



Country Report Outline – TIP Energy Focus Group

FRANCE –Document 3

CASE STUDY – FUEL CELLS

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Introduction

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0.1-Fuel cells and hydrogen system delineation issues

According to innovation process representation which has been presented in the Document 1 (Introduction to the two case studies), empirical and factual information are joined together for delineating a fuel cells (and hydrogen) innovation system in France, that is to say private and public institutions linked to a coordinating body. The currently available information lead to a distinction which did not exist within the upstream oil innovation system. Although there are also in the fuel cells case coordinating institutions within the so-called PACo (Piles à Combustible- Fuel Cells) network, two existing realities prevent from reducing the French sectoral system of innovation boundaries on the fuel cells to the PACo ones.

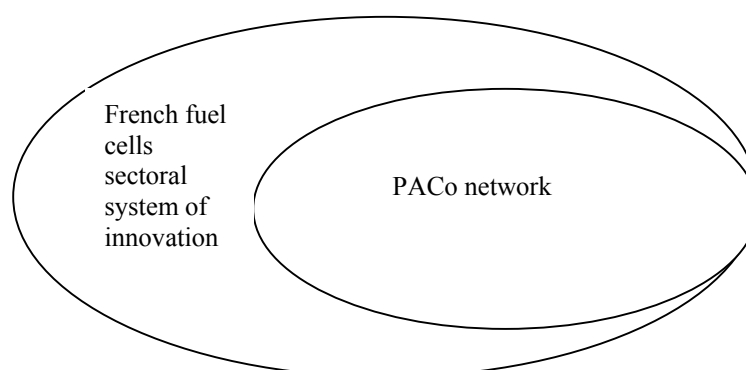
First, although the major important French industry groups have been linked one day or the other to the PACo network for participation in applied research projects, the commitment level of these groups to the network is eminently variable; in particular the French “Multi-National Firms (MNF)” (ie firms with parent companies located in France, but with many foreign subsidiaries) may have R&D activities in the foreign countries where they may find specialized skills and competences in fuel cells technology, and moreover high public R&D programmes in that area, which could constitute supplementary learning opportunities. Moreover these French MNF, and other French research institutions may be often involved in international research and/or demonstration fuel cells partnerships: this trend is even cheered at the European Union level by PACo authorities.

Secondly, there are some important french “missing” groups, that is to say not belonging to that network, (such as Saint-Gobain), or very weakly and occasionally involved industry groups of firms within the PACo network such as chemical groups (AtoFina).

Thirdly, one of the closest sector to fuel cells (electrochemistry and battery industry) is either absent of the French industry structure, or very weak in the French economy.

These features create structural shortcoming which prevent French industry to offer a significant research industry budget support within fuel cells area, and therefore sufficiently large opportunities to develop public/private partnerships in a new industry without near-term markets (see further). They also are sufficiently important to make a distinction between the fuel cells and hydrogen French SSI and the PACo network. The former includes by definition all public and private institutions which are involved in the creation, production and marketing of fuel cells components and systems, while the latter one is a smaller sub-set including only the free-will participants to PACo network. This situation has obviously evolved in the past three years and will likely continue to evolve in the future with an higher participation of large French firms to the network. This report is dealing mainly with the PACo network subset.

Graph 1 : French fuel cells sectoral system of innovation and Paco network boundaries



Source : author

0.2- Three stylised facts about fuel cell innovation in 2003

The presentation of these four “stylised” facts is not specifically linked to the French case study, but nevertheless constitute guiding issues which influence the innovation process. These developments are mainly extracted from Bourgeois B. and S.Mima (2003).

A potential radical and “disruptive” innovation, with a huge potential market in stationary and transport uses

Following the suggested innovation taxonomy by Martin (2000), we may consider fuel cells as a “radical innovation”, that is to say an innovation based on the fact that fuel cell technology is an entirely new chemical process¹ of energy conversion that allows the conversion of a combination of hydrogen and oxygen into electricity power, and water. Fuel cell technology is based on a new set of scientific and technical principles in the history of energy systems, and therefore calls for the building of new blocks of knowledge. This intellectual creation, and the production of the associated *artefacts*, follow a progressive and cumulative learning path. Being in their emerging phase, fuel cells may have also the attributes of “*disruptive technologies*” (Christensen, 1997) limited to narrow niches at the beginning of the transition period between the new and ‘mainstream’ technologies. R.Fri (2003) recalls that for Christiansen “*disruptive technologies*” are rare technologies , which “*simultaneously 1) have capacity to overtake the cost and performance of existing technology both decisively and rapidly, and 2) present new performance characteristics that find value in the market.*” Fuel cells are only a potential “*disruptive technology*” as so far there is still to day a remaining uncertainty on its actual ability to have a quick learning curve with deep slope (remaining technological bottlenecks), and to have valuable performance characteristics for existing and future market : decentralized power supply, environmental benign effect, modular technology, high conversion energy,....

¹ Although the invention of this chemical process dates back to Sir W. Grove’s discovery (1839), the emerging innovation phase in the very limited niches of aerospace applications only began in the 1970s.

The potential market scope is linked to the very nature of this technology: it should allow on the one hand high energy performances (high conversion efficiency, including in the intermittent uses), and on the other hand an outstanding flexibility. This flexibility includes the three following dimensions:

- the broad scope of energy uses potentially supplied by this technology (it could concern (i) fixed power generation for stationary uses, (ii) power generation on-board vehicles for mobile uses and, (iii) micro power generation for portable equipment), where the power range could rank from some watts to several megawatts, interesting distributed electricity generation as well as large power plants supplying national network;
- the scope of fuels that can be mobilised: on the one side petroleum products, methanol and natural gas with processor, on the other side compressed or liquefied hydrogen which can be produced from different renewable or non renewable energy sources;
- an aptitude for modularity, that does not prevent technology from being sensitive to economies of scale.

In other words, this innovation is the likely support of a cluster of new generic energy supply and conversion technologies, which mobilise a large scope of new scientific and technological knowledge. This characteristic addresses the issue of the nature of the institutions and organisations that may develop the required competencies.

Pre-commercialisation stage and uncertain future development

The evolution towards commercialisation phase is still conditioned by the reduction of technical and economic uncertainties. Before massive and successful entry in the market, technologies like fuel cells can still be considered as hypothetical innovation. Despite successful penetration in some limited niches (aerospace uses, some military uses in submarines, and some marginal stationary applications so far, plus a near marketing stage for micro-portable equipment), commercialisation phase is constrained by strong remaining uncertainties, and by overcosts in respect the other existing competitive technologies. Although the latter are obviously inter-linked, we will present them separately.

These uncertainties also concern the reduction of the existing gap between the types of functionality obtained by the prototypes in field tests and the minimal required functionality in each niche. For example the expected improvements in stationary uses rather concern reliability and durability goals, while in transport uses basic improvements are expected in miniaturisation, reliability, balance of plant, and the ability of fuel cells to meet constraints such as load variations and road vibrations.

Moreover these technical uncertainties are combined with the economic ones, which determine the speed of adoption and diffusion of this technology. This economic uncertainty is linked to a very mobile competitive position between fuel cells and its existing or potential substitutes. Today's fuel cells have investment and operating costs several times higher than their substitutes. The technical advances in fuel cells should at least partially reduce these over costs. It looks like a speed race in the performance improvement of competing technologies, sometimes reducing (advances in fuel cells), sometimes increasing (advances in substitutes) the price gap.

According to our most up-date information, the only niche where first commercial fuel cells will begin to be sold in 2004 to market, will deal with “mission critical applications where long back-up times are required”(J.Pouchet, 2003), that is to say in substitution to batteries

for uninterruptible power systems in financial markets, small networks, call center infrastructure, Internet equipment,... Although hundreds of PAFC stationary small power stations have been bought and installed, these fuel cell implementations should only be looked as demonstration , experimentation, trials but not as usual commercial sales. All these developments show

Towards hydrogen civilisation: a long transition process

Fuel cells are mainly a conversion system of hydrogen and oxygen into electric power. Without direct hydrogen supply, a complementary device, the fuel processor, transforms liquid or gaseous hydrocarbons into a gas mix of high hydrogen proportion. But this supplementary stage implies: (i) increased capital and operating costs; (ii) a lower energy efficiency, and therefore increased CO₂ or CO emissions, leading to weaker environmental performance of this technology; and (iii) an inferior operating performance of the fuel cell. In short, energy supplies to fuel cells will face the following dilemma.

- Either within a direct pathway the supplied fuel is hydrogen; but in this case the following issues will have to be solved: (i) hydrogen storage issues: the pressure vessel or “specially shaped conformal tanks” technologies integrated into vehicles remain to be socially accepted, while “both hybrid and carbon nanostructure storage technologies remain immature at this stage” [36]; (ii) hydrogen transport and distribution issues: on a vast territory there are enormous up-front costs for building a new energy network and the modalities to finance them; (iii) hydrogen production issues: a cost-effective way² has to be discovered to mass produce hydrogen under a neutral ecological balance requirement, either from reforming non-renewable carbon fuels with CO₂ sequestration, or from solid bio-mass conversion³.
- Or within an indirect pathway, the difficulty of hydrogen-energy supply is avoided by using the existing petroleum fuel distribution network; but in this case one has to face the simultaneous problems of investment and operating over costs when using the on-board fuel processors.

In a medium and long term perspective, all these issues are likely to be overcome; but their progressive solving requires co-operation between fuel cell developers, energy suppliers, and original equipment manufacturers (for car industry or power generation), in order to benchmark the different feasible technical solutions (see for example the *California Fuel Cell Partnership*). Such collective experimentation together with the necessary improvements of the processor (which needs further miniaturisation) and more generally of the global performances of the whole fuel cell system implies further delays for the commercialisation of fuel cells. In the long term there will be an obvious co-evolution between the successful marketing of fuel cells on the one side, and hydrogen energy networks on the other side. In the short term the absence of such an energy infrastructure can be overcome for marketing fuel cells, but its necessary development will require a long “technology transition” which will require several decades before a massive insertion of hydrogen networks into energy systems.

² This requirement excludes - with the exception of specific niches (large and cheap hydro power plant) - the hydrogen generation from water electrolysis. Small hydrogen production at residential level from photovoltaics or from wind energy does not yet appear as a cost-effective solution. Another future direction remains to be proved technically and economically: steam reforming by high temperature nuclear reactors.

³ Among the different future pathways, the gaseification of wood/crop trees appears as one of the most promising.

Summing up the three characteristics of fuel cells technology, we found that before thinking of the mass marketing of that technology, the current promoters are facing the following difficulties:

- the very broad spectrum of required knowledge and competencies, existing and new ones;
- the still large technical, economic and financial uncertainties that may delay, once more, the future mass-marketing stage;
- the likely very long transition period before fuel cells could be supplied by large hydrogen-energy networks.

*
* *

A- A 2003 picture of the fuel cells system of innovation in France and the PACo network

A.1- Introduction

Over the last thirty five years (1970/2004), a discontinuity was produced in June 1999 with the launching of a new dedicated “National Network of Research and Innovation” (Réseau National de Recherche et d’Innovation Technologique-RNRT), the so-called “PACo fuel cell network”. This discontinuity leads to an historical distinction of the fuel cells development in France before and after June 1999.

A1.1-A short historical survey of fuel cells development in France over the 1970/1999 period.

Over the 1970/1999 period, history of fuel cells development has not been a linear one. Some important contingent events such as :

- oil price shocks (1970/1981) and counter shocks (1985/1990), and correlative succession of fears and negligence about energy supply safety,
 - a progressive awareness of the induced risks from climate change (since the mid of 1990’s)
 - changeable interest from navy and army for these technologies,
- have been key drivers for the “stop and go “policies which have been implemented.

The following survey may be presented (sources : Lamy C. et Leger J.M, 1994, et PACo, fiche d’identité des acteurs réseau) :

- -1960/1975 : Starting research and technology programme within industry (Alsthom, Compagnie Générale d’Electricité-CGE) and Research Laboratory (Institut Français du Pétrole-). From 1967 to 1970 the french nuclear public research and development institute “Commissariat à l’Energie Atomique- CEA”, began research on water electrolysis from an alkaline electrolyte, and first works on conducting ionic polymers
- -1975/1990 : Crossing the desert, with some European oases : some projects are co-financed by European Frame Work Programme
- -1985 : CEA and Centre National de la Recherche Scientifique-CNRS (French major public research center) decide to partner their competences in order to launch the research group “Electrolysis 2000”, with a goal to implement a water electrolysis device from a solid polymer electrolyte. This will be the first basis for the future PEMFC development by CEA.
- 1987/1990 : European Commission , ADEME are co-fiancing PhD students on fuel cells, and more particularly on DMFC within University of Poitiers.
- -1991/1999 : a dedicated research programme to innovation support within the automaker industry , PREDIT 1, -Programme Interministériel Recherche, Industrie, Transport- is set-up; this programme links : i) the major automaker companies PSA, Renault, ii) public research centers such as CENG (the Grenoble ‘s subsidiary of CEA), Universities and CNRS, and Sorapec , a dedicated start-up to fuel cells development; this programme is also co-financed by PCRD subsidies to CNRS and universities research laboratories. The main goal of PREDIT 1 and other successive programmes (PREDIT 2 and 3) is to facilitate the emergence of new energy-efficient and clean car (Véhicule automobile Propre et Econome-VPE). ADEME, the French energy conservation public Agency has the responsibility of financing and follow-up for the sub-programme “VPE/PAC” (energy-efficient and clean car with fuel cell). A comparison between first French prototypes and Ballard ‘s one is realized, and performance are sufficiently close to continue a national involvement.

- 1993 : ADEME co-finance PhD students on SOFC, with EDF and GDF which started a technology watch on fuel cells.
- 1992/1995 : CEA is developing a first 300 Watt PEMFC for automotive drive
- 1996 : a cooperation agreement (Implementing Agreement) is signed between ADEME , on behalf of the French government, and IEA within fuel cells area, with a participation of EDF and GDF in the SOFC group.
- 1995/1999 : CEA participates within the European research programmes “ JOULE-THERMIE” and “ENERGY” to the following projects :
 - -HYDROGEN project which associates Air Liquide, De Nora, PSA, Renault and Solvay, with the aim to supply a 30 Kw PEMFC for a car with high pressure H2 storage,
 - FC BUS project which associates Air Liquide, Scania, De Nora and Genova University, with the aim a second generation of PEMFC for electric bus,
 - FC STAT which partners Air Liquide, De Nora, Schneider... for a 240 Kw stationary PEMFC.

One of the main developed competences is to supply high pressure (700 bars) hydrogen storage device, which will be implemented in 2001 within the Berlingot car of PSA.

- 1999 : Ministry of Research launches a new policy tool : the “RTIN” (see Box 1) with an application in fuel cells : PACo (Pile à Combustible) network.

Next paragraph mainly deals with the after June 1999 fuel cells situation in France .

A.1.2- A Global picture of the French fuel cells innovation system after 1999

During the month of June 1999, Ministry of Education and Research decided the creation of a national Fuel Cell Research and Innovation Network, called PACo (Pile à Combustible) network. The main reason for the creation of this new institution was the awareness by the main public and private decision makers of a lag in respect to the foreign competitors. This diagnosis will be confirmed , two years later, by a report for Ministry of Economy, which states a “low” french position on one side in scientific and in the other side in industrial international competitive fuel cells landscape (Minefi, Digitip, 2001) .

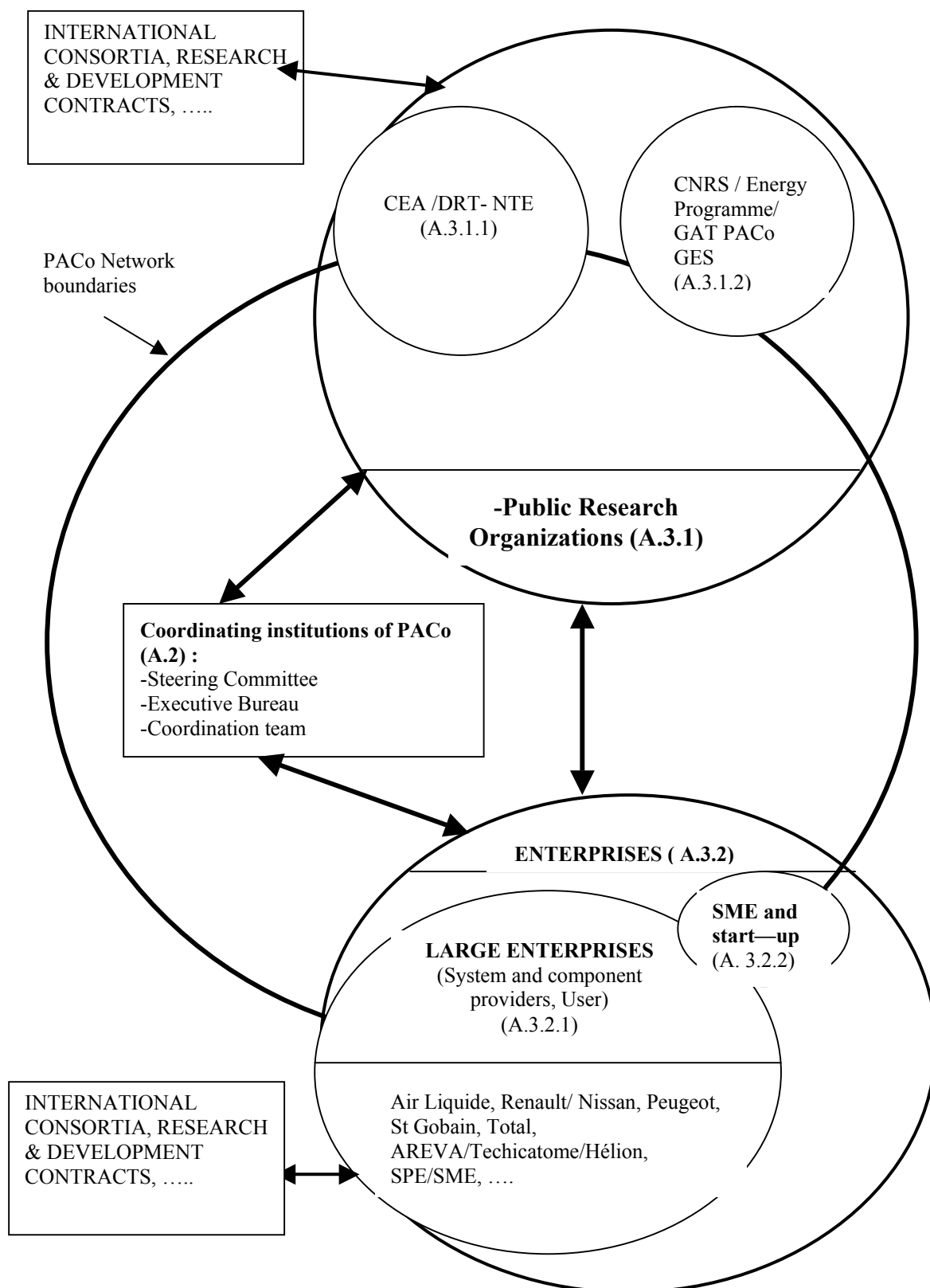
The tasks, operating rules and results of this PACo network will be presented later on within this report.

We may just argue here :

- that within the French sectoral system of innovation on fuel cells network, PACo network has become the main coordinating institution, even if this coordinating influence is not exhaustive and equally distributed among the “coordinated” actors or stakeholders,
- and that the basic influence of PACo network lies in its “labelling power” over proposed public/private projects on fuel cells, which will be later on co-financed by mainly Ministry of Research or Ministry of Economy .

Near the coordinating institution, there are the main public and private institutions which are at least partly “coordinated” on fuel cells development. The same active actors/institutions which already existed before 1999 are included in these “coordinated” institutions

Graph 2 : The fuel cells/hydrogen system of innovation in France and the PACo network in 2003



Source : author; figures are the paragraphs numbers which correspond to each institution/stakeholder involved in the innovation system

(stakeholders), i.e. Public Research Organisations on one side and Enterprises on the other. (See Graph 1 for a global picture).

Some rough indicators may be given here, in the absence of a true statistics system. According to T.Alleau (2002), chairman of the french association for promoting H2 development (AFH2), the total amount of French public institutions investments in fuel cells R&D could reach 37 M€/year in 2001, which includes 9,6 M€ for the PACo network supports. These public institutions include : the Commissariat à l’Energie Atomique (CEA), the Centre National de Recherche Scientifique (CNRS)/Universities, and the Centre National de Recherche Technologique (CNRT/Belfort), plus the following public or semi-public centres such as Ineris (safety, security), Afnor (standardisation) and the IFP (Institut Français du Pétrole). The same author gives an estimation of 35 M€ for the R&D investment of some 15 industrial players during the same 2001 year, which include : Air Liquide, Alstom Transport, EDF, GDF, PSA, Renault, TotalFinaElf, Snecma, Areva, Irisbus, Sorapec, CNIM. In respect to the USA figures (Source : Breakthrough Technologies Institute), the public ratio figure per inhabitant is closed between the two countries, but such as the whole economy average this ratio is much higher in USA for private funding that the French one.

Table 1 : Public and private funding of fuel cells R&D in USA and France (2001)

Units : millions of € and €/hab	R&D Public funding	R&D Private funding	Total R&D funding expenditures
USA : total amount (2002 figures)	159	459	618
USA : funding/inhabitant (2002 figures) €/hab	0,56	1,6	2,16
France : total amount (2001 figures)	37	35	72
France : funding/inhabitant (2001 figures) €/hab	0,62	0,59	1,21

Sources : France : T.Alleau (2001) , USA : Breakthrough Technologies Institute (2003); assumptions in 2001/2002 : 1\$ is approximately equal to 1 €. 2002 figures have been selected in the US case to avoid the non-significant figures of year 2001. The US figures are likely under-estimated, particularly in the public funding.

A.2-The coordinating institutions of the PACo network

PACo network has been set-up according to the institutional rules of an existing research policy tool : RRIT (Réseau de Recherche et d’Innovation Technologique- Research and Technological Innovation Network) (Box 1)

Box 1 : Institutional rules for Research and Technological Innovation Network (RTIN)

Source : Ministère de la Recherche, Réseaux de recherche et d'innovation technologiques

<http://www.recherche.gouv.fr/technologie/reseaux/role.htm>

RTIN are a support to innovation policy which Ministry of Research is steering. Creation of network has been announced by Prime Minister during “Assises de l’innovation” (innovation meeting) in 1998, and then confirmed by “Comité interministériel de la recherche scientifique et technologique” (CIRST- Interministry Scientific and TeChnology Research Committee).

The main goal of Research and Technological Innovation Network is to facilitate public research and industry coupling, within priority areas which are selected by government whereas commitment from existing structures is insufficient. These networks gather firms and public research organisations about projects, in well identified technology areas.

These networks have been commissioned to:

- be aware of the mid to long term socio-economic demand,
- identify technology issues to be solved,
- gather scientific and technology competences,
- implement projects from these competences,
- provoke the implementation of required equipments to partnerships,
- define and cross-share an adequate behaviour of intellectual property,
- encourage transfer to market, particularly by creating innovating Small and Medium Enterprises.

Funding

The first resource within networks is to partner resources, particularly human resources from the public and private research teams which are committed. Their generated projects may also benefit from “Fonds de la Recherche Technologique – FRT (Technology Research Fund)” and “Fonds National de la Science- FNS (National Science Fund)”, which are managed by the “Ministre délégué à la Recherche (Research Deputy Minister)”, and from incentive funds by other departments and agencies. Non French partners , which particularly belong to other EU countries, may also join these projects.

Organisation

Networks organisation may differ according to the different concerned areas, and particularities of sector of application. However, generally speaking, each network is driven by a Steering Committee, which includes industry and public research organisations (Universities and research bodies) representatives. Chair is preferably entrusted to a distinguished person from industry. The daily operations are managed by a select Executive Bureau.

In respect to the previous “Grands programmes technologiques” (Great Technology Programms), the following differences may be quoted with the new “Thematic research and technological innovation network” RRIT/RTIN :

“-important delegation of powers from Ministry offices to the coordinating institutions of the network,

-chairing these networks has been transferred from civil servants to industry representatives,
-public financing may come, and be managed, from different ministry funding : for example subsidies from Ministry of Research, and subsidies and reimbursable loans from Ministry of Economy may be added for the global funding of these networks .”

(Source : OCDE/ Ministère de la Recherche et Ministère de l’Economie, 2003, p.6).

PACo network follow the institutional rules of these RRIT/RTIN networks, and consequently include :

i) the same three following coordinating bodies:

- an Executive Bureau,
- a Steering Committee,
- and a Coordination Team.

ii) the same five purposes, :

- *“Foster the creativity and invention needed for the commercial development of fuel cells,*

- *Encourage public-private partnerships for joint R&D activities and facilitate interdisciplinary cooperation,*
- *Accelerate the progress of technology from the laboratory to the market,*
- *Promote the emergence of a number of industrial activities,*
- *Support funding of selected R&D projects (labelling decision)”.*

(Source : <http://www.reseaupaco.org>)

Moreover a national platform, which is called INEVA CNRT (Integration des Nouvelles Energies dans les Véhicules Autopropulsés-INEVA; Centre National de la Recherche Technologique-CNRT), has been created at Belford (http://www.ineva-cnrt.com/INEVA_CNRT/) after a 5th July 2000 decision of Ministry of Research : this platform, which is open to industrials, is dedicated to automotive fuel cells applications and other land transports. Co-funding from regional and local authorities has been committed too.

The medium-term goals (from 1 to 3 years) of PACo network are decided by “*a high-level Steering Committee which identifies appropriate routes for fuel cell development. It comprises leading representatives from companies, government, universities and research institutes*”. (Réseau PACo, op.cit.).

Table 2 : The Steering Committee line-up of PACo network (at 1st of January 2004)

Name	Institution	Type of institution
R. BALLAY	EDF	LE
J. BARBIER	UNIVERSITE DE POITIERS	PRO
P. BARROYER	VIVENDI DALKIA	LE
P. BEUZIT	RENAULT	LE
M. BRACHOTTE	HELION	SME/LE
D. CADET	ALSTOM Transport	LE
D. DE LAPPARENT	X Technologies	SME
A. DE GUIBERT	SAFT	LE
J.J. DOYEN	SUEZ	LE*
A. FALANGA	CEA	PRO
J.F. FAUVARQUE	CNAM	PRO
E. GEHAIN	GDF	LE
A. KLEIN	PSA	LE
D. LE BRETON	TFE	LE
J.ODDOU	EDF	LE
M. POUCHARD	ICMCB Bordeaux	PRO

J. RILLING	CSTB	PRO
A. ROJEY	IFP	PRO*
B. SPINNER	UNIV. PERPIGNAN	PRO
J.Y. THONNELIER	AIR LIQUIDE	LE

PRO : Public Research Organization; PRO* : Private Research Organization with major public funding;
LE=Large Enterprises; SME= Small and Medium Enterprises; LE* = Large Bank
Source : PACo network, and author.

This **Steering Committee** of 20 persons include 7 representatives of Public Research Organizations and 11 members of large enterprise, plus 2 of Small and Medium Enterprises. The main operating role of the Steering Committee is its labelling decision power, that is to say its empowerment to give a “label” of technical quality to research and development projects which are presented to PACo network for funding. From this technical label quality, the two main funding Ministers, Ministry of Research and Ministry of Economy, plus ADEME, generally decide to follow this technical assessment by a financial support decision. The second operating role of the Steering Committee is to define what will be the scientific and technical priorities of the PACo network for the next two or three following years. These priorities are used by scientific peers, who had been selected by the Committee, as assessment criteria to rank the relative quality of each project.

The Executive Bureau of PACo include a few representatives of Steering Committee (the first three persons in table 2) , plus 5 representatives of funding Ministries, and the three members of the Coordination Team.

Table 3 : Executive Bureau line-up of PACo network

R. BALLAY- Chairman	EDF	Enterprise/Public, user,co-provider
J.F. FAUVARQUE , Vice- President	CNAM	PRO (Grand Etablissement, School of engineer)
P. BEUZIT Vice- President	RENAULT	Enterprise (Private) - User and co-provider
J.Y. THONNELIER Vice- President	AIR LIQUIDE	Enterprise/Private/co-provider, energy provider
M. FRANZ M. C. Le PICARD	MINISTERE DE L'INDUSTRIE	Public Funding Organization
F. LAURENT	MINISTERE DE LA RECHERCHE	Public Funding Organization
F.MOISAN	ADEME	Public Funding Organization
M. DUFAU	ANVAR	Public Funding Organization
M. MUFFAT	MINISTERE DES TRANSPORTS	Public Funding Organization

D. CLEMENT	ADEME*	Coordination Team, Ademe
F. BARBIER	CEA	Coordination Team, CEA
P. MATYSIAK	Secrétariat	Coordination Team, CEA

*ADEME, a public agency dedicated to rational energy use of energy, renewables is funded by Ministry of Research and Ministry of Industry

Source : PACo network, and author.

The funding contributions of public entities, which are detailed in table 4, clearly show the leading role of first Ministry of Research, and then Ministry of Industry .

Table 4 : Public funding contributions to PACo network (1999-2002)

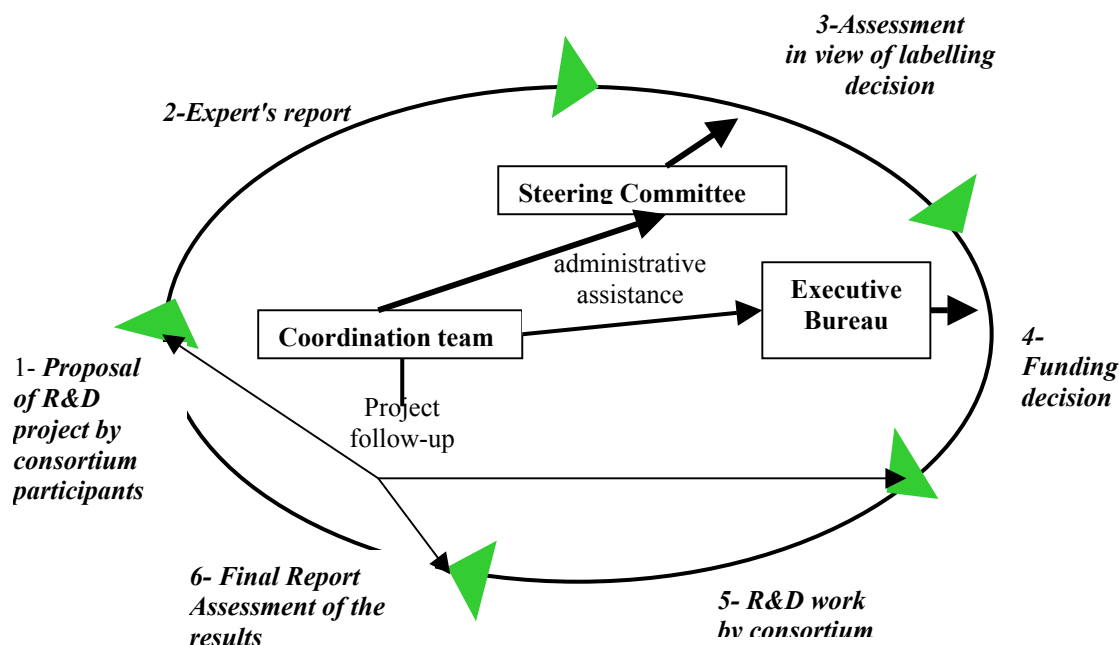
Units : current euros	1999	2000	2001	2002	Total
Ministry of transport			2 486 186		2 486 186
Ademe		4 260 107	1 379 260	2 132 500	7 771 867
Ministry of Research	3 029 416	4 462 492	4 114 096	2 728 939	14 334 944
Ministry of Industry	4 627 085	0	1 612 215	1 141 167	7 380 467
Anvar		54 882			54 882
Total (€)	7 656 502	8 777 481	9 591 757	6 002 606	32 028 346

Source : Ballay, 2003

Finally the third coordinating body of PACo network is the Coordination team, which only includes two half-time civil servants, one from CEA –DRT/LITEN and one from ADEME, plus a secretary. Their task is mainly dedicated on one side to assist the Chairman of the network to define the medium term strategy options, and on the other side to care on the good governance of all operating rules, mainly the follow-up of the R&D projects.

The main interactions between these three coordinating bodies of PACo may be illustrated in the following graph.

Graph 3: Roles of the three coordinating bodies of PACo network to manage the R&D projects proposal



Source : PACo network, and author

A.3- The two main categories of actors within the network

A.3.1- The Public Research Organizations (PRO)

The Public Research Organizations (PRO) include three types of institutions : one more dedicated to “Basic Technological Research” (CEA), one more focused on basic and applied research (C.N.R.S.), and the third one which is in-between : universities closer to the basic research, and school of engineers more specialized in applied research and development. Despite the existence of two legal public status, one for full-time researcher within CNRS which is a public scientific and technological establishment (Etablissement Public à caractère Scientifique et Technique –EPST), and the other one for part time teacher/part –time researcher within universities, which are public scientific, cultural and training establishment (Etablissement Public à Crarctère Scientifique et Professionnel – EPSCP), the general trend is to associate both category of researchers within mixed research units (Unités Mixtes de Recherche, UMR).

One of the main justification of PACo network has been a better coordination between the different PRO organizations, and also a restructuring of their internal organization of each PRO to reach minimum critical size and competences. Despite existing institutional boundaries between each PRO organization, the small size of the scientific community plus the incentives which have been given by PACo network allow frequent research and development partnerships.

A.3.1.1- Commissariat à l’Energie Atomique –CEA- (French Atomic Energy Commission) is an institution usually dedicated to the civil and military nuclear energy applications developpement. While certain development lines of nuclear technologies have been removed (Ex :Fast Breeder) and other increased such as fusion (ITER project), and the main industrial activities (nuclear fuel cycle) transferred to AREVA, the French public authorities (Comité Interministériel de la Recherche- Inter_Ministry Research Committee) have decided a broadening of the original goals. In particular in 1995 CEA received the official duty to participate in the dedicated programme of Fuel cells for transport (PREDIT programme). The same inter-ministry committee decides 1st of June 1999 a higher commitment in new energy technologies including fuel cells, which has been later on (2001)

expressed by the creation of new structure within CEA : "Nouvelles Technologies de l'Energie" (NTE) » (New Energy Technologies), now LITEN (Laboratoire d'Innovations pour les Technologies des Energies nouvelles et les Nanomatériaux), which reports to 'Direction de la Technologie (DRT, one of the five main divisions of CEA.)-DRT is now the steering structure of the CEA fuel cells program which is performed through different research locations within French territory (cf graph 4). This Division has two main tasks : i) improve advanced technologies and ii) "*transfer of knowledge and innovative technologies to industry and small and medium-sized companies and industries*". This mission is later on explicitly confirmed and reinforced (25 January 2001) within the five-years contract (2001-2004) between Government and CEA. At the beginning of 2004 year the Technology Research Division is now made up by the three following sub-departments :

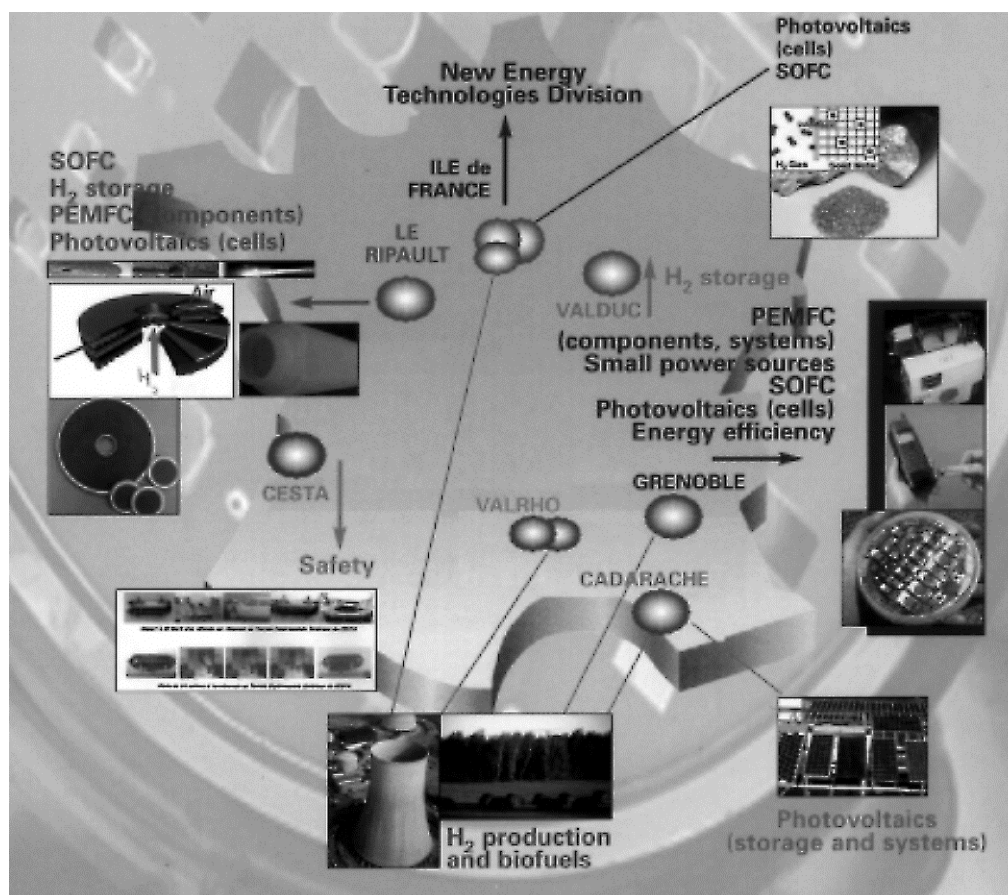
-LETII (Laboratoire d'Electronique de Technologie de l'Information) is specialized in miniaturized technologies, micro-components and their integration systems . (about 500 employees)

- LIST (Laboratoire d'Intégration des Systèmes et des Technologies) focuses on development of numerical systems, and their integration within process and products (300 employees),

- finally LITEN (Laboratoire d'Innovations pour les Technologies des Energies nouvelles et les Nanomatériaux) is dedicated to new energy technologies and materials. ». The new DTEN/LITEN department covers four technology areas : 1-hydrogen and fuel cells, 2- photovoltaics, 3- energy efficiency and particularly thermal exchangers.4- materials.

Over the 200 persons of CEA dedicated employees to new energy technology in 2003 , 21 were working on hydrogen technologies, and 60 on fuel cells.

Graph 4 : Location of the H2 and fuel cells activities of CEA-DTEN/LITEN within France



Source : CEA, Technological Research, From research to industry, Direction de la recherche technologique, Centre de Fontenay aux Roses

A.3.1.2-CNRS

The “Centre National de la Recherche Scientifique”(CNRS), is a public institution dedicated to basic and applied research within all knowledge fields ; it includes 25 000 employees with 11400 researchers and 13 600 research engineers and assistants and a global budget of 2 532,779 millions d'euros (2002), with 1256 research units (“unités de recherche et de service”). The main long term goals and objectives are defined within a “ Contrat d’action pluriannuel”(a pluri-annual contract) which has been signed last 21th of March 2002 over the period 2002-2005. Within this general framework, a new inter-disciplinary program, the “Energy program” has been launched in 2002 over the period 2002-2005.

The main research strategic framework follow the following lines :

- *“Increasing the role of renewable energies and developing new technologies to complement or replace the use of fossil fuels in heat production, transportation as well as in electric generation;*
- *Improving the industrial processes performances in term of energy efficiency, industrial waste reduction and treatment;*
- *Properly managing the various energy carriers: electricity, heat, hydrogen production, storage and transport,*
- *Taking into account the socio-economic aspect of the issues.”*

(Source : CNRS, 2002)

The first year (2002) budget of this program has been 1,5 million € , while the 2003 one has reached a 6 millions € level, with a complementary funding from Ministry of Research, Ademe, and Délégation Générale pour l’Armement (DGA). Over this 1,5 million € figure which do not include wages of the researchers, 0,1 million € has been attributed to CO2 sequestration, and the same amount to fuel cells, while 0,18 million € has been granted to hydrogen production and storage. (Source : B.Spinner, 2003). The other relevant indicator deals with the number of researchers and engineers/assistants which were employed in these programs : 100 to fuel cells, and 61 to hydrogen production and storage.

A.3.1.3- The rest of public research actors

They mainly include :

- universities,
- schools of engineers such as : Ecole Polytechnique- Physique de la Matière Condensée ;- Ecole Nationale Supérieure de Chimie de Paris – ENSCP- Ecole des Mines de Paris-Armines, Centre des Matériaux ; Ecole des Mines de St Etienne, Institut National Polytechnique de Grenoble with Ecole Nationale Supérieure d’Electrochimie et d’Electrometallurgie de Grenoble –ENSEEG and its research laboratory – Laboratoire

d'Electrochimie et de Physico-Chimie des Matériaux et des Interfaces – LEPMI ; Ecole Nationale Supérieure de Chimie de Montpellier- ENSCM : Laboratoire de Chimie Macromoléculaire ;),
 -and other public institutions such as Conservatoire National des Arts et Métiers – CNAM, INRETS (The French National Institute for Transport and Safety Research) .

Among universities teams, the following ones may be quoted :

- University of Bordeaux: Institute of Condensed Matter Chemistry (Institut de Chimie de la Matière Condensée de Bordeaux- I.C.M.C.B.), Group II : Physical Chemistry of Conducting Oxides (J.C. Grenier and M.Pouchard)
- University of Poitiers- , Laboratoire de Catalyse en Chimie Organique (LACCO)
- University of Nantes : Institut des Matériaux J.Rouxel (IMN), Laboratoire de Thermocinétique -LT
- University of Nancy- Laboratoire d'Energétique et de Mécanique Théorique et Appliquée- LEMTA,
- University of Orleans : Centre de Recherches sur les matériaux à haute température (CRMHT)- Groupe de Recherches sur l'Energétique –GREMI,
- University Pierre et Marie Curie, Laboratoire d'Electrochimie et de Chimie Analytique (LECA)
- University Paul Sabatier- Toulouse III- Centre interuniversitaire de recherché et d'ingénierie des matériaux (CIRIMAT)
- University of Montpellier – Laboratoire des Matériaux et Procédés Membranaires (LMPM),
- University Claude Bernard of Lyon- LACE,

....

These research teams are almost always associated with CEA and CNRS, and private industry teams within common research partnerships.

A.3.2- Enterprises / Providers and Users

As so far fuel cells area is a new emerging industry, large enterprises with their core business dedicated to this sector do not yet exist. However large incumbents in other closed sectors may be interested either by an active technology watch in order to launch acquisition proposals when first market applications will be proved (“fast follower” strategy), or by a real commitment to technology development. (“first mover strategy”).

The major part of large firms are belonging to the first category, and some exceptions to the second one, such as Air Liquide. They may be found either in the energy and chemical companies, such as EDF, GDF, TOTAL, RHODIA, Dalkia or in the original equipment manufacturer which will incorporate later on fuel cells technology in automaker (Renault/Nissan, PSA) or in power stations supplier (Alstom), or in portable applications (SAGEM, Thalès, SPE). A few number of small enterprises, generally subsidiaries of large groups, may be found in the core/key technologies area : Sorapec, Helion (Areva group), Axane (Air Liquide group), NGhy. This second group is per definition entirely dependent for their funding from public support and from their group.

A.3.2.1- Large firms

Air Liquide is a private French home-based company, but with large international assets which are mainly focused in industrial gas business, including hydrogen for chemical uses. A perspective is potentially open with a shift from hydrogen for chemical uses to hydrogen for energy use. This perspective of an enlarged market may explain the high level commitment of

Air Liquide to fuel cell and hydrogen R&DD. This 30 800 persons group has approximately spent 1,9% of its 2002 turnover (7 900 millions of €), i.e. 150 millions of € to R&DD. These research and development activities, with a portfolio of 1800 patents, are developed by 550 in-house researchers, who are located in 8 research centers within France, United States, Germany and Japan, but also within the five world engineering centers (poles d'ingénierie) in India, China, France , USA and Japan. These research activities are also developed within 100 international cooperations with universities and research institutes. Three stages may be identified in the Air Liquide research and development strategy (Source : D.Deloche, Paris , 2001) : 1- Stage 0 –Sampling, markets identification, first demonstrators,2-Stage 1: Creation of Axane-fuel cell systems subsidiary in 2001; technology development; reliability, recycling, cost; technology partnerships, maintenance, technical lifetime; Stage 2: from 2004 Beginning of production, marketing and partnerships. Stage 2 will be probably delayed or limited to smaller niche applications.

EDF (Electricité de France) is a an “Etablissement Public à caractère Industriel et Commercial (EPIC)” under French law, with its main assets in electricity generation, transport and distribution, which are located mainly in France and also within some European and South-American countries. This public utility has a turnover of 48 359 millions € in 2002 and 172 000 employees, and has a research specificity. With EPRI in USA, and a few big power companies in Japan (Tokyo Power Company), Hydro-Quebec in Canada, EDF is may be one of the last world utilities which supports a significant level of R&DD expenditures : 424 millions of €, ie 0,9 % of its turnover, with 2 400 employees. But like the other utilities, an important shift is being given to R&DD policy towards shorter term goals, and projects more and more assessed with discounting rate methods. Moreover one cannot forget the very high link of this utility to nuclear power techniques : 85 % of its electricity is generated from nuclear power plants. These combined factors explain the level of EDF commitment to fuel cells technology development : existing but low in respect to the other R&DD priorities, and which do not exclude research works and industry partnership in competing technologies such as lithium-polymer batteries for electric vehicles. Nevertheless EDF supports in its French research laboratories and within the European Institute for Energy Research (Karlsruhe-Germany) i) SOFC research development with other partners (CNRS and ...), ii) methanol fuel cell development for isolated sites, iii) testing of PEMFC...

Gaz de France is an “Etablissement Public à caractère Industriel et Commercial (EPIC)” under French law dedicated to transport, distribution and production of natural gas mainly in France, and a few European countries. This enterprise has 36451 employees and 14 360 millions € of turnover in 2002. The Research and Development Division has an annual budget over 90 millions €, i.e. 0,9% of its turnover , and 610 employees, including 400 researchers, a portfolio of 200 patents in France and 1600 abroad.

“Principal areas of research include:

- *Upstream: Liquefied Natural Gas (LNG), gas networks (pipelines, corrosion , treatment and metering);*
- *The uses of gas in industrial processes (glass making, metallurgy, and agribusiness);*
- *Everyday gas usage: combustion and burners, heating, hot water and cooking;*
- *Innovative techniques: air-conditioning, cogeneration , fuel cells , and Natural Gas Vehicles (NGVs);*
- *Miscellaneous areas: statistics, economics, sociology and the environment.”*

Source : Gaz de France, : http://innovation.gazdefrance.com/public/php/generic_niv1.php?iddossier=0&identifiant=generic_presentation&idespace=2&langue=en

Fuel cells pathway represent strategic and future high-value markets for Gaz de France within several segments of its global market : individual and collective home market, tertiary sector, industry market. As a natural gas supplier, the Gaz de France group is involved in fuel cell development as a designer and operator of thermal systems, as well as for electricity generation in three different types of fuel cell:

- *Phosphoric Acid Fuel Cells (PAFC) :*

Gaz de France and EDF installed and commissioned the first fuel cell in France on a commercial site during winter 2000 in Chelles;

- *Polymer Electrolyte Membrane Fuel Cell (PEMFC) :*

The R&D Division is currently experimenting in its experimental pavilion on a prototype residential fuel cells;

- *Solid Oxide Fuel Cells (SOFC) :*

The Gaz de France R&D Division carries out numerous R&D experiments in a dedicated laboratory and conducts a number of demonstrations”.

Source : <http://innovation.gazdefrance.com/>

Total is a private major oil, gas and chemicals company at world level, but with the main part of its downstream activities in Europe and France. Total has a turnover of 102 540 millions of € in and 121 469 employees in 2002. Total is potentially concerned by fuel cells development on two sides : 1) with its chemical subsidiary ATOFINA and fluoridated polymers in the production of stack components such as bipolar plates and membranes, ii) with its Total Raffinage & Marketing subsidiary for the eventual supply of energy inputs to the fuel cells, with a posted neutrality on the best fuel issue between special gasoline, diesel , LPG, natural gas, oxygenates, hydrogen... In that area, activity seems to be limited to technology watch. According to D.Le Breton (2001), the main decision-maker for this fuel choice will be automakers and heavy truck suppliers. Consequently a research partnership has been implemented in 2002 with Renault to identify what could be the fittest fuel for in-board reforming

Renault, a now private automaker industry, has a turnover of 36 300millions of € and 132 500 employees in 2002. It has become with its alliance with Nissan a bi-national group. This alliance, which main rationale is based on a cost-sharing and increasing coordination of slaes policy has an application in fuel cells area. Accoding to P.Beuzit (2003),”*Renault and Nissan ...believe that hydrogen is the good vector of energy for the future, and secondly think the fuel cell will be the pertinent way to transform it into electricity to feed an electric vehicle.... But, we are also conscious of the terrible difficulties we need to overcome before to industrialize and commercialize fuel cell vehicles.*” Some informations are given then on the four issues/Challenges that the Renault/Nissan research programme looks for solving : 1- Hydrogen supply : Nissan is working on the refuelling and on-board storage problem, while Renault is dedicated to on-board reformer ; 2- Both companies are researching and developing fuel cells efficiency, cost reduction and improved reliability. Significant automotive applications are not expected before 2010.

Source : http://www.renault.com/fr/groupe/activites_p1.htm

Peugeot SA is a private automaker industry with a turnover of 54 400 millions € and 198 600 employees, including 74 900 abroad in 2002 . During this same year, R&DD budget is 1870

millions(3,4% of turnover) , with 17 000 engineers and technicals. A very small part (a few million euros) of this budgets is dedicated to fuel cells research, but focused on some specific goals : participation to PEMFC development with other public and private partners, use of compressed hydrogen for very specific applications in a short-term period of testing, and a niche of experimental applications in urban fleet of light duty vehicles (from M.Garnier, 2002). Recently, (February 2003), the CEO, Jean-Martin Folz argued that “ *The many obstacles that fuel cell cars are meeting justifies our decision...not to embark on large expenses for development of this technology*”. In that vision, hydrogen-powered cars would not be a commercial reality for at least 15 years.

Dalkia is a private firm, provider of energy services to local authorities and companies : integrated on-site energy management, management of district heating and cooling systems, services for industry, facilities management. Dalkia , a subsidiary of Veolia Environment (ex-Vivendi Environment) and Edf, had a turnover of 4600 millions €, and 40100 employees in 2002. Its Research Center , Centre de Recherches pour l’Environnement, l’Énergie et le Déchet (CReeD), has a budget of 2,4 millions € and 70 engineers during the same year. CReeD had five priority lines :

- control over the effectiveness of techniques
- operating productivity and safety
- renewable energies and the environment
- energy management in deregulated markets
- new technologies

Regarding new technologies, CreeD had a participation within fuel cells development and mainly testing, for example with Helps (fuel cells with hydrogen stored to provide a dependable power supply). “*In 2003, Dalkia is, together with CEA, continuing the development of solid oxide fuel cells and considering carrying out tests with 150 to 250 kW pre-commercial fuel cells on several operational sites.*”. In the same direction, a recent (22 th of January 2004) project on a small SOFC prototype has been decided between CEA, Dalkia , Snecma Moteurs and local public authorities (Région Centre, Académie d’Orléans-Tours).

(Source : http://www.dalkia.com/default/doc/fr/rapport_02-chap3_4.pdf)

Alstom is a private group specialised in power generation and transport through its activities in rail and marine. At the beginning of year 2003, Alstom began to implement a severe restructuring plan because of recurrent financing problems . During the same year, the group had a turnover of 21 351 millions of € and 109 671 employees. Research and development activities had a budget of “*€ 575 M each year spent by more than 6000 people around the world*”. Alstom is focusing its fuel cell research activities in SOFC development, as so far “*of the various fuel cell types under development, solid oxide fuel cells (SOFC) offer the greatest long-term potential for stationary markets.*”

Moreover Alstom is also developing an other fuel cells programme on “*embedded fuel cells used in hybrid architectures into transport systems, including energy storage devices such as flywheels or super-capacitors*” (Tarbes- France) (Source : http://www.alstom.com/static/html/acom-AGF_NavPage-NavPage_StandardLeft_1039593796113.html#).

SNPE group is a medium-sized “French chemicals group, founded in 1971. It generates annual sales of 850 million euros, including more than half for exports, and has 5,000 employees in Europe, Asia and North America.” “On January 1, 2003, SNPE was reorganized into five subsidiaries respectively dedicated to energetic materials, explosives for construction, civil engineering and mining, explosive-cladding of metals, fine chemicals and speciality chemicals. SNPE Matériaux Energétiques (SME) is the SNPE subsidiary in charge of energetic materials research, development, production and marketing”. In fuel cells area, research activities seem to be focused on a new hydrogen energy supply device for portable application, in partnership with CEA. Source : <http://www.snpe.com>

AREVA Group is a public industrial firm of 75 000 employees with a turnover of 11 500 M€ in 2002. Since 1st of January 2004 this group includes five departments :

- “Upstream Pole” specialised in uranium mines, chemicals , enrichment and preparation of nuclear fuels,

- “Reactors and services” Pole specialised in the manufacturing of nuclear reactors and its components,

- “ Downstream Pole”, specialised in reprocessing the used nuclear fuels,

- “Electricity transfer and distribution Pole”,

- “Connector Pole”.

AREVA has an R&DD budget of 332 M€ and 2700 employees, which are mainly (65%) devoted to nuclear energy and secondarily (35%) devoted to connector activities. Within nuclear activities, AREVA participates , with CEA , to the emergence of new reactors such as EPR, and in the longer term to the fourth generation of nuclear reactors, mainly with the Very High Temperature Reactors which could lead to the production of hydrogen energy.

Source : www.arevagroup.com/

A.3.2.2- Small and Medium Enterprises and start-ups

Within this last category of stakeholders, two different types of actors are to be presented : i) specialized subsidiaries of large groups, and ii) start-up. Two small specialized subsidiaries have been created respectively during the same 2001 year by a private and a public industrial group.

Axane is a wholly-owned subsidiary of Air Liquide Group which has been created in May 2001. In 2003 Axane had approximately 20 employees. Its “*mission is to develop on a global scale complete packaged systems that produce energy from fuel cells powered by hydrogen.*” Axane “*target three markets that are likely to provide large commercial outlets in the short term:*

- *Portable multi-application generators (500 W to 10 kW)*
- *Stationary applications (more than 10 kW)*
- *Mobile applications for small hybrid vehicles (5 kW to 20 kW)*

The first industrial applications are forecast for 2004, in particular in the portable generators market.” (Source : <http://www.axane.fr>)

Hélion- is a Technicatome group’s subsidiary of the holding company Areva. Helion , set up as a limited company with about 10 employees the 8 March 2001. Helion “*has established a partnership with SORAPEC – the French specialist in electrochemistry for stack development*” which was removed at the mid 2002. Helion “*designs, develops and manufactures fuel cells for applications seeking safe, reliable and environmentally friendly*

technology". Helion is claiming (4/3/2002) the first realisation of a French fuel cell prototype of 2000We. "To meet the needs of anaerobic applications, the prototype not only operates in the Hydrogen/ Air mode, but also the Hydrogen/ Oxygen mode".

Source : http://www.helion-fuelcells.com/press_releasehelion.PDF

Sorapec - This start-up was founded in 1974 from CNRS competences in electrochemistry. It was involved in the research and development of fuel cells and alkaline batteries. In the past five years it has developed PEMFC stacks, MEAs, and composite and graphite bi-polar plate technology. Stacks developed range in size from 100W to 2 kW, and larger systems would have followed up to 50kW. These expectations were frustrated by financial difficulties.

N-GHY fuel processors for fuel cells, S.A. Albi, France "is a private company created in early 2002 to develop efficient fuel processors for Fuel Cells systems. N-GHY proposes a patented reforming technology based on a high temperature non-catalytic process easily adaptable to any type of fuel, coupled with a catalytic unit for reformat gas clean-up". N-GHY had 9 employees in 2002.

CETH- Compagnie d'Etude des Technologies de l'Hydrogène, is one of the fifteen start-up which have been set-up in relationship with research programmes of Ecole Polytechnique, the most famous School of Engineers in France. CETH is located within the incubator X-Technologies, a dedicated subsidiary of Ecole Polytechnique, which is a "technological center open to young doctorates and post-doctorates, and which aims at the industrial and commercial exploitation of the research results". Among the technologies of hydrogen generator, CETH has created one demonstrator of on-board reformer producing hydrogen from ethanol with integrated membranes: this demonstrator has been co-financed by PACo network.

Source : <http://www.xtec.polytechnique.fr/indexe.htm>

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B- Innovation processes : knowledge creation, diffusion and use within the PACo network

Introduction

The very first determinants of learning process in the fuel cells case are tied to the current innovation life cycle stage : somewhere between basic research and first demonstration prototype, according to the different fuel cells pathways. In other words, more and more scientists, public and private decision-makers are discovering or re-discovering to-day (cf for example the outstanding and very well documented last report of National Research Council on Hydrogen economy, 2004) that a great number of scientific and technical bottlenecks are still hampering the development of more efficient fuel-cells and their potential access to markets. The awareness of these bottlenecks has probably been better understood in France than in other countries, due to the recognised existing lags of French research and competences in that area at the end of 1990's. This context may partly explain the reason why apparently the largest share of the learning burden has been mainly supported in France by Public Research Organisations, that is to say mainly by public funds, even if there were significant commitment from some private firms.

However the creation of PACo network in 1999 was also the recognition that some improvements should be implemented within the French innovation system, even if public research organisations were, per definition in the fuel cells case (the current life cycle stage), the main committed institutions (B1). But each main French stakeholder has been unequally committed in this network due to their specific strategy and expectations (B2). Moreover in the fuel cells case, empirical evidence shows that probably due to risk sharing goals, and the desire to catch-up a part of the existing lags, international partnerships have been specially developed, and as such have set up a special form of learning.(B3).

B1-The implemented learning process within PACo network

Because its relevance for fuel cell emerging innovation network, one may start from the Avadikyan and al (2003) representation of the two fundamental roles of network : *“first, they produce a ‘common vision’ of the world amongst heterogeneous agents”; second they set up a cognitive platform for knowledge exchange”*(op.cit.-p.5). Why networks are estimated the main building block of innovation process in the fuel cells case ? Because these *“networks are necessary to trigger the investment dynamics necessary for developing the complementary technologies , which will determine in fine the possible uses of the fuel cells”* (p.6, 7). *“A common vision”* means that in our particular case, PACo may become *“an institutional device that provides a common commitment about what should be done”*(p.5) within a general world of uncertainties for the different committed stakeholders (*“complex and unpredictable environment in which knowledge and data are dispersed”*(p.5),... *“incomplete and imperfect local perceptions”*(p.6)), and possible competition between them. The usefulness of this common vision is to produce *“rules of the game that help to monitor uncertainty”*(p.5) resulting from the fact that the *“outcome of the innovation process is unknown”* (p.5). In that direction, the question is to document what were the current institutional rules and used practices within PACo which might have a positive impact on the progressive common vision. *“A cognitive platform for knowledge exchange”* means that network is *“a way to share and exchange complementary knowledge”*(p.6). This perspective offers the opportunities and associated risks of increased specialisation : some stakeholders agree *“to increase their specialisation in a given form of knowledge”* (p.6), because they trust

that “*the other agents will increase their specialisation in complementary forms*” (p.6). This trust “*also influences the choice between specialisation and co-operation in the production of knowledge*” (p.6). Therefore “*one of the key issues that determine the functioning of innovative networks is the constant trade-off for the agents between the delimitation of property rights on the one hand and the determination of access to complementary forms of knowledge on the other*” (p.6).

This general representation may be then illustrated and specified within the context of PACo network. Three different dimensions or “tools” may be quoted to illustrate the institutional device which has been implemented :

- the first two are directly linked to PACo : labelling decision rules on one side, and yearly internal seminars/conferences (“*Séminaires du réseau*”) on the other side
- the third one – INEVA platform- is only indirectly tied to PACo.

B.1.1-Rules of the “labelling” decision set up the common rules of collective learning framework, between the different stakeholders who decide to cooperate within the PACo network. Their requirements mean the required conditions to belong to the network, and to benefit the subsidy/loans funds from Ministry of Research or Ministry of Industry. Submitted projects to have a chance to reach the PACo label must :

- “-1- *be relevant to market demand and the strategic directions which have been defined by the Steering Committee,*
- 2- *be consistent with an open and synergetic partnership,*
- 3-*include an innovative value added in respect to current state of knowledge and intellectual property,*
- 4-*provide perspectives of scientific, industry and economic impact (patents, innovations, standards, publications, market perspectives, job impact, firms creation)*
- 5- *rigorousness within the definition of intermediary and final results (clarity and relevance of risk analysis, obligation of performance)*
- 6- *Clarity of form filling”*

Source : <http://www.reseaupaco.org>

Criteria 2 is the most explicit from this point of view : partnership is required, and according a complementary public directive (“*le consortium présentant une proposition d’étude ou de développement doit faire intervenir au moins un industriel et un centre de R&D*”), this partnership must associate one or more Public Research Organisations with one or more public or private firm. This requirement matches the government will which aims, at least partially, fill the current gap between public research and private industry, that is to say try to reduce a recognised learning failure in the French innovation system. However the same public directive acknowledges the possibility of partnership including public research organisations only in some cases (“*Cependant, quelques actions de recherche amont pourraient être présentées par des laboratoires ou associations de laboratoires*»). These exceptions may be easily explained in the case of emerging technology with some current bottlenecks, which may call for more fundamental and applied research, such as the cases of membranes and catalysts development for example.

A supplementary condition has been specified with the notion of “*open partnership*” : in order to increase interactions between public and private research teams, or to avoid double financing on the same type of projects, or to increase the critical size of a consortium, the suggested consortium within the initial tender may be opened to new participants. (“*une des vocations du réseau étant d’amener les équipes à interagir entre elles et d’éviter les “doublons”, le réseau peut être amené à suggérer une ouverture du consortium* »).

An other directive states that the creation of consortia/partnerships should include French institutions and firms, as so far the rationale for PACo network is to contribute to an emerging French fuel cell industry (*“le réseau a été créé pour développer une industrie française des piles à combustibles”*). Such as for the previous recommendation, exceptions may be admitted by the Steering Committee as so far in some cases specific skills may be lacking within French territory. (*“ Dans certains cas la réalisation de cet objectif peut passer par des partenariats avec des industriels ou des centres de recherche étrangers, lorsque des compétences particulières manquent au réseau ou lorsque la lourdeur des moyens à mettre en place justifie un partage des dépenses entre pays. »*) Some caveats are added on intellectual property rights, industrial developments and European Union preference for the eligibility of these exceptions, which effectively have occurred in the PACo network. But PACo authorities are encouraging French innovating stakeholders to increase their international commitment, for example in the European projects which are supported by European Union funds.(see B3) (Source : <http://www.reseaupaco.org>).

About « Intellectual property rights » a constant policy of PACo network chairman has been to increase patents awareness for all innovation stakeholders, which is a traditional weakness for many French industry sectors. But a too strong patent policy, which is not the French case, may have negative impact in fuel cells development : Avadikyan et al. (2003) estimate that a risk of over-protection strategies which excessively limit access to knowledge *“may preclude access to the core of (fuel cells) technology, and hence to the precise understanding of the functioning of the components (of fuel cell system) and their interactions.”* (op.cit.p.4).

B.1.2- Consistency of the submitted projects with the “Strategic objectives” of the Steering Committee

After having specified the general learning framework, PACo network indicates to the potential project leaders and stakeholders what technical and scientific area of fuel cell research will be preferentially supported in the next “call for tenders” rounds. In other words PACo Steering Committee defines its strategic priorities which will become the scientific and technical priority research for the future. Definition of these ‘Strategic objectives’ is a progressive and recurrent process, because Steering Committee members must take into account :

- the continuous advances of science and technology at international level,
- the moving expectations of French innovation stakeholders,
- and the effectively obtained results from past research projects

Theoretically these strategic objectives are to be defined for a five-year period. Despite the absence of an official “PACo Roadmap” which is emerging in a new recent research project, following specifications have been recalled by the PACo chairman (Ballay, 2003) :

“The projects are focused on PEMFC and SOFC although Direct Alcohol Fuel Cells (DMFC, DEFC) are also considered. Table 1 presents some characteristics requirements of transportation versus stationary and portable applications.

Concerning PEMFC, R&D includes:

- *Higher temperature (120-150 °C) / higher durability membranes (new materials), for more efficient thermal management, for reducing radiator size for automotive applications and for reduced carbon monoxide management*
- *New catalyst materials and better utilization (resistant to impurities, increased activity)*
- *Optimized design of membrane-electrode assemblies (MEA)*
- *System design and integration*
- *Bipolar plates (materials, new concepts to increase fluid distribution...)*
- *Low cost and high volume manufacturing techniques*
- *Advancements in the understanding of degradation mechanisms*

- *Miniaturization of the system for portable applications.*” (op.cit. p. 5)

“Concerning SOFC and as preliminary developments, the core of the vision is a 5 kW, low cost, high power density, solid state fuel cell stack working at 700 °C for more than 10 000 h and exceeding 100 thermal cycles. The research includes :

New materials (anode, cathode, electrolyte) to reduce operating temperature (< 750 °C), which increases cell life, reduces thermal stresses, improves reliability and reduces cost

- *Development of materials for internal reforming of various fuels (natural gas, syngas...)*
- *Interconnection materials, joining technologies*
- *Stack architecture (mainly planar technology)*
- *Low cost and high volume manufacturing techniques*
- *Advancements in the understanding of mechanisms (interfaces, degradation...).*

The network also supports demonstration projects aimed to validation of the technology.

However, the proportion of funding dedicated to such demonstrations is limited so as not to affect the long-term R&D activity.”(op.cit. p.5,6)

Finally under the name of “cross-cutting topics”, “*The PACo network supports techno-economic analyses to allow orientation among different technologies. It is important that appropriate standards and regulations are in place in order to allow these technologies to successfully enter the market. Projects related to safety aspects and development of standards and regulations are also considered.*” (op.cit.p.6)

B.1.3-INEVA platform

A third potential collective learning process lies in the INEVA platform. This fuel cell technology platform has been co-financed by Ministry of Research, local and regional authorities , and industry. This platform has been implemented in Belfort, not very far from Besançon University and Sochaux plants of Peugeot (automakers company). It has been designed to facilitate integration of fuel cells within land transport uses. This research plant should facilitate interactions between public research organisations and industry research. The following two projects may be quoted : “APUROUTE” in collaboration with Delphi, dealing with modeling and identification of an APU SOFC system within the effective conditions of road transport, and “GENEPAC” , dealing with the technical feasibility of a power generator from fuel cell.

Source : http://www.ineva-cnrt.com/INEVA_CNRT/

PACo ‘s learning process result also from specific commitment of collective stakeholders such as PROs and large enterprises .

B2-The specific learning process of big French stakeholders

Such as the PACo network, learning process by big French stakeholders are mainly driven by the current stage of fuel cells and hydrogen life cycle development on one side, and by their specific skills and expectations. Presentation is mainly here focused on big stakeholders, as so far the smaller ones for these very specific technologies are still in a great funding dependence either from public funds, or from the research and development budget of big private companies. This observation does not mean that the potential contribution of small and medium enterprises is useless : at the contrary, their new ideas and skills may prove in some cases to be decisive in the development of technologies, but provided that they may succeed to find a sufficient stable financing structure to test their initial ideas, and/or a large enterprise to buy back their innovative ideas, due to the still large distance of these technologies to markets. Moreover potential contribution from venture equity is developing from a French low level starting point : but in the fuel cells case, their potential role seems to be limited at least in a short term period. In that direction small and medium enterprises are complementary with the large incumbent ones. Therefore learning process for small enterprises in fuel cells case depend upon very contingent context, within a general framework more or less open to new firms entry. In France one of the national research and development policy goals by Ministry of Research is to facilitate emergence of new firms.

In the present stage of development, several tools and strategies may be used to develop fuel cells technology : mainly basic and applied research on one side, and demonstration/development project for technical and commercial feasibility testing on the other side. Each category of actor is characterized by a specific mix of using these two family of tools.

B21- Public research organisations and their learning process

By definition the main focus of these organisations is exploratory, basic and applied research. However two new trends have increasing their importance : first research organisations are increasing their networking policy between themselves on one side, and between themselves and industry organisations on the other side within French territory, that is to say mainly, but not only, with PACo network. Secondly these networks are more and more international ones, and mainly European ones. This last dimensions will be developed later on (B3 : Learning process by participating in international research and technology consortia).

B211- CEA

The so-called “Hydrogen programme” within CEA “*covers the entire cycle: production, storage, use and distribution for three main domains of application, i.e. stationary cells, transport and portable equipments with priority given to two fuel cell systems, PEMFC (low temperature proton exchange fuel cells) and SOFC (high temperature solid oxide fuel cells)*”.

By giving a great importance to the concept of “**Basic technology research-** (Recherche Technologique de Base)”, CEA in general and LITEN in particular have made the choice of a central positioning in the innovation process, between basic and applied research on one side and development for market applications on the other side. By this choice, CEA is in a good position to have the greatest chances of bridging the two poles (research agenda and application demands) of this innovation process, and transferring technology skills to small , medium and large enterprises. This strategic choice is implemented by increasing the outside contributions share to the in-house research activities. Rationale for this direction is double :

- first sharing the financial burden of developing large new energy technology programme, mainly when failure risk is high such as the case of emerging technologies,
- secondly, increase the learning capabilities performance (scope and timeliness) for specialised and closed scientific areas to the core activities.

Table 5 documents the scope of these French and foreign partnerships linked to the development of hydrogen and fuel cells activities.

Table 5 : The main implemented partnerships by CEA/LITEN in hydrogen/ fuel cells area (2001/2003)

Technology area and sub-area	CEA's department and sites	Research and industry partnerships
HYDROGEN PRODUCTION		
Thermo chemical transfer of biomass	DEN (Grenoble, Cadarache)	-Den SME : TKE - BioSyngas Project with IFP - THERMOBIO Project with ADEME - with 6 th PCRD (UE, UJF-GRECA, Programme AC Energie from CNRS)
High temperature water splitting		
Thermochemical cycles	DEN (Saclay)	RWTH (Aix la Chapelle) ; General Atomics and Sandia National Laboratory ; JAERI
High Temperature Electrolysis	DEN (Cadarache, Valrho)	
Biological pathway	DSV (Grenoble)	
HYDROGEN STORAGE		
High Pressure Storage	DAM (Le Ripault, Valduc), DRT (Grenoble)	Project PHYSE (300 bars), with MEFI, ENSAM-Paris, Composites Aquitaine and Metroplast ; Air Liquide ; Polystock Project with INSA (Lyon), and ULLIT ; du STORHY Project – 6 th PCRD
Nano-carbon structures	DAM (Le Ripault, Valduc)	CASH Project with PACo network label, PICA and Ecole des Mines de Nantes ; Réseau d'excellence HBEST (6 th pCRD) and a ACI from ADEME ;
SAFETY AND ET STANDARDIZATION OF HYDROGEN SYSTEMS	DRT (Grenoble), DAM (Valduc), DAM (cesta)	Future participation to the European project EIHP2 ; participation to the International Standardization Organization ISO /TC197 « Hydrogen Technologies» ; SEREPAC Project from PACo network with INERIS on fuel cells safety ;
FUEL CELLS		
PEMFC		
Conducting Membranes	DAM (Le Ripault), DSM (Grenoble), D	1-Membranes for low power (<100 w) : INPG/LEPMI ; Université de Poitiers ; CNRS/LMOPS, Bolloré ;

	RT (Grenoble)	2-Membranes for transport use : Université de Montpellier ; 3- High Temperatures Membranes : CNRS/LAMMI ; Université Paris VI ; CNRS Orléans ; 4- CNRS.
Catalysts	DRT Grenoble DSM (Saclay) DEN (Saclay)	With PACo network : new electrodes and pluri-metallic catalysts for PEM ; LACCO- CNRS Poitiers ; European Project OPTIMERECELL
Composite Bipolar Plates	DAM (Le Ripault), DRT (Grenoble)	With Atofina for micro-composite powder on bi-polar plates ; With PACo, Sorapec and ECOPAC for testing within stacks prototypes
Stack (Membrane Electrode Assembly)	DRT (Grenoble)	
Integration	DRT (Grenoble)	Deep offshore use within PICOS project (PACo network) in cooperation with IFREMER ; Genepac contract with PSA for design and construction of a high efficiency fuel cell (20 kw in 2004) ; with Air Liquide Acropalce contract for using a few kw fuel cell, with low pressure and minima auxiliaries.
Diagnosis tools for PEMFC	DSM (Grenoble) DEN (Grenoble) DRT (Grenoble)	
SOFC		
Progressive internal reforming for anode	DRT (Grenoble) DSM (Grenoble), DAM (Le Ripault)	SOFC-RIP Project from PACo networks on Progressive internal reforming for anode with LEPMI, LACE, GDF, HEF and 2 HE
Research on new electrolytes	DSM (Grenoble) DAM (Le Ripault)	GDR IT-SOFC with CNRS ;
First demonstrator	DAM (Le Ripault)	Gecopac Project with Région Centre, Académie Orléans-Tours ; Dalkia –France, Snecma Moteur for a cogeneration system with high temperature fuel cell
Microfuel cells	DRT (Grenoble)	Micro fuel cells manufacturing on wafer-silicium with SME, HEF for Peac-Pocket and MicroPC projects
TECHNICO-ECONOMICAL AND MULTI-CRITERIA ANALYSIS	DPG (Paris) DRT (Grenoble)	MASIT Project, in partnership with ADEME, Ecobilan , EDF, LAEPSI laboratory of l'INSA-Lyon ; LBST;

Source : author, from CEA, DRT-LITEN, 2004, Nouvelles Technologies de l'Energie, Rapport d'Activités 2001/2003, 64 p., http://www-drt.cea.fr/docs/liten/RA031209_light.pdf

Moreover CEA departments and institutions have been the most important French committed institution in the PACo research projects portfolio : 25 projects over the 47 ones which have been labelled by the network since its creation. Finally the CEA/DRT/Liten research and developments activities have resulted in a high patent performance within hydrogen and fuel cells areas.

Table 6 : Patents breakdown of New Energy technologies (DRT-CEA) – 1993/2002

	Relative Share	Number of patents
SOFC	2%	2
Micro fuel cells	12%	9
PEMFC	51%	40
Sub-total fuel cell patents	65%	51
Hydrogen storage , transport and distribution	3%	3
Biomass gazeification	1%	1
Total Hydrogen and fuel cell patents	69%	55
Total New Energy Technologies patents	100%	79

Source : CEA, DRT, Liten, 2004, Nouvelles technologies de l'énergie, Rapport d'activités 2001/2003, p. 60

These results also explain why Liten is highly committed in the “European Hydrogen and Fuel Cell Technology Platform” project implementation (see B3).

B212-CNRS and Universities

Within the mixed research units (UMR) which are the basic building blocks of the CNRS and University Research teams, the main learning rule is theoretically depending on the academic research ones, that is to say with “the reward systems and behavioural norms of *'open-science communities'*” (collegiate reputation-based reward system - Dasgupta, P., David P., 1994) . However these general rules are also influenced by three items :

- the rules of this ‘open science behavior’ are interacting with commercial R&D ones more focused on technology development, which traditionally sets the issue of *'maintaining science and technology in dynamic balance'* ;
- the current organizing rules of the specific CNRS Energy Programme (Action Concertée Energie) were defined in order to reach the greatest collective efficiency, that is to say avoiding double projects on the same issue, and obtaining the minimum critical size;
- a general trend of more and more funding research projects, excluding researcher wages, according to a rationale of call for tenders.

Within the Energy Programme, “*CNRS teams are called upon to work along two sets of guideline : 1) Constitution of Team Group Analysis (TGA) networks (Groupes d'Analyse Thématique- GAT), and 2- Integrated Research Projects (IRP) (Projets de Recherche Intégrés- PRI)*”.

“The TGA are constituted as exchanges and discussions cells which involved CNRS scientific personnel, university and other research organization researchers and industrial people in order, first of all, to analyse and identify the domain's strengths and weaknesses. Their mission is to organize priorities among the targeted actions in order to obtain quantifiable progress in a given research field. Their annual report should describe the research progresses obtained in laboratories, as well as the one conducted in foreign labs.”

“Research projects preferably involve many research teams for at least a two years renewable period. The chosen teams will gradually become multidisciplinary. The favoured IPR proposals will result from a common understanding of at least two well identified TGA. Furthermore, at least one enterprise interested in an IRP will be identified. This or these enterprises should be involved through the co-financed Industrial Demand Subventions (IDS). They could eventually be implied in the IRP Program financial support.”

Source : <http://www.imp.cnrs.fr/energie/english/index.html>

The main coordinating structure within the CNRS Energy programme, which is dedicated to fuel cells development is called “PACOGES” (Pile A COMbustible et leur GESTion-Fuel Cells and their management). This coordinating structure includes on one side specialized teams on PEMFC development and on the other side the ones dedicated to SOFC applications. The general main research activities of CNRS and Universities research teams are focused on the following objectives within fuel cells and hydrogen areas :

“Fuel cells - The Program's objectives will be restricted to two types of cell technologies: the low temperature proton exchange membrane fuel cell (PEMFC) and the solid oxide fuel cell (SOFC). A laboratory installation will be constructed in order to achieve a better research coordination within these two domains. Among the expected results of this common Program is a boost to the French research position among the centres of excellence working on hydrogen and fuel cells.

Hydrogen- The research activities on the use of hydrogen as an energy carrier will be oriented along three main lines in order to increase productivity :

- Catalytic generation
- Exploitation of thermochemical cycles
- High temperature electrolysis

New avenues will also be explored making use of renewable energy sources as well as photo-catalytic or photo-biologic conversion processes.

The progressive implementation of hydrogen as an energy carrier, particularly in fuel cells, will require R&D activities in new material for large capacity storage and high power delivery. Two avenues will be explored: the use of metal hydrides and carbon composite materials.”

Source : CNRS, Interdisciplinary Program (2002-2005), Energy Program, <http://www.imp.cnrs.fr/energie/english/index.html>.

A scientific and steering committee of the Energy Program select the research priorities within short /Medium term (10/20 years) and medium/long term (20/50 years), in relationships with the national priorities of the French energy policy, and existing other programs such as European Union programs, PACo network call for tender, and other signals coming from PREDIT and ADEME.

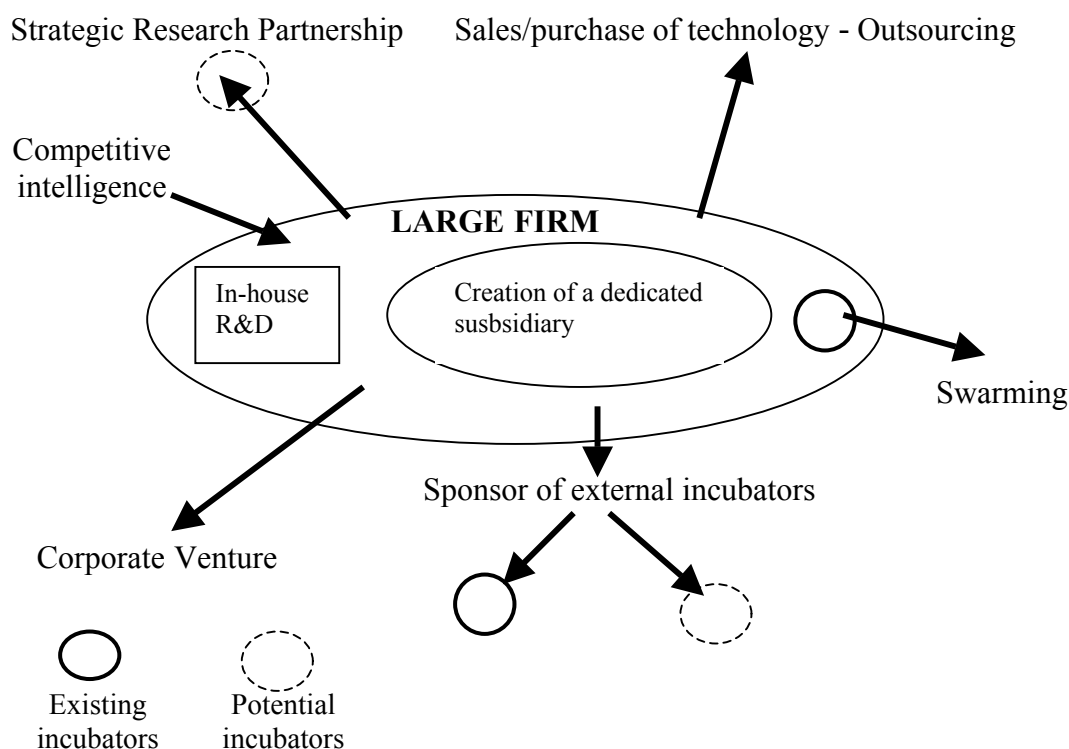
Source : B.Spinner , 2003 b

B22-The learning portfolio options for Large enterprises

Two main issues are structuring learning portfolio options of large enterprises in France, and within foreign countries : first fuel cells technology remain far from market options, to the exception of portable and back-up fuel cells applications, and secondly learning options are relatively larger than for the other innovation stakeholders. Graph 5 illustrates these possibilities : from in-house R&D to competitive intelligence and/or purchase of licenses and

external skills, from creation of a dedicated subsidiary to corporate venture, swarming and sponsor of external incubators.

Graph 5 : the broad range of technology learning options for large groups



Source: from ALBERT , BERNASCONI et al., 2002

No general rules seem to emerge : these learning options are very context-dependent. However four general statements may be presented:

- 1)- the creation of dedicated subsidiary and /or a high in-house R&D budget seem to indicate a larger commitment than the other options.(Example : Air Liquide)
- 2) Very large and cash-rich firms, such as big oil companies, may wait and see, and then decide later on whether its worthwhile to acquire promising small and innovative firms.
- 3)- This broad learning scope for large companies implies dynamic complementarities with smaller and fragile , but innovative start-up. The very small number of these start-ups within France may be interpreted either such as the still too far distance to market and consequently the de-facto impossibility for small firms to survive without permanent public subsidies, or such as one illustration of a traditional weakness within French innovation system.
- 4) The current very large uncertainty stage seems to be an incentive to the creation of a great number of strategic research partnerships, either national or international ones. *“Technology co-operation, and more precisely technology sharing consortia, while allowing fierce*

competition, have been the most frequently used organisational structure.” (Avadikyan et al, 2003). This learning modality could be called “*learning by cooperating*”.

For example in the Renault ’s case, Mr P.Beuzit (2003) (Vice President Research, RENAULT Group) made the following statement “*However, mastering the technology (i.e. fuel cell technology for car applications) requires fields of knowledge and expertise that no single car manufacturer can adequately cover alone. For this reason, Renault is actively working on the subject, and has recently established three partnerships with companies working at the cutting edge of fuel cell technology.*

The first of these partnerships is with Nuvera, an American company specialised in hydrocarbon reforming. Reforming is a process that consists of on-line extraction of the hydrogen contained in hydrocarbons. Nuvera has developed a system that can be used with various types of fuel (petrol, diesel fuel, natural gas, LPG, ethanol) and with different forms of drive application (traction, range extender and auxiliary power unit). Its modular design means that it can be easily modified if new technologies appear in the next few years. The aim of the two partners is to adapt the system to what will be the requirements of the automobile by 2004.

The second partnership is with 3M. Both companies will jointly conduct research into MEA (Membrane Electrode Assembly), the core of the fuel cell. MEA is an assembly consisting of a membrane inserted between two electrodes. There is a great deal at stake with this component because it is at this level that the production of electricity takes place, and this is what determines the performance of fuel cell itself. The fuel cell is actually made up of an assembly of elementary cells, each cell itself containing an MEA. 3M has been developing MEAs for fuel cell applications since 1994. The aim is to develop an MEA that is suitable for automobile requirements for both drive and auxiliary power unit applications. The third partnership that Renault has undertaken is with petrol producer TotalFinaElf, in order to develop the fuel that is most suited to the reforming process. Scientists from both groups will analyse the behaviour of the fuel cell and of the reforming system as a function of fuel formulation, and will study the impact of its components on vehicle performance. Analysis of the life cycle of the selected fuel will also lead to evaluation of the impact of the fuel to be used on the environment, taking account of the entire process from production and distribution.”

-Patenting performance are generally looked as a good technology strength indicator. However attitudes towards patenting are a-priori heterogeneous among French actors, despite a constant awareness effort by PACo network authorities, and some firms have a balanced judgment about a systematic patenting policy : “*« The company (EC Power- Sorapec) relies upon both protection and unpatented proprietary know-how to protect its technology. However, considering the rapid technological change that characterizes its industry, the Company believes that reliance upon patented know-how and on the continued introduction of improvements and new products, are generally as important as patent protection in establishing and maintaining a competitive advantage. In general, however, it is the Company policy to patent specific technological innovations and to maintain as trade secrets production methods »* (EC Power Internet site). Some foreign world leader, such as Ballard, is also looking for an “*intelligent (i.e; not systematic) patent policy : « We certainly need to generate intelligent strategies to treat with IPR issues as this may (by experience) otherwise create a competitive threat for co-operation. »* (Source : André Martin, 2003).

Nevertheless some firms have a different behaviour on that issue, such as Helion, and relies on a broad patenting policy to reach a high protection level, and to allow further autonomous development.

B3- Learning process by participating in international research and technology consortia

B31- The increasing commitment of French stakeholders in the international technology consortia

All the signs are that among the numerous technology consortia which have been set-up with participation of French stakeholders or under their leaderships, more and more have become international ones. This trend is consistent with a world evolution towards increasing international technology learning process. Driving factors for a such evolution are well known. But this increasing international learning process may be ambivalent : in some cases it may be complementary to the current national learning process, that is to say improving it, and within other cases, they may be substitute to a potential national learning process. The precise identification of these two situations is a complex issue. But it is obvious that the intervention of Multi National Firms tends to accelerate this process, because access to foreign skills may often quicken the learning process and often reduce delays and uncertainties of learning which might be otherwise imposed by the Public Research Organisations of the home country of the parent company.

Many examples have already been presented within this report of such international technology consortia (see B.211 and B 22). One global picture at the European level has been presented by the PACo's chairman over the 1999/2002 period.

Table 7 : French participation to EU fuel cells projects during Framework Programme 5 (1999/2002)

Technical area	Number of projects	French participation		French members
		Number of projects (French coordinator)	%	
SOFC-Stationary	8	5	63%	GdF ; EdF ; Turbomeca
MCFC	4	1	25%	CNRS/ENSCP
PEMFC-Stationary	4	1 (1)	25%	Technicatome, Dalkia, CEA
PEMFC - Transport	4	4 (2)	100%	Axane, Schneider, Ineris, CNRS (INPG, INPT, ...) TFE, Iribus, Inrets, CEA, Air Liquide
PEMFC - Components	4	2	50%	CEA ; CNRS (Lammi)
PEMFC – Portable/laptop	2	2 (1)	100%	Air Liquide, CEA, SNPE, F. Telecom,
DMFC	2	2 (1)	100%	Thales, CNRS (ENSCM)
Reformer	6	3 (1)	50%	Armines, CNRS (X2), PSA,
“Networking”	7	5	71%	PSA, Renault, IFP, CEA, Valeo, EdF, GdF, Creed, Saft, Avere, Ademe, CNRS(GDR Itsofc)
	41	25 (6)	61% (25%)	

Source : from Ballay R, 2003

This table shows a large commitment of French stakeholders, including Public Research Organisations and large firms, to European research projects.

B32- The EU research policy case : Is an “European Research Area” a feasible option within fuel cells and hydrogen areas ?

European Union is a “natural” international level of cooperation for the current fifteen EU members countries, and therefore for France. Nevertheless within research areas, this cooperation is still a marginal one, since over 10 euros of R&D expenditures an average of nine is directly managed at the member state level, and the last tenth at the European Commission level. However this Community share is already higher to day within fuel cells and hydrogen areas than for the other industry sectors, since over a global European estimated R&DD budget of 61 millions euros within fuel cells area during the year 2000, the relative share of European Commission would be approximately half (30 millions of €), and the rest for European Member countries. Even if these figures may be corrected and increased later on, there is a global consensus : 1) on the too low level of European R&DD figures in respect to the American zone and the Japanese one, 2) a too weak cooperation/integration between the European Members countries between their respective research policies. This consensus may be applied within the hydrogen and fuel cells areas.

The first issue is the easiest one to illustrate : for the whole economy, according the latest available figures for the year 2002, R&DD expenditures represent 1,99% of the EU GDP(15 countries), i.e. 175, 3 mrds of € in 2001 , 2,8% of the US GDP, i.e. 315,2 mrds of € in 2001, and around 2,98% of Japan GDP , i.e. 153,9 mrds of € in 2000.

There was an increasing R&D budget at the European Commission level in favour of hydrogen and fuel cells technologies.

Table 8 : The R&DD budget of European Commission within fuel cells and hydrogen areas.(current Mio €- 1988/2003)

Second Framework Programme 1988/1992	Third Framework Programme 1992/1994	Fourth Framework Programme 1995/1998	Fifth Framework Programme 1999/2002	Sixth Framework Programme 2003/2006
8		54	130	December 2003- In a first call for tender, EC awarded nine contracts and 60 millions € for hydrogen projects, and six contacts and 30 millions € for fuel cells projects.

Source : European Commission, Community Research, Directorate-General for Research, 2003,

But despite this increasing funding of EU authorities, European Commission’s decision-makers assessment was still unsatisfactory in front of a global insufficient (too low funding level), in respect to US and Japan commitment, and inadequate (too low level of coordination between Member States policies) R&DD policies. This last dimension prevents the addition of R&D expenditures or patents from each member country, and to conclude that this

European “addition” reach an higher level than the Japanese or north-American corresponding figures .

For the funding level aspect, “ *figures for relative spending on research in the field of hydrogen and fuel cells are even more discouraging-around half of Japan and one third of that in the US*” (Busquin, January 2004)

Box 2 : European initiatives in the hydrogen and fuel cells area since 2002

In front of these two structural weaknesses, European authorities are trying, since end of 2002, to launch a new research and innovation dynamics within fuel cells and hydrogen area. This potential new dynamics may be documented by the following events.

-October 2002 : A “*High Level Group*” of public and private decision-makers associated with research and development of hydrogen and fuel cells technology is “initiated” by the Vice President of the European Commission, Loyola de Palacio, Commissioner for Energy and Transport, and Mr Philippe Busquin, Commissioner for Research. Objective : “*to formulate a collective vision on the contribution that hydrogen and fuel cells could make to the realisation of sustainable energy systems in future.*” Among the 19 members of this HLG, the three French “representants” are :

-Mr. Michel Mouliney General Manager Advanced Technologies and Aerospace Division, Air Liquide

-Dr Pierre Beuzit Vice-president of Research, Renault SA,

-Mr. Pascal Colombani , Chairman, CEA

-16-17 June 2003 -A summary report of this “*High Level Group*” is published and presented in Brussels to a ministry conference called “The hydrogen economy – A bridge to sustainable energy”- The recommendations of the HLG deal with “ *a Strategic Research Agenda and a Deployment Strategy*” and . “*The creation of an EU Platform on Hydrogen Technology to optimise European efforts towards the realisation of the potential of hydrogen*”.

-September /November 2003- The President of the Commission put the weight of the whole Commission behind the initiative within a Communication” “*A European Partnership for the Sustainable Hydrogen Economy*”. Later on , in November 2003,through a EC Communication “*A European initiative for growth- investing in networks and knowledge for growth and jobs*” European Commission highlighted hydrogen as a potential “Quick-start” project. The Brussels European Council in December 2003 endorsed the list of projects.

Technology platform is seen as “*a focal point for building the momentum, trust and cooperative spirit that can lead to a fully integrated European Research Area (ERA)*” (Busquin, 2004).

- 17 th December 2003 : 1st meeting of the Advisory Council of the European Hydrogen and Fuel Cell Technology Platform. Over the 36 members of this Advisory Council there were five French members :

-FLORETTE Marc, Gaz de France, Vice-President of Research Energy companies (Hydrogen production and distribution, utility),

- BEUZIT Pierre, Renault, Vice-President Research FC equipment (Automotive, user),

-BALLAY Roger, Independent Consultant (Nominated by ADEME) Chairman of PACo Network Public Authorities/ user (National FC network),

-BUGAT Alain , French Atomic Energy Commission (CEA) Administrateur Général Research providers (FC and H2 related research),

-FROIS Bernard,Ministry of Research, Director Energy Department, Chairman of MS Mirror Group.

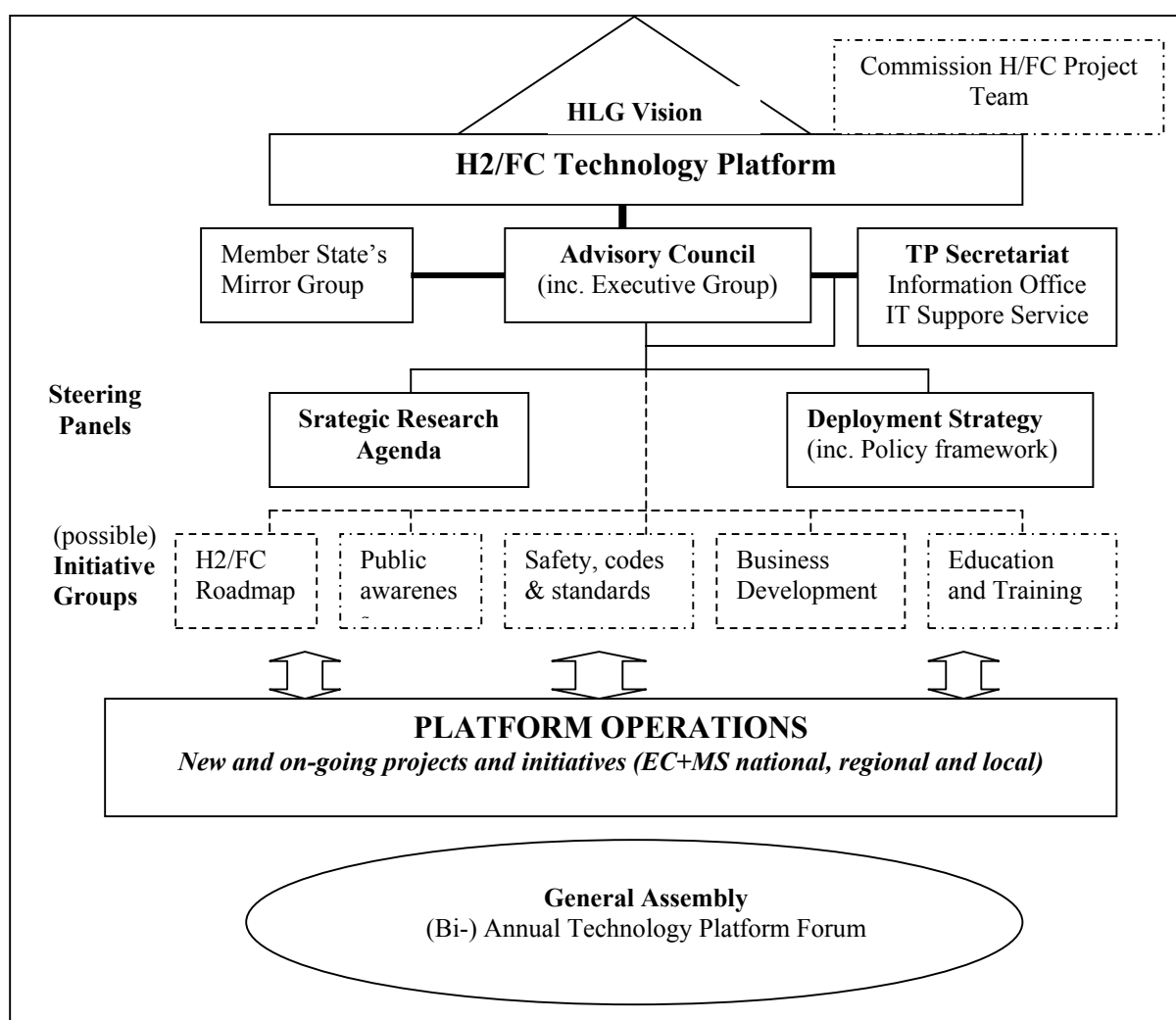
-End of 2003 year : Proposals of a 2,8 billions € budget for the next ten years in “Light houses projects” within hydrogen and fuel cells area. These very large scale projects are

demonstration and deployment projects related to the various components of the hydrogen option, “*which alone will have the necessary leverage effect to launch hydrogen markets*”. The hydrogen and fuel cells projects are looked by EC as a first attempt to implement the concept of European Research Area.

- **20 th January 2004** : A new European conference launch the Hydrogen /Fuel Cell Technology Platform.

At this time the current complex organization of this H2/FC Technology Platform can be summarized in the following graph.

Graph 6 Structure and organisation of the European H2/FC Technology Platform (beginning of 2004)



Source : Pablo Fernandez Ruiz, 2004,

According to the views of Braess Holger and Büniger Uli (2004), managers of the HYNNet project, European initiative towards a future likely roadmap might be implemented within the three following stages :

2003/2004 : the development of a “*qualitative vision*” , and a “*stakeholder consensus on tentative quantitative key objectives*”

2004/2005 : “*Evaluation of technical options – Develop rules for economic and policy consistency of objectives and 1st order EU roadmap (6 countries)*”

2005/2006 : *“Harmonised strategic recommendations for action by all stakeholders at all levels, (macro, meso, micro) evaluation and final validation of economic consequences (costs, benefits) for all stakeholders”*.

The constant initiatives of the EC authorities since 2002 had then the double perspective of simultaneously launching the hydrogen economy project in European Union and of implementing a “European Research Area” policy within this new sector, through a future likely European Roadmap. This Roadmap will set up the future research agenda within all linked areas to hydrogen and fuel cells technologies, and might become one of the most important document for all European innovation stakeholders , including the French ones. But this new ambition for European research policy is so important that observers are obliged to ask themselves where the success/failure balance will evolve in the future. In other words, the Director of Research at the European Commission : *“we must recognise that the hydrogen economy is a global game, both of co-operation and competition. The key for us is to coordinate and integrate European programmes and activities to ensure a consistent approach in facing the international challenge.”* This perspective should be consistent with other international partnership, such as the “International Partnership for the Hydrogen Economy”.

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C- Some first elements on the performance of the Fuel Cells Sectoral Innovation System in France : the case of PACo network

Introduction

Usefulness of networks, and then PACo one, was theoretically and empirically legitimated by highlighting two dimensions : networks reinforce learning process by creating “ *A common vision*” and “*A cognitive platform for knowledge exchange*” between innovation stakeholders. Then the question is to assess the extent to which PACo has more or less succeeded in these two directions. Some initial difficulties must be previously recalled to understand the constraints framework of this learning process : relative youth of this new public/private institution (recall : creation at mid 1999), the relatively weak resources which were initially devoted to the network management consistent with a “slim” organization goal, and a relatively dispersed scientific and industry community, with rather initial poor scientific and technology performance. In other words PACo network had a tough challenge to produce this “*common vision*” and this “*knowledge exchange*”. The issue is to assess the extent to which PACo has succeeded in reducing the learning failures which existed before 1999.

It is still an impossible task to define a synthetic and objective quantitative measure for this reduced learning failures assessment. Three different approaches will be used :

- performance assessment of PACO network “per se” (C1), i.e. an assessment of the main network impacts due to its running,
- a performance assessment of French innovation system in respect to the foreign one, regarding the patents and scientific publications indicators (C2)
- a first discussion of the possible impact of new fuel cell international context on the PACo’s network (C3)

C1- An on-going performance assessment of PACo network

PACo network managers have decided to launch a two years performance assessment of its activities since 1999. At the beginning of 2004, this process is only halfway achieved. Some quantitative results of this first stage process has been presented at the end of 2003, with a public support of 30 millions of € over the 1999/2002 period.

Table 9 : Impacts of the 24 PACo labelled projects (1999/2003) *

Patents	Scientific publications	Communications	PhD	Post-PhD	Induced Jobs**
11	20	44	28	20	17

* 9 completed and 15 to be completed projects in December 2003; other new 2003 launched PACo projects, and other french non-PACo projects are not included.

** Estimation from project coordinators

Source : from Fauvarque J.F., 2003

These first quantitative impacts may be complemented by the qualitative following ones.

-Despite scientific or technical failure of some projects, PACo network has succeeded in a partial mobilization and coordination of public and private stakeholders.

-Limited number of yearly flow of projects (15 per year) was consistent with relatively limited funding and management capabilities.

-A balance has been apparently found between an increasing quality of labelled projects and a minimum number of these projects.

C2- Patents and scientific publications performance of France in respect to foreign countries

Patents and scientific publications indicators are more and more often used as proxy of quantitative assessment of performance in technology and science activities. However, because these both indicators are reflecting codified knowledge and not tacit knowledge, and because patents results are directly linked to partially contingent rules of sample definition, one cannot but agree on the following assessment : « *Bibliometric and patent findings should consequently preferably be accompanied by expert opinions, qualitative case studies, or other evaluate procedures to help assess their meaning and relevance.* » (Emmanuel Hassan, 2003, p.39).

Consequently to reduce the risk of biased assessment which could emerge from the results of referring to only one sample, several samples (Box 3) would be used and only the common conclusions would be highlighted.

Box 3 : The available samples of patent and scientific publications of data for fuel cells which have been used in this report

OECD secretariat has provided statistics first on “triadic” patents (common applied for patents within USPTO, JPTO and EPO offices over the 1990/1996 period) and then on the EPO applied for patents over the 1990/1999 period and scientific publications related to fuel cells (1990/2000), from a detailed study report by Emmanuel Hassan (2003). These samples will be then called OECD Patents (568 patents) and publications (1286 publications) data.

Richard Seymour, from Johnson Mattheys, has recently published (2004) a short and not fully explicit, but interesting article on patents related to fuel cells. Apparently his sample covers the two periods 1991/2000 (1922 patents) and 2001/2003 (5821 patents). Numbers of fuel cell patent applications are “*obtained from a search of US, EP, PCT and GB patent collections, looking for occurrences of the term “fuel cell” in the title, abstract or claims, and “deduplicated” so that the invention filed in more than one country/region is not counted twice.*”(p.3). This sample will be called “Seymour data”.

Bernard Bourgeois (LEPII/EPE- UPMF) has constructed an USPTO patents database from an extraction of Class : 492 (- Chemistry : Electrical Current Producing Apparatus, product , and Process Fuel cell, subcombination thereof or method of operating) and sub-class 012 to 046. The selected patents category has been defined by the combination of “ Granted patents- Original patents- Utility patents”, over the period 1969/2002. This sample of 1353 patents over the period 1990/ 2002 (first 4 months) will be called UPMF 1 data.

Roger Coronini (INRA-UPMF) has set-up two data bases. One from Current Contents Connect concern scientific publications over the 1997-2003 period, and has provided 5030 bibliographical notes of article. Number of articles per country was proxied by the number of address of laboratory within which authors have made their publications. This sample is called UPMF 2 data.

The second database deals with EPO applied for patents , with an search equation which has provided 3114 patents over the 1991/2002 period.

Table 10 : Patents performance (number of patents) within fuel cell area according to the different samples

Sample	Performance by country (Ranking by decreasing order of number of patents)
“OECD data”	<p>Period 1990/1999- Cumulative number of patents at world level : 568</p> <p>“Class” of 169-203 : Japan, US “Class” of 102: Germany “Class” of 32-34: UK, Canada “Class” of 10-13 : France, Italy</p>
“Seymour data” (numbers are estimated from a graph)	<p>Period 1991/2000- Cumulative number of patents at world level : around 1100</p> <p>Class of 400-350 : USA, Japan Class of 250 : Germany Class of 50 : Canada, UK Class of 10-20 : Switzerland, Australia, Italy, Netherlands, Class of 0 patent : France</p> <p>Period 2001/2003 : Cumulative number of patents at world level :5821</p> <p>Class 1000-850 : Japan, USA Class 520 : Germany Class 200 : Canada Class 100-50 : UK, France, Korea</p>
“UPMF 1 data”	<p>Period 1990/1999- Cumulative number of patents at world level : 886</p> <p>Class of 427 : USA Class of 244 : Japan Class of 56-48 : Germany, Canada Class of 21-16 : UK, Switzerland Class of 6-5-2 : Netherlands, Italy, France</p> <p>Period 2000/2002- Cumulative number of patents at world level : 467</p> <p>Class 230 : USA Class 137: Japan Class of 41 : Germany Class of 18 : Canada Class of 10-9 : France, Korea</p>
“UPMF 2 data”	<p>Period 1991/1999- Cumulative number of patents at world level : 1368</p> <p>Class of 528 : USA Class of 381 : Germany Class of 291 : Japan Class of 52 : United Kingdom Class of 16-12 : France, Italy, Australia</p> <p>Period 2000/2002- Cumulative number of patents at world level : 1746</p> <p>Class of 656 : USA Class of 441-400 : Japan, Germany, Class of 55-48 : UK, France Class of 10 : Italy</p>

Source: author

Table 11: Scientific publications performance within fuel cell area according to the different samples

Sample	Performance by country (Ranking by decreasing order of number of patents)
“OECD data”	Period 1990/2000- Cumulative number of scientific publications at world level : 1286 “Class” of 258-279 : Japan, USA “Class” of 115-119: UK, Germany “Class” of 49-66: Canada, Italy “Class” of 24 : France
“UPMF 2 data”	Period 1997/2003- Cumulative number of address of bibliographical notes : 5030 Class of 1023-749 : USA, Japan Class of 446 : Germany Class of 288-267 : UK, South Korea Class of 169-139-103 : Italy, France, Sweden,

Source: author

The following conclusions may be drawn from these tables :

- patents ranking of France fluctuates between the fourth and the fifth rank, closed to Uk and Italy, but far behind Canada, Germany, USA and Japan,
- scientific publications ranking also reaches the same level, with a closed international hierarchy to the patent ones,
- there is a net increasing number of patents and scientific publications after year 2000 at the world and French level. Even if more detailed results would be necessary to support the idea of a direct influence of PACo network on these performance, it can be argued that without PACo existence, French performance could have been worse.

C3-Conclusion : Will PACo’s network shift its initial goals within the new fuel cell international context ?

C31-the global performance assessment of the PACo network : a still open issue.

French actors, which were clearly lagging behind their main competitors during the 1990’s decay according to the most used standards/indicators have undoubtedly improved their performance during last four years with the creation of PACo network. So there is no doubt that the creation of PACo network has succeeded by reducing a certain share of the “systemic failures” of the French fuel cells system of innovation. But conversely these actors are far from belonging to the leaders categories.

For all that have they succeeded to reach the “middle class” ranking ?

Table : A graphical representation of the potential systemic failures reduction between 1998 and 2003

<u>1-Technical and scientific ranking</u> of France before and after PACo network				
	Non-existent	<u>Weak</u>	<u>Average</u>	Strong
1998* (Before PACo)				
2003 (4 years after PACo)				

<u>2-Industry and trade ranking</u> of France before and after <u>PACo network</u>				
	Non-existent	Weak	Average	Strong
1998* (Before PACo)				
2003** (4 years after PACo)				

*1998 diagnosis by Minefi in Technologies clefs 2005

**2003 : an hypothetical assessment

It is still an open issue today, as so far international benchmarking remains a complex exercise for a very volatile and not yet marketed technology, whereas the main impacts of R&D expenditures lie in knowledge increase; and therefore meanings of “weak”, “average”, “strong” remain debatable for sectoral systems of innovation located in very different countries and national systems of innovation. In particular can we imagine, and compare, weak, average and strong position for first movers countries, and for fast followers one ?

C32- Innovation process in respect to a balanced assessment of future deployment agenda of hydrogen technologies

Any assessment of French fuel cells sectoral system of innovation performance, and foreign too, over the last five years (1999/2004) should be very cautious as so far they must refer to a realistic agenda of its likely deployment. On that issue, Mr. Daniel Clement, Director of Research at ADEME, and team-coordinator of PACo network with Mrs F.Barbier of CEA), brings some lights within this large uncertain context : *“Any assertion on future hydrogen pathways is meaningless as so far the different terms of its realisation are not explicated. In a short term period, from now to 2020, some feasibility demonstration projects and prototypes can only be implemented. Between 2020 and 2050, the first true industrial projects could be realized. A shift towards hydrogen economy could only be imagined from the 2050’s”*. (*Toute affirmation sur la filière hydrogène est dénuée de sens si on ne précise pas les échéances. A court terme, d’ici à 2020, on ne verra que quelques démonstrations de faisabilité et des prototypes. Entre 2020 et 2050, les premiers vrais développements industriels verront le jour. Ce n’est qu’à partir de 2050 qu’on peut envisager de basculer vers une « civilisation de l’hydrogène »*). (D.Clément, 2004)

When taking into account these still very far distances between current technologies to market on one side, and the very short life existence of PACo network on the other side, any balanced performance assessment exercise at a national level should be implemented within very closed limits. Moreover because a new fuel cell and hydrogen international context suddenly emerges during 2002 and mainly 2003, relevant issues seem should refer more to international agenda, and more particularly to European Union ones.

C33- A possible redefinition of PACo’s network goals within the new European H2/FC Technology Platform

PACo ‘s network managers will have obviously take into account the new European H2/FC Technology Platform opportunities and threats (see B32). But to what extent ? Despite large remaining uncertainties, a much broader integration of European Union policy goals, and even may be of some reference to the International Partnership for the Hydrogen Economy might be implemented. PACo goals and performance criteria should be adapted to these broadened national goals. Nevertheless if the learning capabilities of French Public Research Organisations and private firms continue to improve, they constitute a promising characteristics of a French satisfactory participation within these future international networks

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REFERENCES

- Albert Philippe , Bernasconi Michel , Gaynor Lynda, 2002, Les incubateurs : Émergence d'une nouvelle industrie-Comparaison des acteurs et de leurs stratégies : France ~ Allemagne ~ Royaume Uni ~ Etats-Unis, Minefi, DIGITIP, *Avril 2002, Rapport de recherche*
- Alleau T., 2002, Hydrogen and fuel cell activities in Western Europe, WHEC 2002, Montreal, Canada, 12 pp.
- Avadikyan A., Cohendet P., Héraud J.A., Editors, 2003, Introduction : the economic dynamics of fuel cell technologies, Chapter 0, *The Economic Dynamics of Fuel Cell Technologies*, Springer
- Ballay R., 2003, Impacts and Experience learnt from public policy support to fuel cell technology development , The case of the French Fuel Cell Research and Innovation Network, Communication to EHEC 2003 Conference, Grenoble, 4 September 2003,
- Ballay R., 2003, Rappel des objectifs, activités du réseau PACo, et conclusions, Séminaire Annuel 2003 du Réseau PACo, Présentation de R.Ballay , Président du réseau PACo, Grenoble, Alpexpo, 2 Septembre 2003
- Beuzit P., 2003, : HYDROGEN ECONOMY AND THE AUTOMOTIVE INDUSTRY :THE RENAULT-NISSAN VIEW-1st EUROPEAN HYDROGEN ENERGY CONFERENCE at GRENOBLE on SEPTEMBER 2, 2003-Pierre BEUZIT, Vice President Research, RENAULT Group
- Bourgeois B., Mima S., 2003, Rationales for co-operation between firms and States within an emerging radical innovation, Chapter 3, pp.79-114, in Avadikyan A., Cohendet P., Héraud J.A., Editors, 2003, *The Economic Dynamics of Fuel Cell Technologies*, Springer
- Braess Holger / BMW AG , Bünger Uli / LBST, 2004, HyNet, On the way towards a European Hydrogen Roadmap, European Hydrogen and Fuel Cell Technology Platform ,First General Assembly 20-21 January 2004
- Breakthrough Technologies Institute , 2003, Fuel cells at the crossroads, Attitudes regarding the investment climate for the US fuel cell industry and a projection of industry job creation potential, A report for de Argonne National Laboratory, Avril 2003
- Busquin P., 2004, Speech of Commissioner Busquin to the European Hydrogen and Fuel Cell Technology Platform Generral Assembly, 20 th January 2004-03-03
- CEA, DRT-LITEN, 2004, Nouvelles Technologies de l'Energie, Rapport d'Activités 2001/2003, 64 p., http://www-drt.cea.fr/docs/liten/RA031209_light.pdf
- CEA, Technological Research, From research to industry, Direction de la recherche technologique, Centre de Fontenay aux Roses
- Christensen CM (1997) *The Innovator's Dilemma*. Harvard Business School Press, Boston
- Clement D., 2004, Interview given to Cécile Michaut, 2004, L'hydrogène, miroir aux alouettes ?, *Environnement Magazine- Enquête- N° 1625-Mars 2004*, p.20-23
- CNER, Comité National d'Evaluation de la Recherche, 2003, La recherche publique française : une évaluation- Rapport au Président de la République Française, Avril 2003, La Documentation Française, 50 p. <http://www.cner.gouv.fr/fr/pdf/rpr.pdf>
- CNRS, 2002, CNRS Interdisciplinary Program (2002-2005), Energy Program, <http://www.imp.cnrs.fr/energie/english/index.html>
- Dasgupta P., David P., 1994, Towards a new economics of Science , *Research Policy* 23 (1994), pp.487-521
- European Commission, Community Research, Directorate-General for Research, 2003, European Fuel Cell and Hydrogen Projects, 1999-2002, Project Synopsis, EUR 20718,
- European Commission, 2003, Conference on "The hydrogen economy - a bridge to sustainable energy", Brussels, 16-17 June 2003, http://www.cordis.lu/sustdev/energy/h2_pres.htm
- European Commission, 2004, The European Hydrogen and Fuel Cell Technology Platform-2nd Meeting of the Advisory Council, Brussels, 21 th January 2004, <http://forum.europa.eu.int/Public/irc/rtd/eurhydrofuelcellplat/library>
- Fauvarque J.F., 2003, Avancées technologiques générées par le réseau PACo, Evaluation du réseau PACo, Séminaire Annuel 2003 du Réseau PACo, Présentation du Pr. J.F.Fauvarque, Grenoble, Alpexpo, 2 Septembre 2003

- Fri Robert W., 2003, The role of knowledge : Technological Innovation in the Energy System, The Energy Journal, Vol. 24, N°4, pp. 51-74
- Gaz de France, site Internet : http://innovation.gazdefrance.com/public/php/generic_niv1.php?iddossier=0&identifiant=generic_presentation&idespace=2&langue=en
- Hassan E., 2003 , “Mapping the knowledge base of a technical field : the case of fuel cells technology”-1er Aout 2003, Draft Version,
- Lamy C., Leger J.M, 1994, Les piles à combustible : application au véhicule électrique, Journal de Physique IV, Colloque C1, supplément au Journal de Physique III, Volume 4, Janvier 1994, pp. C1-253/C1-279
- Le Breton D., 2001, Le choix d’un vecteur énergétique, Communication au séminaire annuel 2001 du réseau PACo, Paris, 13/12/2001
- Martin André, ,Managing Director Europe and Transportation Programs-Ballard Power Systems, 2003, Considerations for a European Hydrogen and Fuel Cell Research Agenda, Communication à European Conference, « The Hydrogen economy- A bridge to sustainable energy », Brussels, 16/17 June 2003, http://www.cordis.lu/sustdev/energy/h2_pres.htm
- Martin JM (2000) Le changement des technologies de l'énergie: genèse, modalités et hypothèses explicatives. In: Bourgeois B, Finon D, Martin JM (eds) Energie et Changement technologique. Economica, Paris, pp 17-64
- Minefi, DIGITIP, 2001, Technologies clés 2005, 1^{er} Mars 2001
- Mima S., Criqui P., 2003, The future of fuel cells in a long term inter-technology competition framework, Chapter 2, p.43-78, in Avadikyan, Cohendet, Héraud, op.cit.
- National Research Council, National Academy of Engineering, 2004, The hydrogen Economy: Opportunities, Costs, Barriers and R&D Needs, The National Academy Prtess, Washington, D.C.,
- OCDE/ Ministère de la Recherche et Ministère de l’Economie, 2003, Les partenariats publics-privés pour l’innovation : Analyse comparative internationale France, Autriche, Pays –Bas, Australie- Etude de 7 réseaux de Recherche et d’Innovation Technologique en France, mimeo, Avril 2003
- PACo network, <http://www.reseaupaco.org/>, Fiche d’identité des acteurs réseaux, Les actions de l’ADEME, Les actions du CEA,
- PACo network/ CM International, 2003, Evaluation des résultats obtenus dans les projets labellisés par le réseau de recherche et d’innovation technologique sur les piles à combustible (réseau PACo), Internal Report,
- Pouchet J., 2003, Joint Press Conference between MGE and Ballard, 14 th October reproduced in The Hydrogen & Fuel Cell Letter, November 2003, Vol XVIII, N° 11, p.7
- Brussels, 20 January 2004
- RTD J-2/GE/mor D(2004)
- Ruiz Pablo Fernando, 2004, Commission View of the Technology Platform Structure and Organisation, European Hydrogen and Fuel Cell Technology Platform ,First General Assembly 20-21 January 2004
- Seymour R. (Johnson Matthey), 2004, Fuel Cell Market Survey : Patents, A rich Vein of Knowledge, 27 February 2004, Fuel Cell Today, http://www.fuelcelltoday.com/FuelCellToday/FCTFiles/FCTArticleFiles/Article_757_patentsurvey0204.pdf
- Spinner B., 2003, Pourquoi un programme Energie au CNRS ?, Le Journal du CNRS, N° 160-161, Avril/mai 2003, p. 28
- Spinner B., 2003b, Evolution du Programme Energie, Novembre 2003, <http://www.imp.cnrs.fr/energie/>
- US DoE (2000) SECA - Mass produced ceramic fuel cells for low-cost power, National Energy Technology Laboratory, SECA brochure, July 2000.

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