COUNTRY PAPER - FRANCE

Brief summary of France priorities

As Bernard Bigot said in Washington on behalf of French Government, France welcomes IPHE initiative, believes strongly in the coordination action for Hydrogen economy development and will involve very actively in IPHE partnership. From France ' point of view, Important points for the coordinated work in IPHE activities could be summarized as follows:

1) Importance to avoid duplication of effort between different international initiatives . Stress to coordinate the activities with other international organisations such as IEA, UN/ECE/WP29 and ISO.

2) Importance to support R&D or demonstration projects through IPHE. Steering committee has to propose special procedure for projects proposal, evaluation and financing.

3) Importance of global evaluation of program, projects between the different countries. Hydrogen option has to prove its feasibility from a technical, economical and environmental point of view. Others option without hydrogen are existing for the future (major use of electricity and batteries, liquid synthetic and biofuels, use of bioheat …) and it is important to assess the hydrogen options between different options. So we stress the importance of socio-economics studies, multi criteria analysis, but also the dialog with others possible energy options and energy carriers during the early phases. A special attention has to be underlined on global evaluation tools for hydrogen chains. Another point is the global comparison between all primary energy sources roles for Hydrogen economy, including fossil, renewables, and novel routes for nuclear energy(fission and fusion). At the second level, a special effort has to be undertaken to assess R&D programs, example on Hydrogen production , Fuel cells technological breakthroughs, hydrogen storage …

4) As demonstration projects are necessary but expensive too, it will be important to share the information and results of the demo projects around the world, through information tools (web site …) but also through specific actions (group, forum …).

5) Share and exchange on National road maps, targets and national experience, including the European Hydrogen Plat-Form considered by France as a very important step in a strong international partnership.

6) On a more technical point of view:

    a. Importance of codes and standards, and safety issues. International cooperation is a priority in this field but taken into account the existing initiatives.
    b. Importance of sharing R&D program on more fundamental or long term issues:
        i. Innovative hydrogen storage materials and processes
        ii. Link with the Carbon Sequestration Leadership Forum, CSLF
        iii. Innovative and long term Hydrogen production processes including nuclear, biological, high temperature solar and photoelectrochemical routes.

iv. Importance of biomass use for hydrogen production (gasification…)
v. Innovative fuel cells technologies including major technological breakthroughs.

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DRAFT

Hydrogen and Fuel Cell activities in France

Report completed for the IEA Hydrogen coordination group
26/01/2004

1. Past activities

Fuel cells

Research on fuel cell started in France in the early 1960s, mainly conducted by most of the major players in the energy sector: Gaz de France, Alstom, Thomson, IFP, Renault, CGE,… For different reasons, in particular – but on only - repeated technical failures, these companies progressively slowed down their activities in this field before finally abandoning them in the late 1970s. During the same period in France, the CEA (Atomic Energy Commission) was familiarising itself with PEM technology, at the request of ELF and then the Direction Générale pour l'Armement (DGA), on account of its usefulness in water electrolysis and, in 1987, the CEA 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. Then, Renault decided to join PSA and, in November 1989, they jointly proposed to the CEA to continue this activity in the automobile field. In 1990, the French government launched the national VPE (*Véhicule automobile Propre et Econome en énergie* - Clean Energy-saving Automobile Vehicle) programme, which included technologies of the future such as hydrogen and fuel cells. In this frame, CEA and CNRS (Centre National de la Recherche Scientifique) worked in close collaboration. The work was extended to other partners in 1995-2000 via the European *Hydro-Gen* project demonstrating a fuel cell vehicle, based on high pressure gaseous hydrogen tank. In this frame, the CEA developed with the French company Composites Aquitaine, 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 and to encourage public-private partnerships and 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 (www.ineva-cnrt.com). With fuel cell test capacities with a power up to 200 kW, this platform has just recently become operational.

Hydrogen

Work on production, storage and transportation of hydrogen as an energy vector was carried out in France in 1975-1980 by the DGRST (Délégation Générale à la Recherche Scientifique et Technique) and also in the frame of the Energy R&D European programme. Hydrogen production via high temperature processes (water dissociation by thermochemical cycles and electrolysis) was studied by actors such as Uranium Pechiney Ugine Kulhmann, Automobiles Citroën, EDF, GDF, Laboratoires de Marcoussis, SRTI/Creusot-Loire, CEA, IFP…Then, the Hydrogen R&D activity was progressively reduced with the stabilization of energy markets.

In 1986, the Association Lorraine pour la Promotion de l'Hydrogène Et de ses Applications (ALPHEA) was created in Forbach to evaluate the potentialities of the Hydrogen energy. 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 (process heat, hydrogen production, ….). At the same period, the CNRS launched the programme "Energy" with different themes on hydrogen.

2. Current activities

Section A: R&D in the public sector

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 has an important work on hydrogen for space applications in the framework of the ARIANE launchers program but this part is not considered in the present document.

As regards fuel cells, the activities are concentrated on two families: PEMFC technology (including DMFC technology) and SOFC technology. The main financing bodies are, with decreasing order of involvement : the PACo network - which provides approximately 80% of the public financing (excluding own ressources of the public research bodies), ADEME, PREDIT (Programme de Recherche sur le Développement des Transports Terrestres), ANVAR (Agence Nationale de Valorisation de la Recherche), the DGA (Délégation Générale pour l'Armement) and French regions (via Regional Councils), departments (via Departmental Councils) and Districts.

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).

A.1 Financing structures

Of the diverse structures listed above, the two most important ones are the PACo network and ADEME.

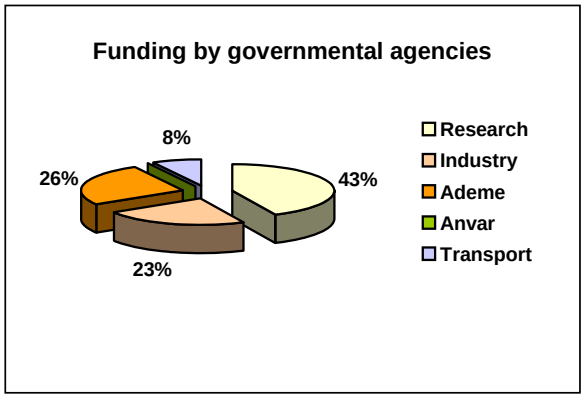
The PACo network.

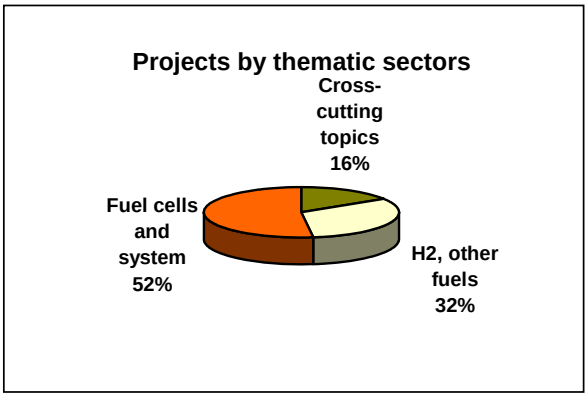
This network was created in June 1999 to encourage the combining of public research and industrial research in the fuel cell field. It supports funding of selected R&D projects (labelling decision). The PACo network is guided by a high level Steering Committee which comprises leading representatives 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).

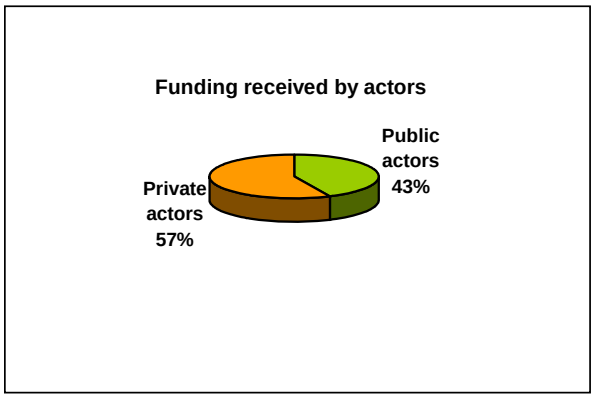
Although focused on fuel cells, the network also deals with the question of the fuel via the development of small reformers for hydrogen production and the development of hydrogen storage technologies. The R&D priority effort includes:

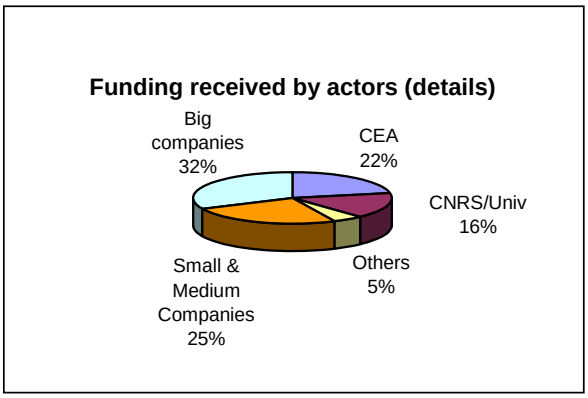
- Small reformers supplied with different fuels (natural gas, gasoline, methanol, ethanol…). This includes small units for stationary applications (5 kW) and on-board reformers for transport applications.
- Materials and components for hydrogen storage (gas storage, hydrides, carbon materials)
- Materials and components of PEMFC and SOFC stacks (membranes, MEA, bipolar plates…)
- APU (PEMFC, SOFC) for transport applications
- Projects deploying residential fuel cell systems (PEMFC, SOFC)
- DMFC and innovative concepts for portable applications
- Optimised design and integration of fuel cell stacks
- Realisation of demonstrators
- Safety, regulations
- Techno-economic analyses

More than sixty teams are involved in the network. The public funding for PACo is about 10 M€/year. In December 2003, 52 projects had been labelled and financed (ratio funding close to 45 %). The following figures present funding details.









The network enabled the launching of a real scientific and industrial activity in France. Two companies have made an entry into the fuel cell market (Axane, Helion) and start-ups (CETH, N-GHY) have also emerged to develop compact fuel processors for fuel cell systems. R&D on fuel cells is better structured and knowledge is increased.

Fuel cell demonstrations for stationary applications are undertaken on various French sites and others are in progress

ADEME (Agence de l'Environnement et de la Maîtrise de l'Energie)

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.

A.2 Public research centres

Of the various public bodies listed above, the key players in terms of financial and intellectual efforts are the CEA, CNRS and IFP.

The CEA (Atomic Energy Commission)

The Atomic Energy Commission was created in October 1945 by General de Gaulle to provide France with a body dedicated to both military and civilian uses of nuclear energy. Around fifteen years later, the wide variety of expertise acquired allowed it to expand its activities to new energy technologies (non-nuclear technologies such as solar, thermal and wind energy), and it is in 1967 that we find the first recorded work of the CEA, in collaboration with ELF (now TOTAL), on the understanding of the relationship between the structure and properties of ionic polymer conductors, particularly Nafion™, which were the forerunners of PEM cell electrolytes. A few years later, new projects enabled the CEA to acquire expertise in the storage of hydrogen, particularly in hydrides and glass microspheres.

The resources devoted to the development of hydrogen and fuel cell technologies grew constantly thereafter.

The main lines of the CEA programme are currently as follows:

- production of hydrogen: thermochemistry and steam electrolysis combined with future high-temperature nuclear reactors, biomass gasification and research on biological routes for hydrogen production

- storage of hydrogen: high pressure storage and new types of storage for portable applications, carbon nanostructures

- PEM type fuel cell: components (electrolyte, electrodes, bipolar plates), systems (modelling and design) and phenomenology (thermohydraulics). Study and development of micro-cells for portable applications.

- SOFC type fuel cell: components and stack

- transverse studies for the Acceptability and Credibility of future Hydrogen Economy (technology watch, techno-socio-economic studies, safety, etc.)

These studies are conducted in the different CEA centres. About 135 people (researchers and technical staff) are devoted to this program in CEA in 2003.

The CNRS (Centre National de Recherche Scientifique)

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:

- Energy programme : this programme unit is managed by the CNRS with the participation of the DGA (Délégation Générale pour l'Armement) and the Ministry of Research and New Technologies. It has around a dozen programme lines including hydrogen and fuel cells and finances projects proposed by the various teams of the CNRS, both on hydrogen (bio-production, storage on metal hydrides and carbonated materials, safety) and on solid electrolyte fuel cells.
- In 2002, the CNRS opened a research program on Energy. In the field of Hydrogen and Fuel Cells, four projects in 2002 (H2 production, H2 storage, biomass, FC) and five projects in 2003 (H2 storage) are financially supported by the French research ministry. Each project has a duration of 2-3 years and an annual budget of 70 k€.
- PACEM research group: this group, created in January 2002 for a period of 4 years, brings together the teams working on PEMFC and DMFC cells. Their activities are centered on the following subjects: cell components (electrodes, electrolytes and catalysts and their behaviour in real situations) and systems (in particular, the study of a 1 kW generator with Thalès, using DMFC technology, as part of a European program).
- SOFC research group: this group, created in January 2001 for a period of 4 years, brings together the teams working on SOFC type fuel cells. Activities are centered on the technologies associated with the lowering of the operating temperature (IT SOFC), in particular the electrolyte and the bipolar plates.

The IFP (Institut Français du Pétrole)

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 :

- Production : IFP is investigating different processes for producing hydrogen through the generation of synthesis gas from fossil fuels and biomass.
- Transportation of hydrogen in pipelines ; IFP participates to the Naturalhy project , evaluating the possibility to use the natural gas distribution network to carry hydrogen to the final user.
- Storage : IFP is studying and selecting new materials for storage of hydrogen in solid phase through molecular simulation

IFP is also active in the area of the economic evaluation and life cycle analysis of the different options involved and in association with the CEA will contribute to the "Hyfrance" project, whose main goal is to build a hydrogen roadmap for France. This last project is part of the FP6 integrated project "Hyways".

A.3 Public financing in 2002

All the financial commitments of the public bodies listed above were determined following a survey carried out among all the parties involved. The reference period chosen was the 2002 fiscal year. The total amount determined by this work was 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, and which comes to approximately 4.5 M€ for the year 2002.

If we compare this figure with the amount estimated for the year 2001 equal to 37 M€, to which the E.U.’s contribution should be added, we note a relative stagnation of public investment in France between 2001 and 2002. However, French public authorities have expressed the desire to develop these technologies more extensively. On the 15th of September 2003, the Prime Minister confirmed the “Clean vehicles” plan, which should lead to additional support of 40 M€ over a period of 5 years. This plan comprises 5 main research themes, including one entitled “fuel cell development”, to which 5.8 M€ is allocated for 2004.

A.4 Activities on fuel cells

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 recalled hereafter:

- 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.

a) PEMFC
R&D areas include slightly higher temperature (120 °C) and lower cost membrane materials, resistant and low-cost catalyst materials, long life. The technology must met 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
    - Combipol, devoted to new composite bipolar plate system

b) 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
- APUROUTE : Study of an APU SOFC for transport applications
- GECOPAC: a regional project to develop a SOFC prototype of 5 kW within 4 years and to test it in a college. The final purpose of the project is the development of a cogeneration system of 100-500 kW.

c) 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, integration of 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

d) 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 liters 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

d) Systems, tests and demonstrations

Examples of projects (non exhaustive):

- Epacop project: 5 PEMFC prototypes of 5 kW delivering electricity and heat are under demonstration on different sites in France.
- Spact project: PEMFC 5 kW stack behaviour for transport constraints (fuel cell test platform of Belfort)

- Genepac project: realization and test of a 60 kW PEMFC stack for transport application (1.5 kW/l, 1 kW/kg).

A.5 Activities on hydrogen production

a) Production through synthesis gas generation :

Different french companies like Air Liquide and Technip are active in this area and develop innovative options.

As a research center, IFP investigates innovative options at the different stages of synthesis gas production, hydrogen / CO2 separation and hydrogen purification. IFP is also developing new options for producing hydrogen with CO2 sequestration.

Alstom and IFP participate at different studies concerning clean power generation through hydrogen production from coal or natural gas and participate to the FP6 Encap project , which gathers european companies and research centers around this goal.

b) High temperature processes :

France, through research Institutes CEA, CNRS and associate(at small level) industrial companies like EDF and Framatome are carrying out a R&D program on massive Hydrogen production with Innovative High Temperature processes. One part of this program (CEA) is a joint program 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. There is some collaborations with Japanese Jaeri . Another project in the same field is an European Project, HYTHEC, with different European laboratories on study on thermochemical cycles, with use of heat from nuclear or concentrated solar energy. Different types of thermochemical cycles are studied but main effort is focussed now on Iodine/Sulfur Cycle. 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. Experimental loops will be build a,d shared both in France and in USA.

CNRS at Odeillo has some facilities to study applications of high temperature concentrated solar applications, eventually hydrogen production.

c) Low or room temperature processes

R&D on Photobiological processes is carried out in CEA and CNRS, in relation with European programmes :

Scientists in CEA, CNRS, University of Orsay are actively involved in research on different aspects of research in this area.

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. One of these, Ru-Mn chemistry for Artificial Photosynthesis for fuel production (1996-2000) was co-ordinated from the Swedish Consortium for Artificial Photosynthesis. With the 6th framework program underway, new networks are being formed. Again, the Swedish Consortium and the French groups have tied together and have taken a new initiative, which

has brought together leading European groups from Germany, Greece, Hungary and the Netherlands. The new network that is requesting joint funding is named “Solar-H: hydrogen from sun and water - a blue skies research project for a greener planet”.

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Section B: R&D in the industrial sector

The industrial companies which conducted activities in the hydrogen energy and fuel cell field in 2002 are as follows: Air Liquide and its subsidiary Axane, Alstom Transports, CETH, Composites Aquitaine, Ullit, N-GHY, Dalkia, Electricité de France, Gaz de France, Hélion (Areva/Technicatome), Irisbus, PSA, Renault, Sagem, Snecma, Schneider Electric, Thalès, Total, Delphi France.

Some examples of industrial involvements:

- EDF and GdF are focused on demonstration projects and tests on fuel cells stacks and system, both on low temperature and high temperature fuel cells.

- Dalkia, a utility company involved in water, heat, waste management is carrying out some demonstration project in fuel cell system testing for cogeneration applications (PEMFC and SOFC).

- Air Liquide has many activities in Hydrogen storage to develop High pressure and innovative tanks. Air Liquide is strongly focused on Hydrogen cahin, some of the projects are demonstration project especially in Grenoble area. Axane, a subsidiary of Air Liquide located in Sassenage, has the objective to develop and commercialise small PEMFC power unit for a lot of niches markets: back up, portable applications.

- Helion, a subsidiary of Areva located in Aix en Provence is developing and commercialising specific PEMFC fuel cells with pure Oxygen / Hydrogen couple, for submarine applications or extreme conditions applications. Helion intends to develop PEMFC for niche markets, public transportation and stationary markets.

- Total as a global oil and energy company is committed in fostering the development and the introduction of emerging fuel technologies. Concerning hydrogen and fuel cells, this has been illustrated through the announcement of partnerships with major players from the automotive side (Renault) or from the OEM side (Delphi). A masterpiece of Total actions on hydrogen infrastructure is the hydrogen competence center in Berlin and the associated hydrogen station, in cooperation with BVG, Berlin public transit company.

- Snecma, the company for innovative aeronautic and spatial engine, will launch a new activity to integrate components and propose systems for cogeneration including SOFC technology (Gecopac project).

Generally speaking, the fields concerned are highly varied:

- **Hydrogen:**
  - transport by pipes mixed with natural gas
  - ultra-pure hydrogen generators (methanol reforming, new separation membranes, PEM electrolysis)
  - production from biomass

- purification and distribution of hydrogen
- high pressure storage and storage on hydrides
- economic studies

- **Fuel cells**
  - studies of new components and improvements of cell components (electrolyte membrane, bipolar plates, MEA production)
  - testing of systems in residential, tertiary and industrial environments
  - on-board reforming
  - integration in a light vehicle and in a bus
  - development of stationary generators
  - coupling of stationary generators to the electricity grid
  - hybrid fuel cell/battery systems for telecommunications
  - study and development of generators for undersea applications

This list is not exhaustive because many industrial companies do not make public details of their activities. It is estimated that the total amount of finding is close to 50 M€, to be compared with 35 M€ in the year 2001.

3. Budget (Estimation)

Budget for 2002	Public financing	Industrial financing	European financing
	40 M€ (including PACO and european financing)	50 M€ (estimation)	2 to 3 M€ ?

Useful links

- http://www.reseaupaco.org/
- http://www-drt.cea.fr/
- http://www.afh2.org/
- http://www.alphea.com/
- http://www.cnrs.fr/DEP/prg/Energie.html