)).
- Thematic network on SOFC Technology (SOFCnet) (Risø National Laboratory (DK) together with 45 European partners from academia and industry).

Apart from these projects supported by FP5-ESSD, Danish partners are involved in 4 other EU fuel cell projects with a total budget of more than €8.6 million:

- Advanced solid polymer fuel cells for operation at temperature up to 200°C (Clc Srl (IT), Technical University of Denmark (DK), Foundation for Research and Technology Hellas (GR)).
- Ammonia Cracking (Intema Consult (AT), University of Rome (IT), Risø National Laboratory (DK), VITO (BE), Agrolinz Melemin GmbH (DE), Advanced Lightweight Engineering Bv. (NL), DFG-Energie Institute (DE), Graz University of Technology (AT), Netherlands energy Foundation (NL)).
- Synthesis, fabrication and characterisation of alternative anodes for direct methane oxidation in SOFC (School of Chemistry University of St. Andrews (UK), University of Aveiro (PT), University of Patras (GR), University of Twente (NL), Risø National Laboratory (DK), Forschungszentrum Jülich GmbH (DE), BG Plc (UK)).
- Advanced prediction, monitoring and controlling of anaerobic digestion processes behaviour towards biogas usage in fuel cells (Profactor Produktionsforschung (AT), Consejo Superior de Investigaciones Científicas (ES), Energieverwertungsagentur - Verein zur Förderung der Sinnvollen Verwertung von Energie (AT), University of Agricultural Sciences Vienna (AT), Matadero Frigorífico del Nalon (ES), Gascon (DK), Slovenska Polnohospodarska Uni v Nitre (SK), EBV Management GMBH & CO.KG (DE), Saria Bio-Industries GmbH (DE), Farmatic Biotech Energy AG (DE), Biogas Barth GMBH (DE), Seaborne Environmental Research (DE)).

4.6 Nordic energy research

Nordic Energy Research Programme is a Nordic institution under the Nordic Council of Ministers and is funded by the Nordic Governments. In the area of hydrogen and



consequences of climate changes for the energy sector, €2.3 million have been allocated to 6 hydrogen energy projects. Danish partners participate in all projects.

The projects are:

- Biohydrogen (Roskilde University (DK), University of Jyväskylä (FI), Tampere University of Technology (FI), University of Akureyri (IS), Norwegian Institute of Water Research (NO), University of Uppsala (SW), Linköping University (SW)).
- Hydrogen Production – electrolysis (Risø National Laboratory (DK), Helsinki University (FI), University of Oslo (NO)).
- New Metal hydrides for hydrogen storage -- (Technical University of Denmark (DK), Helsinki University of Technology (FI), University of Iceland (IS), IFE (NO), University of Oslo (NO), Uppsala University (SW), Stockholm University (SW)).
- NORSTORE (advanced hydrogen storage materials and their integration) (Technical University of Denmark (DK), Helsinki University of technology (FI), University of Iceland (IS), IFE (NO), Studsvik Neutron Research laboratory (SW)).
- Nordic and Baltic Applied Fuel cell network (Technical University of Denmark (DK), IFE (NO), Statkraft (NO), Kgl. Tekniska Högskolan (SW)).
- Nordic Hydrogen Energy Foresight (Risø National Laboratory (DK), Energi E2 (DK), IRD Fuel Cells (DK), DGC (DK), IDA (DK), VTT (FI), Wärtsilä (FI), Fortum (FI), ABB (FI), University of Iceland / Icelandic New Energy (IS), NTNU / SINTEF (NO), Norsk Hydro (NO), Swedish Defence Research Agency (SW), Vattenfall (SW), AGA (SW), Swedish Hydrogen forum (SW)).



4.7 Key players

Major public and private organizations involved in fuel cell R&D projects are:

	SOFC	PEM
Public	<p>Risø National Laboratory (www.risoe.dk)</p> <p>Technical University of Denmark, the Interdisciplinary Research Center for Catalysis (www.icat.dtu.dk)</p>	<p>Technical University of Denmark, Chemical Institute (www.materiale.kemi.dtu.dk)</p>
Private	<p>Haldor Topsøe A/S (www.topsoe.dk)</p>	<p>IRD Fuel Cells A/S (www.ird.dk)</p> <p>American Power Conversion Denmark (www.apc.com)</p> <p>Danfoss A/S (www.danfoss.dk)</p>

Risø National Laboratory is a national laboratory under the Ministry of Science, Technology and Innovation in Denmark. Within the area of energy the focus is on wind energy, fuel cells, bio-energy, energy materials and systems and technology analysis. Risø are a key task leader in Roads2HyCom.

Other key players in hydrogen related R&D activities are:

- Danish Gas Technology Centre A/S (www.dgc.dk)
- Folkecenter for Renewable Energy (www.folkecenter.dk/en/)
- Danish Technological Institute (www.danishtechnology.dk)
- University of Southern Denmark (www.sdu.dk/indexE.html)

4.8 Useful links

www.teknologiforskning.dk (site about Danish energy research)

www.h2foresight.info (about the Nordic Hydrogen energy foresight with background info on R&D activities and demonstrations)

www.risoe.dk/nej/ (Nordic Energy Index – database with descriptions on ongoing and completed energy research, development and demonstration projects in Denmark, Finland, Norway, and Sweden)



5. Finland

5.1 Priorities and targets

The hydrogen strategy is to focus on distributed hydrogen related energy systems, network with international activities (EU, IEA, Nordic) and connect with fuel cell activities in Finland.

Finland's fuel cell strategy is a bit more developed, with plans to focus on systems, fuel cell demonstrations and applications, build a close relationship with industry, creating a national fuel cell group, and networking with international fuel cell activities [2].

5.2 Programme activities

- Low temperature Fuel Cells (PEM, AFC, DMFC): The aim of the project is to improve the overall performance of low temperature fuel cell technologies studied in Finland. The technologies included are alkaline fuel cell (AFC), proton exchange membrane fuel cell (PEM) and methanol fuelled enzyme catalysed fuel cell i.e. biofuelcell (BIO). The main target of the research during the year 2003 was to verify by demonstrations the performance of the fuel cell technologies in different applications. At the moment the AFC has successively been integrated and tested in a boat (200 W) and once tested in a small-scale electric vehicle application (1 kW). A free convection PEM fuel cell (10–100W) for a portable computer application is under design and construction and a PEM module for microCHP (combined heat and power) is under construction (1,5 kW). The first BIO prototype is completed and will be demonstrated as a power unit in a mobile phone application. Participating companies: Alkomohr Biotech Ltd, EL-3 Ltd, Finnish Chemicals, Gasum, Oy Hydrocell Ltd, Labgas, NAPS Systems, Prizztech, Woikoski and Wärtsilä. Research Partners: Laboratories of Automation technology (Aut), Advanced energy systems (Ene), Physical Chemistry and electrochemistry (Fyke), Materials processing and powder metallurgy (MVT), Applied thermodynamics (Sote) and Industrial chemistry (Tek) from Helsinki university of technology, Processes group from Technical research centre of Finland (VTT) and Inorganic chemistry from Åbo akademi university (ÅA). 1 370 047 Euros10
- FINSOFC 2002 - 2006 "Business for Finnish companies": To generate sufficient know-how in selected areas; To build a sufficient platform for SOFC related research and development; To build SOFC-network between companies and research institutes; International networking and co-operation, especially within the EU; Promotion of SOFC technology and it's business potential; To generate new business opportunities for Finnish companies within FC technology. Concentrates on fuel reforming and SOFC Construction & demonstration. VTT Processes, Wärtsilä Oyj, Fortum Oyj, Patria Vehicles Oy, VNT Management, Jyväskylän Energia Oyj, Espoon Sähkö Oyj, Joroisten Energia, Helsingin Energia, Haminan Energia. 2003 budget = €1.12 M; for the 5 years period estimated volume is close to €5 M.
- DENSY (Distributed Energy Systems) programme is financed by Tekes, with the goal to grow the export income of Finland. Tekes will invest 21 billion



euros to the DENSYS programme during its five-year programme period and expects enterprises and partners to raise the total sum up to 47 billion euros. In addition to Tekes and Merinova – whose main field is energy technology - also the Finnish National Fund for Research and Development (SITRA), Finpro and the Ministry of Trade and Industry take part in the programme.

5.3 Budget

Fuel Cell R&D [6], [7]

- 2006: €6M
- 2005: €4.5M
- 2004: €4.5M
- 2003: €4M
- 95-03: €11.5M

Hydrogen [8]

- 2003: €0.68M
- 00-03: €1.4M

5.4 Key players

Research organizations

- VTT Processes -- hydrogen R&D activities
- Helsinki University of Technology (HUT) -- metal hydrides and hydrogen production
- University of Jyväskylä -- hydrogen production from biogas by fermentation
- University of Tampere -- NEFP project "BioHydrogen"
- University of Helsinki / Laboratory of Polymer Chemistry
- Åbo Akademi University

The Finnish fuel cells industry

- NAPS Systems -- Develop PV-hydrogen energy systems
- Labgas / Reijo Varila -- Develops and sell hydrogen generators for laboratories
- Hydrocell -- Develops alkaline fuel cells and metal hydride storages
- Woikoski -- Produced hydrogen gases for industrial use
- Finnish Chemicals -- Produces hydrogen as a by-product in paper chemical manufacturing



5.5 International activities

Hydrogen

- IEA Hydrogen implementing agreement
 - Production (photoelectrolytic, photobiological, hydrocarbons)
 - Storage (solid and liquid state materials)
 - Design and optimization of integrated systems
 - Finland is not participating
- EU / 6.WP / Sustainable energy systems
- Nordic Energy Forskning Programme (NEFP)
 - New metal hydrides for hydrogen storage, 0.5 M€, HUT/SoTe
 - BioHydrogen, 0.8 M€, JU, TUT
 - Integration of advanced H storage materials and systems into society, 1.2 M€, HUT/Advanced energies
- Nordic Industrial Fund
 - Hydrogen energy foresight in the Nordic countries, VTT, ABB, Wärtsilä, Fortum O&G

Fuel Cells

- Nordic Co-operation (Denmark, Finland, Iceland, Norway, Sweden)
 - Hydrogen production and storage (3 projects)
- European Union
 - SOFC Network (VTT/Processes, Wärtsilä)
 - Fuel Cell Testnet (VTT/Processes)
- OECD / IEA / Advanced Fuel Cell Implementing Agreement
 - Stationary applications development (VTT/Processes)
 - SOFC development (VTT/Processes)
 - Preparing PEM (HUT/Automation)

5.6 Useful links

National Technology Agency of Finland

<http://www.tekes.fi/eng/default.asp>



6. France

6.1 Fuel Cells

Research on fuel cells started in France in the early 1960s, mainly conducted by the major players in the energy sector before it was abandoned in the late 1970s. Research organizations such as the CEA (Atomic Energy Commission) which was familiarizing itself with PEM technology, in 1987 decided to begin research work by adapting this PEM technology to fuel cells. In 1989, the car manufacturer PSA prepared a working document for a development programme including hydrogen and fuel cells and was later joined by Renault. In 1990, the French government launched the national VPE (Clean Energy Vehicle) programme, which included technologies of the future such as hydrogen and fuel cells, and consequently French research agencies the CEA and CNRS worked in close collaboration in this field. The work was extended to other partners in 1995-2000 via the European Hydro-Gen project demonstrating a fuel cell vehicle, based on a high pressure gaseous hydrogen tank. Along with the French company Ullit, the CEA developed the first 700 bar composite hydrogen storage tank. In 1999, the Ministry of Research, in association with the Ministry in charge of Industry, created the Fuel Cell Technological Research Network (PACo network) to contribute to the French energy policy for the development of new energy sources. The purposes of the network were to foster creativity and innovation needed for the commercial development of fuel cells, to encourage public-private partnerships and to facilitate interdisciplinary cooperation. In July 2000, the same ministry decided to launch the CNRT (Centre National de Recherche Technologique) in Belfort-Montbéliard, involving the construction of a fuel cell test platform dedicated to transport applications. With fuel cell test capacities with a power up to 200 kW, this platform has recently become operational. Fuel cell activities are concentrated on two families: PEMFC (including DMFC technology) and SOFC technologies. France is developing innovative concepts for portable applications of the DMFC. The main financing bodies are (with decreasing order of involvement): the PACo network, ADEME, PREDIT, ANVAR, the DGA, and French regions (via Regional Councils), departments (via Departmental Councils) and districts.

6.2 Hydrogen

Work on production, storage and transportation of hydrogen as an energy vector was carried out in France in 1975-1980 by the DGRST under the Energy R&D European programme. Hydrogen production via high temperature processes was studied by participants including, Uranium Pechiney, Ugine Kulhmann, Citroën, EDF, GDF, Laboratoires de Marcoussis, SRTI/Creusot-Loire, CEA, IFP. In 1986, the Association Lorraine pour la Promotion de l'Hydrogène et de ses Applications (ALPHEA) was created in Forbach to evaluate Hydrogen energy potential. In 1998, the Association Française de l'Hydrogène (AFH2) was founded, bringing together all French players in this field. The Hydrogen R&D activity started again in 2001 after CEA decided to support the development of high temperature gas cooled nuclear reactors, which cover a wide variety of high temperature applications. In France, general R&D efforts deal with fuel related issues for fuel cells via the development of small reformers for on-board hydrogen production. Concurrently, the CNRS launched the programme "Energy" with different themes on hydrogen.

France, through the French Petroleum Institute (IFP), participates in the "NaturalHy" project, evaluating the possibility of using the natural gas distribution network to carry



hydrogen to the final users. Also, both the IFP and the Atomic Energy Commission (CEA) will contribute to the “Hyfrance” project, whose main goal is to build a hydrogen roadmap for France.

Numerous public structures take part in the financing, researching and development of hydrogen and fuel cells in France, using their own resources or resources either from industry or from European programmes (in particular the European Commission’s FP5 programmes). Furthermore, it has to be noted that France is engaged in important work on hydrogen for space applications in the framework of the ARIANE launchers programme but this part is not considered in the present document. The main public research bodies are: the CEA, the CNRS, the INERIS (Institut National de l’Environnement industriel et des RISques), Universities, the INRETS (Institut National de Recherche sur les Transports), the CNRT (Centre National de Recherche Technologique) in Belfort-Montbéliard and a few engineering schools (Ecole des Mines, CNAM).

6.3 Programme activities

- Production through synthesis gas generation: Air Liquide and Technip are active in this area and develop innovative options. IFP is investigating options at the different stages of synthesis gas production, hydrogen / CO₂ separation and hydrogen purification as well as developing new options for producing hydrogen with CO₂ sequestration. Alstom and IFP are involved in different studies concerning clean power generation through hydrogen production from coal or natural gas and participate in the FP6 Encap project.
- High temperature processes: the CEA, CNRS and industrial companies such as EDF and Framatome are carrying out R&D programs on massive Hydrogen production using innovative High Temperature processes. One part of this programme (CEA) is a joint programme with US DOE under GEN IV Umbrella, with Sandia and General Atomic to check feasibility and develop Thermochemical cycle in order to produce clean H₂ from Heat from future HTR nuclear plants. CEA is carrying out some experimental work on thermodynamics, kinetics, materials to characterize the chemical reactions and to determine the key points and the breakthroughs needed. The CNRS has facilities that study high temperature concentrated solar applications and possible hydrogen production from these means.
- Low or room temperature processes: R&D on Photobiological processes is carried out in CEA and CNRS in cooperation with European programs. French teams have been funded by the EU for some years by programs for artificial and natural photosynthesis within research networks involving other leading European groups – the Ru-Mn chemistry for Artificial Photosynthesis for fuel production (1996-2000) was coordinated with the Swedish Consortium for Artificial Photosynthesis. With the 6th framework programme underway, new networks are being formed. The Swedish Consortium and the French groups have brought together leading European groups from Germany, Greece, Hungary and the Netherlands to form a new network called “Solar-H: hydrogen from sun and water - a blue skies research project for a greener planet”.



- Small reformers: R&D areas include compact and low cost reformers (1-5 kW) to convert fossil fuels (natural gas, gasoline) or biomass fuels (ethanol) to hydrogen via different processes (steam reforming, partial oxidation, auto-thermal, non catalytic hybrid steam reforming), improvements in reformer efficiency, capacities and response times, and integration of a purification unit.

Examples of projects (non exhaustive):

- Opale project: reforming of fuels by POX
- Refopem project: reforming of natural gas by autothermal process in coupling with PEMFC
- Saparef projects: on-board reforming for automobile applications (APU coupled to PEMFC)
- Biostar project: reforming of ethanol with integrated purification metallic membrane

6.4 Hydrogen storage

R&D is conducted to have lightweight, low cost, and low volume hydrogen devices (storage capacity target > 6.5 wt%). Examples of projects (non exhaustive):

- Physe project: development of a new plastic-lined and carbon over-wrapped tanks (water volume of 3 litres and storage pressure of 300 bars)
- Polystock project: development of plastic lined composite tank (higher volume, development of materials for pressure of 700 bar), study of fast filling procedures
- Cash project: hydrogen storage in activated carbons

6.5 Budget

The total amount of funding provide by public entities in 2002 was estimated at 40 M€. This figure includes all subsidies provided in France by the European Union for “hydrogen and fuel cells” work, as part of the FP5 programme.

French public authorities have expressed the desire to develop these technologies more extensively, and the French Prime Minister confirmed the “Clean vehicles” plan, which should lead to additional support of 40 M€ over a period of 5 years.

6.6 Key players

- The PACo network: This network was created in June 1999 to encourage the combining of public research and industrial research in the fuel cell field and to support funding of selected R&D projects. The PACo network is guided by a high level Steering Committee which comprises leading representatives from companies, government, universities and research institutes and identifies appropriate routes for fuel cell development. Several governmental



agencies provide funding to labelled R&D projects (Ministries of Research, Industry and Transport, ADEME, ANVAR). Although focused on fuel cells, the network also deals with the question of the fuel via the development of small reformers for hydrogen production and the development of hydrogen storage technologies.

- CNRS: Of the numerous structures of the CNRS, three concern hydrogen and fuel cells -- one programme unit and two research groups (GDR) working on fuel cells.
- CEA: The main lines of the CEA programme are the production of hydrogen (thermo chemistry and steam electrolysis combined with future high-temperature nuclear reactors, biomass); storage (high pressure storage and new types of storage for portable applications, carbon nanostructures); PEM type fuel cell (components, systems, and phenomenology); SOFC type fuel cell (components and stack) and studies on the feasibility of a Hydrogen Economy (technology watch, techno-socio-economic studies, safety, etc.)
- IFP (French Petroleum Institute): IFP has been active for many years in the area of hydrogen production, transportation, storage and use. Hydrogen is also a key component for the industrial processes developed by IFP. IFP are a Work Package leader in Roads2HyCom, and have been very much involved in the JRC/EUCAR/CONCAWE "Well to Wheels" study.
- ADEME: This national agency deals with all problems associated with renewable energies, energy savings and their associated technologies. Fuel cells and hydrogen were included in its sphere of activities in the early 1990s and numerous actions labelled by the PACo network are financed by this body. In addition, ADEME provides backing for several dozen theses on the subject.

The key players in terms of financial and intellectual efforts are the CEA, CNRS and IFP.

Other players:

- Air Liquide is a French-based group, world leader in industrial and medical gases. Its core business is to supply oxygen, nitrogen, hydrogen and many other gases and services to most industries in more than 65 countries. In the hydrogen sector, Air Liquide has the largest worldwide and European pipeline networks. Air Liquide supports many Hydrogen projects and are a WP leader in Roads2HyCom.
- Gaz de France is one of the largest European gas utilities with more than 14 million customers worldwide. Since 1996, Gaz de France has had a leading role in the development and implementation of fuel cell and hydrogen technologies, in particular seeing synergy with gas distribution operations. Gaz de France is a member of Roads2HyCom.



6.7 The French fuel cells industry

The PACo network mainly contributes to the fuel cell activities of the R&D public sector. Although focused on fuel cells, the network also deals with the question of the fuel via the development of small reformers for hydrogen production and the development of hydrogen storage technologies. The main topics are:

- Small reformers supplied with different fuels (natural gas, gasoline, methanol, ethanol).
- Materials and components for hydrogen storage (gas storage, hydrides, carbon materials)
- PEMFC (also DMFC)
- SOFC
- Systems, tests, demonstrations
- Cross topics: Safety, regulations, techno-economic analyses

It is not possible to detail the 52 projects in progress in the network. Depending on topics, some examples can be given.

PEMFC: R&D areas include slightly higher temperature (120 °C) and lower cost membrane materials, resistant and low-cost catalyst materials, and long life. The technology must meet all the basic criteria for performance, durability and cost. Examples of projects (non-exhaustive):

- Ecopac project: polymer membranes prepared by extrusion
- New membranes for alkaline fuel cells (Alcapac project for microfuel cell, Palcam project)
- Alternative polymer membranes for higher temperature applications (sulfonated polyimide blends), degradation studies
- Development of CO resistant catalysts
- Micromet project: manufacturing of MEMS fuel cells with high power density
- Pactol direct project: development of catalysts working with ethanol at low temperature

SOFC: R&D areas include stack material and architecture combinations that allow effective sealing and reduction in life-limiting thermal stresses, material combinations allowing high power densities at moderate temperature, long life and reduced costs, architecture and materials that can realistically implement internal reforming. Examples of projects (non exhaustive):

- SOFC-RIP project: SOFC stack with internal reforming



- SOFC-BT project: development of materials for operation at 600-800 °C
- APURROUTE: Study of an APU SOFC for transport applications

6.8 Useful links

<http://www.reseupaco.org/>

<http://www-drt.cea.fr/>

<http://www.afh2.org/>

<http://www.alphea.com/>

<http://www.cnrs.fr/DEP/prg/Energie.html>



7. Germany

Germany has been at the forefront of hydrogen fuel cell technology development and implementation worldwide. Germany has various federally organized initiatives and numerous regional initiatives in place. There has been strong cooperation between public and private enterprises, with involvement from DaimlerChrysler, Opel, Ford, BMW and Ballard Power Systems among others. Particularly well known is the NEBUS passenger bus demonstration project. Another is the hydrogen service station at Munich airport. In Germany, intense R&D on hydrogen technologies took place between 1988 and 1995 and concentrated on the development of specific technologies (production from electrolysis and storage) as well as on larger projects to demonstrate the work supply chain (HYSOLAR and BAYSOLAR). Following this work, there are currently no projects being funded specifically for hydrogen. The "Programme on Investment into the Future" (German abbreviation "ZIP") started in 2001 to accelerate the development and deployment of key hydrogen technologies, including fuel cells, such as programs for the development and demonstration of fuel cells for residential applications (2-5kW PEM). Projects related to hydrogen technologies are currently funded under the ZIP Programme. Noteworthy state research programs include Bavaria's "Hydrogen Initiative" which is funded at €75 million and has developed the first public hydrogen refuelling station in the world. By the end of 2006, there were more than 15 hydrogen filling stations in operation. The North-Rhine Westphalia state hydrogen R&D programme is well-funded at €77 million, with a research focus on PEFC and DMFC, component, stack, reforming and systems developments; and hydrogen storage and system analysis. In addition to this programme, a new vision on hydrogen technologies has been drawn up by the Federal Ministry of Economics and Labour (BMWA) in a report delivered in 2004. Other key initiatives include the public/private Transport Energy Strategy (TES), the establishment of the Society for the Promotion of Renewable Energy (FEE), the Hydrogen Technology Initiative (2002) in the State of Mecklenburg-Western Pomerania, and the State of Hesse founded the Hydrogen and Fuel Cell Initiative in Frankfurt-Hoechst, in collaboration with universities and industry.

7.1 Priorities and targets

The Transport Energy Strategy (TES) is a joint project undertaken by the motor vehicle manufacturers BMW, DaimlerChrysler, MAN and Volkswagen and the energy supply companies ARAL, RWE and Shell along with the Federal Ministry of Transport, Building and Housing are developing a strategy to introduce alternative fuels for broad-based use in transport. The project's results indicate that hydrogen is the most promising fuel in the long term.

German companies and research centres participate in international programs such as the ECS 5th and 6th framework programs, and under these frameworks have established broad targets to develop mature and complete fuel cell systems including:

- To reduce costs to competitive level of €1,000-€1,500 kW in stationary applications and €50 kW in mobile applications.
- To improve lifetime with only minor degradation of 40,000 h for stationary and 5,000 h for mobile applications.



- To reach full capacity to compete with other technologies
- After ten years of intensive R&D a launch programme can be started, concentrating on stationary applications like block power plants and house applications, as well as mobile and portable applications.

7.2 Programme activities

Though there is no programme specialized on hydrogen, R&D on hydrogen technologies has been a key area of research under the Federal government's "Programme on Energy Research and Technologies".

Within the ZIP programme, four projects are under way on developing hydrogen-fuel cell buses including the fuelling stations. Germany has conducted intensive R&D on fuel cells over the last 10 years, concentrating on new materials, improved components and system integration.

Fuel Cells: Germany's fuel cell programme and R&D has received strong national funding, and has made notable progress in a number of key areas including production, electrolysis, and storage; development of high temperature fuel cells (MCFC, SOFC) for stationary applications; development of an MCFC system; a biogas-fuelled MCFC in cooperation with Austria; tube concept for SOFC; planar SOFC concept; development of a fuel cell system for house applications. Public funding for fuel cell activities amounts to €8-10 million annually and combined with private sector support, this yearly amount reaches €16-20 million annually. Germany is now concentrating on developing new materials and on improving components and system integration. Fuel cells have become an option for a broad application in stationary and automotive applications reducing investment costs from €50,000 kW to €10,000 kW, but still does not allow for immediate commercialisation.

- Development of high temperature fuel cells (MCFC, SOFC) for stationary applications (block power plants, 100-300 kW)
- Development of an MCFC system
- Tube concept for SOFC
- Planar SOFC concept
- Development of a fuel cell system for house applications with components made in Germany
- Further development and demonstration of 250 kW block power plants
- Demonstration of the SOFC tube concept in block power plants
- Development and demonstration of fuel cells for house applications (2-5 kW PEMFC)
- Education and technical training
- Further development of components for automotive applications



- On board reforming of fuels
- Demonstration of fuel cell buses

ZIP programme funding from 2001-2005 reached €120 million. All together, the total public (EU, federal, and state) financing comes to approximately €80-90 million/year, compared to about €3 million/year in the UK and about €25 million/year in Canada.

State-specific spending figures include:

- North-Rhine-Westphalia: Funding of hydrogen and fuel cells since 2000 reached €77 million for 42 projects, primarily fuel cells.
- Bavaria: €75 million for 30 projects, primarily fuel cells.
- Baden-Wuerttemberg: Funding of fuel cells.

7.3 Key players

- DaimlerChrysler – world leading manufacturer of a wide range of automotive products, mainly passenger cars and commercial vehicles. DaimlerChrysler have been a pioneer in the application of Fuel Cells to cars and buses, and are a key player in very many projects and demonstrations. DC are a Core Group member of Roads2HyCom.
- Adam Opel – part of General Motors, also a pioneer in the application of Fuel Cells to cars and other applications. Opel are again a key player in transport-based projects.
- Ballard (through joint efforts with DaimlerChrysler) – Canadian-based pioneer of PEM fuel cell technology, their systems have been used in many applications.
- MTU CFC Solutions
- Proton Motor
- Smart Fuel Cells
- Vaillant
- Siemens
- Celanese
- OMG
- Schunk Kohlenstofftechnik
- Süd Chemie
- Linde Gas Division



- ARAL
- Total Deutschland
- E.ON Energie
- EnBW
- EWE
- Thyssengas
- ZSW (Center for Solar Energy and Hydrogen Research)
- Fraunhofer Institut
- Forschungszentrum Jülich
- The Institute für Technische Thermodynamik
- Federal Ministry of Economics and Labor www.bmwi.de
- Federal Ministry of Transport
- Federal Ministry of Environment
- RWTH Aachen - IKA (Institut für Kraftfahrwesen) - hybrid, electric vehicles and fuel cell vehicle technology. Active in many EU funded projects, WP leader in Roads2HyCom.
- FEV - independent internationally recognised leader in the design and development of power trains, power units and burners. Active in many EU funded projects, Key task leader in Roads2HyCom.
- PLANET (Planungsgruppe Energie und Technik) - independent engineering company in the fields of renewable energies, energy efficiency and building services. Active in the field of hydrogen and fuel cells, including R&D projects, Hydrogen filling stations, Wind-Hydrogen, and WP leader in Roads2HyCom.
- AIRBUS is the major aerospace company in Europe, and is involved in R&D relating to Hydrogen in Aircraft and Airport infrastructures. Airbus are a Roads2HyCom member.
- Energie Technologie GmbH – exploiting Hydrogen technologies from the space sector, test facility engineering, construction and operation and in hydrogen and corresponding safety techniques, engaged in the Munich Airport Hydrogen Project. Roads2HyCom member.



7.4 The German fuel cells industry

It is probably fair to say that the German fuel cell industry is the market leader in Europe, not only in terms of number of companies involved and people employed, but also in showing interest through demonstration projects. More than 70 percent of today's European fuel cell demonstration units are in Germany. The strengths of the German industry as a whole lies in strong manufacturing background, the willingness of established companies to invest money, federal and state government sponsoring, a strong research background, and the preparedness to use foreign technology for demonstration projects.

7.5 Other activities

Germany is participating in the EU Hydrogen and Fuel Cells Technology Platform and is involved in the initial negotiations and meetings on the International Partnership on Hydrogen Economy (IPHE). German companies, research institutes and universities are actively participating in the EC's 6th Framework. Germany has been involved in demonstrating hydrogen technologies over the past decade including the HYSOLAR and BAYSOLAR projects demonstrating full system integration on a few hundred kW level. The "Programme on Investment into the Future" (ZIP) includes projects specifically related to hydrogen technologies, such as demonstration of infrastructure for fuel cell buses and concentrates on further development and demonstration of 250 kW block power plants, the demonstration of the SOFC tube concept in block power plants, and the development and demonstration of fuel cells for house applications (2-5 kW PEMFC).

- Under the EU project "Fuel Cell Buses for Berlin, Copenhagen, and Lisbon", the Berlin Senate coordinates the demonstration and funding of a public transport bus equipped with a Nuvera fuel cell.
- "The Clean Energy Partnership Berlin" is an alliance between the German federal government and eleven companies (with two service stations in Berlin), aiming to the demonstration of the usability of hydrogen as a fuel. The project will last four years, during which time a hydrogen filling station will be built by Germany's major gasoline distributor ARAL. Automakers BMW, DaimlerChrysler, Ford, MAN, OPEL, the Berlin public transport provider BVG, and gas supplier Linde are amongst the participants in the programme.
- Under Bavaria's Hydrogen Initiative, a "Hydrogen and Fuel Cells" exhibition is being planned for the new traffic centre at the Deutsche Museum in Munich.
- Germany is actively investigating options for producing hydrogen from fossil fuels with CO₂ capture and sequestration.
- The COORETEC research concept will be implemented over the next 20 years, exploring options of CO₂-free production of hydrogen.
- Under the EU CUTE programme, German cities Hamburg and Stuttgart built a hydrogen filling stations in order to run three Mercedes-Benz Citaro fuel cell buses up to 2005.



- Probably the biggest demonstration project in Germany, and the world, is the Sulzer Hexis residential fuel cell demonstration. The Swiss company will test up to 400 1kW solid oxide fuel cells all over Germany and some more around Europe. The systems will be managed by various utilities including EnBW, EWE, EWR, E.ON, GVM, RWE, Thyssengas, and VNG.
- The Munich Airport Demonstration project demonstrated hydrogen refuelling stations and the daily use of fuel cells in buses. Two different refuelling units, one for the refuelling of three MAN buses with gaseous hydrogen and one for the refuelling of BMW passenger cars with liquid hydrogen, were installed. MAN and Ballard performed further shipments of fuel cell buses to the project in 2004. The project finished in 2006.
- The “Innovationspark Brennstoffzelle” showcases a 250kW natural gas powered PEM fuel cell and various prototypes that can be viewed by the public.
- Other interesting fuel cell and hydrogen related projects include the launch of a fuel cell powered submarine class by the German Navy in 2003 and various stationary fuel cell systems supplied by UTC and ONSI.

7.6 Useful links

www.innovation-brennstoffzelle.de

www.h2guide.de/projekte

www.wiba.de

www.brennstoffzelle-hessen.de

www.fuelcell-nrw.de

www.dwv-info.de



8. Greece

Although Greece has no specific national plan on hydrogen and fuel cells, the topics have recently been included in the Greek national research agenda of the Operational Plan of Competitiveness published by the General Secretariat of Research and Technology of the Ministry of Development. Past research activities in Greece on these two topics have been funded primarily by EC funds.

The Greek Hydrogen Association was formed in 2000 but has not been particularly active, mainly due to a lack of funds. This changed in 2004 and the Association organized the 1st National Conference on Hydrogen as an energy carrier in September 2004. Greek public authorities related to the subject, namely the General Secretariat of Research and Technology (GSRT) and the Ministry of Development have recently taken an interest in Hydrogen as an energy carrier thanks to:

- The political support to H₂&FC demonstrated by the European Commission that led to activities like the formation of the High Level Group, the launch of the European H₂&FC Technology Platform (TP) with its various committees and instruments, the European Growth Initiative that includes H₂&FC.
- The formation of the International Partnership for the Hydrogen Economy initiated by the US.
- The formation of the Hydrogen Co-ordination Group by the IEA of the OECD.
- The pressure applied by related research institutions for Greece to take an “official stance” and actively contribute towards the Hydrogen economy at a national and European / International level.

As a result, the GSRT organized a meeting of interested parties in January 2004 in order to decide on the representation of Greece in various bodies (e.g. the Mirror Group of the H₂ & FCs TP, the participation of Greece in the ERA-NET for H₂ & FCs, etc.), in order to diffuse recent developments to interested parties and lastly in order to facilitate the preparation of a national strategy in the field.

8.1 Priorities and targets

No specific priorities and targets have been set at a national level for Hydrogen and fuel cells. It would be difficult to state that Greece has a concrete national energy policy. Priorities and targets are usually set at the level of each research or industrial “unit” and are most of the times related to the existing “market forces”, i.e. if funds are available for performing RT&D work in a certain field (a case of funds-pull rather than strategy-push). Hydrogen and fuel cells on the other hand have been included in recent national R&D programs. There are however specific features of Greece in terms of its natural resources and its industrial and academic base that could form the basis of national priorities and targets. These features would include:

- The dependence of Greece on imported fossil fuels, especially in the transport sector.
- The rich resource of renewable energy sources (sun, wind, geothermal).



- The abundance of small autonomous (not connected to the mainland) electrical grids of Greek islands and remote communities, where electrical energy is expensive and the penetration of renewables is limited for technical reasons.
- The existence of a light industry with adequate expertise for diversifying into the development and packaging of hydrogen energy technologies like electrolyzers and fuel cells.
- The existence of an active and “state-of-the-art” research community that is already contributing in hydrogen economy issues or could well diversify in this field, that has been nurtured by mostly European funds.

8.2 Programme activities

Measure 4.5 of the Operational Programme for Competitiveness was related to R&D Consortia in fields of national priority, one of them being “Renewable Energy Sources and Energy Saving”. There were 9 thematic priorities involved, one of them being Hydrogen technologies and fuel cells. Sixteen projects have been accepted for funding, three of them being related to hydrogen. Only two of them were turned into successful contracts with a total national funding of €1.5 million, covering:

- Storage of hydrogen in nano-structures.
- Development of high temperature PEM fuel cells.

A plethora of R&D activities is being undertaken by Greek research institutions in the context of EC co-funded projects. Some of these institutions have formed an informal network of laboratories the activities of which is presented below. The network has tried to support the funding of its activities through the ERA-NET scheme of the EC.

8.3 Hellenic hydrogen and fuel cell technologies network

Listed below is a list of research institutions participating in the network, along with their areas of activity in the field.

University of Patras

- Design and synthesis of materials
- Characterization of materials
- Catalyst development and evaluation
- Advanced electrochemical reactors
- Solid Oxide Fuel Cells
- Electrodes
- Reforming of fuels

Chemical Process Engineering Research Institute (C.P.E.R.I.)

- Bench and pilot plant hydrogen production units



- Solid oxide fuel cells
- Polymer electrolyte proton conductors
- High-temperature electrocatalytic processes

Center for Renewable Energy Sources (CRES)

- Development & demonstration of systems with integrated RES & Hydrogen Technologies
- Hydrogen production via high pressure electrolysis, utilizing wind energy
- Hydrogen storage technologies
- Modelling and optimization of RES&H2 systems
- CRES are a WP leader in Roads2HyCom

National Technical University of Athens (NTUA)

- Hydrogen production from waste gases
- Production of hydrogen from solid fuels
- Water-Gas-Shift reaction catalysts
- Membrane separation
- Gasification of solid fuels (syngas production for FCs)
- Simulation of advanced power systems based on FCs
- Hydrogen production and infrastructure
- Hot water boiler certification body

University of Thessalia Department of Mechanical and Industrial Engineering

- Design, construction and testing of SOFC components
- Solid oxide electrochemical reactors
- Reforming reactions

Institute of Chemical Engineering and High Temperature Chemical Processes (ICE/HT)

- Design, construction and testing of PEM FC components
- Electrochemical reactions/reactors
- Electrocatalysts for PEM FCs
- Hydrogen production by catalytic processes and water splitting

“Demokritos” (NCSR) Institute of Materials Science

- Preparation & characterization of nanostructured materials
- Metallic and metal – oxide contacts



- Preparation of thin/thick films
- Hydrogen storage

8.4 Budget

The total budget of these R&D activities is greater than €5 million.

8.5 The Greek fuel cells industry

HELBIO, Hydrogen and Energy Production Systems S.A. has planned to commercialise in 2005 an ethanol fuel processor system for hydrogen production from biomass – derived ethanol (renewable hydrogen) for stationary fuel cell applications. The target market is remote, off-grid locations and areas of inexpensive ethanol production (Brazil, India, China, Hawaii). HELBIO is also developing a reformer for Liquefied Petroleum Gas (LPG) that will be used for hydrogen production for industrial applications. This product was supposed to be commercialised in 2006* (<http://www.helbio.com>).

* Greek survey



9. Italy

Italy has invested in hydrogen and fuel cell technology development since the early 1980's. At the time, R&D activities concentrated on the development of fuel cell technologies (particularly PEMs for stationary and automotive applications), while a moderate R&D commitment was addressed towards the production of hydrogen as a sustainable energy carrier. In the beginning of 1990s, projects were carried out for the production of hydrogen from renewable energy sources and its utilization in internal combustion engines (ICE). Italy's ENEA laboratories have developed an integrated plant for the production and utilization of hydrogen. This plant (hydrogen production from photovoltaic system, hydrogen storage and hydrogen utilization on a fuel cell) has been built and tested, under the auspices of EU frameworks. In more recent years, industrial involvement has increased in the development of hydrogen vehicles, under the auspices of either national or international programs. In February 2001, Fiat introduced its first prototype of a fuel cell car called the "Seicento Elettra H₂ Fuel Cell". A more advanced prototype of the same car was presented in 2003. Both Fiat prototypes use compressed hydrogen as fuel and fuel cell stacks supplied by Nuvera. A national R&D Programme on "Hydrogen and Fuel Cells", supported by the Ministry of Research and University and Ministry of the Environment, was outlined in the framework of the National Research Plan (PNR). Furthermore, in March 2003, the Ministry of Research launched a call for proposal on "New systems for energy production and management". Italy is active in international cooperative agreements, and is at the forefront of many EC fuel cell and hydrogen initiatives.

9.1 Priorities and targets

The following areas have been identified as priorities for hydrogen as a sustainable energy carrier:

- 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 distributed generation.

The R&D priority areas related to fuel cells technologies 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.



Particularly the following targets have been set up for polymer electrolyte fuel cells (PEFCs):

	Objectives of demo phase		Long term Commercial target	
	Stationary	Transport	Transport	Transport
Stack cost, €/kW	1,000	100	300	30
System cost, €/kW	3,000	150	1,000	50
Durability, hours	10,000	2,000	40,000	5,000

And for molten carbonate fuel cells (MCFCs):

	Current Status	Objective of Demo Phase	Long-term Commercial Target
Stack Life (hours)	> 12,000*	≥ 30,000	≥ 40,000
Electrical Efficiency (%)	≥ 47.0%	≥ 49.0%	≥ 55.0%
Efficiency Using Cogen (%)	≥ 80.0%	≥ 80.0%	≥ 80.0%
Decay Rate(% mV/1000h)	1.0%	< 0.5%	< 0.2%
Production Cost (€/kW)	≥ 5,800	≤ 2,300	1,200

9.2 Programme activities

Activities in hydrogen and fuel cell field are increasing within the framework of national and European programs. Currently, around 250 people are engaged in fuel cell activities, about half of them from the industry. The definition of R&D activities, shared by public organizations (research institutions, universities) and national industries (oil companies, electric and gas utilities, research groups) is yet in progress. The main proposals submitted within the PNR Programme (FISR 2003-2005) were:

- Production
 - Hydrogen production through thermal solar (process with metal oxides/redox process) - Long term;
 - Hydrogen production through thermal solar (iodine-sulphur and UT-3 processes for water dissociation) - Transition phase;
 - Hydrogen production with ZEC (Zero Emission Coal) process - Long term.
- Storage
 - Development of innovative materials - Transition Phase / Long term;
 - Development of components and storage systems for stationary and



transport applications - Transition phase; Partners: ENEA, CIRPS, Trento University, Ansaldo Ricerche. Total estimated activity cost: ~ 20.65 M€ (for production and storage).

- CO₂ Logistics & Sequestration
 - Study of various separation and sequestration methods - Short-medium term;
 - Demonstration of CO₂ sequestration in depleted gas wells or aquifers - Short-medium term;
 - Evaluation of storage capacity in Italy - Short-medium term.
- Production, Storage and Utilization
 - Development of innovative technologies, components and systems for hydrogen production and for H₂/CO₂ separation;
 - Development of materials and systems for hydrogen storage;
 - Development of technologies, components and systems for hydrogen utilization in transport and for distributed power generation.
 - Partners: CNR Institutes (CNR-ITAE, CNR-IRC, CNR-IM), CIRPS, EniTecnologie, Messina University, Fiat Research Center, SOL, Ansaldo Ricerche. Estimated activity cost: ~ 19 M€
- Production
 - Innovative method for hydrogen production from biological processes. Activity leader: University of Padova. Estimated activity cost 10.4 M€
 - Hydrogen production from fossil fuels with CO₂ sequestration and co-production of electricity. Activity leader: Polytechnic of Milan. Estimated activity cost: 8.6 M€
- Fuel Cells
 - Development of PEFC technology, with realization of demonstration plants for stationary and transport applications through: R&D of materials and components to improve system performance and to reduce cell and stack costs; Development of fuel cell stacks with new design; Demonstration of 1-10 kW PEFC system. Partners: ENEA, Nuvera Fuel Cell Europe/DNTE, Arcotronics Fuel Cells.
 - Development of MCFC technology, with realization of demonstrative plants (125-500 kW) for stationary applications, including: R&D of innovative materials and components and of manufacturing processes suitable for mass production; Development of a 125 kW fuel cell/gas turbine system; Demonstration of a 125 kW power plant fuelled with different bio-fuels. Partners: ENEA, Ansaldo Fuel Cells Co, FN, CSM. Collaborations with CESI, Venezia Tecnologie and other research organizations (CNR and universities). Total estimated activity cost ~ 20.6 M€



- Development of fuel cell systems (PEFC, SOFC), through: Improvement of system performances and cost reduction through development of materials, components and innovative cell configurations; development and testing of fuel cell systems for transport, stationary power generation and for portable uses; Testing of demonstration plants fuelled with different fuels. Partners: CNR Institutes (CNR-ITAE, CNR-IENI, CNR-IMM), EniTecnologie, ENEL Produzione, Nuvera Fuel Cells Europe/DNTE, Pirelli Labs, INSTM. Estimated activity cost ~ 20 M€
 - Development of fuel cells powertrain for hydrogen urban vehicles. Partners: FIAT Research Center (CRF), Nuvera Fuel Cells Europe, ENEA, CNR-ITAE, Polytechnic of Turin. Estimated activity cost ~ 15 M€
 - Development of a pressurized MCFC plant and testing of a 500 kW demonstration plant fuelled with syngas at different composition. Activity leader: University of Genoa. Estimated activity cost: 9.1 M€
 - Demonstration of FC systems operating with different fuels for stationary applications and naval transport. Activity leader: Trento-Idrogeno Consortium. Estimated activity cost: 10.4 M€.
- Demonstration Programme
 - As an example of an integrated project for H₂ development in urban areas, the “Bicocca Project” can be mentioned. It has been set-up, as a demonstration project, from Milan Municipality and Lombardy Region. This Project is important because it will give valuable information on how to carry out hydrogen penetration in urban areas. This project is partially funded by the Ministry of the Environment (about 4.6 M€) with a total estimated activity cost of around 20 M€.

9.3 Current Projects

- 1999/2003 – Polymer electrolyte fuel cells for electric vehicles (50 % public financial support): Development and testing of a 15 kW power generating system using polymeric fuel cells. Activity cost: 3.150 M€ (1.725 M€ ENEA). Partners: Nuvera Fuel Cells Europe, CNR-ITAE, Polytechnic of Milan, Universities of Genova and Rome.
- 2000-2002 - Construction and testing of a 30 kW hybrid system including 5 kW polymer electrolyte fuel cell stack for propulsion purposes. Activity cost: 0.502 M€.
- 2000-2003 – Development of stack and components PEFC (1- 5 kW). Activity cost: 0.600 M€. Partner: Arcotronics Fuel Cells.
- 2003-2004 – Construction of a 1 kW stack with novel solutions and low cost; development of a fuel processing system. Stack engineering: R&D activities on crucial subjects (components and engineering). Partner: ENEA, Arcotronics Fuel Cells, Research Institutions. Systems: development of key components (fuel processing systems, controlling systems, auxiliaries);



construction of prototypes and testing. Budget: 2.88 M€ (Ministry of Research funding about 50% - FISR Programme). Partners: ENEA, Arcotronics Fuel Cells, Universities and CNR.

- Development of cell, stack and system components: Improvement of efficiency and durability and cost reduction of MCFC systems through optimization of cell and stack components; Cost-benefit analysis to overcome the technical and economic barriers to the development and deployment of MCFC. Budget: 2.6 M€ (Ministry of Research funding about 50% - FISR Programme). Partners: ENEA, Ansaldo Fuel Cells Co, CNR-ITAE, CESI, Universities of Perugia, Messina and Genova.
- Development of storage systems with metal hydrides for FCEV: R&D of novel Mg-based metal hydrides; design and engineering of a working prototype based on conventional AB₅ metal hydrides; process development and production of specialized metal hydrides (high energy density and high cyclability); bench test and in-vehicle testing. Partners: ENEA, SAES Getters, CNR-ITAE, Universities. Budget: 1.55 M€ (Ministry of Research funding about 50%- FISR Programme).
- Development of carbon-based materials (nanostructures): materials preparation and optimisation through chemical and physical characterization and molecular modelling. Partners: ENEA, ELETTRONAVA, Universities. Budget: 1.24 M€ (Ministry of Research funding about 50% - FISR Programme)

9.4 Budget

Three-year national public funding amounts to 90 M€, of which 51 M€ is available for hydrogen and 39 M€ for fuel cell development and deployment. Most related projects are cost-shared with the private sector and as such, the overall budget can be estimated at roughly 130 M€, corresponding to a yearly budget of close to 43 M€.

9.5 Key players

Key players in Italy's fuel cell and hydrogen sector span public and private entities including active participation from technical universities and research centers.

Public authorities: the Ministry of the Environment; Ministry of Production Activity; Ministry of Research and University; Regional governments (e.g. Lombardia, Piemonte, Tuscany, Veneto) and Local authorities (e.g. Municipality of Florence, Municipality Mantova, Municipality of Milan)

Public research institutions: ENEA, National Research Council (CNR) Institutes: CNR-ITAE, CNR-IENI, CNR-IMM, CIRPS.

Technical centres: CESI; Venezia technologie; also CRF (Centro Ricerche FIAT) who are developing hybrid vehicles (running with different fuels – gasoline and natural gas) and fuel cell vehicles, and are a key task leader in Roads2HyCom.

Universities: Genova, L'Aquila, Messina, Milano, Pavia, Perugia, Roma, Siena, Torino, Trento



Urban Buses Services: ATM Turin, ATAF Florence

9.6 The Italian fuel cells industry

Currently fuel cell activities are focused on the development and demonstration of various technologies including PEFCs for stationary and automotive applications; MCFCs for on-site and distributed generation; and some research on materials and components for SOFCs. A few demonstrations of phosphoric acid fuel cells were also carried out to evaluate and validate the performance and durability of small on-site co-generation systems. (including 50 kW at Eniricerche in Milan and 200 kW at ACoSeR in Bologna). A 1.3 MW demonstration plant for utility applications has been constructed by Ansaldo Ricerche, in cooperation with ENEA and AEM (the Municipal Energy Authority of Milan), and tested in Milan. However, activities were stopped in 1997 due to ongoing difficulties of reducing cost for the introduction into the market (1,000-1,500 €/kW). Carbonate fuel cells for stationary applications have been successfully demonstrated in Italy. The first hydrogen-powered urban fuel cell bus has been developed by IVECO/IRISBUS for the municipal transport authority of Turin, in 2001. The bus, in hybrid configuration, is fuelled with electrolytically produced hydrogen and equipped with a battery system. The fuel cell, supplied by International Fuel Cells, has a power of 60 kW.

International Cooperation

- PIP–SOFC - Pressurized IP-SOFC: a path to successful SOFC/Hybrids. The project's main aims are to develop a pressurized 10 kWe FC block with integral reforming and operate it with a hydrocarbon fuel representative of operation on natural gas. (FP5 – Italian partner: University of Genova).
- IRMATECH - Integrated research on materials, technologies and processes to enhance MCFC in a sustainable development. Goals: Reduce costs of MCFC through a cost reduction for materials and manufacturing processes; improve the compactness and increase the stack lifetime; minimise the environmental impact and used energy relating to some manufacturing processes. (FP5 - Italian partners: AFCo, ENEA, CESI, EniTecnologie, Electric Power Systems, Technip/KTI, University of Genova).
- TWINPACK - The purpose of the project is the design, construction and testing of a pressurised MCFC Clean Power and Heat Cogeneration Compact Plant, sized for a power output up to 500 kW. (FP5 - Italian partners: AFCo, Azienda Municipale Gas Palermo, ENEA).
- MOCAMI – MCFC/MTG hybrid power plant toward low-cost production. The main objective of the project is to develop and demonstrate a small-sized hybrid system with a combination of MCFC technology and micro gas turbine (MGT). The hybrid plant will be suitable for CHP supply at high electrical efficiency and very favourable environmental impact. (FP5 - Italian partners: AFCo, CESI, ENEL Distribuzione, Ansaldo Energia)
- FRESCO – Fuel Cell Scooter – green option for urban mobility. The main objective of this project is to prove the viability of the clean cell propulsion for small vehicles, by developing a dedicated system and by integrating it in a modern mass-production type scooter. The technological achievements



comprise a compact water-cooled PEM fuel cell stack, a super capacitor peak-power device, an innovative electric motor and traction converter allowing for regenerative braking. (FP5 - Italian partners: Piaggio&C, Selin Sistemi).

- CityCell – Fuel cell energy in cities. This project demonstrates five FC hybrid vehicles applied in the inner-city environments of Turin, Berlin, Madrid and Paris. The project is aimed at demonstrating viable “zero emission energy efficient vehicles” in response to the needs of operators, EU objectives and Commission policies. (FP5 - Italian partners: ATM Turin, Ansaldo, ENEA, Sapio, CVA.)
- PEM – ED Proton exchange membranes for medium temperature fuel cells. Goals: Development of thermally stable protonic membranes based on sulfonated polymers and on hybrid inorganic-organic systems that can be produced on an industrial scale, which will comply with the technical requirements necessary for a reliable system performance in a medium temperature hydrogen-air-PEM-FC stack. (FP5 - Italian partners: CNR, University of Perugia, Nuvera Fuel Cells Europe)
- DREaMCAR – Complete direct methanol fuel cell system. The primary objective of the project is to develop highly efficient, low emission automotive fuel cell propulsion systems that meet customer requirements in terms of cost and performance (better range, safety and reliability than conventional vehicles). (FP5 - Italian partners: Centro Ricerche Fiat, CNR)
- BIOFEAT – Biodiesel processor for on-board fuel cell APU. The expected major result is a fully tested modular 10 kWe biodiesel fuel processor for a SOFC or PEMFC auxiliary power unit (APU) for a vehicle. This will be supported by a validated design tool, which will enable scale-up to different sizes for different applications. (FP5 - Italian partners: Politecnico di Torino, Centro Ricerche Fiat, Scandiuzzi Advanced Technologies)
- BIO-H2 – Producing clean hydrogen from bioethanol. Objectives: The primary purpose of the project is to develop a complete ethanol reformer system for the production of hydrogen. The process is designed to allow easy integration with fuel cells for the production of electric power in mobile applications. (FP5 - Italian partners: Centro Ricerche Fiat, ENEA)
- CLEAN ENERGY FROM BIOMASS. The project is addressed at demonstrating the industrial feasibility of the integration of biomass steam gasification with a MCFC for clean and renewable power generation. Achieving the above objectives involves the assembly and operation of an integrated pilot plant that includes a 500 kWth gasifier, a hot clean-up system and a 125 kWe MCFC. (FP5 - Italian partners: University of l’Aquila, Ansaldo Ricerche, Ansaldo Fuel Cell, ENEA)
- HyNet – A platform for hydrogen energy in Europe. Aims: To advice the EC on hydrogen energy related research through a consortium of relevant stakeholders from industry, institutes and the regions as well as to disseminate the progress to the public via an Internet page and a European product, services and expert database. (FP5)



- HYSOCIETY – Promoting a hydrogen-based society. The main objectives are to propose an action plan to overcome the identified barriers and to quantify the technological, social, economic and environmental impacts of hydrogen in European society. (FP5 - Italian partner: ENEA)
- HyWays – The development and detailed evaluation of a harmonised European hydrogen energy roadmap. Goals: To develop the European hydrogen energy roadmap. It will comprise a comparative analysis of regional supply options and energy scenarios, including renewable energies. Results of the process will be disseminated to stakeholders and the public via internet. (IP FP6 - Status: Ongoing)
- ZERO-REGIO – Lombardia and Rhein-Main towards Zero Emission: Development and demonstration of infrastructure systems for alternative motor fuels. Specific objectives include: use of hydrogen as an alternative motor fuel, produced as primary or waste stream in a chemical plant or via on-site production facilities; development of infrastructure systems for alternative motor fuels (bio-fuel & hydrogen) and integrating them in conventional refuelling stations; showing ways and prospects for faster penetration of low-emission alternative motor fuels in the market at short and medium term. (IP FP6 - Italian partner: Lombardy Region. Status: Ongoing)

9.7 Useful links

www.ansaldofuelcells.com

www.arcotronics.com

www.crf.it

www.enea.it

www.itae.cnr.it

www.ieni.cnr.it

www.imm.cnr.it

www.nuvera.com



10. Netherlands

The Dutch hydrogen energy activities started in the seventies. However, once major natural gas supplies were discovered, the R&D on hydrogen energy decreased significantly. As of 1985 the National fuel cells programme focused on efficient and clean use of natural gas and coal-gas. Hydrogen production and conversion has been part of the activities. These activities continued under the NECST programme (New Energy Conversion Systems and Technologies) and have been extended through other parallel generic energy programmes. Separately, the Dutch energy industry is actively involved in different aspects (e.g. as transportation fuel and transition ways from a natural gas to hydrogen energy structure). In 2003, the “Hydrogen Networking” programme started which aims to stimulate National and International co-operation and programmatic tuning. In addition the public-private funded “Sustainable Hydrogen” programme has been initiated. Its objective is to stimulate hydrogen research activities at the academia level.

The public funded fuel cells research programme started in 1985. The main part of activities has been performed at the Energy Research Centre of the Netherlands (ECN). The objectives of the programme were initially oriented on the application of coal gas in MCFC based systems. The MCFC activities were terminated in 2001 after an evaluation failed to indicate its commercial viability with natural gas. Instead, the activities shifted to SOFC and PEMFC technology for high efficient conversion of natural gas in small-scale decentralized units.

Research on SOFC started in 1990 for CHP applications and PEMFC activities started in 1992; the aim being CHP, traction and portable applications. Hydrogen technology is part of these developments. Both types of systems are being actively pursued, and market opportunities are found in early demonstrations and niche markets. Furthermore the use of fuel cells and bio-gas or biohydrogen is studied.

As indicated below, extensive hydrogen activities are proceeding. Possibly, the Netherlands’ intensive experience with natural gas technology promotes these developments. An example is the study on the possible introduction of hydrogen in the natural gas grid. In this way substantial amounts of hydrogen could be introduced in the energy-infrastructure. Not only R&D institutes are active in hydrogen, also the energy industries have become strongly involved in hydrogen (e.g., Shell-Hydrogen, GasUnie). These perform their own research and participate in multiple EU co-funded and other international projects.

10.1 Priorities and targets

Current activities are performed in multiple programs. These mainly generic programmes aim at the clean and sustainable use of natural gas (so including CO₂ reduction) and the use of renewable sources. Priorities are related to the existing natural gas infrastructure and competence, in an international framework.

10.2 Programme activities

- General R&D on hydrogen. All aspects on hydrogen R&D are being covered at universities, research institutes and in the private sector. It includes: production, handling, storage, infrastructure, and its applications (including



fuel cells). Also non-technical issues are subject, including public awareness, normalization, safety, codes and standards.

- Hydrogen from biomass.
 - Many biological projects run in the Biohydrogen Platform (11 Dutch institutes, universities)
 - Various thermal and hydrothermal processes (BTG, TNO, ECN and institutes)
- Policy Studies on infrastructure considerations and transition management activities (Gasunie, ECN, CEA)
 - Fuel Cell RD&D activities.
 - SOFC and PEMFC cells, stacks, systems are being developed in relation to local generation, CHP and u-CHP (ECN, NedStack, Utilities)
- Systems field testing Siemens-Westinghouse, Sulzer, Plug-Power (Utilities)
- Participant: CUTE project (EC bus project; Amsterdam public transportation, Shell, Hoek-Loos, etc.)
- Participant: EIHP (European codes & standards ; Shell)
- Participant: NaturalHy (EC H₂ mixtures in natural gas ; Gasunie)
- HyNet (EC Industrial oriented: Shell)
- Hyways (European Road Maps : Novem, ECN)
- Fresco Hydrogen-Fuel cell Scooter project (EC project: ECN).
- Virtual powerplant EU Fieldtesting project over 30 PEMFC systems (GasUnie, Vaillant, Plug Power NL, etc.).
- In the Netherlands, activities include non-technical issues such as normalization, safety, codes and standards (TNO).

10.3 Budget

The hydrogen and fuel cells projects are mixed public-private funded and through tax incentives. No detailed information is currently available. The estimated annual budget is over €30 M, which includes about €8 to 10 M public funding*.

* "Hydrogen and fuel cell activities in the Netherlands" presentation at IEA IA "Hydrogen" October 7th, 2003, dr. H. Barten, Netherlands Agency for Energy and the Environment. File: Netherlands_Barten.ppt.



10.4 Notable activities

Hydrogen production

Intensive R&D is underway on the production of hydrogen from natural gas and biomass. Concerning biological hydrogen, a National co-operative platform has been formed with 11 institutes and universities. In addition, thermal (pyrolysis) and hydrothermal processes are being studied at multiple places.

CUTE project

The Amsterdam bus-project started in the autumn of 2003. The EC co-funded project is part of a pan-European CUTE project located in 10 cities, each testing three hydrogen-fuel cell buses and relevant infrastructure. The three Amsterdam buses are being used in the regular service.

Fieldtesting 100 kWe SOFC system (Siemens-Westinghouse)

The 100 kWe SOFC CHP test unit was installed at a Dutch cogeneration plant in 1998 as one of several units to be tested in the joint government-industry development effort. The test is being carried out at the local utility in Westervoort by NUON, which operates the system for EDB/Elsam; a group of Dutch and Danish utilities. Funding for the test is also being provided by the Dutch government agency Novem*.

The test unit, the world's largest SOFC system, has operated for a record 8,760 hours. The unit fuel-to-electricity efficiency reached 46% - significantly better than a conventional power system of this size that typically converts only 33-35% of the energy value of fuel to electric power. It supplied 110 kilowatts of electricity to the local power grid - better than its "nameplate" capacity - along with hot water to the area's district heating system. Emissions of nitrogen oxides were below 0.2 ppm, well within the most stringent of air quality standards. Sulphur oxides, carbon monoxide and volatile hydrocarbons were all measured at less than 1 ppm.

The test phase in the Netherlands has been completed; the system has been transported to Germany where it undergoes an additional test phase.

10.5 Key players

- Ministries of Economic Affairs; Housing, Spatial Planning and Environment; Transportation
- Shell: Fuel processing, Refueling, Traction (GVB: CUTE)
- Gasunie: R&D, EU Virtual power plant and "Green Gas" (NaturalHy)
- Utilities: fieldtests FC-u CHP

* Substantial additional funding in the developments by the US DoE and Siemens-Westinghouse. See full text at: http://www.fe.doe.gov/news/techlines/00/tl_sofcdemo.html



- Innovative SME's: BTG, Sparqle, Plug-Power, NedStack, Hexion
- Institutes: ECN, TNO, JRC: R&D, production, components, modelling, systems, strategic infra-structural studies:
 - ECN (Energy Research Centre of the Netherlands) – focuses on the needs of the energy industry and government in their objectives, and contributing to sustainable development of a reliable, environmentally sound and cost-effective energy sector and economy. Currently approximately 70 people are involved in fuel cell development and fuel processing activities. Research on hydrogen focuses on production of hydrogen from hydrocarbons and on end-use technologies, including mobile applications. ECN are a Core Group member of Roads2HyCom.
 - TNO (The Netherlands Organisation for Applied Scientific Research) - Industrial safety, risk management for hydrogen applications, infrastructure requirements for hydrogen and natural gas mixes, introduction and application of alternative fuels in vehicles, participant in many projects. TNO are a key Task Leader in Roads2HyCom.
 - JRC Institute for Energy - part of the Directorate General Joint Research Centre (JRC) of the European Commission - role is to support EU policies by providing independent scientific and technical reference to the Commission, the European Parliament, the Council and the Member States - hydrogen chain from production to end-use with a view to the long-term use of hydrogen as an energy carrier for electricity, transport and heat applications. JRC are a Work Package leader in Roads2HyCom.
- Universities: Twente, Delft, Wageningen, Amsterdam, Leiden, Utrecht, Eindhoven: fundamental and applied research

10.6 Useful Links

www.Novem.nl Netherlands Agency for Energy and the Environment

www.ECN.nl Energy research Center of the Netherlands

www.nedstack.com Nedstack Fuel Cells and Systems

www.hoekloos.nl Commercial gasses

www.biohydrogen.nl Dutch Biohydrogen Platform



11. Norway

The hydrogen and fuel cell related activities in Norway have mostly been parts of larger R&D programmes within the field of renewable sources of energy, with no large public programme specified for hydrogen research, development and demonstration. With respect to fuel cells, in 1990 some government funded research work was conducted on SOFC, however the major part of this activity has been terminated. More recently, there have been a few projects on FC activities funded through other energy research programmes.

The main effort during the last 5-10 years has been related to more or less fundamental and basic R&D. The basic research has mostly been related to material science with potential application, especially within membranes for fuel cells, catalysts for PEM-fuel cells, electrolyses, and materials for hydrogen storages (mostly hydrides) [2].

11.1 Priorities and targets

A recent government paper on energy and environment noted that hydrogen will be important, and will play a vital role because of its advantages when it comes to environmental impacts. Important areas of focus will be:

- Hydrogen from natural gas
- Hydrogen by electrolysis
- Storage in solid materials
- Material sciences with relevance to hydrogen related challenges
- System analysis, including safety

The plan in the current Energy R&D-programme also notes that “the programme shall contribute to the development of 3-5 technologies of products to prototype stage within the fields of hydrogen/fuel cells”. Parliament has also established a national Hydrogen Committee to define national targets to develop hydrogen as an energy carrier, identify means and instruments for added value and better environment, identify necessary participation from government and framework conditions, and propose organization, responsibility and necessary funding for a national hydrogen programme [9]. The Committee delivered a report in 2004. Additionally, the Norwegian government provides Tax Exemptions for FC and now for hydrogen combustion vehicles.

11.2 Programme activities

Project Overview [9]:

- Hydrogen Production (10 projects)
- Hydrogen Storage (6 projects)
- Hydrogen Combustion (2 projects)



- System Analysis (8 projects)
- Fuel Cells (5 projects)

Specific Project Activities (figures for public funding associated with each project are for the total project period):

- Programme EMBA: A fuel cell research element in the overall energy technology development programme plan. 2001–2006 - €200,000.
- Energy for the future: Basic research and education of Phd students - €1M.
- The Utsira project: Utsira is a small community on an island, isolated from the electricity grid and thus making it possible to demonstrate an autonomous energy system. The project consists of using a wind turbine to produce electricity. Excess electricity is used to produce hydrogen by electrolysing water. The hydrogen is then stored, and used as backup by producing electricity from a hydrogen combustion engine (later FC) when there is no wind. The installation was ready in 2004. €1.7M in public funding. Total cost is far higher.
- Hydrogen for gasification PhD study and integrated SOFC and biomass gasification: Overall objective is to identify a process to gasify biomass and receive hydrogen with a purity sufficient for SOFC using a sand filter - €0.58M
- Photobiological production of hydrogen - €0.56M
- Chemical / Metal hydrides: This is an important area in Norway and there is a substantial effort being put into this area. There are 5 different projects going on with different approaches. However they are all related to metal hydrides - €3.3M
- Alanates: This is a joint postdoctoral project between the Institute for Energy Technology and the Physics institute, University of Oslo - €0.17M
- Carbon nano-tubes: This is a postdoctoral project at the Institute for Energy Technology and the Physics institute - €0.18M
- In addition there are 5 projects covering different aspects of system challenges when integrating hydrogen technology into an energy system. Important objectives are: Safety codes and standards; Dynamic behaviour of fuel cell systems; Evaluation of demonstration projects - €1.69M
- Electrochemistry: Presently 2 projects going on (one recently terminated but accounted for budget vice). Major focus on material science related to membranes/proton conductors. Topics are hydrogen separation membranes; proton conductor; fast oxygen and proton conductors - €0.39M
- PEMFC: The effort on PEMFC is mostly at the NTNU in Trondheim. The activity is presently concentrated around 2 projects with a total funding of 1,8 MNOK. The major objectives are two-fold: develop alternative catalysts or



processes reducing the use of platinum as a catalyst; fundamental research on reversible PEMFC / Electrolyser - €0.25M

- SOFC: One activity is on solid oxide fuel cell technology (SOFC) project is to open up for offshore production of oil and gas without CO₂ emissions to the atmosphere. Another activity is concentrated on improving the working efficiency and competitiveness of SOFC fuel cells for power generation with natural gas. The third R&D activity on SOFC is related to filter mechanisms for cleaning H₂ from gasified biomass to reach the sufficient purity - €2.67M

11.3 Other activities

Projects from the 5th EU Framework [2]:

- HyNet (Industry collaboration) (Norsk Hydro)
- HySociety (Social scientific – routes and barriers) (Sintef etc.)
- Renewable Islands (Hydro)
- EIHP (European Int. H₂ Project) (Hydro)
- Renewable Hydro (AC) (Hydro, with Peter L. etc.)

Projects from the 6th EU Framework:

- Hyways (Roadmaps for Europe) (Veritas, Hydro, Statkraft, VF)
- HySafe (Safety) (Norske Veritas, Hydro, GexCon)
- StoreHy (H₂ Storage) (IFE)
- NATURALHY (H₂ in N.G. system) (Statoil, Bellona, NTNU)
- New-H-Ship (F.C. with H₂ in ships) (Sintef, Veritas etc.)

11.4 Key Players

Norsk Hydro is a leading energy and aluminium supplier, and the world's fourth largest offshore producer of oil and gas. Hydro is also at the forefront of wind and hydrogen energy production. Hydro is engaged in a number of projects related to hydrogen and fuel cells and is involved in the planning and execution of several demonstration projects for transportation and for the stationary use of hydrogen and fuel cells. Hydro is a key task leader in Roads2HyCom.



11.5 Budget

Total project funding (over project lifetime).

- Fuel Cells: €5.36 M
- Production of hydrogen: €6.43M
- Hydrogen storage: €3.71
- Hydrogen combustion: €0.24M
- Hydrogen systems analysis: €3.14

11.6 Useful links

www.emba.no



12. Russia

Federal Republic of Russia participates in the International Partnership for Hydrogen Economy and has set its short-term R&D goals. Russia has initiated the Federal target scientific and technical programme “Studies and developments in priority trends of science and Technique development” (2002-2006), where hydrogen technologies have been incorporated. According to this programme the main targets of Russia for R&D in the field of hydrogen are [17]:

- Effective hydrogen production, including production from hydrocarbons in stationary and transport systems
- Systems of storage and transportation of hydrogen on the basis of hybrid systems, metal hydrides and composite nanostructural materials
- Power systems on the basis of solid oxide fuel cells
- Hydrogen combined cycle and steam electric generating plants
- Portable fuel cells
- Problems of hydrogen security, development of rules, codes and standards of security
- Hydrogen production from renewables and nuclear reactors

12.1 Government and Private partnership

- 3-year collaborative “Norilsk Nickel” corporation and the Russian scientific organizations programme
- Joint working programme between the company “Gasprom” and the Russian Federal Agency on Atomic Energy

12.2 Universities

Five Russian universities perform training of specialists (students, postgraduate students, scientists) in the field of “Hydrogen and Electrochemical Energy”

12.3 Specialised journals

- Electrochemical Energy
- Alternative Energy and Ecology

12.4 International Scientific and Technological Cooperation

- 6th Framework Programme on Research and Technological Development for 2002-2006
- “Fuel Cells Initiative” of the International Science and Technology Centre



- Joint Programme of the Russian Ministry of Atomic Energy and the US Department of Energy on high temperature reactor with helium heat carriers (programme NE-2010)
- Civilian Research and Development Foundation (CRDF) programme

Kurchatov Institute (Cortes) is supporting the Roads2HyCom project. The leading state national research centre for Nuclear energy, supporting research into Nuclear-Hydrogen energy chains including Electrolysis and Thermal reactions.



13. Spain

Spain initiated activities in hydrogen and fuel cells research in the early 1990s, and continues to focus its work in the areas of hydrogen production (particularly from photovoltaic powered electrolysis), hydrogen storage (tested in compressed gas cylinders and metallic hydrides), the development of materials for MCFC and PEMFC, fuel cell design (validation of 2.5 kW PEMFC) and fuel cell testing for AFC, PEMFC, PAFC and MCFC stacks and components. At present there is not a specific programme devoted to hydrogen energy and fuel cells in Spain. However the Spanish Plan for Scientific Research, Technological Development and Innovation (2004-2007) in the energy area will consider these topics as separate items included in the priority devoted to renewable energies and emerging technologies. This means that part of the R&D budget will be allocated for hydrogen and fuel cells projects but competing with the rest of renewable energies projects. There are no policy analysis or projections for Spain, nor a roadmap. However, Spain has participated in the foundation of the High Level Group for Hydrogen and Fuel Cells, and, as a consequence, is taking part in the design of a European Hydrogen Roadmap and in the EU H₂ and FC Technology Platform. In addition, Spain has representatives working in the European projects Hynet and HySociety, with the objectives of analysing and facilitating the introduction of hydrogen in to the European Society. The most relevant contributions have been the construction and operation of a 100 kW MCFC stacks; the industrial hydrogen production plant based in the utilization of coal in IGCC (Integrated Gasification Combined Cycle), owned by ELCOGAS and sited in Puertollano (Central Spain). The level of involvement of Spanish car industries is clearly increasing, as well as other industries including industrial gas, utilities and renewables players. Up to the present, the Spanish industries have taken part as partners in European hydrogen and fuel cell European projects. Currently, this participation is growing as Spanish Research Centres and the private sector are coordinating some major European projects.

13.1 Priorities and targets

The following areas have been identified as priorities for realizing the potential of hydrogen and fuel cells:

- Production: Without CO₂ emissions, from water, employing electrolytic methods (with renewable energy or nuclear) or another emerging as photoelectrolysis, photobiology or biomimetic and from renewable or fossil (preferably with CO₂ sequestration) raw materials by means of reforming process, partial oxidation, gasification or others.
- Storage: Compressed, liquid or through metallic hydrides and carbon nanotube structures.
- Distribution and final supply: Utilization of existent and new infrastructures, distribution methods and end supply installations.
- Standards and specifications for equipment, safety and product quality.
- Putting into operation pilot and demonstration installations of integrated systems based on hydrogen.



- Development of other fuels for feeding fuel cells (natural gas, methanol, bioalcohols, oil fractions etc.) relative to profitable and clean production, purification and infrastructure development.
- With regard to low temperature fuel cells (PEM), efforts must be guided to materials development (catalysts, electrodes, electrolytes, plates, seals, etc), fuel cell components development and their manufacturing methods, fuel cell prototype development, systems based on fuel cells for transport, stationary and portable applications, and fuel processors.
- High temperature fuel cells (solid oxide and molten carbonates): efforts must be guided to materials development (catalysts, electrodes, electrolytes, plates, seals, etc), fuel cells components development and its manufacturing methods and fuel cells prototypes development.
- Utilization of fuel cell systems for cogeneration, distributed or centralized electric generation, integrated with renewable energy, as auxiliary power units, as motor source for transport, etc. and development and validation of simulation tools for fuel cells systems analysis by computational methods.

13.2 Programme activities

- The most important market introduction initiatives have been taken by Madrid and Barcelona Urban Transport Enterprises, which have allowed buses to run on hydrogen in Madrid and Barcelona. These buses are part of the demonstration of the CUTE (Clean Urban Transport for Europe) project and the CITYCELL project (proposal). Moreover, Madrid was the first city to which a CUTE project bus has been delivered.
- Development and construction of an urban bus for Madrid with hydrogen fuel cell: The main scientific objective is the demonstration of the technical and economic viability of an advanced fuel cell propulsion system combined with innovative vehicle concepts for public transport application. September 2000 - January 2004, PROFIT (Technical Investigation Promotion Programme), €4.300.000 [2].
- Mini Electricity Generation with SOFC: Development of 1 to 2 kW SOFC for application in distributed generation. The process for hydrogen production is natural gas steam reforming. January 2001 - December 2003, €2.113.000 [2].
- ESH2: Hydrogen Refuelling Station in Madrid: Demonstration of viability of hydrogen supply in refuelling stations with on site production of hydrogen from natural gas reforming. February 2002 - December 2005, €2 .021.000
- H₂ Refuelling station in Barcelona: Electrolysis production of hydrogen, which will be stored and supplied at high pressure to 3 buses participating in the European CUTE project. It will be the first hydrogen production plant endowed with a solar photovoltaic system, which will produce 10% of electricity needs, so 90% of the electricity needed to produce hydrogen with electrolysis shall be supplied by the grid. January 2002 – December 2005, €2 million



- DICCOM – FC Development in Izar: Production of power and heat with 250 kW MCFC for utilization in motor factory. January 2003 – May 2005, €1,529,000
- Fuel Cells for Defense Application: This R&D Fuel Cell Programme for defence applications has the main objective of analysing the current fuel cells and reformers state of the art, as well as to analyse and promote their integration in mobile and stationary applications for defence. During 2004 the diesel reformer development will be completed and the construction of the ethanol reformer will start. The design tools will be improved with the results obtained during 2003 and then they will be applied to the fuel cell test benches. January 2003 - December 2006, €1,867,000
- MIGREYD - Modular IGCC concepts for In-Refinery Energy and Hydrogen Supply - Goals: production of hydrogen and enhancing the competitiveness of IGCC (Integrated Gasification Combined Cycle) power plants focusing on applications based on refinery residues. Achievements: Clean and affordable co-production of Hydrogen from residues at IGCC Power Plants. Optimisation of the integration of an IGCC in a refinery. Refineries CO₂ emissions reduction. Co-gasification of biomass in IGCC plants. Coupling of gasification with SOFC fuel cells. Time plan: June 2003 – June 2006. Current status of the project: in progress
- EXPERT AUTOTHERM: Development of 75 kW methanol reformer for working with 75 kW PEMFC integrated in automobile vehicle. Goals: Serial production of 75 kW methanol reformers with unity cost of €1200, CO content under 100 ppm and space requirements of 0,7 kW/litter. Time plan: January 1999 – September 2005.
- Development of hydrogen production model via electrolysis from wind energy. 329.053a.
- R+D for hydrogen production for its utilization in fuel cells, based in Syngas obtained through gasification process. 2.022.685a
- BIOCELL: Bioethanol utilization as fuel for fuel cells. Goals: Analysis, definition, design, engineering and development of a power generator prototype system based in bioethanol reformer, hydrogen conditioning, PEMFC, output power (10 kW) conditioning and overall control system. Time plan: April 2002 – October 2005.
- BIOPLASMA: Development of bioethanol to hydrogen conversion reactor through low temperature plasma. Production of hydrogen using plasma. Goals: optimisation of the process. Time plan: April 2002 - April 2004.
- Biohydrogen: Hydrogen production by fermentation using wastes. Goals: develop a new process for energy recovery from wastes using fermentation technology. Time plan: January 2003 – December 2004. Current project status: Analytical and experimental critical functions identified.
- CRYOPLANE: “Liquid Hydrogen Fuelled Aircraft-System Analysis”. Goals: A large consortium of companies, research institutions and universities of 11



European countries, co-ordinated by DaimlerChrysler, Aerospace Airbus GmbH, in which the Spanish participation was held by CASA and the Polytechnics University of Madrid. The project objective considered liquid hydrogen as the only known fuel suitable for aviation to be produced from renewable energy sources and offering extremely low pollutant emissions. The project has assessed all relevant aspects: configuration, architecture, engine concepts, airport infrastructure definition, transition scenarios. Time plan: 2000 – 2002.

- SIDMT: Metal Hydrides Manufacturing. Goals: Increase the Hydrogen content in the Metallic Hydrides. Synthesize Metallic Hydrides by conventional techniques and by Self-propagation High Temperature Synthesis. Time plan: January 2003 – December 2004.
- Nanotechnology and its application to hydrogen storage: Goals: Opportunity identification for industrial production of hydrogen storage equipment. Time plan: October 2002-September 2003.
- Hydrogen Storage by adsorption in nanotubes and molecular sieves. Goals: Big scale production of carbon nanotubes by catalytic decomposition of hydrocarbon materials over nanostructural metallic surfaces, and determination of its hydrogen storage capacity. Alternatively, it will be also studied the hydrogen adsorption capacity of carbon molecular sieves, in some cases drugged with alkaline elements. Time plan: February 2001-January 2004.
- Research, development and exploitation of SOFC. 425.000a
- Development of new methods for catalysts application over electrodes for fuel cells. 82.939a
- New solid electrolytes with high electric conductivity from polymeric nanofoams. 112.000a
- PEM 500: Research, development and manufacturing of 500W PEMFC. Goals: Research, development, manufacturing and distribution of PEM fuel cells, until a maximum power of 2 kW. Time plan: January 2003 – December 2005.
- Pilot plant for technological components development for fuel cells. 1.794.967a
- TELEPEM: Design and experimental validation of experimental PEMFC up to 1 kW for telecommunications. 1.053.788a
- COPICO-GAS: Development of a domestic cogeneration system based on the use of fuel cell using natural gas as raw fuel (PEMFC). Goals: foster the use of fuel cell as residential energy source, by developing an optimum system for the energy provision from the use of natural gas. Time plan: April 2001 – December 2003. 901.520a.



- Technology development of 5 kW PEMFC integrated with reversible heat pump and photovoltaic field. Goals: Development of 5 kW PEMFC, with water refrigeration and fed with pure hydrogen. Pilot plant with PEMFC, heat pump water-air and PV panels for powering air conditioning and electric installations owned by CARTIF Technological Centre in Castilla y León. Development of regulation and control modules. Trials, characterization and optimization of system. Time plan: June 2001 – September 2003. Seeking partners for collaboration and investors for techno – economic assessment.
- Development of a 50 W DMFC for portable applications. Goals: Construction and evaluation of a 50 W DMFC Prototype, scalable for use in portable computers, phones, videos, etc. Achievements: It was finally not possible to construct it because of problems found in components development. Time plan: July 2001- April 2003.
- FEBUSS Fuel Cell Energy Systems Standardized for Large Transport, Buses and Stationary Applications. Goals: Fuel Cell Energy Systems Standardized for Large Transport, Buses and Stationary Applications. Time plan: 1/2002 - 12/2006. 85.500a
- Design and Demonstration of safety and competitive use of residual hydrogen for combined cycle energetic optimisation. Goals: Achieve 70% of energy efficiency in a natural gas combined cycle with supplying residual hydrogen from propane dehydrogenation (to produce propylene) to the recovering boiler. Current efficiency is 50%. Time plan: 2000-2003.
- Hydrogen for Pamplona City Buses Goals: Electrolytic production of hydrogen that shall be utilized in Internal Combustion Engines of buses in Pamplona city. The electricity was supplied from the grid. Time plan: July 2003 – June 2005

13.3 International cooperation

- Since 1995, Spain has been a member of the Hydrogen Implementing Agreement of IEA, as well as of the Advanced Motor Fuels Implementing Agreement. Moreover, it has participated in the foundation of the European High Level Group for H₂ and FC, and is also participating in the EU H₂ and FC Technology Platform.
- FIRST – FC Innovative Remote system for Telecom. Photovoltaic powering systems are used in telecom applications when AC Mains is not available due to reliability and simplicity reasons. However, solar powering systems have the problem of sun radiation unpredictability, and relatively high cost and size. These problems could be solved using fuel cells in combination with solar powering systems improving power availability and reducing size and cost (this last parameter in medium term following the European Commission predictions). The main objective of this project has been to reduce cost and improve availability by taking advantage of the fuel cell performances (very high energy density, zero emission, soundless, simple, modular, portable and potentially low cost in a medium term) for powering remote telecom equipment. March 2000 – February 2004, European Commission, €722,000.



- RESH2 – Cluster Pilot Project for the Integration of RES into European Energy Sectors using Hydrogen. The main objective of the project is the integration of RES, hydrogen production and utilization into energy sectors. This is currently being done by designing, constructing and evaluating self-sufficient energy systems driven by wind energy, capable of generating hydrogen, electricity and water making use of the features of hydrogen as an energy vector. There are two demonstration sites: Spain (Canary Islands) and Greece. January 2002 – October 2007.,€5,360,000.
- CEXICELL - Development of Cost Effective and High Quality Planar Solid Oxide Fuel cells by Using Advanced Thermal Spray Techniques. The aims of the project lies in developing Solid Oxide Fuel Cells (SOFC) stacks by using advanced spray techniques never used so far to develop SOFC cells elements. These techniques are: 1) High Velocity Oxi-Fuel Spraying (HVOF); 2) High Frequency Pulse Detonation Spraying (HFPD); 3) Suspension Plasma Spray (SPS); 4) Triplex Atmospheric Plasma Spray (Triplex APS). These deposition techniques will be used within this project to deposit the various layers in planar SOFC. October 2002- October 2005, €3,030,000
- HyNet - European Thematic Network on Hydrogen Energy. Goals: Advise the EC on hydrogen energy related research through a consortium of interested and relevant stakeholders from industry, institutes and the regions as well as to disseminate the progress to the public via an internet page and European product, services and expert database. Time plan: 2/2002 - 2/2005.
- HySociety. Goals: Propose an action plan to overcome the identified non-technical barriers and to quantify the technological, social, economic and environmental impacts of the introduction of hydrogen in European Society. Time plan: 2/2003 - 2/2005.
- European Integrated Hydrogen Project - Phase II.EIHP2. Goals: Provide inputs for regulatory activities on a EU and global level to facilitate harmonized procedures for the approval of hydrogen fuelled road vehicles (with both internal combustion engine and fuel cell drive trains), hydrogen refuelling infrastructure and the relevant interfaces between the vehicle and the filling station. Time plan: 2/2001 - 1/2004. The results include the determination of optimum hydrogen storage pressure for single deck city buses and the guidelines for hydrogen refuelling stations.
- Advanced PEM Fuel Cells. APOLLON. Goals: Development and construction of Advance polymeric fuel cells which will be able to operate under H₂ and/or methanol fuels, aiming to thermodynamic efficiencies exceeding 50% with power densities of the order of 1W/cm² and significantly reduced manufacturing cost of the membrane electrodes assembly. Time plan: 12/2001 - 12/2004. Current Status of the project: completed. The results include the development of a nanoparticle colloidal method for catalyst preparation.
- AMONCO. Advanced Prediction, Monitoring And Controlling of Anaerobic Digestion Processes Behaviour Towards Biogas Usage In Fuel Cells - Target Action H. Goals: A knowledge based Decision Support Tool (DST) with the capability to predict trace gases in dependence of the fermented substrates



and a cost-effective Cleaning Process removing the significant trace gases must be developed. Time plan: 12/2001 - 12/2004.

- FCTESTNET. Goals: Fuel Cells Network for Tests and Standardization. Time plan: 2/2003 - 2/2005. The results include the establishment of common measuring criteria and the development of further methodologies.
- For DMFC, University of Alicante participated in two projects co-ordinated by the University of Poitiers and the National Centre for Scientific Research (CNRS) in France. For SOFC, CSIC-ICV collaborated in one project co-ordinated by the National Polytechnic Institute of Grenoble (France).
- Coal gasification: ELCOGAS participated in a European project with its the industrial hydrogen production plant based in the utilization of coal in IGCC (Integrated Gasification Combined Cycle), sited in Puertollano (Central Spain).
- Methanol reforming: the University of Barcelona co-operated in this project coordinated by Ansaldo Ricerche Srl involving research into heterogeneous catalytic reactor for methanol partial oxidation and theoretical and experimental studies for a compact hydrogen generator. CSIC-ICP concurred to these two projects, the first one coordinated by the national Council of Research (CNR) in Italy and the second one co-ordinated by Advanced Technology R&D Srl in Italy.
- Industrial development: Construction of 100 kW MCFC Plant located in San Agustín de Guadalix (near Madrid), with the participation of Ansaldo, ENEA and ITAE in Italy and the Spanish partners Iberdrola, Endesa and Babcock & Wilcox. This test facility is unique in Europe.
- Development of 1 kW reformed methanol fuel cell, carried out by CIEMAT, CSIC and SEAT in Spain with the participation of KTH (Sweden) and UTAD (Portugal).

13.4 Key players

Public research institutions:

- CIEMAT: Research Centre for Energy, Environment & Technology www.ciemat.es
- CSIC: High Council for Scientific Research.
 - IAI: Institute for Industrial Automatics (www.iai.csic.es)
 - ICP: Institute for Catalysis and Petrochemistry (www.icp.csic.es).
 - ICV: Institute for Ceramics and Glass (www.icv.csic.es).
 - ICTP: Institute for Polymers Science and Technology (www.ictp.csic.es).
- INTA: National Institute for Aerospace Technology (www.inta.es)



Technological centres:

- CARTIF: Centre for Automatics, Robotics, Information Technology and Manufacturing (www.cartif.es).
- CIDAUT: Centre for Automobile R&D (www.cidaut.es)
- CIDETEC: Centre for Technological Research in Electrochemistry (www.cidetec.es)
- IKERLAN: Basque Foundation for Development of Energetic Technologies (www.ikerlan.es)
- INASMET: www.inasmet.com
- ITC/ITER: Technological Institute of Canary Islands (www.itccanarias.org).
- NTDA: R&D in the field of SOFC; integration of hydrogen/fuel cell systems with wind and solar generation as well as with cogeneration systems; planning of hydrogen infrastructure development at regional and local level. NTDA are highly active in European and local activities, and a core group member of Roads2HyCom.

Universities:

- Alicante
- Barcelona
- Burgos
- Cantabria
- La Laguna (Canary Islands)
- Rey Juan Carlos
- UPM (Politécnica Madrid)
- UCM (Complutense Madrid)

Public Entities and non-profit institutions:

- IDAE: Institute for Energy Savings and Diversification (www.idae.es)
- Regional/Provincial Energy Agencies:
 - Basque Country: www.eve.es
 - INEGA: Galicia Energy Institute (www.inega.es)
 - Huelva: www.apeh.org

Urban Buses Services:

- EMT (Madrid): www.emtmadrid.es
- TMB (Barcelona): www.tmb.net



Foundations:

- FAEN: Asturias Energy Foundation (www.faen.info)
- FITSA: Foundation for Technical Research on Automobile Safety

13.5 The Spanish fuel cells industry

Moreover there are more than 40 private companies participating in hydrogen and fuel cell technologies.

In addition, the Spanish Hydrogen Association has been set up in 2002 and is already member of the European Hydrogen Association. Also it has being constituted the Spanish Association for Fuel Cells and a Scientific Thematic Network for Fuel Cells.

13.6 Other activities

Public information initiatives:

- Spanish Hydrogen Association: www.aeh2.org
- High Council for Scientific Research Fuel Cells Network: www.csic.es/redes/pilas/pilasc.htm
- Spanish Association for Fuel Cells.: www.appice.es

13.7 Useful links

www.aeh2.org

www.csic.es/redes/pilas/pilasc.htm

www.appice.es

www.basf.es

http://www.irisbus-iberica.es/notes/art_310303-02.html

<http://www.energias-renovables.com>

<http://www.izar.es/cgi-bin/pye.dll/propulsion/jsp/home.do>

www.inta.es/first

www.hyweb.de/pro/



14. Sweden

A number of initiatives have been taken by different public and private sector actors; however there is no national programme or strategy for hydrogen related activities existing in Sweden today. Nevertheless, the Swedish National Energy Agency has pointed out hydrogen and fuel cells as one of the strategically important areas for governmental funding in the future and is actively involved in funding fuel cell and hydrogen-related projects.

Past activities in the area of hydrogen related projects have until now been entirely government supported, but today there is increasing support from industry for scientific and technology R&D. The only large-scale programme is the consortium for artificial photosynthesis, which is a consortium between several Swedish Universities. The project is focusing on basic R&D the Energy Agency has created a reference committee representing industry to support the more applied side of the programme

14.1 Priorities and targets

The Swedish National Energy Agency has set a 2006 target to reform hydrogen and oxygen from water with sun energy through artificial photosynthesis.

14.2 Programme activities

- Under the Swedish Consortium for Artificial Photosynthesis, the University of Uppsala, Peter Lindblad (photo biological hydrogen production) and Sten-Eric Lindquist (photoelectrochemical production of hydrogen), and KTH, Björgvin Hjörvarson (storage of hydrogen) cooperate to develop an educational exchange between students at the different faculties. Since 2003, this programme includes photo biological hydrogen production from cyano bacterias.
- Sweden has several R&D programmes related to stationary and transport fuel cell applications. Much of the government activity has been in cooperation with the automobile industry (Saab and Volvo), which is highly knowledgeable of system analysis, components and small-scale niche markets. Examples of successful Swedish experiences in small-scale enterprises are Opcon Autorotor (compressor systems for fuel cells in vehicle) and Catator (small scale reformer for natural gas).
- The ongoing programmes related to fuel cells in Sweden are basic research programmes that are a part of larger energy research programmes on PEMFC, SOFC and MCFC applications. Research is also being conducted in power systems in vehicles, hybrid vehicles, combustion engines, and “green cars” applications.

14.3 Key players

- The Swedish National Energy Agency: <http://www.stem.se/english>



- Volvo Technology Corporation (VTC), developing road transport technology including Fuel Cell / Hydrogen applications for trucks. VTC are a member of Roads2HyCom

14.4 The Swedish fuel cells industry

- The University of Lund and the Royal Institute of Technology Stockholm (KTH) cooperating to improve knowledge of stationary fuel cells (programme funding from the Swedish National Energy Agency). Elforsk, the research organization for the Swedish power producing industry, is coordinating the programme.
- Batteries and Fuel Cells for a Better Environment: the Chalmers University of Technology Gothenburg and the Royal Institute of Technology Stockholm are conducting research that is being funded by Mistra, The Foundation for Strategic Environmental Research.

14.5 Useful links

<http://www.biokem.lu.se/AFS-WWW/index.htm>

<http://www.fos.su.se/%7Edag/>

<http://www.elforsk.se/varme/varm-bcell.html>

<http://fuelcell.mvs.chalmers.se/>



15. Switzerland

In the Swiss National Energy Research and Development Programme, hydrogen is considered as one of the most important future secondary energy carriers as well as an economically important chemical commodity. Consequently, the Swiss authorities continue to support activities for the sustainable production, safe storage and efficient use of hydrogen. The latter also includes fuel cells, which may become an important component in future energy supply systems. Switzerland has been engaged in hydrogen and fuel cell development for roughly 25 years. The work has focused on:

- **Hydrogen production**

Topics investigated include high pressure electrolysis of water using Switzerland's extensive hydropower, thermo-chemical splitting of water using a high temperature metal/metal oxide redox cycle driven by concentrated solar radiation, and room-temperature generation of hydrogen by the photo-catalysed splitting of water using solar radiation via the so-called tandem-cell. In addition, hydrogen production from fossil-fuel sources (de-carbonisation) as well as from bio-mass has been studied.

- **Hydrogen storage**

Efforts have been made to identify and test metals and alloys to optimise hydrogen storage capacity, and to explore technically feasible charge/discharge characteristics. Analogous efforts were carried out to develop quasi-liquid systems, i.e. suspensions of microscopic metal hydrides in organic solvents. Studies are being performed on high pressure storage of gaseous hydrogen in light weight CNG-4 tanks.

- **Cells Topics**

Include both solid oxide (SOFC) and our polymer electrolyte (PMFC) type fuel cells. Also the direct methanol fuel cell (DMFC) has been investigated. Emphasis was given to solving problems related to fulfilling the market requirements of the SULZER HEXIS SOFC. The goal is to increase both reliability and the power conversion rate, while reducing costs. Considerable efforts were also invested in the development and demonstration of the PMFC. Outcomes of this work include a 60 kW stack for cars and 1 kW-unit "Power Pac".

15.1 Priorities and targets

Switzerland's main goal is to regionally produce hydrogen by splitting water using hydropower / electrolysis or solar radiation. Thereby, fossil fuels can be substituted by renewable and efficient hydrogen supply chains. The present and future policy aims at identifying and developing key activities rather than supporting a large spectrum of dispersed projects. The strategy for hydrogen technology focuses on its production using renewable energy and storage and distribution logistics (high pressure technology, fast filling, etc.). Considerable attention is being given to testing and developing novel materials and devices, which will safely and reliably serve different functions along the whole hydrogen supply / production / utilization chain. Fuel cell activities address SOFC and PMFC systems supplied with either



natural gas / biogas or hydrogen. For both technologies scientific as well as manufacturing problems are under investigation.

The commercialisation plan for hydrogen:

Start demonstration:	now – 2030
Start market introduction:	2015 – 2050
Market penetration 5% of energy use:	~2060

15.2 Key players

Research and development of hydrogen energy and technology are logistically coordinated and financially supported by the Swiss Federal Office of Energy. Federal and cantonal research institutes as well as private institutions and industries guarantee additional financial support. The Swiss Hydrogen Competence Centre, Hydropole² exists since autumn 2000. This centre surveys ongoing pilot and demonstration projects, and documents and promotes new alliances among institutional and industrial partners. All activities are closely co-ordinated with the IEA and EU research programmes.

Hydrogen research is carried out in different institutions: solar driven hydrogen production is under investigation at the Paul-Scherrer-Institute, while photocatalytic splitting of water is the focus of work by an alliance of the Universities of Bern and Geneva and the Federal Institute of Technology Lausanne; hydrogen storage is being explored at the Universities of Freiburg and Geneva (both are focusing on metal hydrides) and at the University of Applied Science in Geneva. Using hydrogen to produce chemical commodities is under study at the Federal Institute of Technology Zurich; and functional materials are being developed and tested at the Federal Institute for Material Testing. Close collaboration exists with the University of Augsburg. Research on SOFC is concentrated at Sulzer HEXIS in close collaboration with the Federal Laboratory for Materials Research and the Federal Institutes of Technology Zurich and Lausanne. These activities led to the start up company HT-Ceramics with a specific (anode supported thin layer electrolyte) SOFC system. The PMFC research is carried out by the Paul Scherrer Institute in collaboration with the Federal Institute of Technology Zurich. The Paul Scherrer Institute is researching DMFC systems, while the Federal Institute of Technology Lausanne is studying AFC systems.

15.3 Budget

In the last 25 years CHF 150 million (\approx €100 million, current real value) were spent by public institutions for hydrogen research. Today's annual budget amounts to about CHF 6 million (€4 million). An additional CHF 1.5 to 2 million are invested annually in different hydrogen-related projects in the use of hydrogen as a fuel or chemical commodities as well as for programme management and information activities. The funding for fuel cell R&D adds a further CHF 9 million (€6 million) annually to the budget. The Board of the Swiss Federal Institute of Technology funds 30% of this, the Swiss Federal Office of Energy funds 25%, Cantonal Universities fund 25% and the Swiss National Foundation funds the remaining 20%. Private funding for



hydrogen R&D is about half a million Swiss Franks per year, while fuel cells receive about CHF 4 Million annually.

15.4 The Swiss hydrogen and fuel cells industry

Research activities, including novel hydrogen production and storage technologies, are carried out by closely interacting teams from research institutions and industry.

Industries like HRAND DJEVAHIRDJIAN SA, Monthey (production of sapphire and other precious stones, large scale hydrogen production by a high pressure electrolyser), PANGAS AG, Winterthur (hydrogen trader), LINDE CRYOTECH AG, Lucerne (liquefaction of hydrogen), AMMONIA-CASALE, Lugano (use of hydrogen in industrial plants for producing ammonia and methanol) and several chemical industries are all engaged in hydrogen technology. Due to economical reasons, however, the implementations of novel processes as well as the enhanced large-scale application of hydrogen as a fuel are still very problematic.

Major industries involved in fuel cell technologies are: SULZER HEXIS (presently pilot runs of a natural gas fuelled SOFC for single family houses), HT-CERAMIX (development of anode supported SOFC) and ELEKTRA BIRSECK (testing of the PAFC and PMFC fuel cell systems in the 250 kW class).

15.5 Useful links

www.energy-research.ch

www.psi.ch

www.hydropole.ch

www.hexis.ch



15.6 Turkey

Turkey has engaged in limited work on hydrogen in fuel cells. Most of the effort is driven by the TUBITAK Marmara Research Centre (TUBITAK-MRC), involving selected hydrogen related projects and fuel cell development. Turkey has also investigated applications of Boron compounds, which are considered as promising candidates among the metal hydrates for the storage of hydrogen. To this end, Turkey's National Boron Research Institute has been established, which will investigate new application areas for boron and its compounds. Much of the work on hydrogen is currently oriented toward utilization in transport and stationary applications on both civil and military levels. In addition, Turkey is also working on [10]:

- Catalytic hydrogen combustion, hydrogen combustion, hydrogen utilization in PEM fuel cells, hydrogen production from fossil fuels (TUBITAK-MRC)
- Universities in Turkey have been studying on hydrogen energy technologies widely
- Some private sector entrepreneurs have been studying on application of fuel cells

A number of policy studies have also been undertaken:

- Energy production plant based on new, renewable and national energy sources.
- Revise the present law about energy to reach the European Union standards.
- The National Research and Technology Foresight (Vision 2023) has been announced.

15.7 Priorities and targets

Turkey has recently announced the National Research and Technology Foresight (Vision 2023). There is no dedicated and active national programme for hydrogen and fuel cells. In the announced foresight report, medium and long term technological opportunities were identified for Turkey. Concerning hydrogen and fuel cells, transport and stationary applications were selected as most promising application areas in which the high priority technologies are PEMFC, SOFC and MCFC.

15.8 International activities

Turkey was a project base partner in EU 5th FP and now is the full partner in the EU 6th FP. Turkey has also participated in Western European Armament Organization research areas. Under these programmes, there are some ongoing international research projects as given below (Turkey also hosted the international Hydrogen Energy Congress and Exhibition in Istanbul in July 2005):

- Hydrogen production from diesel for PEM fuel cells (TUBITAK-MRC)
- Hydrogen rich gas production from diesel for MC Fuel cells (TUBITAK-MRC)



- Hydrogen natural gas mixtures (NaturalHy, EU 6th FP project) (TUBITAK-MRC and IGDAS)
- 500 kW Molten Carbonate Fuel-Cell Plant (international project) (TUBITAK-MRC)
- MOCAMI- Small-sized hybrid system with a combination of Molten Carbonate Fuel Cells (MCFC) technology and Micro Gas Turbines (MT). (EU 5th FP project)
- IRMATECH- Integrated Research on Materials, Clean and efficient energy Technologies and processes to enhance MCFC in a sustainable development (EU 5th FP project)

15.9 Budget

The budget of some selected projects are given below:

- 500 kW Molten Carbonate Fuel-Cell Plant (TUBITAK-MRC, Total budget is 8 Million Euro, Turkey's contribution is 4 Million Euro for the period of 2002-2005)
- Hydrogen production from diesel for PEM fuel cells (TUBITAK-MRC, Total budget is 5.5 Million Euro, Turkey's contribution is 576 kEuro for the period of 2001-2004)
- Development of PEM Fuel Cell Technologies in Direction to the Production of Clean Energy (TUBITAK-MRC, TOFAS, Ford-Otosan, Arcelik, Turkish Technology Development Fund-TTGV) (Total budget 2.6 Million Euro for the period of 2004-2007)
- Integrated Research on Materials, Clean and efficient energy Technologies and processes to enhance MCFC in a sustainable development (IRMATECH-EU 5th FP) (TUBITAK-MRC, Total budget is around 4 Million Euro, Turkey's contribution is 120 kEuro for the period of 2003-2005)
- MOCAMI: Small-sized hybrid system with a combination of Molten Carbonate Fuel Cells (MCFC) technology and Micro Gas Turbines (MT). (MOCAMI-EU 5th FP) (TUBITAK-MRC, Total budget is around 4 Million Euro, Turkey's contribution is 100 kEuro for the period of 2003-2006)
- Hydrogen utilization in vehicles (national industrial project) (TUBITAK-MRC, 150 kEuro)
- Hydrogen combustion (national project) (TUBITAK-MRC, 350 kEuro)

15.10 Key players

- TUBITAK – the Scientific and Research Council of Turkey
<http://www.tubitak.gov.tr/english/>



- TUBITAK Marmara Research Centre
<http://www.mam.gov.tr/english/escae/index.html>

15.11 Other activities

Turkey will be among the first countries to manufacture a hydrogen car. Turkey signed an agreement with the United Nations Industrial Development Organization (UNIDO) to build in Istanbul a \$40 million International Centre for Hydrogen Energy Technology (ICHET), entirely financed by Turkey. Beyond helping Turkey to increase the amount of energy produced from non-fossil fuels, UNIDO's project is aimed at transferring existing hydrogen technologies from Turkey to other developing countries to help them to catch up with the developed world in the field of renewable energy resources.

Since about 64% of world boron reserves are found in Turkey, scientific studies on boron have been conducted to investigate the potential of boron as a hydrogen carrying material in fuel cells. Turkey is planning to upgrade the utilization of this natural source, and would like to invite researchers, investors and international organizations to closely cooperate on Hydrogen Energy Studies.

15.12 Useful links

<http://www.mam.gov.tr/english/escae/index.html>



16. United Kingdom

The UK has a very strong fundamental research base that is active in the fields of materials science, catalysis and bio-engineering. At least 22 UK universities have been involved in researching issues associated with hydrogen and a large number of these have ongoing research into chemical and physical hydrogen storage. In addition companies located in the UK such as BP, Shell and BOC have been active in assessing safety issues related to the storage and distribution of hydrogen [2]. The UK DTI has been supporting industrial research on fuel cells since 1992 under its Advanced Fuel Cell Programme. During its lifetime the focus of the programme has changed from supporting studies designed to inform the DTI and the industry regarding the prospects for fuel cells to work to supporting the development of UK capabilities. Since its inception the programme has supported a total of 156 projects involving total DTI expenditure of £12.4m. Currently the programme is funded at about £2m per annum. Over the last year, the UK has aggressively investigated the potential of hydrogen and fuel cells, and has introduced a number of documents to guide the development of its fuel cell industry.

- November 2002: The Technology Route Map – Suggested actions and targets based on published benchmarks for major fuel cell development programmes around the world as well as in the UK. A set of development targets were established with the objective of giving the UK a competitive position in certain fuel cell markets [12].
- February 2003: Review of UK Fuel Cell Commercial Potential – This study provided an assessment of the main applications for fuel cells, the drivers for fuel cells in these areas and the fuel cell technologies likely to be chosen. The UK was assessed both as a potential market for fuel cells and as a supply base, with its strengths and weaknesses used as a basis for identification of key opportunities [13].
- February 2003: Energy White Paper — The White Paper sets out a strategy for the long term, and to give industry the confidence to invest in a truly sustainable energy future. The paper commits to cutting carbon dioxide emissions by 60% by 2050 and notes the need/potential of fuel cells to play a greater part in the economy, initially in static form in industry or as a means of storing energy, but increasingly in transport. The paper sets the goal that hydrogen will ultimately be generated primarily by non-carbon electricity [14].
- May 2003: the Fuel Cell Vision, the First Steps – This document is intended to be the starting point for the development of a UK fuel cell vision. It carries forward on the commits laid out in the Energy White Paper and builds upon the study on the Commercial Potential of Fuel Cells in the UK [15].
- May 2003: Fuel Cells UK -- A new body to drive forward the development of fuel cell technology was launched. Fuel Cells UK will help the emerging UK sector by helping promote and raise the profile of the fuel cell industry in the UK. It will also act as a central contact point of contact for national and international companies and the research community [16].
- September 2003: the Fuel Cell Vision Paper – notes that the UK should take a leading role in the development and deployment of fuel cells, and sets out



various scenarios for the short, medium and long term. Additionally, it specifies various R&D focus areas and mechanisms for the government to influence the development of the industry [2].

16.1 Priorities and targets

The UK Fuel Cell Vision Paper sets out the following scenarios for the development of the industry:

- Short term: 2003 – 2007, will focus on demonstrations to prove the economic and technical feasibility of the technology, establish carbon reduction potential and foster the development of early hydrogen infrastructure. They will also play an important part in increasing awareness of fuel cells and the benefits that they can bring. This will sit alongside complementary awareness raising initiatives. Building on this Vision, the Government will develop a clear policy framework for fuel cells in order to provide a long-term continuity and a context in which industry can flourish.
- Medium term: 2008-2012, will see value will move downstream, and as a consequence, systems integration and other support will be of increasing prominence. Research will continue to focus on long term challenges in areas such as next generation materials, fuels and fuel processing, integration and manufacturing and automation technologies. Structured and targeted training will help to ensure that skills needs are met.
- Long term: 2013-2023, will see a shift in emphasis towards a much wider spectrum of commercial fuel cell applications, with a diminishing requirement for government intervention. The market will be increasingly consumer driven, and a high proportion of the population will have first-hand experience of fuel cells. Hydrogen infrastructure will continue to grow through the period to support the widespread application of fuel cells (including, towards the end of the period, significant car penetration). Renewables will play an increasingly prominent role. Codes and standards will be revised and updated to reflect new developments. Demonstrations will be driven and funded by industry for incremental improvement.

The Fuel Cell Vision Paper also described elements of an R&D programme for DTI, ESRC, EPSRC and the Carbon Trust, focusing on:

- Next generation materials (including catalysts / membranes / electrolytes).
- Fuels (especially renewable) and fuel processing.
- Hydrogen storage and hydrogen grid.
- Hydrogen economy (including integration with fuel cells).
- Integrated fuel cell systems including control, manufacturing and automation technologies.
- Supply chain development.
- Health & safety.



- High temperature PEMFC systems.
- Electrolysers.
- Micro-scale fuel cells.
- Socio-economic studies including through life cost of fuel.

The UK DTI Route Map for fuel cells laid out the following actions and targets. These were based on published benchmarks for major fuel cell development programmes around the world as well as in the UK.

Activity	Target date
Construct and evaluate a novel SPFC stack with the following characteristics: <ul style="list-style-type: none"> • power density: >1kW/litre • capacity: >50kWe • CO-tolerant to at least 100ppm • pressure: <2bar • performance degradation <1% over 1000 hours. 	2003
Construct and evaluate a novel SPFC stack of ~1kWe, with a power density of ~500W/litre and operating at ambient pressure	2003
Construct and evaluate a ~20kW SOFC system operating on natural gas.	2003
Design, construct and evaluate a compact integrated auxiliary power unit (APU) of ~5kW, together with fuel reforming facilities.	2003
Identify in detail those component technologies in which the UK could gain market leadership and the most effective means of supporting the associated development.	2003
Ensure that the UK has clear permitting systems / approval frameworks in place for the operation of fuel cell vehicles and power plant. Achieve connection agreements for systems of ~1MW and a few kW.	2004
Identify and evaluate a range of possible market enablement measures that are likely to serve UK interests the most effectively.	2005
Construct and evaluate a novel, planar SOFC stack of ~20kWe that internally reforms natural gas and delivers an efficiency of >50% (LHV). The stack should be capable of manufacture using a viable (if not yet proven) process, and with materials costs of less than US\$300/kW.	2005
Build and evaluate a compact, integrated, self-sustaining system around a ~50kWe SOFC stack, achieving an electrical efficiency of >40% (LHV).	2005
Design, construct and evaluate a compact, responsive, natural gas fuel processor, scaleable between ~1kW and ~50kW, and hence suitable for residential through to small commercial CHP systems. The system should achieve a power density of >1kW/litre, a performance degradation of <0.5% in 1000 hours, <10ppm CO output, and a 10,000-hour operating life.	2005
Design, construct and evaluate a compact, responsive, liquid-fuelled fuel processor, suitable for passenger cars, that achieves a power density of >1kW/litre, a performance degradation of <0.5% in 1000 hours, <10ppm CO output, and an operating life of 10,000 hours.	2005



Activity	Target date
Develop and evaluate a viable hydrogen storage system suitable for passenger cars.	2005
Review the prospects for MCFC, DMFC, IT-SOFC.	2005
Build and evaluate a pressurized SOFC stack of ~50kWe, complete with immediate BoP and control system.	2006
Develop and demonstrate in the UK an integrated pressurized SOFC/gas turbine (GT) hybrid system of ~1MWe, complete with BoP and control system and with well-optimized distribution between SOFC and GT.	2008
Evaluate a small fleet of fuel cell vehicles on commercial routes in the UK.	2010
Demonstrate a series of at least four fuel cell systems in commercial and residential applications for stationary power in the UK.	2010
Subject to the above targets being successfully met: <ul style="list-style-type: none"> • conduct extended field trials of passenger cars throughout the UK • conduct extended field trials of distributed power and CHP fuel cell systems throughout the UK. 	Post 2010
Subject to the continued good progress of fuel cells towards commercial competitiveness and the provision of energy and environmental benefits, implement a market enablement scheme to encourage widespread market deployment in the UK.	Post 2010

16.2 Programme activities

- DTI New and Renewable Energy Programme (now incorporated into the DTI Technology Programme). To assess technical and commercial prospects for fuel cells. To encourage internationally competitive industries in the UK to develop and utilize capabilities for domestic and export markets. To quantify potential environmental benefits associated with fuel cells. (Part of wider programme supporting various technologies with budget of roughly £18M per year). 1992- onwards.
- Evaluation of three hydrogen fuel cell buses in London. 2001-2006, €3.75 million + infrastructure costs [2].
- Tees Valley Hydrogen Project. Hydrogen fuelling and hydrogen production from renewable sources [2].
- EPSRC project. To support basic strategic and applied research and related postgraduate training in the engineering and physical sciences. To pay due attention to meeting the needs of the users of research and training in industry, commerce, government and the service sector. £1,133k, 1998-2003 [17].
- EPSRC Supergen Hydrogen Consortium. To explore options for hydrogen as the clean fuel of the future, £3.4m, 2002-2006 [16].



16.3 Key players

Governmental

- The DTI Advanced Fuel Cells Programme (now part of the DTI Technology Programme). DTI has been supporting industrial research on fuel cells since 1992 under its Advanced Fuel Cell Programme (part of the Renewable Energy Programme). During its lifetime the focus of the programme has changed from supporting studies designed to inform the Department and the industry regarding the prospects for fuel cells to work to support the development of UK capabilities. DTI now operate an approach based on the development of a technology roadmap (prepared in consultation with industry) and regular calls for proposals. The independent Fuel Cells Advisory Panel considers proposals. Since its inception the programme has supported a total of 156 projects involving total DTI expenditure of £12.4m (total project value £92.4m). Currently the programme is running at about £2m per annum.
- EPSRC. The mission of the Engineering and Physical Sciences Research Council (EPSRC) is to support basic strategic and applied research and related postgraduate training in the engineering and physical sciences. In allocating those funds, it is required to pay due attention to meeting the needs of the users of research and training in industry, commerce, government and the service sector and to underpin the quality of life of the UK's citizens. Research into new and renewable energy technology forms an important part of the portfolio of research targeted at improving quality of life in the UK through improvements to sustainability in energy generation. The portfolio also includes research on photovoltaics, fuel cells, wind power, wave power, biomass and other technology approaches such as the hydrogen economy.
- The Carbon Trust. The role of the Carbon Trust is to support the innovation required to underpin the commercialisation of new and emerging low carbon technologies. Through its Low Carbon Innovation Programme, it is developing a range of financial instruments to implement this role. In addition, the Carbon Trust uses its influential and impartial position to broker more productive relations in the fuel cells sector and between the sector and Government. The goal here is to help build a solid, robust, commercially vibrant industry sector, focusing on those elements of the emerging fuel cell business (including system design and balance of plant) where the UK can compete successfully.
- The Energy Savings Trust (EST) operates a variety of initiatives encouraging and promoting energy efficiency and low-carbon technologies. The EST's Low Carbon R&D programme supports research projects in the transport sector, including Hybrid, Electric and Fuel Cell vehicles.
- The Low Carbon Vehicle Partnership (LowCVP) is a Government-Industry partnership to promote the shift towards the use of low carbon vehicles and fuels. The LowCVP provides a forum for all stakeholders to work towards this goal, and to input to Government strategies to deliver lower carbon dioxide emissions and air quality improvements from road transport in the UK.



- The Centre of Excellence for low carbon and fuel cell vehicles (CenEX) is a new initiative to promote the adoption of new technology in the transport sector, by encouraging collaborative initiatives and facilitating procurement of pilot fleets of vehicles with new technologies.

Industry

- Intelligent Energy Ltd. is a UK based SME specialising in PEM fuel cell technology systems design, development and prototype production facilities, and as such is the UK's leading developer of PEM fuel cell technology. In addition to PEM fuel cell systems Intelligent Energy has substantial expertise in hydrogen generation systems with fuel reforming capability across a range of fuels (including ammonia, ethanol, natural gas, LPG and GTL fuels). Intelligent Energy are a member of Roads2HyCom
- Ceres Power Ltd is a UK based SME specialising in unique Medium Temperature Solid Oxide fuel cell technology, with a focus on kW-scale applications in fields such as domestic CHP and auxiliary power.
- Ceramic Fuel Cells – High temperature SOFC technology for CHP application.
- Johnson Matthey are the major international precious metal supplier, and a leading developer of MEA technology for PEM fuel cells, as well as other catalyst / reformer technologies
- Rolls Royce Power are a leading developer of Fuel Cell technology for power generation applications
- Air Products is a major player in the European industrial gas market. Hydrogen is a core competence of Air Products: they are the largest supplier of merchant hydrogen in the world and the company designs, builds and operates its own production plants. During the last 10 years, the company has built 30 different fuelling stations in the USA and Europe for a variety of transport projects, ranging from buses and taxis to submarines. Air Products are a Roads2HyCom member
- Core Technology Ventures Services (CTV) is an independent advisory team focused on the European hydrogen and fuel cell industry, especially equity financing of start-ups and innovative technology companies. CoreTec are a key task leader in Roads2HyCom.
- Element Energy Limited is an engineering consultancy practice operating in the energy sector, taking an integrated approach to the areas of renewables, hydrogen, fuel cells and other low-carbon energy technologies. Element are a key task leader in Roads2HyCom .
- Ricardo plc is a leading provider of innovative technology, engineering services and strategic consulting to the world's transport and energy industries. Recent research and technology development has included Hybrid vehicles and the use of Fuel Cells in APUs and CHP, as well as strategic roadmapping in transport and energy. Ricardo authored the UK



“Carbon to Hydrogen Roadmap for passenger cars”, which proposed combustion-electric hybrids as evolutionary steps to hydrogen fuel-cell vehicles, and is now coordinator of Roads2HyCom.

Universities

- Imperial College, London
- Loughborough University
- University of Birmingham
- University of Glamorgan
- University of Salford (HyTrain coordinator)
- University of Ulster (HyCourse coordinator)
- Plus many more not yet mapped

16.4 The UK fuel cells industry

Currently, over 100 UK companies are contributing to the creation of the global fuel cell industry. The knowledge and expertise of the UK industry spans the full length of the commercial value chain, from R&D to systems integration, and from finance to servicing. Many of these capabilities have been developed in partnership with companies and organizations from across the world. The breadth of the UK Fuel Cell Industry's experience encompasses:

- Low temperature fuel cell stacks and components: Here, the focus is on higher value stationary and portable applications. In the longer term, there is the potential to be engaged in high volume markets by exploiting knowledge and experience in scaling production processes.
- High temperature fuel cell stacks and materials: Currently, UK companies are active at the short stack and subsystem level. For the longer term the industry expects to build on this materials research strength to provide competitive advantage through enhanced performance and lower costs.
- Balance of Plant: Significant pockets of skills in component areas such as fuel processors, power conditioning mechanical balance of plant and hydrogen production and storage are important for all fuel cell applications. The UK's engineering capability has a long history of successful innovation creating tangible commercial advantage. The fuel cell industry is demanding such innovation along its supply chain and the UK is in a strong position to deliver.

The UK also has strong capabilities in system design, packaging and systems integration, and production engineering. There are world-class power plant vendors with significant activity and manufacturing in the UK. Important opportunities are therefore likely to exist for UK industry in the design, manufacture, installation and maintenance of fuel cell systems, particularly for stationary power and CHP applications. There are good quality research teams in UK Universities, with world-



class expertise in key areas such as materials and catalysis. Equally important is the fact that many of the global energy companies (eg Shell, BP) have significant R&D capabilities in the UK. The launch of The Low Carbon Vehicle Partnership (LowCVP) demonstrates the Government and industry's commitment to promoting the shift towards the use of low carbon vehicles and fuels. A groundbreaking initiative to promote innovative low carbon vehicles and fuels in the UK, the LowCVP will ensure that UK industry is fully involved in the shift to low-carbon transport, maximizing competitive advantage for UK businesses and securing a brighter cleaner environment for all our children. The LowCVP will provide a forum for all stakeholders to work towards this goal. It will also have an important input to Government strategies to deliver lower carbon dioxide emissions and air quality improvements from road transport in the UK [15].

16.5 Review of the UK fuel cell vision paper

- The UK should take a leading role in the development and deployment of fuel cells. Adopting such a leading role will bring huge benefits to the UK in terms of meeting its policy goals sooner and at lower cost than would otherwise be possible. It will also enable UK industry to play a greater role in this global industry, generating new jobs and stimulating exports.
- Fuel cell and hydrogen businesses already support over 800 jobs in the UK. Forecasts of commercial sales give a global market size of above £20 billion in 2011. There is an opportunity for the UK to build a sizeable industry centred on fuel cells and the hydrogen economy, covering all stages of the value and supply chain.
- The focus in the near term is to improve the attractiveness of the UK as a location for the development and deployment of fuel cells. Fuel Cells UK already provides a mechanism for UK companies to contribute to this; enhanced mechanisms for dialogue with appropriate parts of Government and global fuel cell companies are needed.
- In the transportation area, the Low Carbon Vehicle (LCV) Partnership has been established to promote the shift to low carbon vehicles and fuels in the UK. Hybrid vehicles feature highly in the Partnership's thinking and the link to fuel cell vehicles is clear. Fuel Cells UK will, as a matter of priority, establish a dialogue with the LCV Partnership and, through this, the UK based automotive sector (including bus, van and car makers, key component suppliers and designers / developers), the fuel cell sector and international OEMs to establish what initiatives would materially encourage the deployment of fuel cell containing vehicles in the UK. The outcome will be a set of guidelines and recommendations to UK industry, Government and Universities on how to support the pathways set out earlier
- The situation in stationary distributed power generation is more complex. The power generation industry is subject to a strong regulatory framework and is naturally risk adverse. Demonstrations of fuel cell technology are critical to establishing the case and currently no satisfactory mechanisms exist to support these. Fuel Cells UK will identify key groups to engage with to ensure that appropriate frameworks are in place to encourage the



development and deployment of fuel cell distributed power generation in the UK.

- Government needs to provide mechanisms to listen to and support this fledgling industry in the UK. Dialogue with Government is complicated by the wide range of issues fuel cells can influence and hence the lack of a single natural point of contact.
- Government has a huge opportunity to influence the development of this industry - for example:
- Clear support at a high level within Government has a huge impact and is undoubtedly needed if the UK is to aspire to a leadership role. The US has benefited tremendously from Presidential support.
- A long term commitment and clear policy framework would inspire confidence and enable forward planning. Companies and financial markets will commit funds provided public policy gives confidence in the commercial prospects.
- Strategic leadership by the Government on fuel and fuel infrastructure is needed to prepare the UK for the hydrogen economy
- Demonstration activities require substantial support at both the national and regional levels.
- Funding mechanisms for research, development and demonstration need to be transparent, as do routes for the dissemination of findings. Alternative approaches to research support, such as US style solicitation, may deliver better outcomes and should be considered.
- International research collaboration mechanisms need to be strengthened.
- Emerging codes and standards need to be actively considered to facilitate rather than hinder the introduction of fuel cells.
- A possible new mechanism to consider these issues is the cross-departmental Environmental Innovation Advisory Group being chaired by Lord Sainsbury and Lord Whitty. It advises JEMU, a joint unit of DTI and DEFRA. Just as the Low Carbon Vehicle Partnership developed from the Automotive Innovation and Growth Team so this new body has its origin in the Environmental Goods and Services Innovation and Growth Team report. Its remit is to provide an industry view on actions to enable innovation in the environmental sector. Fuel Cells UK proposes to establish a dialogue with organizations such as EIAG to inform Government on how best to assist the fuel cell effort in the UK [15].

16.6 Useful links

http://www.dti.gov.uk/energy/renewables/technologies/fuel_cells.shtml

<http://www.dti.gov.uk/energy/publications/pdfs/carbrevfuelcell.pdf>

<http://www.dti.gov.uk/energy/publications/pdfs/index.shtml>



<http://www.fuelcellsuk.org/>

<http://www.grovefuelcell.com/>

<http://www.fuelcellsuk.org/>



17. Australia

The National Hydrogen Study (September 2003) outlined Australia's initiative to investigate the role of hydrogen in the energy future mix, particularly in the context of the country's abundance of fossil fuel and renewable energy resources and its opportunity to produce hydrogen for domestic use and for export markets. The findings and recommendations of the National Hydrogen Study are direction setting in nature, and are designed to lay the foundations for Australia's participation in a future hydrogen economy. The recommendations include adoption of a national vision for hydrogen; reduction or removal of policies and regulations that represent barriers to hydrogen; participation in international research and industrial collaboration programmes; and formation of an Australian hydrogen entity to foster communication with stakeholders.

It is assumed that the main potential end uses for hydrogen for Australia in the period to 2050 will be road transport; portable electrical appliances (for example portable computers and mobile phones); and distributed generation.

Australia conducts general R&D to support MCFC systems as part of a project to develop advanced system integration techniques and catalysts for internal reforming fuels cells. The aim is to enable a wide range of fuels to be used with MCFCs for small scale stationary applications, suitable for remote areas in Australia. Australian programmes look at the use of coal-gas, natural gas, and coal seam methane to produce hydrogen for use in fuel cells for transportation and co-generation.

Specific programmes include:

- Perth Hydrogen Bus Trial. Trial and demonstrate the operation of three hydrogen powered fuel cell buses. Evaluate the potential impact on West Australian and Australian community. Australian Government, Western Australian State Government, Murdoch University. BP, Daimler-Chrysler \$10.72 million (cash) \$5 million (in kind).
- Hydrogen Energy Systems in Antarctica Research Programme. Identification and analysis of the barriers and opportunities related to the use of hydrogen energy technologies in remote regions. Detailed technical analysis of the potential role of hydrogen energy technologies in a number of energy use scenarios, and possible impact on performance, based on the Australian Antarctic Programme. Development of a strategy to effectively, efficiently and safely implement hydrogen energy technologies into Antarctic operations, and specific recommendations to overcome the key barriers. Development of experiences and recommendations for the implementation of hydrogen energy technologies in other regions. International Expand the existing collaboration with IFE (Norway) via a researcher Collaboration exchange in 2004 which will develop improved H₂ energy system.

(IEA HCG Report, Mr. Bob Pegler Minister-Counsellor, Industry, Tourism and Resources Australian Delegation to the OECD 4, rue Jean-Rey F-75724 Paris Cedex 15 – France, bob.pegler@dfat.gov.au Phone: 33 1 40 59 33 56 Fax: 33 1 40 59 33 94).



Australia is an example where H2&FC R&D is an element of the government's broader programme to reduce the greenhouse gas intensity of energy supply and use, with the 2003 National Hydrogen Study a key effort to investigate how Australia can take advantage of its abundant fossil fuel and renewable energy to produce hydrogen, both for domestic use and for export. H2&FC work also emerges as an element of Australia's COAL 21 programme, which includes research into hydrogen production by coal gasification (and employing carbon sequestration) as part of the national clean coal strategy.

According to Australia's National Hydrogen Study, local Governments should provide a clear and unambiguous signal that hydrogen has emerged as an important policy issue in relation to meeting Australia's long-term energy supply and addressing important environmental issues. Such a signal sends an important message to both researchers and industry stakeholders that hydrogen is now very much on its national agenda. With relation to R&D strategies of Australia, the National Hydrogen Study suggests that Australia's portfolio of strategies should remain flexible and international collaborations should be pursued. Moreover, the Government will support the creation of an Australian Hydrogen Group comprising interested parties who can assist driving the hydrogen agenda and the implementation of agreed recommendations [17], [18], [19].



18. Brazil

Little data about Brazil's activity on hydrogen energy policy are available. Brazil has entered IPHE, but there is no national R&D agenda on the development of hydrogen communities.

Recently (26 August 2006) Brazil has joined the industrialised countries in the race for hydrogen power, announcing the development of public buses running on this source of "clean" energy. Five buses with hydrogen fuel cells will be put to the test in 2007 in Sao Paulo and neighbouring cities. The four-year experiment calls for total travel of one million kilometres. If they pass the test, the hydrogen bus fleet will be expanded to 100 or 200. A similar project will get under way next year in Rio de Janeiro.

One source of hydrogen is production through the electrolysis of water, or from natural gas or alcohol. The hydrogen bus project in Sao Paulo, which has the backing of the United Nations Development Programme (UNDP), opted for electrolysis, the most simple and readily available technology.

At the Federal University of Rio de Janeiro, a project in consortium with several companies -- the state-owned oil company Petrobras, several bus manufacturers, and scientific institutions -- will produce hydrogen from natural gas to supply a bus that is also slated to begin circulation next year, near the university. The objective of that project is to develop the technology and research, distinguishing it from the otherwise similar effort in Sao Paulo, focused on testing the buses in practice.

In Brazil there would not be any great difficulty to supply electricity for electrolysis, but also promising is obtaining hydrogen from ethanol, which is already produced in massive quantities in this country, has high energy efficiency and important environmental advantages.

For now, faced with the uncertainty surrounding hydrogen energy, Brazil is staking its bets on hybrid electric vehicles. This technology, used in 43 buses already serving the Sao Paulo metropolitan area, combines an internal combustion engine with an electric machine and battery pack. The electric machine either generates electricity (e.g. when braking) or acts as a motor when more energy is required (e.g. when driving uphill) [20].



19. Canada

The vision of the national programme is to strengthen and enhance Canada's leadership position in the supply and demand for renewable and sustainable energy from fuel cells and hydrogen with the ultimate goal of accelerating the commercialisation of Canadian fuel cell and hydrogen products for Canada and the world. Canada's programme targets are delineated in 3 phases:

- **Phase 1: RD&D and Early Deployment (0 - 5 years)** – R&D that supports industry's pre-commercial efforts such as testing prototypes, R&D will focus on bringing down the cost of units; begin the development of a hydrogen supply infrastructure; establish programmes to support commercialisation (market demonstration and government first purchase); lead building across all applications (stationary, portable and mobile); lead the development and implementation of international codes and standards for hydrogen safety; education of professionals and technical staff including: engineers, researchers, educators, technologists and mechanics; establish policy measures (fiscal and regulatory); increase public awareness of the benefits of hydrogen and increase confidence in safety and performance.
- **Phase 2: Broad Based Deployment (5 -10 years)** – Work with industry and all levels of government to review and re-evaluate overarching strategy based on findings of first five-year period; re-allocate funding and emphasis if necessary; continue with demonstration projects and showcasing of new technologies; implement new policy measures (fiscal and regulatory) such as buy-down programmes for emerging technologies; expand hydrogen supply infrastructure to allow for inter-city commuting.
- **Phase 3: Market Expansion (10 - 20 years)** – cost reductions of fuel cells through the development of large-scale manufacturing (mass production); continue hydrogen supply infrastructure development on a national level; refinement of policy measures (fiscal and regulatory); continued support of RD&D in areas of new advancements in hydrogen and fuel cells

The Government of Canada announced a \$215 million investment that will capitalize on the use of hydrogen and fuel cells. The investment is directed by three strategic priorities:

- Early adoption of hydrogen technologies through integrated demonstration projects undertaken by partnerships that will showcase a working model of the hydrogen economy in real-world settings;
- Improved performance and reduced costs of hydrogen technologies, and extension of Canadian leadership through research and development of innovative new applications in strategic areas of the hydrogen value chain;
- Initiatives to establish a hydrogen infrastructure through Sustainable Development Technology Canada, building on the foundation's success in establishing successful, partnership projects.

Accelerating the development, commercialisation and early adoption of hydrogen technologies and applications in Canada is a key element of these investments. The



Government of Canada will partner with eligible recipients to demonstrate these technologies and to integrate them into a comprehensive working model of the hydrogen economy. This includes fostering clusters of expertise and partnerships in the form of real-world "hydrogen villages". As part of this, Industry Canada and its Portfolio partners, such as Technology Partnerships Canada and the National Research Council will dedicate more than \$85 million to hydrogen economy efforts, advancing the work already underway, and increasing hydrogen activity across industry.

In the context of creating real-world "hydrogen villages", a proposal for an innovative project combining a commercial-scale wind farm, hydrogen production, fuel cells and hydrogen-powered internal combustion engines just received a CAD\$ 5.1 million dollar boost from the Canadian government. The project will use wind energy as the primary energy source and produce hydrogen to provide backup and primary electricity for industrial, farm and household needs, as well as hydrogen fuel for transportation solutions. A range of engine technologies will be showcased, including fuel cells, purpose-built hydrogen internal combustion engines and retrofitted internal combustion engines. The project includes the installation of a hydrogen energy station, a hydrogen storage depot, and a wind-hydrogen and wind-diesel integrated control system to power a number of homes and buildings within North Cape. The next step will be the expansion of the wind-hydrogen village to allow for a farm operation, and hydrogen transportation solutions, such as shuttle buses and fuel-cell utility vehicles. The prospective solutions will meet the needs of the local community and be easily replicable in other locations elsewhere in Canada. The project will develop the Canadian hydrogen supply chain as well as marketable knowledge, services and electronic applications, tested and proven in real-life situations, and showcased to the world [21].



20. India

The Ministry of Non–Conventional Energy Sources (MNES) is the main organization of India’s government with regard to Renewable Energy Sources. The Ministry does not have specific programmes or R&D agenda for the development of hydrogen communities but it has supported research, development and demonstration projects on various aspects of hydrogen energy including its production, storage and use as a fuel for production of mechanical / electrical energy.

As a result of initiatives taken by MNES, the applications of hydrogen in fuel cells for power generation and automotive applications have been demonstrated. Hydrogen fuelled small power generating sets, two wheelers (hydrogen powered motorcycles), three wheeler, fuel cell – battery hybrid van and catalytic combustion systems for residential and industrial sectors have been developed and demonstrated.

Generally, India’s objectives and activities on hydrogen energy are:

Objectives:

- Study & evaluate the feasibility of production of hydrogen by various processes / technologies, especially based on renewable energy methods.
- Development of materials / processes / sub-systems / systems for storage of hydrogen.
- Support projects on utilization of hydrogen as a fuel for stationary, automobile and portable applications.
- Support projects for development of hydrogen infrastructure for production, storage and applications of hydrogen, including safety, standards and codes, capacity building & public awareness.
- Support demonstration projects relating to production, storage and applications of hydrogen.

Activities:

- Research in materials / processes / pilot plant for production, storage and use of hydrogen as a fuel.
- Development and demonstration of applications of hydrogen for power generation and transport sector.
- Training/ manpower development.

In addition, the ongoing projects and the achievements that have already been done at the hydrogen energy sector are:

Ongoing Projects:

- Scale up studies on production of hydrogen from *entrobacter cloacae* IIT – BT 08.



- Solar hydrogen production from water for fuel cell application.
- Synthesis and Evaluation of Hydrogen Absorbing Alloys by Mechanical Alloying.
- Development of Polymer Membrane Gas filters for Hydrogen.
- Demonstration of a solar heat driven metal hydride based water pumping, cooling and heating hybrid system.
- Demonstration of Ten Hydrogen Fuelled two-wheeler Road Transport.
- Development, installation and Demonstration of a Hydrogen Genset Unit.
- Development of hydrogen fuelled agricultural diesel engine.

Achievements:

- National Hydrogen Energy Board has been set up for guiding implementation of the National Hydrogen Energy Programme.
- National Hydrogen Energy Road Map has been prepared for developing National Hydrogen Energy Programme.
- Environmentally benign processes/technologies for the production of hydrogen developed and demonstrated.
- Materials / alloys / methods developed for storage of hydrogen as metal hydrides.
- Hydrogen based two-wheelers, three wheeler, catalytic combustion systems, fuel cell power systems, etc developed and demonstrated [22].



21. Japan

Japan does not have a specific R&D agenda for the development of hydrogen communities; nevertheless the country has a strong activity on large-scale demonstration projects. The Japanese government started "The New Sunshine Programme" in 1993, which aims at developing innovative technologies to create sustainable economic growth while solving energy and environmental problems. One of the new and important projects in this programme is "International Clean Energy Technology Utilizing Hydrogen (World Energy Network; WE-NET)".

Goals of the WE-NET project consist of developing technologies necessary to construct a worldwide hydrogen energy network, including production, transportation, storage and utilization. The electric power to produce hydrogen will be supplied by renewable energies, such as hydroelectric power, photovoltaic cells, etc.

The project is conducted by The New Energy and Industrial Technology Development Organization (NEDO), and carried out by nine Subtasks. It extends twenty eight (28) years from 1993 until 2020, and is divided into three phases:

- Phase I 1993-1998: Conceptual design of the total system / Basic R&D of elementary technologies
- Phase II 1999-2003: Construction and operation of small scale plants
- Phase III 2004-2020: Construction of pilot system in worldwide scale

Another more specific aspect is that of commercialisation plan. As delineated by Japan's Policy Study Group for Fuel Cell Commercialisation, the country's fuel cell development strategy is based around a three-stage commercialisation plan through 2020, which integrates the development of fuel cell, concurrently with the implementation of demonstration programmes, vehicle sales, construction of refuelling infrastructure, establishment of codes and standards, and a general push to enlarge the consumer market for fuel cells and fuel cell vehicles.

Commercialisation phases

According to Ministry of Economy, Trade and Industry's (METI) commercialisation strategy, 2002-2005 will focus on continued technology development, vehicle and stationary fuel cell demonstrations, development of soft infrastructure and codes & standards, and the establishment of fuel standards; 2005-2010 is to be the Introduction Stage, when the introduction of vehicles will be accelerated along with the gradual establishment of the fuel supply system. Finally, the Diffusion Stage will encompass initiatives taken forward from FY2011, particularly the establishment of fuel supply system and 'self-sustained growth' driven by private sector promotion and adoption.

Commercialisation targets that will drive the strategy through 2020:

By the end of the Introduction Stage in 2010

- 50,000 fuel cell vehicles



- 2.1 GW of stationary fuel cell co-generation systems

By the end of the Diffusion Stage in 2020

- 5,000,000 fuel cell vehicles
- 4,000 hydrogen stations
- 10 GW of stationary fuel cell co-generation systems.

Fuel cell performance targets:

	Fuel Cell Vehicles	Stationary Fuel Cells:
Stack Efficiency	Power generation efficiency over 65%(LHV) and over 55%(HHV)	Power generation efficiency over 55%
Overall Efficiency	Tank to wheel efficiency: <ul style="list-style-type: none"> • Hydrogen loading type - approx. 60%(LHV), approx. 51%(HHV) • Gasoline loading type - approx. 48%(LHV), approx. 45%(HHV) 	System: <ul style="list-style-type: none"> • Power generation efficiency over 40%(HHV); • Total efficiency over 80%(HHV); • Durability over 40,000hours
Cost	Below 5,000 yen / kW	<ul style="list-style-type: none"> • Home use below 300,000 yen/system; • Business use below 150,000 yen/kW
Hydrogen Storage	On vehicle 5kg hydrogen storage (over 500km cruising)	

Another important Japanese demonstration project is the 'Japan Hydrogen and Fuel Cell Demonstration Project' (JHFC). Organised by the Ministry of Economy, Trade and Industry, it involves a wide range of activities (experiments – acquisition of data, seminars, events) related to the use of fuel cell vehicles and hydrogen stations. Also, a number of companies participate in JHFC, conducting demonstration experiments and holding events and seminars. JHFCs' activities are geared to the future of FCVs. The main purposes are:

- Determination of energy saving effects achieved by FCVs and hydrogen stations
- Determination of environmental load reduction effects achieved by FCVs and hydrogen stations
- Data acquisition for preparing specifications, regulations and standards concerning the safety of FCVs and hydrogen stations
- Activities for familiarizing the general public with FCVs and hydrogen stations
- Solving of problems involved in the dissemination of FCVs and hydrogen stations



- Efficient recovery of hydrogen from by – product gas, and development and verification of an efficient liquefaction technique

JHFC has also set up a hydrogen and fuel cell park. It consists of five main parts. The first is hydrogen production and storage. There is also a refuelling station next to it where fuel cell vehicles (FCVs) are refuelled. The FCVs are maintained in the maintenance room where many safety management devices are furnished to reduce the risk of hydrogen-sourced accidents. The fourth part of the park is the garage room, which is not only used for FCV storage but also for check on hydrogen leakage and for data acquisition and analysis. Finally there is a showroom where various exhibits are in public view. This helps visitors to increase their knowledge and understanding of FCs and FCVs. In general, the JHFC Park has two main functions. It serves as a base for projects that involve supplying FCVs with hydrogen and collecting test data, and also as a facility to present and teach information about FCVs and hydrogen energy.

Two other significant demonstration projects are currently under development in the country:

- Stationary Fuel Cell Demonstration Project. In order to estimate the efficiency and identify the problems of commercialisation of stationary PEFC, this project operates 31 stationary fuel cells in various sites such as residential areas, heavy traffic areas, and seaside areas. It will also evaluate various fuel types (i.e. natural gas, LPG and kerosene). The budget allocations for 2002-2003 total JPY 1.8B; the 2003 allocation is JPY 1.3B
- Demonstration Project on Distributed Power Generation and Grid Connection. In order to introduce distributed energy systems, such as solar, wind and fuel cell, it is necessary to optimise the fluctuation of the output. Therefore, this project operates solar, wind and fuel cell (typically MCFC) simultaneously by using information technology (IT) and establishes technologies for minimizing fluctuations. METI/NEDO. The budget allocation for 2003 is JPY 3.483B [23] [24].



22. Korea

22.1 Targets

A National RD&D Organization for Hydrogen and Fuel Cell was constructed in December 2003 by MOCIE (ministry of commerce, industry and energy) for expediting the commercialisation of hydrogen and fuel cell technologies. It will not only develop a national plan and strategies but also co-ordinate national projects by controlling governmental funds. The governmental RD&D budget for the organization from 2004 to 2011 is expected to be over US\$ 400 million dollars. This does not include funds from private sector.

In terms of hydrogen production, the target for 2012 is the development of an efficient prototype hydrogen production system, utilizing water-splitting technologies (photocatalytic / thermochemical, etc) or NRSE sources. Another target is the development of high-purity hydrogen production / supply system utilizing fossil fuels such as natural gas / LPG / methanol / naphtha, etc.

In terms of hydrogen storage, the target for 2012 is the development of high-pressure gas-storage cylinder (700 atm) and also cryogenic technology to store liquefied hydrogen.

With respect to fuel cells, Korea is working to build up highly competitive capabilities for manufacturing advanced fuel cell technology. The target for 2012 is to introduce stationary fuel cell (370 MW) into the market. In addition, 10,000 fuel cell vehicles are planned to be running on the road by 2012.

Korea also plans to introduce new regulations recommending that new buildings owned by the public sector utilize NRSE technologies like PV, fuel cell, etc. from 2004. The government is also planning to establish a coordination committee composed of all stakeholders (public, private, academia) as the members and to reinforce R&D efforts, etc. – which will soon be finalized after policy review. The national strategy will determine the R&D portfolio best suitable to the economy and also other administrative / financial matters necessary for early introduction of hydrogen economy. Safety codes / standards and market introduction policies / measures, etc. will emerge as key issues in the near future.

There is not a specific R&D agenda on the development of hydrogen communities, but significant demonstration projects on hydrogen technologies in general, are being realized.

22.2 Programme activities

- 21st Century Frontier Hydrogen R&D Programme. Established in September 2003. Work under this programme will be funded by MOST at the level of US\$ 90 million over 10 years from 2003 to 2012. The programme is to be the cornerstone for the development of hydrogen technology in Korea.
- Programme by National RD&D Organization for Hydrogen and Fuel Cell. Established in January 2004. Work under this programme will be funded by MOCIE at the level of US\$ 400 million dollars over 8 years from 2004. This



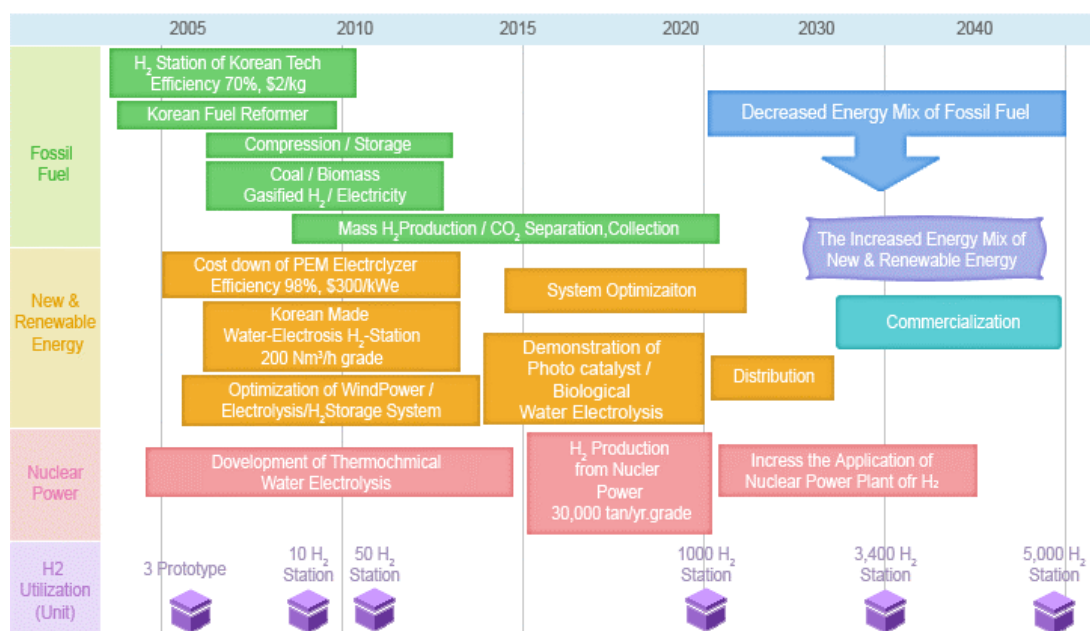
programme is to expedite the commercialisation of hydrogen and fuel cell technology

- Development of hydrogen production process. Basic research of hydrogen storage and utilization. From 1992 to present.
- Development of hydrogen production technology from water splitting. Oct. 2000 – Oct.2003 (3 years).
- Hydrogen production from natural gas. 2001 – 2006.
- 100kW MCFC System Development. 2001-2003. Industrial participants include: KEPRI, Hyosung Heavy Ind., Samsung Eng.
- 100W DMFC System Development. 2001-2004. Industrial participants include: LG Chemical Co, LG Electronics Co.
- Install & Testing of Proto-type 50kW PAFC System. 2000-2001. Industrial participants include: LG Caltex.
- 3kW PEMFC for Residential Purpose. 2001-2004. Industrial participants include: CETI, LG Chemical Co, Kukdong Towngas Co, KOGAS Corp, KEPRI, etc.

22.3 Roadmap

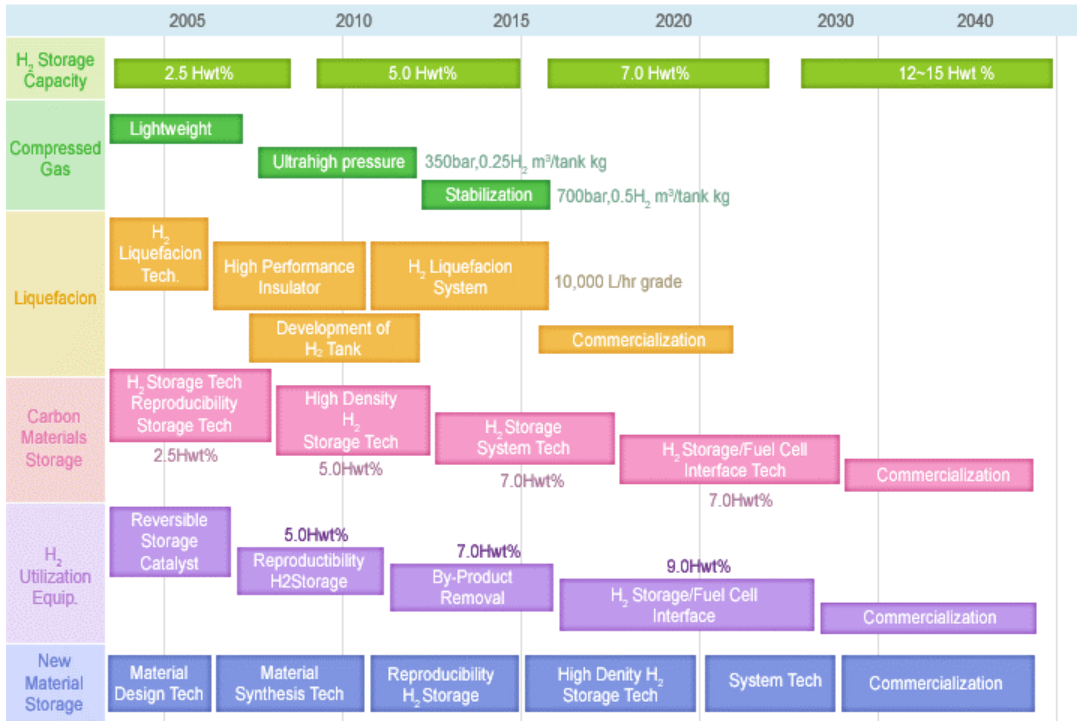
The Korean Roadmap for hydrogen technologies is presented below:

Hydrogen Production

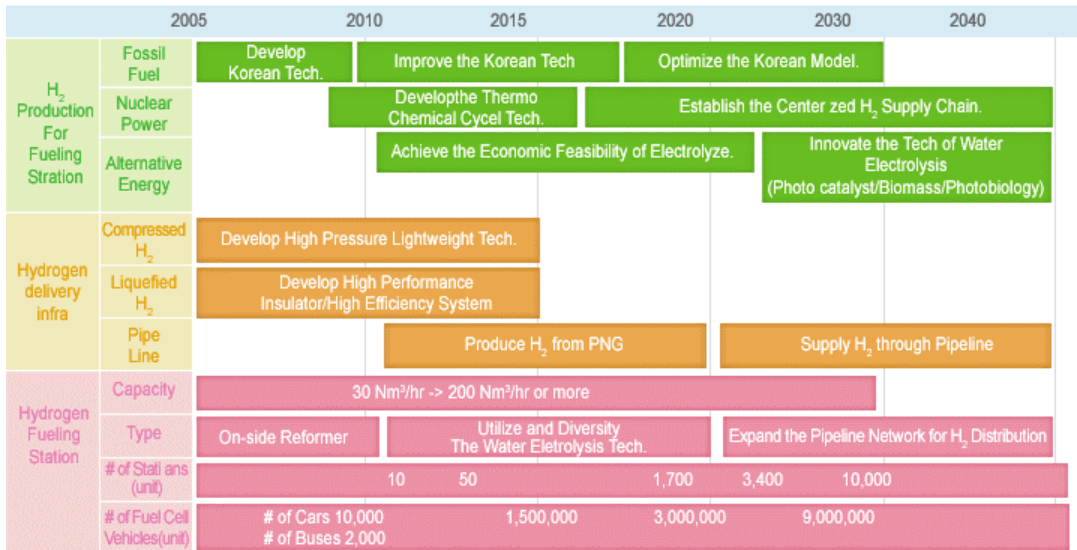




Hydrogen Storage



Hydrogen Infrastructure





23. New Zealand

New Zealand does not have a specific R&D agenda for the development of hydrogen communities. Nevertheless, it has launched already a National Programme to facilitate the first steps towards hydrogen economy in the country.

23.1 New Zealand National Programme

New Zealand has launched a \$NZ 1.2 million annual programme in order to start moving to a hydrogen based energy economy. In the context of this programme, research will develop technologies, knowledge and expertise to underpin the introduction of a parallel infrastructure and addresses issues of greenhouse emission reductions from the energy and transport related sectors. During the first steps, focus will be to generate hydrogen that is of sufficient quality to be used in the high efficiency fuel cells and advanced engines that will increasingly become part of the New Zealand transport and energy generation landscape.

23.2 Programme outcomes

The main outcome is to provide New Zealand with a technological basis to initiate development of a hydrogen energy infrastructure. There is compelling evidence that the developed world is moving towards a hydrogen based energy economy.

This programme is designed to begin the transition to a new energy infrastructure in New Zealand by developing a base of technological skills and, through emphasis on demonstrating new hydrogen based energy technologies, attracting investment from energy stakeholders.

The programme has two main themes:

- Development of technology to deliver distributed electricity supply from New Zealand coal through hydrogen production and fuel cells
- Development of a capability for production of distributed hydrogen by electrolysis from renewable energy

The two main goals for New Zealand on hydrogen research technologies are:

- i) Hybrid solid state hydrogen storage materials
- ii) Micro-scale electrolyser product development

A significant demonstration project running on New Zealand is entitled: “Coal to Fuel Cell Grade Hydrogen Technology Package”, in the context of which knowledge and expertise will be developed to facilitate New Zealand’s transition to hydrogen economy. This is a 6-year government project (2002-2008) with a total budget of \$8 million. Hydrogen will be produced through coal gasification and then will drive an alkaline fuel cell to produce Combined Heat and Power.

A second New Zealand’s demonstration project, which is related to a community, is the Totara Valley Farming Community project, where grid connection of hydrogen



distributed energy at the consumer level will take place. The project comprises [25]
[26]:

- i) Integration of hydrogen technologies,
- ii) Wind-electrolyser-pipeline hydrogen storage and delivery of household energy services,
- iii) Electricity hydrogen fuel cell,
- iv) Water heating – hydrogen combustion.



24. United States

The US has one of the most significant hydrogen and fuel cells programmes in the world. A number of initiatives like the “President’s Hydrogen Fuel Initiative”, the “Freedom Car” and “Freedom Fuel” Partnerships are some of the frameworks supporting the development and demonstration of such technologies. The US is also acting as the Secretariat of the IPHE and has a prominent involvement in the IEA and the Hydrogen Implementing Agreement.

There are no specific hydrogen community research programmes, however there are large scale demonstrations. The State of California is supporting the “California Fuel Cell Partnership” that is supporting the creation of a hydrogen and fuel cells community.

24.1 United States National Programme

The main challenges or targets set by the US programme are:

- Reduce cost of hydrogen at the pump to 2-3\$/gge* by 2015 (2.5\$/gge from distributed NG reforming, 2.85\$/gge from distributed electrolysis, 2.6 \$/gge from biomass)
- Reduce cost of hydrogen delivery to 0.90\$/gge by 2010
- Improved hydrogen storage aiming for 2kWh/kg, 1.5kWh/L and 4\$/kWh by 2010 and 3kWh/kg, 2.7kWh/L and 2\$/kWh by 2015
- Develop a PEM for transport applications running on hydrogen, that is 60% efficient and costs 45\$/kW by 2010 and 30\$/kW by 2015
- Develop a PEM for stationary applications running on NG that is 40% electrical efficient, has 40,000 hours of durability and costs 400-700\$/kW by 2010
- Validate hydrogen vehicles with +250miles range and 2,000 hour FC durability by 2009 and +300 miles and 5,000 hours respectively by 2015
- Validate wind-driven electrolyser costing 400\$/kW an efficiency of 65% and operating pressure of 350 bar.

The Department of Energy (DoE) is managing the funds for the research effort undertaken in order to meet the previous targets. The annual budget for year 2007 is estimated to be of the order of \$US 290 million, originating from a variety of sources (EERE-Hydrogen, Fossil Energy, Nuclear Energy and Science) broken down as follows:

- 13% for basic research
- 50% for applied research
- 22% for development
- 15% for demonstration



The DoE programme is structured under six thematic areas:

1. Hydrogen Production & Delivery
2. Hydrogen storage & basic sciences
3. Fuel cells
4. Applications – Technology Validation
5. Safety, codes and standards
6. Systems analysis

Roads2HyCom has produced a set of reports covering the projects that fall under these topics, as presented in the US Programme Review Days, May 2006. A summary of this material in the form of a listing of the major projects is presented below, as per thematic area. Large scale demonstrations (budget higher than 80M\$US) that are most relevant to hydrogen communities projects, are presented under “Applications – Technology Validation”.

24.2 Hydrogen Production and Delivery

Project Acronym & Title	Coordinating Organisation	Funding (M\$)	Objectives	Start-date & Duration
Integrated Hydrogen Production, Purification and Compression System	BOC Group Inc	3.8 M\$	<ul style="list-style-type: none"> • To develop a fuel processor system that directly produces high pressure, high-purity hydrogen from a single integrated unit • To integrate the membrane reformer developed by Membrane Reactor Technology (MRT) and the metal hydride compressor (MHC) system developed by HERA USA in a single package 	April 2005 - June 2008
Distributed bio-oil reforming	NREL	0.4M\$	<ul style="list-style-type: none"> • Develop the necessary understanding of the process chemistry, compositional effects, catalyst chemistry, deactivation, and regeneration strategy as a basis for process definition for automated distributed reforming of bio-oils 	2005-2010
Photoelectro-chemical Hydrogen Production: UNLV-SHGR Program Subtask	University of Hawaii	0.5 M\$	<ul style="list-style-type: none"> • To develop technology to produce hydrogen using solar energy to photoelectron-chemically split water-specifically focusing on multi-junction thin film devices using metal oxides and other low-cost materials. 	2004-2005



Project Acronym & Title	Coordinating Organisation	Funding (M\$)	Objectives	Start-date & Duration
Renewable Electrolysis Integrated System Development and Testing	NREL	2M\$	<ul style="list-style-type: none"> • Characterize electrolyser performance under variable input power conditions • Design and develop shared power electronics packages and controllers to reduce cost and optimise system performance and identify opportunities for system cost reduction through breakthroughs in component integration • Test, evaluate, and optimise the renewable electrolysis system performance for both <ul style="list-style-type: none"> – Dedicated hydrogen production – Electricity/hydrogen cogeneration 	2003-on going
Advanced Alkaline Electrolysis	GE Global Research Centre	2.1 M\$	<ul style="list-style-type: none"> • Develop a commercial strategy for low cost alkaline electrolysis • Demonstrate a laboratory scale proof of concept • Develop plastic cells for low cost, high efficiency • Perform numerical modelling of cell performance 	2004-2005
Hydrogen Delivery Infrastructure Options Analysis	Nexant, Inc	1.9M\$	<ul style="list-style-type: none"> • Refine data for H2A model in terms of hydrogen delivery • Explore new options to reduce H₂ delivery cost • Expand H2A model to include new options • Provide bases for developing H₂ delivery strategies 	2005-2007
Development of Solar-powered Thermo-chemical Production of Hydrogen from Water	UNLV Research Foundation	5M\$	<ul style="list-style-type: none"> • Identify a cost competitive solar-powered water splitting process for hydrogen production • Continue experimental cycle studies needed for final quantitative selection • Numerical and experimental evaluation of solid particle receiver performance • Optimise heliostat / tower / secondary concentrator characteristics and configurations for various operating temperatures 	2003-2005



Project Acronym & Title	Coordinating Organisation	Funding (M\$)	Objectives	Start-date & Duration
Laboratory-Scale High Temperature Electrolysis System	Idaho NL	6.2 M\$	<ul style="list-style-type: none"> • Develop and demonstrate energy-efficient, high temperature solid oxide electrolysis cells (SOECs) and stacks for hydrogen production from steam. • Demonstrate technology at progressively larger scales • Perform flow sheet analyses of systems-level HTE processes to support planned scale-up to Integrated Laboratory-scale, Pilot-scale and Engineering Demonstration-scale experiments. • Develop detailed CFD models of operating SOECs; validate with experiment data • Investigate alternate cell materials (e.g. alternate electrode and/or interconnect materials) alternate cell configurations (e.g. porous-metal substrates, tubular cells, porous electrodes) and applications of inorganic membranes 	2003 - 2015
Low-cost, High Pressure Hydrogen generator	Giner Electro-chemical systems	3M4	<ul style="list-style-type: none"> • Develop and demonstrate a low-cost, high-pressure PEM water electrolyser system • Demonstrate a 3,300scfd high-pressure electrolyser operating on a renewable energy source 	2003-2007

24.3 Hydrogen Storage & Basic Sciences

Project Acronym & Title	Coordinating Organisation	Funding (M\$)	Objectives	Start-date & Duration
Metal Hydride Center of Excellence	Sandia National Lab. (SNL)	6.33 in 2006	<p>The MH CoE is organized in 5 project groups :</p> <ul style="list-style-type: none"> A) destabilized hydrides (leader HRL) B) complex anionic materials (leader SNL) C) amides/imides (M-N-H) (leader SNL) D) alanes AlH₃ (leader BNL) E) Engin., analysis & design (leader SRNL) 	2005 5 yrs



Project Acronym & Title	Coordinating Organisation	Funding (M\$)	Objectives	Start-date & Duration
Complex hydride compounds	United Technol. Res. Center	2.1 (73%)	Develop new complex hydride compounds capable of reversibly storing hydrogen with capacities > 7.5 wt %. Assess potential volumetric capacity of new materials.	2002 4 yrs
Molecular modelling, Combinatorial methods	UOP	2.0 (40%)	Validation and demonstration of VHTS (Molecular Modelling). Medium and high throughput combinatorial tools. Downselect from Na, Li, Mg/AlH ₄ systems. Expand phase space to LiBH ₄ -MgH ₂ -LiNH ₂	2004 3 yrs
Lightweight intermetallics	General Electric Global Res.	2.78 (80%)	Combinatorial synthesis and high-throughput screening methodology for metal hydride discovery. Identify crystal structures of Mg(BH ₄) ₂ . Combinatorial and computational screening of catalysts and dopants for Mg(BH ₄) ₂	2005 4 yrs
Alanes for automotive applications	Brookhaven National Lab. (BNL)	3.0 (80%)	Understand the strengths/weaknesses of using AlH ₃ as a storage medium by quantifying the reaction kinetics, thermodynamics, and energy requirements for regeneration	2005 5 yrs
Nanophase materials for reversible H ₂ storage	HRL laboratories	2.0 (73%)	Hydride destabilization to overcome thermodynamic limitations, resulting in lower ΔH and desorption temperature, and nano-engineering allowing enhanced reaction rate and improved cycling. Application to LiBH ₄ -MgX system, to nanoparticles of MgH ₂ -Si, and to nanoporous scaffolds for LiBH ₄ in C-aerogels	2005 5 yrs
Structure, Chemistry, Electronic structure	Univ. Illinois	1.25 (80%)	Provide center partners with structural and chemical insight of candidate systems. Experimentally based validation of 1 st principles theoretical modeling and thermodynamic calculations using DFT and VASP (Vienna Ab-initio Package Simulation)	2005 4 yrs
Evaluation of advanced hydride systems	Jet Propulsion Lab. (JPL)	1.78 (80%)	Analysis and characterization of selected hydrides from the various MH CoE project groups. Prototype hydride beds development and life testing.	2005 5 yrs

24.4 Fuel Cells

Project Title	Coordinating Organisation	Total / DoE Funding (M\$)	Objectives	Start-date & Duration
High-Temperature Polymer Electrolyte Membranes	Argonne National Laboratory	1.635	<ul style="list-style-type: none"> High, sustained proton conductivity (0.1 S/cm) at <120°C and < 1.5 kPa water 	Oct 2001 – Terminates Upon Tech



Project Title	Coordinating Organisation	Total / DoE Funding (M\$)	Objectives	Start-date & Duration
			<ul style="list-style-type: none"> vapor pressure Proton conductivity (0.01 S/cm) at temperatures as low as – 20°C Low oxygen and hydrogen cross-over (2 mA/cm²) Low cost, \$40/m² Durability of 2,000 operating hours (at >80°C) Survivability to – 40°C 	Transfer
MEA and Stack Durability for PEM Fuel Cells	3M	10.1 / 8.08	Develop an MEA with enhanced durability which is: <ul style="list-style-type: none"> manufacturable in a high volume process capable of meeting market required targets optimised for field ready systems 2000 h system demonstration 	9/1/2003 – 6/30/2007
Novel Approach to Non-Precious Metal Catalysts	3M	3.6 / 2.9	<ul style="list-style-type: none"> durability >2000 h less than 10 % power degradation 	9/1/2003 – 8/31/2007
Integrated Manufacturing for Advanced MEAs	E-TEK division, PEMEAS Fuel Cell Technologies	19.5 / 14.5	2010 targets: <ul style="list-style-type: none"> PM loading 0.2 g/KW Durability 5000 h < 45 \$/Kw_e 	Oct 2001 – Aug 2006
Advanced MEAs for Enhanced Operating Conditions, Amenable to High Volume Manufacture	3M	9.02 / 6.99	2010 targets <ul style="list-style-type: none"> Durability > 5000 h Cost 15 \$/KW PGM Total 0.5 g/KW ECSA loss by Stop/Start < 40 % Electrochemical support loss at high potentials < 40 mV after 100 h @ 1.2 V 	1/1/2002 – 6/30/2006
Development of High Temperature Membranes and Improved Cathode Catalysts for PEM Fuel Cells	UTC Power	9.5 / 7.6	<ul style="list-style-type: none"> Anode and cathode kinetics System heat management Improve power density Lower cost, \$/KW 	2002
Fuel Cell Systems Analysis	Argonne National Laboratory	0.45 / 0.45	<ul style="list-style-type: none"> Support DOE in setting and evaluating R&D goals and research directions Establish metrics for gauging progress of R&D projects 	Oct 2003
Back-up/Peak-Shaving Fuel Cells	Plug Power	7.201 / 3.6	<ul style="list-style-type: none"> Life 1500h Coolant: Propylene Glycol H₂ management 	Aug 2003 – Apr 2007



Project Title	Coordinating Organisation	Total / DoE Funding (M\$)	Objectives	Start-date & Duration
			<ul style="list-style-type: none"> • Energy Storage: Ultra Caps • Stack Cells (Relative): 71% • Humidifier: Membrane • Siting/H₂ Exhaust < 1000 ppm 	
Scale-Up of Carbon/Carbon Bipolar Plates	Porvair Fuel Cell Technology	8.078 / 3.897	<ul style="list-style-type: none"> • Component Costs: 4\$/kW • Component Weight: <1kg/kW • Hydrogen Permeability <2 • Conductivity: > 100 S/cm • Resistivity & Contact Res. < 0.1 ohm/cm² • Flexural Strength: > 4 MPa (crush) 	May 2002 – Nov 2006



24.5 Applications – Technology Validation

Project Title	Coordinating Organisation	Funding (M\$)	Objectives	Start-date & Duration
Hydrogen Technology Park	DTE Energy	4 M\$	<ul style="list-style-type: none"> To validate \$3.60/gge hydrogen production and 8¢/kWh power production for PEM fuel cell energy station By 2008, validate an electrolyzer (powered by a wind turbine) with capital cost of \$600/kWe and efficiency of 68% (incl. compression to 5,000 psi) By 2008, develop a dist gen PEM fuel cell system that achieves 32% electrical efficiency and 20,000 hours durability at \$1500/kW* 	2002-2009
Power Parks System Simulation	Sandia NL	0.25M\$	<ul style="list-style-type: none"> Develop a flexible system model to simulate distributed power generation in energy systems that use H₂ as an energy carrier Analyze the performance of demonstration systems to examine the thermal efficiency and cost of both H₂ and power production Analyze H₂ and electricity as energy carriers and evaluate synergies Analyze advanced power parks for production of both H₂ and electricity - Determine the economics of H₂ and electricity co-production 	2003-2006
Development of a Natural Gas-to-Hydrogen Fuelling System	Gas Technology Institute	4.7 M\$	<ul style="list-style-type: none"> - Develop and validate onsite, integrated natural gas-to-hydrogen fuelling stations 40 to 60 kg/day system with nominal 350 bar (5075 psig) dispensing 	2002-2006
Development of a Turnkey H ₂ Refueling Station	Air Products	11M\$	<ul style="list-style-type: none"> To demonstrate the economic and technical viability of a stand-alone, fully integrated H₂ Fueling Station based on reforming of natural gas 	2001-2006



Project Title	Coordinating Organisation	Funding (M\$)	Objectives	Start-date & Duration
Hydrogen Vehicle and Infrastructure Demonstration and Validation	General Motors	88M\$	<ul style="list-style-type: none"> To deploy a system of hydrogen fuel cell vehicles integrated with a hydrogen refuelling infrastructure to operate under real world conditions Demonstrate progressive generations of fuel cell system technology Demonstrate multiple approaches to hydrogen generation and delivery for vehicle refuelling Collect and report operating data 	2004-2009
Hydrogen to the Highways	Daimler Chrysler	88M\$	<ul style="list-style-type: none"> To collect data and evaluate the technology status of: Fuel cell powered vehicles (OEMs) Hydrogen infrastructure (energy companies and suppliers) 	2004-2009
Hydrogen Fuel Cell Vehicle & Infrastructure Demonstration Program Review	Ford Motor Company	88M\$	<ul style="list-style-type: none"> To gain FCV operational data in differing climate conditions to direct and augment future design efforts 	2004-2009
Controlled Hydrogen Fleet and Infrastructure Demonstration and Validation Project	Chevron Hydrogen	94M\$	<ul style="list-style-type: none"> Demonstrate different methods of on-site hydrogen generation Collect data on FC vehicle operation Develop Auto Thermal Reformer Develop Low pressure steam methane reformer Set up data collection and fleet monitoring system Obtain data in hot and high altitude environments 	2004-2009
Controlled Hydrogen Fleet and Infrastructure Analysis	NREL	2M\$	<ul style="list-style-type: none"> Validate H₂FC Vehicles and Infrastructure in Parallel Identify Current Status of Technology and its Evolution Re-Focus H₂ Research and Development Support Industry Commercialization Decision by 2015 	2003-2009



24.6 Safety Codes and Standards

Project Title	Coordinating Organisation	Funding (M\$)	Objectives	Start-date & Duration
Research and Development for Hydrogen Safety, Codes and Standards	Sandia National Laboratories	DOE share: \$5.4M	<ul style="list-style-type: none"> Conduct materials testing in hydrogen gas up to 100 MPa Storage 	Oct 2003 to Sep 2015
International Projects: Global Technical Regulations Global Technical Regulations	Los Alamos National Laboratory Institute for Hydrogen and Fuel Cell Research	\$1,125K / \$1,125K	<ul style="list-style-type: none"> Safe design of structures for storage and transport Provide the technical basis for the development of new hydrogen codes and standards Provide advocacy and technical support for the codes and standards change process 	Sep 2003 to 2010/12

24.7 Systems Analysis

Project Title	Coordinating Organisation	Funding (M\$)	Objectives	Start-date & Duration
Impact of Hydrogen Production on U.S. Energy Markets	Brookhaven NL	1.3 M\$	Use of MARKAL tool <ul style="list-style-type: none"> Develop a consistent, integrated framework for evaluation of impacts of hydrogen production within U.S. energy markets Evaluate costs and timeliness of various scenarios of a developing hydrogen supply infrastructure Evaluate impacts on U.S. energy markets including price and consumption changes for coal, natural gas, renewables and electricity 	May 2005, Sept 2008
Analysis of the Hydrogen Production and Delivery Infrastructure as a Complex Adaptive System	RCF Economic and Financial Consulting, Inc	3.6M\$	<ul style="list-style-type: none"> Use agent-based modeling (ABM) to provide insights into likely infrastructure investment patterns Provide answer to the question, "Will the private sector invest in hydrogen infrastructure?" 	July 2005- December 2008



Project Title	Coordinating Organisation	Funding (M\$)	Objectives	Start-date & Duration
HyDS Modelling Environment	NREL	100k\$	GIS-Based, Supply-Side Transition Analysis <ul style="list-style-type: none"> • Cost out pathway for cities within a region • Determine the infrastructure layout for different production/delivery choices • Consider electricity sector impacts and contributions to hydrogen economy 	May 2005-Oct 2006
Macro-system model	Sandia NL	0.7M\$	Develop a macro-system model (MSM) aimed at: <ul style="list-style-type: none"> • Performing rapid cross-cutting analysis • Supporting decisions regarding programmatic investments and focus of funding • Supporting estimates of program outputs and outcomes 	2005-2010
Geographically Based Hydrogen Demand & Infrastructure Analysis	NREL	0.4M\$	<ul style="list-style-type: none"> • Quantify and locate a minimal interstate-based hydrogen infrastructure • Quantify hydrogen demand in the U.S. • Estimate costs to support infrastructure to meet emerging hydrogen demand 	2004-2006
Hydrogen Analysis Resource Centre (HyARC)	PNNL	0.2 M\$	<ul style="list-style-type: none"> • Develop a publicly accessible, web-based hydrogen analysis resource centre to provide access to data and tools for use in hydrogen-related analyses • Support the development of tools, methods and data for the analysis of hydrogen production /delivery costs, markets, policy options 	2005 – on going



24.8 Programme outcomes

A number of major goals have been reached, including:

- Reduction in fuel cell cost to \$110/kW (at high volume)
- Cost of hydrogen from natural gas reduced to \$3.00/gge
- Learning demos validate the technology through ~ 60 FCVs and 6 fuelling stations

24.9 Useful links

<http://www.hydrogen.energy.gov/index.html>

<http://www.fuelcellpartnership.org/>



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