Cooperation rationales between firms and States within an emerging radical innovation : the fuel cells case.

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ABSTRACT

We deal first with the main characteristics of fuel cells (F.C.) innovation. After a review of previous technical and economical contributions on that technology, we found that their current promoters are facing four types of difficulties : 1)- the very broad spectrum of required knowledge and competencies, existing and new ones, 2)-the still large technical, economical and financial uncertainties that may delay, once more, the future mass-marketing stage, 3)-the likely very long transition period before fuel cells could be supplied by large hydrogen-energy networks, 4)- the near-future race between large oligopolies for learning by doing, and then the market-share rivalries,. To face these challenges, the different actors seem to have given greater importance to an organizational form : the technology consortium (T.C.) one.

We then highlight the complexities of the coordination pathways in these T.C. due to a triple heterogeneity of the innovation stakeholders. The first one is a sector-based heterogeneity. Because of the large scope of required skills to master the further technological improvements of F.C., many T.C. combine the key competencies of a sub-area of electrochemistry industry to produce the fuel cells stacks with other complementary and more traditional competences. These latter ones may include, on the one side "upstream" industries such as energy providers and component (catalyst, fuel processor, membrane electrode assembly) suppliers, and on the other side "downstream" industries such as automakers or power equipment suppliers. The second heterogeneity is an institutional one. Because of the large remaining uncertainties and long delays before commercialization, a very large scope of contributing firms is involved in the development of F.C. from large incumbent oligopolies to recent and fragile "inventors" start-up. The third one is based on a differentiation of internationalization between the FC TC, due to their specific goals and learning ways. These three types of heterogeneity may obviously combine between themselves, which explain the very large scope of the existing TC, and their very large differentiated learning goals.

Moreover neither the large existing oligopolies nor the start-up could develop this technology without the decisive leverage of public interventions, very often within the framework of public-private partnership. The rationale of such partnership is also linked to an innovation race between the three poles of the triad, and therefore between the different national innovation systems and their public actors. We try to assess the current triadic hierarchy in the world fuel cells sector, showing that two poles (North-American and Asia) are leaders, while the European one is a follower. In order to decrease development costs, different cooperation implementing agreements have been designed between the concerned I.E.A member states, and between US government and EU Commission: their relative impact remains limited to mainly exchange of information.

To conclude, we highlight the likely increased support from public authorities in the three poles of the triad, due to the very nature of the fuel cells innovation, and its likely continuing differentiation due to their specific competitive position and the remaining specificities of their NIS.

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INTRODUCTION

Technology consortia (T.C.) are becoming one of the most usual organizational form selected by high-technology firms to develop their innovations. The explaining factors of a such success, and behind that, the cooperation rationales of this type of organization are recalled by Baumol (2002). While economists used to mainly highlight the dimension of sharing the financial burden of high-cost innovation within a group of firms rather than a single enterprise, he focuses on the complementary dimension[1] of technical changes particularly along the vertical relationships which are implied in rapid evolving technology industry. Following this direction, Baumol adds the following empirical and theoretical result : "*Firms that pool their innovation gain a competitive advantage over firms that depend only on their own R&D resources. The resulting competitive handicap to non participants in a Technology Consortium (T.C.) can grow cumulatively as time passes*."(op.cit.p.94). The identification of a such dynamic trend between world-level competing firms, but also between competing nations is a first importance issue to understand innovation race at the world level, and possibly to shift public policies at a national and regional level. But a such evolution is simultaneously generating new issues, such as the allocation of intellectual property right between the increasing number of involved stakeholders in the more collective innovation process.

This co-operation dimension seems also most relevant in the fuel cell (F.C.) technology case. The development of F.C. and hydrogen technologies are taking an increasing place within a very lively, and sometimes confusing, public opinion debate with apparently equal contributions of pro's and con's. Between the new massive R&D push of the beginning of nineties in fuel cells areas and now, T.C. are present, but with at least two main evolutions:
-the number of these TC has dramatically increased,
-and the coordination schemes have shifted to more hybrid (public/private actors) and international ones.
In this chapter, we focus on the rationales of cooperation involved in the development of that innovation, and particularly on the great scope of T.C. either from an sector-based and institutional point of view, or from a country point of view.

To reach this objective, we will divide our presentation according to the three following parts. We deal first with the four main economic characteristics of a such innovation. We then highlight the broad scope of the coordination schemes in these T.C. due to a triple heterogeneity of the innovation stakeholders (firms). We finally focus on major involvement of national public authorities in fuel cells development and T.C.

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* We deeply thank Patrick Cohendet for its comments and suggestions, and Arman Avadykian for our numerous phone discussions.

[1] A closed idea may be found in the concept of complementary assets. (See B.Guilhon, 2001).

I-Four stylised facts about fuel cells innovation in 2003

What are the main fuel cells characteristics which scholars should take into account within their analysis of this innovation process, in particular for the either competing or convergent initiatives by the big stakeholders, be it National Innovation Systems or Multi National Firms? Based on a factual basis developed from many investigations by recognized experts in this area, which include works from Mima S., 2000, Avadikyan A., (2003), National Academies (2002), Steinerman P.P., (1999), Alleau T., Barbier F., (2001), four stylized facts may be identified.

I.1- Fuel cells innovation is a radical one, which potential market scope seems huge in stationary and transport uses.

Following the suggested innovation taxonomy by J.M. Martin (2000, p.35), we may refer to the notion of radical innovation. This type of innovation is based on the fact that fuel cells technology is an entirely new physical process[2] of energy conversion which allows to convert a combination of hydrogen and oxygen into power electricity. As such fuel cells technology requires a new set of scientific and technical knowledge in the history of energy systems, and therefore calling for the building of new sets of knowledge. This intellectual creation , and the production of the associated artefacts, are following a progressive and cumulative path. Within this path the emerging phase encompasses the notion of "*disruptive technologies*" (Christensen, 1997), that is to say technologies limited to narrow niches at the beginning of the transition period between the new and 'mainstream' technologies, because some attributes of the new technology remain inferior to the pre-existing one. Progressively with different learning processes, these inferior performances may be improved and therefore new niche markets will become competitive ones. In the medium and long term, this kind of radical innovations involves a "*technology transition*" which "*do not only involve changes in technology, but also changes in user practices, regulation, industrial networks, infrastructure, and symbolic meaning or culture*"(F.Geels, 2002).

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

- either with the broad scope of energy uses which potentially may be supplied by this technology (1- fixed power generation for stationary uses, 2- power generation within vehicles for mobile uses and 3- micro power generation for portable equipment), within a power scope ranking from some watts to several megawatts, therefore from distributed electricity generation to the power plants dedicated to the great national networks supplies.
- or with the scope of fuels which can be mobilized : on one side petroleum products, methanol and natural gas with processor, on the other side compressed or liquefied hydrogen which has been produced from different renewable or non renewable energy sources.
- or with its aptitude for modularity, which does not mean that this technology is insensitive to scale economies.

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[2] Although the invention of this physical process dates from Sir William Grove's discovery (1839), the emerging innovation phase in the very limited niches of aerospace applications only begins in the 1970's.

In other terms, this innovation is the likely support of a cluster of new generic energy supply and conversion technologies, which mobilize a large scope of new scientific and technological knowledge. This characteristic addresses the issue of the nature of the institutions and organizations which may overcome the required competencies.

I.2- In 2003 this innovation has reached a pre-commercialization stage for which the future development timetable is still spoilt by many uncertainties

The evolution towards a commercialization phase is still conditioned by reduction of technical and economical uncertainties, which give to that technology a still hypothetical character of innovation, given that innovation implies a successful entry on the market. Despite the succeeded penetration in some limited niches (aerospace uses, some military uses in submarine, and some marginal stationary applications until today, plus a near marketing stage for micro portable equipment), remaining uncertainties are preventing the commercialization phase. These uncertainties are obviously interlinked. However they will be separately presented here.

Despite significant advances during the 1990[3] decay, some outstanding scientific and technical uncertainties remain to be solved. They first deal with complexity, that is to say the interdisciplinary nature of the emerging new knowledge basis. For example, SECA program (2000) in USA argues that in order to reach minimum performance/costs goals in the Solid Oxyde Fuel Cells (SOFC) pathways, breakthrough innovations are required in many areas, such as ceramic materials, power electronics, advanced manufacturing techniques for cheap stacks production, miniaturization of components and in-board fuel processors, ….
Then these uncertainties cope with the reduction of the existing gap between the obtained functionalities by the prototypes in field test and the minimal required functionalities in each niche. For example the expected improvements in stationary uses are rather dedicated to the reliability and durability goals, while in transport uses basic improvements are hoped in miniaturization, reliability, balance of plant, and the ability of fuel cells to fit 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 substitutes, or its improved performance substitutes. Today FC have investment and operating costs several times higher than their substitutes. The technical advances in FC should at least partially reduce these overcosts. But this looks like a speed race in the performance improvement of competing technologies, sometimes reducing (fuel cells advance), sometimes increasing (substitutes advances) the price gap. This theoretical possibility becomes a practical one when the competing technologies benefit from the support of public authorities in some important National Innovation System. Because these issues are in-depth developed by S.Mima and P.Criqui in their contribution (The future of fuel cells in a long term inter-technology competition framework), readers are invited to refer to this chapter.

Finally one should also take into account the financing uncertainties of a certain number of small fuel cells developer firms. Many of these start-up with small equity and without market are financially dependent on the stock market expectations about their economic future. When

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[3] T.Alleau (1998) points out many advances in power density increase of fuel cells stack, the decreasing required quantity of catalyst (platinum), the components durability,….

stock market is bearish, these start-up may be very fragile. Moreover commercialization public announces have been clearly too optimistic[4] since the end of 1990's, either by public or private actors. These two combining factors, a depressed stock market for the high tech societies and an imprudent and excessive optimism, have forced small and medium firms from the years 2000/ 2001 to explicit all the incurred risks by their current or future shareholders. However the long list of these risks, which is presented in Box 1 for the Plug Power case (Annual report 2001), may persuade risk-adverse investors not to go.

Box 1 : Existing threats and uncertainties in 2002 about the future commercialisation schedule of fuel cells : the case of Plug and Power Inc.

Because of several factors, small fuel cells developer companies are now forced to explicitly mention the main risks and uncertainties which could prevent or delay their forward-looking statement on commercialization milestones and their future results. In its 2001 Annual Report on Form 10-K , Plug and Power Inc. stated an impressive list of not less than 31 of such factors. Despite some US traditions (the high role of lawyers in current management issues), and some Plug and Power Inc specificities (small company involved in the development of PEM fuel cells, dependency for commercialization to an exclusive distribution agreement with General Electric Fuel Cell Systems, securities class action litigation), we believed this list is relevant to understand what were the existing threat and uncertainties in 2002 for this kind of small companies about the future development and commercialisation schedule of fuel cells.
For simplification reasons, we decide to regroup this list of 31 factors into the following four broad categories (quotations are italic written):

1-Technical uncertainties on future development performance:
-*"We may never complete the research and development of commercially viable stationary fuel cell systems."*
-*"We have not fully developed and produced the product that we have agreed to sell to GE Fuel Cell Systems"*.
-*"We have not met in the past and may not meet in the future product development and commercialization milestones."*
-*" Our fuel cell systems use flammable fuels which are inherently dangerous substances."*
-" *Failure of our field tests could negatively impact demand for our products."*

2- Limiting/restricting business conditions :
-" *We have incurred losses and anticipate continued losses for at least the next several years."*

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[4] Many examples may be quoted : we choose to give the following ones in stationary application. Around the year 1997/98, the Federal Energy Technology Center (Office of Fossil Energy-US DOE) announced within the framework of the "Advanced Clean/Efficient Power Systems" program in a "project FACTS" related to the Research and Development program on Solid Oxide Fuel Cell Project by then Westinghouse Electric Corp, that "*The program goals are to commercialise the tubular SOFC technology by 2002.*" (Source : http://www.h2fc.com/companies.html). In 2001," The Solid State Energy Conversion Alliance", an alliance of U. S. industry, universities, and other research organizations to promote the SOFC technology, announced in 2001 the new commercialisation goals of low-cost solid oxide fuel cells : 800$/kw in 2005 for the residential market, and 400 $kw in 2010 for the commercial and utility market. In November 2002, Melanie Forbrick, spokeswoman of Siemens Westinghouse Power Corp, made the following statement : " *What we are going to do is remain in the pre-commercialization phase for longer than we originally anticipated, with the economic US situation spilling over into the worldwide market.*"

-“ *A viable market for fuel cell systems may never develop or may take longer to develop than we anticipate”*
-“ *We face intense competition and may be unable to compete successfully.”*
-“ *Future acquisitions may disrupt our business and distract our management.”*
-“ *Our stock price has been and could remain volatile.”*

3- In-house limited competencies/skills
-“ *We have only been in business for a short time, and your basis for evaluating us is limited.”*
-“ *We have no experience manufacturing fuel cell systems on a large-scale commercial basis.”*
-“*Delays in our product development will likely have a material impact on our commercialization schedule”*
-“ *We must lower the cost of our fuel cell systems and demonstrate their reliability.”*
-“ *We may be unable to raise additional capital to complete our product development and commercialization plans.”*
-“ *We may not be able to protect important intellectual property.”*
-“ *We may have difficulty managing change in our operations.”*
-“ *Our future plans could be harmed if we are unable to attract or retain key personnel.”*
4- Dependency from outside institutions behaviour, shareholders conflicting objectives, substitute products competition, unfavourable fuel inputs evolution
-“ *We are heavily dependent on our relationship with GE Fuel Cell Systems and its commitment to develop the fuel cell market.”*
-“ *We depend on third parties for certain aspects of product development, manufacturing and the development and supply of key components for our products.”*
-“ *We will rely on our partners to develop and provide components for our fuel cell systems”.*
-“ *Changes in government regulations and electric utility industry restructuring may affect demand for our fuel cell systems.”*
-“ *Our business may become subject to future government regulation which may impact our ability to market our products”*
-“ *Utility companies could place barriers on our entry into the residential marketplace”*
-“*Alternatives to our technology could render our systems obsolete prior to commercialisation”*
-“ *The hydrocarbon fuels and other raw materials on which our systems rely may not be readily available or available on a cost-effective basis.”*
-“ *We will need to establish additional strategic relationships to complete our product development and commercialization plans.”*
-“ *We face risks associated with our plans to market, distribute and service our products internationally.”*
-“ *Our government contracts could restrict our ability to effectively commercialize our technology.”*
-“ *GE MicroGen and DTE Energy have representatives on our Board of Directors.”*
-“ *We are subject to a securities class action litigation..”*

Source : authors, from Plug and Power Inc Annual Report –2001-Form 10 K.

1.3- Massive insertion of FC innovation in the energy systems implies a long transition period before its coupling with the hydrogen energy pathways

Fuel cells are mainly an hydrogen and oxygen conversion system into electric power. Without a direct hydrogen supply, a complementary device, the fuel processor, transforms liquid or gaseous hydrocarbons into a gas mix with high hydrogen content. But this supplementary stage implies : i) increased capital and operating costs, ii) a lower energy efficiency, and therefore increased CO2 or CO emissions which decrease the environmental performance of this technology, and iii) if the case arises an inferior operating performance of the fuel cell. In short, energy supplies to fuel cells will to 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 included into vehicles remain to be socially accepted, while "*both hybride and carbon nanostructure storage technologies remain immature at this stage*" (SAE Automotive Engineering, 2002), ii) hydrogen transport and distribution issues on a vast territory: issues are to find the way to finance the enormous up-front costs, that is to say a new energy network, iii) hydrogen production issues : a cost-effective way[5] has to be discovered to mass- produce hydrogen under a neutral ecological balance requirement, either from reforming non-renewable carbon fuels but with CO2 sequestration, or from solid biomass conversion[6].

-Or within an indirect pathway, the difficulty of hydrogen-energy supplies is avoided by using the existing petroleum fuels distribution network; but in this case one has to face the simultaneous problems of investment and operating overcosts when using the on-board fuel processors.

In a medium and long term perspective, all these issues may likely be overcame; but their progressive solving requires cooperation between fuel cells developer, energy suppliers, and original equipment manufactures be it automakers or power plant providers, in order to benchmark the different feasible technical solutions (cf. for example the California Fuel Cell Partnership). This supplemented experimentation with the necessary improvements of the processor unit miniaturization and more generally of their global performances implies new lead times for the commercialization of fuel cells. In 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 short term the absence of such energy infrastructure can be overcame for the fuel cells marketing, but their necessary creation will require a long "*technology transition*" which will require several decays before a massive insertion of hydrogen networks into energy systems.

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[5] This requirement excludes, unless 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 temperatures nuclear reactors.

[6] Among the different future pathways, the gazeification of wood/crop trees appears as one of the most promising.

I.4-Specific learning routes and scope of potential markets are structuring the competitive expectations from big actors within strategic games of innovation race.

Experts generally forecast that, despite a given development stage, the main improvement perspective of fuel cells will be mainly based on learning by doing. This changed way of learning would determine the transition from emerging to key technology, and then to basic technology.

According to Alleau and Barbier (2001), the « *contraintes d'industrialisation en grande série* » give incentives to a selection of two pathways among the eight ones which have been explored : « *...la filière des piles à électrolyte polymère solide (PEMFC) et celle des piles à oxyde solide (SOFC)* »(op.cit. p. 56,57). SECA program has announced a such objective to be reached in ten years ((2010) : the objective of 400 $/kW in the fuel cells with solid electrolyte[7].

Even if auto-promotional aspects have to be taken into account in such program expectations, the competitiveness condition within a five to ten years term in stationary uses lies on mass production for increasing size niches, which will be accessed through decreasing costs[8].The same type of change is expected by big automakers in the PEMFC pathway, but with a time lag of two to five years in respect to the stationary uses.

During that evolution one may note the change of learning way[9]. After the learning trough increased variety during the very first stages of innovation process (benchmarking between several technical pathways), a new learning type would follow : learning trough specialization/standardization which be based on learning by doing, with transition issues between these two types. This expectation is shared by fuel cells manufacturers, and all the others involved stakeholders in cooperation networks. The new strategic issue that the big industrial groups are facing could be expressed in this way : what pathway should we follow today in order to be in a position of participating to morrow into the innovation race through learning by doing ?

Faced with this perspective of a new selection stage, the "shake-out" one when economic competitiveness and industrial maturity are reached, one perspective might be to look for « network externalities » ; these « network externalities » could be obtained through consortium which would progressively succeed in standardizing and transforming the different fuel cells component into compatible and efficient ones. In that perspective the market takeoff will mainly or uniquely benefiting to the standardized products of the consortium (winner takes all strategy), because their stakeholders have succeeded to

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[7] « *The basic building block will be a 5-kW solid state fuel cell module that can be mass-produced and used for residential or auxiliary power unit applications. The mass-produced 5-kW core modules will be combined like batteries for applications with large power needs, thus eliminating the need for custom designed fuel cell stacks to meet a specific power rating. SECA technology will ultimately lead to megawatt size configurations for commercial/light industrial packages and Vision 21 central power station applications*" (SECA,US DOE, 2000, p.1).

[8] From information collected in Dupont-Roc and al (2001), and Alleau and Barbier (2001), the following markets may be reached according to the following investment cost : 1) between 6000 and 4000 €/kw, back-up for premium power applications: computer centers, hospitals,…; 2) between 3000 and 2000 €, portable equipment; 3) between 1500 and 800 €/kw, electricity supply for small firms and services sector; 4) between 800 and 300 €/kw, individual electricity generation for residential , 5) from 300 €/kw, electricity generation for networks; 6) from 200 to 150 €/kw, heavy duty vehicle; 7) between 100 and 50 €/kw, light duty vehicle.

[9] On the relationship between uncertainty forms and learning forms, E Conesa, (1998) identifies the two following modes : in the first place in front of structural uncertainties, which fit the area of radical innovations, the focused type of learning will be the variety one; in the second place in front of parameter uncertainties, which fit the area of incremental innovations, the focused type of learning will be the specialization/standardization one.

continuously and homogeneously improve their products performance, and therefore able to capture the greatest share of new markets. Its this kind of market leadership that the US promoters of SOFC pathway were referring to (Siemens group, Westinghouse technology) when they announced their intention to replicate in the future world power plants market the technological advance that General Electric succeeded to build within the gas turbines area[10].

Conclusion

Summing up the four characteristics of fuel cells technology, we found that before thinking mass marketing of that technology, their current promoters are facing the following difficulties :
- the very broad spectrum of required knowledge and competencies, existing and new ones,
-the still large technical, economical 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.
- the near-future race between large oligopolies for learning by doing, and then the market-share rivalries.

All together, the main arising question becomes : what has been the main organizational structure the different players have found to face these different challenges ? Empirical facts- which will be presented in more details later on, show that the technology cooperation, and more precisely sharing technology consortia, while allowing fierce competition, have been this most used organizational structure. In the next two sections we will assess the extent to which the forms of these fuel cell cooperation agreements are matching these four characteristics of an emerging radical innovation.

2. The triple heterogeneity of the fuel cell technology consortia

We now focus on the coordination schemes which have been implemented up to now in these TC, in highlighting the complexities of these coordination models due to the triple (sector-based , institutional, internationalization) heterogeneity of the innovation stakeholders.

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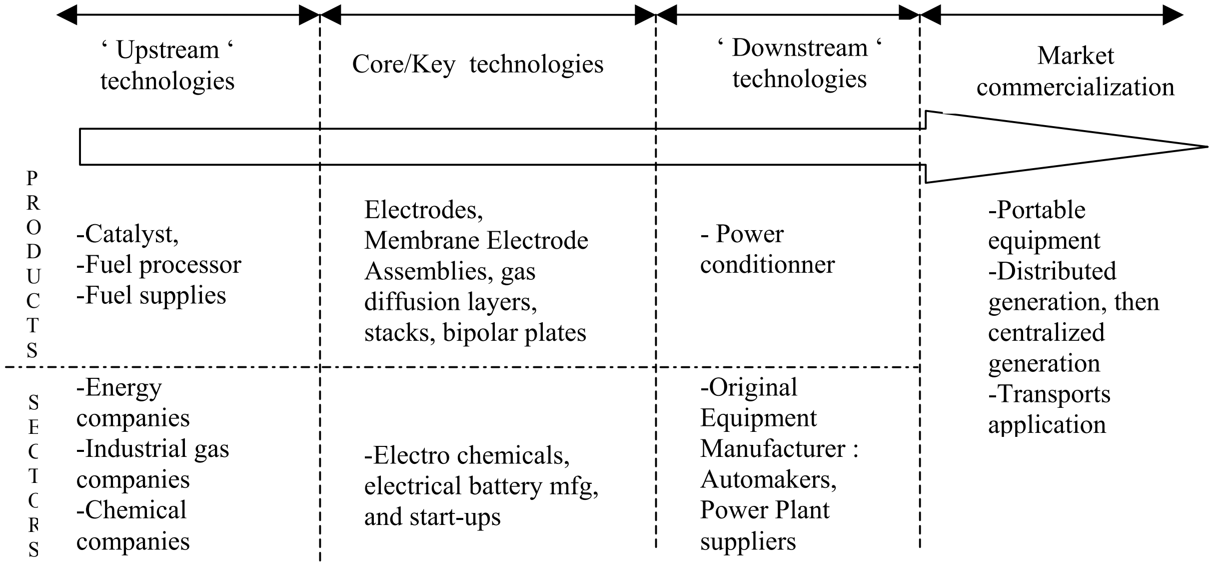
[10] " *Commercialization of the Westinghouse concept- the only fuel cell type in which American technology clearly leads the world- could offer a new approach to generating power in the United States and worldwide. It could create a new solid state manufacturing industry, employing skilled workers to design and fabricate power technologies for tomorrow's energy needs*." Source : Federal Energy Technology Center, US D.O.E., Advanced Clean/Efficient Power Systems ,Project facts-PSO25.0897M- Developing the Solid Oxide Fuel Cell.

2.1 Sector-based heterogeneity of the technological consortia like answer to the complexity of competences needed for the development of the fuel cells

When looking at the main specialization profiles[11] of the involved firms in the fuel cells T.C, one may divide the resulting scope into two different parts : on one side the fuel stacks and closed components[12] which are the technical core of the innovation, and on the other side the necessary upstream and downstream complements (equipments or fuel inputs) of these stacks.

Graph N° 1: A simplified splitting of fuel cell innovation into three technology subsystems



	' Upstream ' technologies	Core/Key technologies	' Downstream ' technologies	Market commercialization
PRODUCTS	-Catalyst, -Fuel processor -Fuel supplies	Electrodes, Membrane Electrode Assemblies, gas diffusion layers, stacks, bipolar plates	- Power conditionner	-Portable equipment -Distributed generation, then centralized generation -Transports application
SECTORS	-Energy companies -Industrial gas companies -Chemical companies	-Electro chemicals, electrical battery mfg, and start-ups	-Original Equipment Manufacturer : Automakers, Power Plant suppliers	

Source : authors

2.1.1 The required skills for producing fuel cell stacks and related components

To manufacture fuel cells stacks, the basic building block of the fuel cell system, one founds either electrical battery manufacturers, or new specialized firms (for example Ballard, Nuvera, Plug Power, International Fuel Cells, now UTC), which succeed to control and develop electro-chemical knowledge, and new catalysts and performing materials. Closed to these specialized knowledge, chemicals skills are necessary to master the connected technologies to the stack ones : i.e.membranes, electrodes, Membrane Electrode Assemblies (MEAs). That is the reason why in many T.C., one founds big chemical companies such as Du Pont de Nemours, Aventis, Dow Chemical, Kureha Chemicals, …

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[11] We do not enter here in the presentation of the different TC which are specialized in the development of one given fuel cells pathways, such as PAFC, AFC, PEMFC, SOFC or DMFC. On that issue, see for example Alleau, Barbier (2001).

[12] The precise division line between core technology and the upstream and downstream subsystems of the fuel cell innovation system may become a specialist debate object, for example when concerning the following technologies : fuel processor, electronics, integration of the fuel cell system, catalysts,…Moreover we did not mention the presence of many supporting auxiliary devices along the three subsystems.

2.1.2-The required skills for “upstream” and “downstream” technologies of the fuel cell

Fuel cell upstream technologies deal with fuel inputs, either hydrogen or hydrocarbons, while the downstream ones involve the equipment in which fuel cells are integrated, generally within a vehicle or a power plant.

Fuel providers

Oil and gas companies, companies specialized in hydrogen production and storage are cooperating to an unusual degree on research on fuel cells. None of the alternative fuels has shown its supremacy, each representing advantages and limits particularly in mobile markets. Hydrogen fuelled FC Electric Vehicles are likely to provide the lowest greenhouse gas emissions of the non renewable fuel chain options but fuel infrastructure is to be constructed and the capital cost is very high. In this framework gathering data about costs, emissions, the real life operation and maintenance of vehicles relating the fuel used is very important for good future decisions. Many examples show the implication of oil and hydrogen companies in different demonstration fuel cell projects. For example, recently, Shell and Texaco, DaimlerChrysler, Ford and Ballard joined the state of California and formed “California Fuel Partnership-Driving for the future". The partnership is dedicated, between 2000 and 2003, to demonstrate and test approximately 30 cars and 25 buses powered by engines using Ballard fuel cells. In addition to gathering data about the real life operation and maintenance of vehicles, the collaboration will focus on requirements relating fuel and fuel infrastructure for FCEV.

General Motors has a similar agreement with Exxon and Arco, while Mobil (now Exxon-Mobil) has teamed up with Ford. Another example is the five year Memorandum of Understanding between Petro-Canada (Canada’s largest oil and gas companies), Ballard and Methanex (leader in the production and marketing of methanol) : “Fuelling a Cleaner Canada”. They will collaborate in laying the groundwork for a pilot project involving the supply and distribution of appropriate fuel, starting with methanol, to facilitate the introduction of FCEV.

Shell, Exxon-Mobil, and Arco are specifically working on the use of gasoline in fuel cells. Gasoline would involve more complex technology for auto makers and higher emissions, but has existing infrastructure.

Fuel cells provide equally a new valorisation of the natural gas so for gas companies as for users. The firsts tempt to seize this new opportunity to increase sales of gas. For these reasons Praxair Inc (US), Tokyo Gas (Japan), Osaka Gas (Japan), British Gas (United Kingdom), Ruhrgas (Germany), SNAM and Eni (Italy), Naturgas Syd (Denmark), Imatran Voima (Finland) are already very active actors in the development of fuel cells.

We deal now with the “downstream” integration issues of fuel cells either in power plants or in vehicle, which imply a cooperation respectively from power plant suppliers or from automakers.

Utilities and Power Plants Suppliers

In the framework of the recent progress in the deregulation of the power generation industry, fuel cells hold a particular interest for utilities around the world. Because high efficiencies can be achieved in low capacity units, fuel cells are particularly suitable for distributed power generation located closer to the end users than large centralised power generation. For utilities this means to avoid the need for new power lines, the reduction of transmission losses and the improvement of the reliability of the supply. Small scale generation of this kind is also being increasingly popular among large power consumers who are able to generate their own electricity on-site and benefit from the high efficiency and economy of cogeneration.

Moreover, several utilities have started to think in a more strategic way about environmental issues. In this context fuel cells offer an attractive solution for clean and efficient electricity generation. For this reasons GPUI, General Electric (US), Fuji Electric Company, Mitsubishi Electric Company (J), Elkraft, Elsam (DK); Sydrakft, Vattenfall (S); ENEL (IT); SEP (NL)..., have been working vigorously on a combination of research and demonstration's projects in order to acquire experience concerning this new technology. Some of them are already pursuing business arrangements with fuel cell manufacturers to distribute the technology in competitive customer markets. For example the world’s first 100 kWe class Westinghouse SOFC was sponsored by EDB/ELSAM, a consortium of Dutch and Danish utilities. Other SOFC has been tested also at Kansai Electric Power Company in Japan and Ontario Hydro in Canada.

Large constructors of power plants (Alstom (France), Mitsubishi Heavy Industries (Japan), Siemens Power Generation (Germany), GE Power Systems (US)) are also interested in the development of fuel cells. So for example GE Power Systems has acquired Honeywell's Fuel Cell operations including the intellectual property and certain equipment. The same company has also signed exclusive marketing agreements with Plug Power. The Fuel Cell assets will be used to provide research and development expertise for fuel cell power generation components.

Automakers

Automotive firms and component suppliers devote, with more or less enthusiasm, a growing share of their budget to the research of a Supercar without harmful emissions. In fact automakers are in a crossroad. In front of hardening of environmental constraints anticipations in middle and long term they have not many choices : because the progress in the batteries technology leaves much to be desired, electric vehicles are considered as a technological and commercial fiasco ; hybrid vehicles are costly because of their double motorisation and well adapted only for combined urban-suburban circulation ; further reductions in emission rejections of traditional cars, are becoming more and more expensive, while fuel cells which are prone to be the best solution have not yet satisfied all their potentialities and infrastructure problems seems to be an important constraint.

However, among the various options explored, fuel cell vehicles are attracting world-wide interest. Fuel cell 2000 has identified 96 fuel cell vehicles and buses demonstration projects in the world since 1991, 25 of which took place only in 2001. The increased number of demonstration projects last years is accompanied also by an increased number of the automakers implicated in them. The most actives are DaimlerChrysler, Ford, General Motors, Honda, Toyota, Nissan, PSA Peugeot Citroen …. which always according to Fuel cell 2000 have carried out the following number of demonstration projects.

Table 1 : Most active automakers in FCEV demonstrations

Automaker	Fuel cell manufacturer	Number of demonstration projects	Years
DaimlerChrysler	Ballard	15 (12 cars&3buses)	1994-

			2002
Ford	Ballard	5	1999-2002
General Motors	Ballard (1), GM (7)	8	1997-2002
Honda	Ballard(4), Honda (1)	5	1999-2002
Toyota	Toyota	5	1996-2001
Nissan	Ballard	2	1999-2001
PSA Peugeot Citroen	Nuvera (1), HPower(1)	2	2001
BMW	UTC	2	2000-2001

Source : authors, from Fuel Cell 2000

Through demonstration and test programs, automakers, fuel cell manufacturers and fuel providers gain information and experience for improving their next generation products. For automakers the question is not whether fuel-cell electric vehicle (FCEV) will be developed, but what type of fuel pathways FCEV and who will gain the upper hand in this technology race. So, each of automakers try to chose its own best strategy which can better mitigate risks and permits them to maintain their technology lead relying upon know-how and trade secrets.

2.2. Institutional heterogeneity of the technology consortia in front of the uncertainties and future strategic advantages of the fuel cells development

We already mentioned the different types of firms which are involved in this innovation development, for example from large oligopolies to small independent firms[13]. We then present the different types of cooperative arrangements which have been implemented in the technology consortia.

2.2.1- The large institutional diversity between private firms and their assumed complementarity

In his last book, Baumol focuses on the existing complementarities, which he *calls "division of work*", between "*independent inventors*" with their new major or revolutionary technological contributions, and oligopoly corporations more dedicated to "routinized" innovations, that is to say with improvements and extensions of the independent inventors heterodox contributions. Is that division of work a relevant one in our fuel cells technology case ? More particularly are the "independent inventors" only found in the fuel cell stack manufacturing, while the large oligopolies would deal with the other parts of the innovation fuel cell system, i.e. the most traditional ones ? Do we observe many technological sharing agreements between these two types of firms ?

Global answers to these questions are positive ones, provided that some important corrections are brought to that too general picture. On the one side, there are oligopolies also in the newest part of the fuel cells innovation system, i.e the fuel cells stack, because they are already consortia, such as UTC, which include a dedicated department to fuel cells activities

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[13] While the difference between public and private organizations may be clearly identified under the concept of different institutions, we choose here to keep the same concept of different institutions when dealing with very different types of private firms, such as large oligopolies and small start-ups. Aoki (2001) would rather use in this case the notion of different organizational buildings.

or because they have acquired a previous independent inventor. And on the other side, some independent inventors are also found on the other more common parts of the fuel cells systems : for example Athur D.Little in fuel processor. Despite these existing gaps with the general scheme, an increasing trend of cooperation between specialized start-ups in fuel cells stacks and large oligopolies is observed during the last ten years. The main explaining factor lies on the one side in the financial weakness of independent inventors which may be temporarily solved by the negotiated or imposed support from large oligopolies, and on the other side in the large oligopolies strategies of expanding their knowledge base. So the divison line between small independent inventors companies and large routinized oligopolies is a blurring one, as so far some very large oligopolies in the "downstream technologies" (cf some world automakers and power generating equipment supplier) are among the most active stakeholders in fuel cells technologies development.

The "valley of death" threat for start-up firms in the fuel cells area

The stock market evolution, particularly in North America, after a very « bullish» period during the year 2000, has reached very low levels of market value : the so called « technology bubble » exploded. And now, analysts such as Andrew Bradford (2002) are becoming more cautious : " *…now, the stock market hasn't been particularly co-operative with their vision of the long-term plan to raise funds as was required*".

Graph 2 Index of US small and mid-cap stocks of fuel-cell developers companies[14] (September 1999-November 2002)

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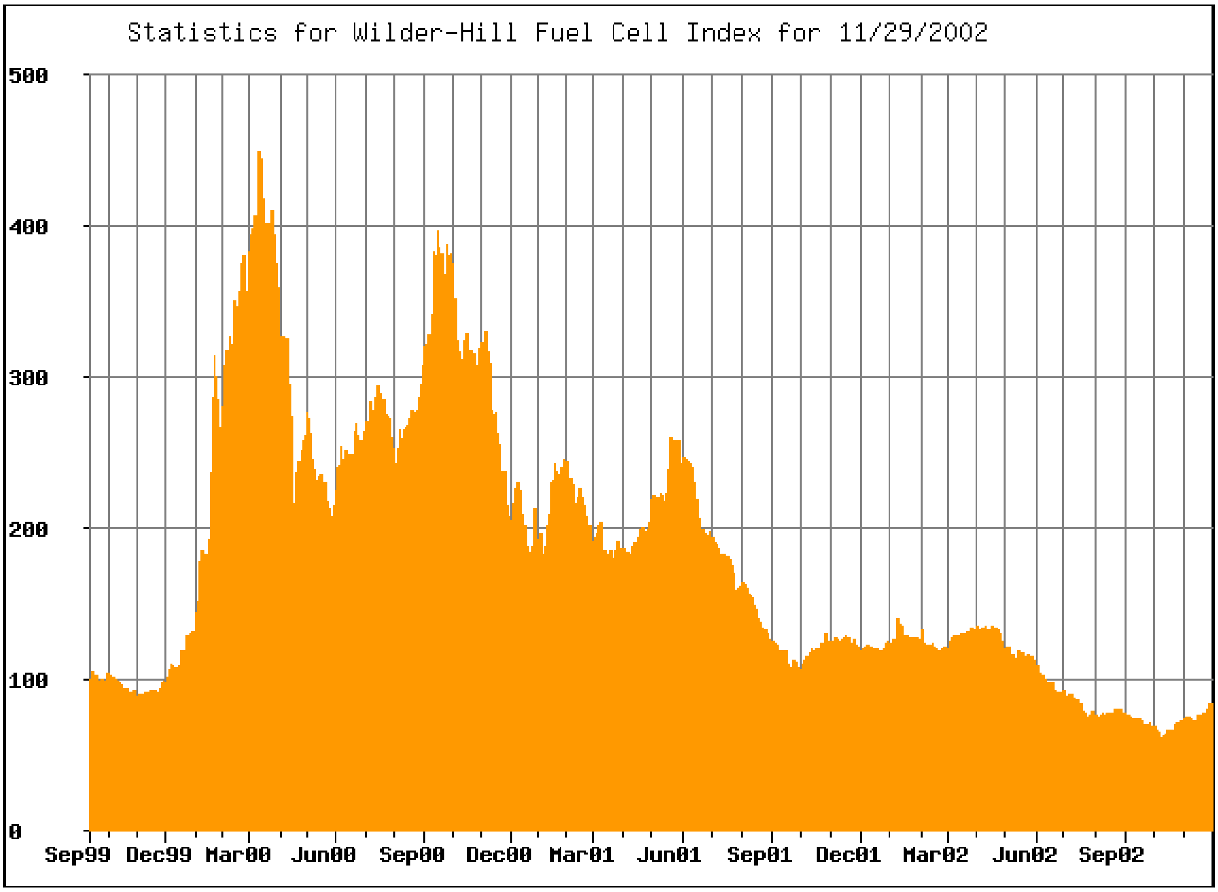
[14] This sample includes the following twenty one small and mid-cap companies : 1-Avista Laboratories, 2-Ballard Power Systems, 3- DCH Technology, 4- Energy Conversion Devices, 5- FuelCell Energy, 6-Global Thermoelectric, 7- Hpower, 8- Hydrogenics Corp., 9-Idacorp, 10-Impco Technologies, 11-Millenium Cell, 12-Medis Technologies Ltd, 13- Methanex, 14- Manhattan Scientifics, 15- Mechanical Technology, 16- Plug Power, 17- Powerball Technologies, 18- Proton Energy Systems, 19-Stacon, 20-Stuart Energy, 21-Syntroleum.



Source : Wilder-Hill Index from "Source: The Hydrogen Fuel Cell Institute.-Internet site : http://www.h2fuelcells.org/bigchart.htm

That evolution particularly hits the fuel-cell developer companies, and their financing perspectives. They must face the "valley of death"[15] threat. So the still high financial burden of developing fuel cells before their marketing will likely be only de facto shared between large oligopolies and public authorities. Cooperation between these large firms and small fuel cells developper are more and more imposed ones to the later. Furthermore financial autonomy of these small inventor companies is more and more controlled by their big "partners" which often are funding a major part of their R&D budget. A such evolution is even observed in the PEMFC leader, the Ballard case.

2.2.2-The different kinds of arrangements between big stakeholders within technology consortia

Several kinds of arrangements took place during the last decade between big stakeholders of the innovation process, or between them an independent inventors : strategic partnerships, integration into one company, fusion of companies, customer relationships (business arrangements with Utilities and Constructors of Power Plants), cooperating agreements of fuel providers (with oil and gas companies), professional and marketing associations and national or supranational technological programs. Some examples are presented.

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[15] This expression indicates the cumulative negative cash-flow problems that an ordinary venture capital/incubator/Angel capital company must face during the first years of its existence, i.e. during the following phases of :concept, pilot, prototype, demonstration and beginning of sales. US statistics seem to show that 70% of these business companies fail when annual cash flow becomes positive, i.e . seven years after the starting year.

Strategic partnerships

Generally the partners bring extensive experience in complementary fields like in electrical power conversion and control systems, product design and manufacturing processes, in optimizing the application of fuel cells to specific client requirements. Sometimes the cooperation begins with a supply agreement which emerges areas of mutual interest for broader strategic relationships.

Lets begin for illustration with one of the oldest fuel cell manufacturer (40 years of experience in the fuel cell business) and the only company in the world producing commercial stationary fuel cell systems having delivered more than 245 PC25 systems installed in 19 countries on five continents : UTC Fuel Cells, former IFC. Although UTC is a unit of United Technologies Corp. which conducts research and development activities in excess of $1 billion annually and enjoy multiple competences in aerospace, transportation and energy conversion, they have partnered with international car companies : Nissan, Renault, Hyundai and BMW to develop emission-less, fuel cell-powered cars for the commercial market. In addition, the company has teamed with Irisbus, to develop a zero-emission transit bus.

FuelCell Energy, Inc., formerly Energy Research Corporation (ERC) is a leading developer and manufacturer of clean and efficient electric power generators based on the company's Direct FuelCell® technology. In april 2002 FuelCell Energy announced a 10-year-agreement extendable in 5 year increments, graduated incentives with Caterpillar for the delivery of orders up to 45 megawatts, an expanded dealer network that will sell Direct FuelCell® power plants throughout North America, and the development of Caterpillar-branded fuel cell power plants. They have announced also a market development agreement with MWH. MWH brings additional technical expertise and market knowledge in the integration of on-site generation to wastewater treatment facilities. Their expertise in anaerobic digester gas processing is a key strength for the development of this renewable, biogas market that combines high electrical efficiency with reductions in harmful emissions that contribute to global warming.

New assets acquisitions and fusion of companies

On the first and risky strategy during this pre-commercial uncertainty phase, one may give the Ballard's example, among many other ones. Ballard Power Systems, the world leader in developing, manufacturing and marketing PEM fuel cells, has become one of the favourite partner for many big companies. Ballard has secured alliances with selected global players in all its target markets having as result the foundation of some jointly-owned companies.). Recently intending to expand its strength, Ballard tried to provide access to new markets and earlier revenue opportunities, broadened its product range, increased the commitment from its partners, expanded its extensive intellectual property portfolio, and increased the value capture by providing complete system solutions. In order to realise these objectives and particularly enhance their capability to provide a complete fuel cell solution for their customers, Ballard has acquired XCELLSIS Fuel Cell Engines Inc. and Ecostar Electric Drive Systems from DaimlerChrysler and Ford; acquired the carbon products division of Textron Systems to form Ballard's Material Products division[16] and has streamlined their stationary alliance. But due to the above mentioned to stock market environment, success of a such strategy is not guaranteed. In fact at mid-December 2002, Ballard could not escape a new restructuring plan because its recurrent cash-problems : apparently DaimlerChrysler and Ford which will inject 97 million $ more to their previous development programs, and will also,at

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[16] This division is focussed on carbon materials that can be used in several applications including fuel cells.

least for the former company, reemploy "*100 employees from Ballard's Nabern, Germany operations*" (Eyeforfuel cells, 12/10/2002)

Another form of relationships between heterogeneous actors may be also the fusion of companies or subsidiaries of parent corporations in order to put together the necessary now-how for the production of new or better products. The example of Nuvera seems very relevant. With operations in Milan, Italy and Cambridge, Massachusetts, Nuvera Fuel Cells is a designer and developer of fuel cell stacks, fuel processors, and integrated fuel cell systems for stationery, premium, and transportation applications. Its fuel cell stacks and fuel processors have been successfully tested and evaluated by major automobile and appliance manufacturers, research institutions, and industrial and energy companies. Nuvera's fuel processors have demonstrated the ability to extract hydrogen from a number of commonly available hydrocarbon fuels, including gasoline, ethanol, methanol, natural gas, kerosene, propane, butane, home heating oil, and diesel. Formed in April 2000 through the merger of De Nora Fuel Cells S.p.A. and Epyx Corporation, the company's investors include Gruppo De Nora, Arthur D. Little, Inc., and Amerada Hess Corporation (a leading U.S. East Coast provider of fuel oil, natural gas, and electricity to industrial and commercial customers..). Then Amerada Hess recently takes the control's majority. De Nora Fuel Cells, in combination with Gruppo De Nora – its parent organization and a world leader in electrochemical engineering and membrane technologies – has delivered more than 310 fuel cell stacks to customers around the world in the stationary and transportation markets since 1993. The fuel cell stacks utilize the hydrogen created by the Epyx' fuel processors to generate clean, efficient energy. Together, as Nuvera, the entities offer a unique combination of proprietary technology, industry know-how, and global research.

Professional and marketing networks

As we have just underlined, fuel cells require much cross disciplinary innovation efforts so networking and R&D co-operation are necessary ways to put together dispersed capabilities and knowledge and if it is possible to create new ones. Interactions guarantee retrospectives modifying of the innovation rendering it more relevant with its selection environment. Thus the producers of fuel cells and other actors that are situated to the periphery of the innovation participate actively to its dynamics sharing their "learning by doing" and "by using". Several professional associations as European Fuel Cell Users (Sweden), Fuel Cell Marketing Group (USA), North American Fuel Cell Owners Group (USA), The Solid Oxide Fuel Cell Commercialization Association SOCA (USA)..., contribute to hype fuel cells through conferences, workshops, publications and realisations of pilot projects. A particular trait of these associations is the multiplicity of actors participating in different associations. The same manufacturer or the same company of gas or of electricity participates in associations that defend different types of fuel cells. This confirms the fact that for the moment there is no one fuel cell winner. The competition between them is just beginning.

2.3- Internationalization of the technology consortia as a differentiated way of learning

2.3.1. The broad range of internationalization patterns of FC TC

Internationalization patterns of fuel cells technology consortia are very diversified. In the first place all fuel cells TC are not internationalized, that is to say implying a partnership between firms of different countries, but many are. Secondly some internationalized FC TC are major ones, while others are marginal ones, involving for example partnerships between two small firms on a specific component. Among the former ones, one may quote the following examples. For mobile applications, the "Fuel Cell Alliance" gathers a world-leading Canadian fuel cells provider (Ballard) with two world major automakers : Daimler Chrysler (Germany) and Ford Motor Company (USA). Their association has leaded to a coordination between four research facility locations : Poway (California-USA), Vancouver (Canada), and Nabern (Germany), which integrate into fuel cell drive systems, while Dearborn (Michigan-USA) is dedicated to the integration of motors and power electronics into electric vehicle drive systems. For stationary use the already quoted SECA program allows a coordination between US government (DOE), US manufacturers firms (Honeywell, ….) and an american one (Siemens –Westinghouse Power Generation) controlled by a german parent company (Siemens). Many other examples could be presented also which deal with Japanese and US partners.

Without having the possibility to bring the required empirical basis, we think that these international partnerships are increasing in number and size.

2.3.2- The rationales behind the increasing internationalization

The following factors may be presented to explain the rationales of a such internationalization process. Firstly there is an increasing internationalization in fuel cells technology consortia, because their main stakeholders are individually increasing their own internationalization in technology creation. If one takes the rate of internationalization of technological activities at the average world level for the fuel cells patent activity (United Sates Patent Classification (USPC) class 429, subclass 12 to 46) of firms with more than five granted patents in the 1985/2002 period, one founds a 3,4% internationalization rate[17] in the 1985/1989 sub period and a 5,7% rate in the 1997/2001 sub period (Source : Jacquier Roux, Bourgeois, 2003). Such as many other technologies the highest rates are observed for European based firms and the lowest ones for Japanese based ones. Secondly firms are internationalizing their research and development activities in fuel cells into foreign countries, because their home-based countries is lagging behind their competitors. In this case teaming-up with foreign partners is a way to increase its own learning abilities. Thirdly if fuel cells technology may be looked as a future world market one, it is worthwhile to test fuel cells prototypes in different advanced countries to acquire experience from users firms, and to inform future likely clients about the real performance of this new technology.

Conclusion

Taking into account the current four characteristics of fuel cells innovation, the different involved firms must address some basic knowledge gaps which prevent them to reach the first market niches. Nature and extent of these knowledge gaps are very broad. To a large extent the diversity of fuel cells technology consortia is explained by the large heterogeneity of specific goals to fill these knowledge gaps through an equally broad set of learning pathways. So to match these gaps, fuel cells technology consortia may have been created in order to either complete the sector based competencies of existing firms, or to suplement their knowledge base with linking advanced inventors but fragile firms with large oligopolies, or to increase their field tests or to complete their strategic relationships with foreign based firms. These three types of heterogeneity may obviously be combined between themselves, which explains the very large range of the existing TC, and their very large differentiated learning goals. But an other major specificity of fuel cells technology consortia is their hybrid nature,

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[17] Internationalization rate is defined as the ratio between on the one side the number of invented patents in foreign countries and controlled by a firm, and on the other side the total number of controlled patents by that firm.

that is to say the mixed institutional stakeholder's contribution: private firms on the one side, public interventions in the other side. This third part is focused on the understanding of the public contributions to that innovation.

3-The decisive leverage of public interventions in fuel cells development and Technology Consortia

Introduction : rationales for public intervention in fuel cells development.

When looking for the explaining factors of public interventions in fuel cells innovation process, we may roughly divided them into two subsets, although they are frequently combined in the current life :

-1) public authorities intervene because their contribution is asked by the others innovation stakeholders, and so when positively answering their interventions lead to hybrid technology consortia, mixing private and public supports,

-2) public authorities intervene because between technology advanced nations there is a competition closed to the oligopoly's one at the world level, in other words a kind of country's innovation race.

We first present some information elements on the first subset. In the context of revised and delayed development milestones, it is easily understandable that the future marketing stage of fuel cells will depend, as a last resort, of a continuing and, may be increasing, support from public authorities. One of the main reason is that public authorities are supposed to be the only category of actors, with some large oligopolies, which may have long and very long term expectations, a prerequisite in the fuel cells case : "*This fuel cell-based hydrogen economy is a marathon and we're probably 100 yards away from the starting line*," (Christine Sloane, director of advanced technology strategy at General Motors Corp., 2002). But despite their long term expectations, and their large financial possibilities, some managers of these powerful oligopolies are now arguing that their own financial support will have some limits in near future : "*As mentioned above the FC market does not exist yet; but the belief is 2004-2005 will see the commercialization of FC technology. The FC market has been on probation for the last 30 years. Therefore it is a must that a commercially viable industry develops by 2004-5 as major corporations will not infinitely pump internal resources into the industry".* (Tixhon J.M.- European Fuel Cells Director, Du Pont, 2002, p1,2-). So the necessary financial support by public authorities is one consequence of the current stage of fuel cells innovation process. Finally public supports are much more than a catalyst in the innovation process : they have a decisive leverage on it, when taking into account not only their financial subsidies to R&D programs (see further), but also their regulation programs and their technology adoption impacts. This confirms a well known statement by different economists, such as Mowery and Simcoe (2002) , Dalpé, Chris de Bresson, Xiaoping (1992), which focused on the role of public demand "*in the early stages of the emergence of radically new technology systems* "(Freeman, Pavitt, 2002).

After having highlighted these first rationales elements of public involvements[18], we present these interventions in fuel cells development into the two following parts. In the first one we focus on the rationale of public interventions which result from the triadic competition, while in the second one information are given on the use of cooperation policy by the state authorities either with private firms (public/private partnership in fuel cells technology consortia) or with other national authorities through specific agreements.

3.1. Public interventions of most advanced technology countries as a result of the innovation race between the poles of the Triad

Introduction

Innovation race between firms and countries is one of the main competitive policy used by the most advanced technology countries, that is to say the triadic countries. The required scientific and technological competencies for fuel cells development are so high that mainly (only) these most advanced technological countries are equally the most concerned ones. Furthermore one would assume that more a technology is considered as a "strategic" one, more intense will be the worldwide innovation race. To what extent fuel cells technology may be looked as a "strategic" one ? No definitive answer can be given for the time being to that question, because on the one side all the remaining uncertainties which are linked to its emerging stage, and on the other side the requirement of a "*technology transition*" between the "old" fossil-fuel based energy system and a "new" more sustainable one is at least a very unequally and unevenly world shared goal.

Under these caveats, one may bring the following attributes to that likely "strategic" nature of fuel cells technology. Some strategic attributes are linked to the stylised facts which have already been presented in the first part : a huge potential market scope in energy stationary and transport uses, a look for a competitive positioning today in order to be able to participate into the likely learning by doing race of tomorrow at the world level, and the de facto requirement of teaming with other national and foreign partners. Moreover fuel cells are likely to be a key technology in the transition towards a more sustainable energy systems. Furthermore fuel cells is a dual use technology, that is to say with civil and military applications : national defence objectives may be partially matched by fuel cells technology control[19]. Finally fuel cells technology may become tomorrow a key technology for power generation equipment industry and for automakers industry, that is to say industries, which both have a strong influence on public policy makers[20].

Taking into account these elements, and other ones which will be now presented, we first present a quick comparison between the three main industrialized world zones of their fuel cells development involvement , and then we bring some first empirical evidence on the likely existence of a triadic innovation race in fuel cells.

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[18] We do not mention here, although they are obvious explaining factors of public interventions, the energy policy goals for some countries either totally energy-dependent from foreign supplies (ex : Japan), or which have renounced to the nuclear option (ex Germany, United States).

[19] In USA, "*The Defense Department has identified fuel cells as a "critical technology" whose development is vital to the nation's long-term defense*." Source : Rose R., 2002, p.3

[20] In USA the industry lead Council on Competitiveness has designated fuel cells as one of seventeen critical technologies.

3.1.1. A temporary view on the current hierarchy between the three poles

To establish a general –but very temporary- view on the current hierarchy between the three poles we will look for technology indicators. Among the most used technology indicators, one founds the input (research and development expenditures) and the output ones : patents and first experiments /applications. But obviously the practical use of these three families of indicators is limited by information access restrictions. These restrictions are very severe for the first indicator, while they are not absent for the two others one.

Available information is either very poor and speculative for public R&D expenditures, or quasi totally absent for private R&D budgets[21] : in this later case one might think to use the available information within research project database which are co-financed by public funds, either in US the FERD data base from the Department of Energy, or in the European Commission Cordis RTD Projects database. But all publicly supported projects are not included, and by definition no information is released when dealing with in-house projects. About public R&D expenditures, one might think to use the IEA R&D database : in fact the fuel cells technology is included with other technologies in an item called "Others", and most frequently this item has no figure, because the IEA member states do not release this information.

Table n°2 An estimation of the triadic public fuel cell R&D budget (2000)

Japan	US[22] and Canada	Total European Union	Including European Commission[23]	Including total European Union Member States
≈ 240 Mio $	≈ (130/180+ 76 Mio $) = 210/260 Mio $	≈ 61 Mio €	≈ 30 Mio €	≈ 31 Mio €

Legend : ≈ = rough estimate; The total of EU member states and European Commission are estimates.
Source : Authors, and Lequeux G., 2001

According to these figures North America and Japan have comparable R&D budgets, while the European Union is lagging far behind, approximately one fourth of the two formers.

The others technology indicators which are available at a country level, deal with outputs : patent and project applications. Patents are measuring, under some assumptions, the intensity of technological creation. United States Patent and Trademark Office (USPTO) data have been used, because US technology market is the world leading one. USPC Class 429 and

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[21] According to different experts, estimations of fuel cells R&D expenditures by Daimler Chrysler may vary between 20 millions of euros (Orselli and Chanaron, 2002) to several billions. At the world level, the Robert Rose 's report give an "*Estimates of annual spending range from $1 billion to $3 billion*" for the private sector.

[22] "*A recent Congressional Research Service Issue Brief (IB10041) estimated that federal research support for energy technologies totaled $84.0 billion between FY 1973 and FY 1999, including $19.7 billion for renewable energy and efficiency technologies. In the same period, we estimate the federal investment in fuel cell research at less than $1 billion.*" Source : Rose, 2002, p.10. Therefore in the USA case, cumulative public fuel cells R&D would have represented 1,2% of the total cumulative public energy R&D.

[23] Apparently DG Research has only a very vague estimate of European Union Member States R&D expenditures in fuel cells, because these States do not release that information; while at EC level, the available information from each program supported by the different DG do not seem quickly and reliably collected, nor redistributed to the Member States.

subclass 12 to 46 have been selected to reflect the contributions to the fuel cell stack development. Despite a bias risk which leads to overestimate US figures, table n°3 shows a North American leadership, followed by the Japanese zone, and far behind by the European Union, in spite their increasing but still minority share.

Table n°3: Share of the patents for three geographic zones within 429 class (1985/2002)

	1985/1989	1990/1996	1997/2001	1985/2002
North America zone	(188/278) 67,6 %	(243/471) 51,6 %	(257/463) 55,5 %	(697/1238) 56,3 %
Japaneese and Korean zone	(79/278) 28,4 %	(175/471) 37,2 %	(124/463) 26,8 %	(392/1238) 31,7 %
European Union	(9/278) 3,2%	(30/471) 6,4 %	(70/463) 15,1 %	(112/1238) 9 %

Legend: figures between brackets are the absolute numbers of utility patents for granted year; firms and public institutions are taken into account.
Source : Jacquier Roux, Bourgeois (2003) ,elaborated from USPTO data.

We finally use a technology application indicator, employing Fuel Cells 2000 World list of fuel cells projects. Despite a likely bias of collected data (probably very good coverage in North America, but much more incomplete in the other world regions, particularly in Japan) the table 4 shows a very large share of USA in fuel cells stationary use applications, but a much more balanced triadic repartition for fuel cell vehicle application.

Table n°4- Inventory of the world fuel cells projects by home based countries of fuel cells manufacturers and by type of application (1994/2002)

Regional Zone or Country	Fuel Cell Installations	Fuel Cell Vehicles	Fuel Cell Buses
1.1- USA	210	23	10
1.2- Canada	14	0	0
1.3- Total North America	224	23	10
2.1 Japan	4,5	18	1
2.2- Other Asian Countries	0	2	0
2.3-Total Asian Countries	4,5	20	1
3.1- European Union Member States	24,5	21	13
3.2- Rest of Western Europe countries	6	1	0
3.3- Total Western Europe	30,5	22	13
4- Other Non triadic countries	0	2	0
5- Undetermined home based FC manufacturers countries	9	2	3
6-Total world list of projects	268	69	27

Source : authors : personal counting , from Fuel Cells 2000 World list of fuel cells projects (Completed + in production+ on going+ Not installed +Ended+To be delivered+….) – Created by Fuel Cells 2000 and US Fuel Cell Council- Updated 8/14/02 for fuel cell vehicles, for fuel cell installations, 8/21/02 for fuel cell buses
- site : http://www.fuelcells.org/fct/buses.pdf + http://www.fuelcells.org/fct/carchart.pdf

From these three tables we think that within fuel cells case triad includes two leaders (North America and Japanese zone) and one follower (European Union).

3.1.2- Some first empirical evidence on a triadic innovation race in fuel cells.

Involvement of public authorities within the fuel cells research and development programs is partly interlinked between the three poles competition of triad, just like "*a competitive arms race in innovation spending*"(Baumol, op.cit, p.43) . To give a very summarized picture of this race, we may start from the following trend : Japan had apparently tripled its fuel cell's research program since 1995. Last 5th of September 2002, a so called "Fuel Cell Advocates" group of thirty companies[24] launched a campaign in the USA calling the US Congress for a tripling of public funding in the next ten years : from currently 180 mio $ to an average of 550 mio $ per year[25]. After this North American initiative, the European Commission considers in October 2002 that the efforts are scattered in the European level, the resources dispersed and the costs extremely high. A major effort is needed in European level in order to rationalize and to stimulate the convergence of the various initiatives in a logical way. That is why the European Commission has launched a high level group on technologies of hydrogen and the fuel cells, for likely taking new reinforcement measures within the existing European program.

Although these informations are very incomplete ones, they tend to suggest a triadic race for fuel cells development. And this dynamics seems so strong that some government officials begin to worry on the increasing pressures of fuel cells budgets. This likely increased triadic competition may also be linked with increased creation of research joint ventures. Albert Link, David Paton and Donald Siegel (2002) found from research joint ventures (RJVs) filing data to the Department of Justice in USA, that *"the propensity of firms to engage in RJVs is sensitive to changes in the global competitiveness of US high-technology industries",* and that policy actions from "*Commerce Department's Advanced Technology Program (ATP), which provides financial support to firms that engage in collaborative research projects, induced firms to engage in additional (privately financed) RJVs*"(A.Link, op.cit. Abstract). Although some 10% of ATP funding for Energy Research (30 millions $ in 2000) has been allocated to fuel cells, no direct transposition may be achieved. It remains to be see whether a such link may also exist between increased foreign competition and more research joint ventures in the fuel cells case, mainly when favourable national policies are supporting such partnership.

To conclude on this triadic innovation race, we would assume that increased triadic competition in fuel cells had or will also have positive inducement effects on the firm's propensity to team up. National policies may increase this likely trend, in order to boost the competitive position of each pole of the triad.
We now examine the extent to which cooperative policy might be also used to reach this goal.

3.2- The look for cooperation policy by the States in the world fuel cells innovation race

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[24] Among which one founds the following supporters : Art Katsaros, Group VP Engineered Systems and Development, Air Products and Chemicals ; Firoz Rasul, Chairman and Chief Executive Officer, Ballard Power Systems ; Robert Rose, Executive Director, Breakthrough Technologies Institute ; Claude Duss, Chief Executive Officer, IdaTech; Mark Schmitz , Chief Financial Officer, Plug Power ; Thomas Voigt, President, Siemens Westinghouse Stationary Fuel Cells ; William T. Miller, President, UTC Fuel Cells

[25] see "Fuel Cells and Hydrogen : The path forward- A Comprehensive Strategy For Federal Investment In Fuel Cell Technology And Fuel Infrastructure" (2002)

Cooperation policy may be implemented either between firms and states, or between different states. Both possibilities have been put into practice within the fuel cells case.

3.2.1- The cooperation with home-based and foreign companies : the public/private partnership in technology consortia

Among different questions dealing with innovation public management, we now focus on an apparently general organizational way of fuel cells innovation : the public-private partnership. Three regional examples are presented.

In 1999, the U.S Department Of Energy creates the Solid State Energy Conversion Alliance (SECA), made up of commercial, developers, universities, national laboratories, and government agencies, to develop low-cost, high, power density, solid-state fuel cells for a broad range of applications. The two host laboratories, NETL and PNNL, are the driving force behind SECA, providing the leadership, focus, and integration needed to bring solid-oxide fuel cell technology into near-term markets. SECA has been formed to both accelerate the development of the industrial base needed to commercially produce low-cost solid-oxide fuel cells and to provide a core research program to provide any advancements necessary to achieving the aggressive SECA goals. The objective of SECA is to create a SOFC technology by 2010 available at less 400 $/kW for stationary, transportation and military applications. Long-term cost goals for military and transportation applications are $50 to $200 per kilowatt. Efficiencies for all applications will be greatly improved over current state-of-the art. The results of this program will also provide early low-cost power systems for mature distributed generation market applications, and will feed directly into the Vision 21 Fuel Cells Program. SECA technology will ultimately lead to megawatt size configurations for commercial/light industrial packages and “Vision 21” central-station power applications. SECA will be an internationally cooperative effort. Through the SECA Core Technology Program, DOE expects to co-operate with the European Union, and others.

In European Union, one can quote the “European Fuel Cell Bus Project” which intends to introduce fuel cell technology in 30 Mercedes-Benz Citaro buses in 10 European cities (Amsterdam (Netherlands); Barcelona & Madrid (Spain), Hamburg & Stuttgart (Germany), London (Great Britain), Luxembourg, Porto (Portugal), Stockholm (Sweden) and Reykjavik (Iceland)). So this project is being realised at a pan-European level, in co-operation with several European manufacturers and public transport operators and also financed by them, with co-financing from the THERMIE-Programme of the European Commission, Directorate-General XVII. The goals of the European Fuel Cell Bus Project are: the development, testing, and demonstration of low floor city buses for commercial use; technological leadership and safeguarding employment in Europe; increasing attractiveness of the public transport sector to solve traffic environmental problems in urban areas; early acquisition of experience; short term - Resource saving mobility; long term - Mobility based on non-fossil fuels. The co-ordinator of this European Community project managed by MVV InnoTec GmbH is the Berliner Senatsverwaltung für Wirtschaft und Technologie. The other partners in the project are : Berliner Verkehrsbetriebe, BVG, Berlin, (Germany) ; MAN Nutzungsfahrzeuge Aktiengesellschaft, Munich, (Germany) ; Air Liquide Division des Techniques Avancées, Sassenage, (France) ; Copenhagen Transport, Copenhagen, (Denmark) ; Instituto Superior Técnico, Lisbon, (Portugal) ; Companhia de Carris de Ferro de Lisboa, S.A., Lisbon, (Portugal) ; Sociedade Potuguesa do Ar Liquido, "Arliquido" Lda., Lisbon, (Portugal).

In Japan also, the METI is engaged in a programme of support for the industrial research and the development of infrastructures. The Japan Electric Vehicle Association (JEVA) announced that the government of Japan will soon launch a three-year joint test of hydrogen and fuel cell vehicle (FCV) technology on the country's roads. The test project will include Japanese automakers Toyota Motor Corporation, Honda Motor Company and Nissan Motor Company, U.S. auto manufacturer General Motors (GM) Corporation and German-U.S. carmaker DaimlerChrysler AG. The Japan Hydrogen and Fuel Cell (JHFC) demonstration project will be sponsored by Japan's Ministry of Economy, Trade and Industry[26].

To conclude, public/private partnerships appear to be one of the most pre-eminent form of technology consortia in the three poles of triad. However their scope (niches strategy for the "follower" European Union, the whole fuel cells components systems for the "leader" North America and Japan) , their rules and dynamics are likely depending from the relative strengths and weakness of each poles of the triad, that is to say from the remaining specificities of each Nation Innovation System.

3.2.2.- The look for cooperation policy between States

European Union is the regional zone where R&D cooperation policy between different Member States is the most discussed and implemented one : but because European Union is a special case, with very unequal involvement[27] by the different European countries for fuel cells development, we will not discuss here intra-european cooperation stakes, but we will come back later on in the conclusion. We only deal with two other cooperation cases : on the one side the IEA policy, and on the other side the EU-EC/ USA agreement.

A-The cooperation between IEA member states

The basic assumption of such programs lies in the following statement : " *National energy R&D demonstration programmes become more effective and efficient when incorporated into the larger context of international interdependence*". (IEA, Internet homepage, Energy Technology, Implementing Agreement Framework, http://www.iea.org/techno/aboutia.htm).
In this perspective IEA used the "Implementing Agreement"[28] procedure in order to organize an inter-gouvernemental collaboration in new (or improved) energy technology. In the 40 current Implementing Agreement, one is dealing with fuel cells since 1990 (IEA Advanced Fuel Cells Implementing Agreement) and another with hydrogen (IEA Implementing Agreement on "Production and utilization of Hydrogen"). Two indicators show an apparently increasing interest for this procedure in fuel cells : 1) number of participating countries to the Implementing Agreement has grown from 5 in 1990 to 13 in 2002 (see Table 5), 2) number of annexes has increased from two to fifteen; but in fact five are only active to day.

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[26] http://www.fuelcells.org/fcnews.htm

[27] Very high for Germany, relatively strong for France with its catching-up policy, meaningful for Italy, Great Britain and Netherlands, and symbolic for other Member States.

[28] In a few words , Implementing Agreement is "*a standard legal structure defining the commitments and rights of Contracting Parties*"; "*Contracting Parties undertake tasks identified in Annexes to the Implementing Agreement*"; an "*Executive Committee*", acting as "*board of directors*" *is nominated by the Contracting Parties* (government organisation or private entities designated by their respective governments". "*The Executive Committee designate an Operating Agent for each task – Annex- who is responsible for management of collaboration and who provides infrastructure as needed*". Resources are provided by two mechanisms : "*Cost sharing, in which participants contribute to a common fund…*" , and "*Task sharing in which participants devote specified resources and personnel…*". Source : IEA, Internet home page, http://www.iea.org/techno/aboutia.htm.

Table n°5 Participants Countries in the five “Tasks” of the IEA Implementing Agreement (1999/2003) on “Advanced Fuel Cells”

Country and signatory					
	XI Polymer Electrolyte Fuel Cells	XII Fuel Cell Systems for Stationary Applications	XIII Solid Oxide Fuel Cells	XIV Molten Carbonate Fuel Cells towards Demonstration	XV Fuel Cell Systems for Transportation
Australia, Ceramic Fuel Cells Limited (CFCL)		●	●		
Canada, Government of Canada	●		●		●
France, L’Agence de l’Environnement et de la Maîtrise de l'Energie(ADEME)		●	●		
Germany, Forschungszentrum Jülich GmbH	●	●	●	●	●
Italy, Ente per le Nuove Tecnologie, l'Energia l'Ambiente (ENEA)	●	●		●	●
Japan, New Energy & Industrial Technology Development Organization (NEDO)	●	●	●	**OA**	●
Korea, Korea Electric Power Corporation (KEPCO)	●			●	
Netherlands, Stichting Energieonderzoek Centrum Nederland (ECN)	●	●	●	●	●
Norway, Research Council of Norway		●			
Sweden, Swedish National Energy Administration	●	**OA**	●		●
Switzerland, Office Fédéral de l'Énergie			●		●
United Kingdom, Secretary of State for Trade and Industry	●		●		●
United States, United States Department of Energy	**OA**		**OA***	●	**OA**
OPERATING AGENT (OA)	Kumar Argonne National Lab.	Ridell Sycon Energiekonsult	Singal Siemens-Westinghouse	Nakayama NEDO	Ahluwalia US DOE

Source : IEA/EET , 2002, Brief Status Reports on Implementing Agreements (9 April 2002)

This table shows that no major contributing country in FC development is absent from this 2002 list. Moreover when ranking these different countries according an index of cooperation commitment[29], the resulting hierarchy (1-USA, 2-Japan, 3- Sweden, 4-Netherlands) is closed to the leaders countries in fuel cells development (1-USA and Japan, 3- Germany and Canada). But when trying to understand where is the self-interest of these leading countries with cooperation agreement, one has to check the very nature of these agreements. A first indication lies in the type of mobilized resources: cost-sharing is only used to finance administrative secretariat, while task sharing is supporting the remaining whole budget. In fact the Advanced Fuel Cells Implementing Agreement (AFCIA) seems mainly to be information exchange without formal or informal co-ordination of R&D activities, to the exception of some marginal cases. Although Implementing Agreement *“... can be used in all phases of the energy technology cycle, that is, research and development; demonstration and validation of technical, environmental and economic performance; market deployment (for instance, through joint performance testing)*”(IEA Internet Home page, Implementing Agreement Framework), apparently the information exchange in fuel cells case mainly focus on basic or applied research, and rarely with demonstration and validation stages.

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[29] This index may combine presence of country since 1995, nationality of operating agent, and number of agreed tasks.

B- The EU-EC/ USA cooperation

After a first agreement for scientific and technological cooperation, which had been signed the fifth of December 1997, between European Community and the Government of United States of America, and then a signed Implementing Agreement for Non-Nuclear Energy Scientific and Technological Co-operation, an exploratory workshop on EU/US co-operation on fuel cell research, development and demonstration took place 14th September 2001 in Brussels. Real results of this trans-atlantic cooperation, between one leading zone (USA) and one follower (European Union), seem to be three workshops mainly dedicated to exchange of information.

When trying to assess the effectiveness of such exchange of information, one should ask on the extent to which the exchanged information are relevant for each government representative, and whether these representatives are incited to reveal this information, be it a success or a failure. Without an in-depth study no general conclusion could be drawn. But we will assume that such cooperative agreement are at best a complement to a previously existing policy of national competencies building, mainly when the gap of these competencies is high between the two (or more) potential partners. Moreover inter-governmental cooperation seems to be expected by fuel cells industry for i) the creation of unified norms/codes and standards, ii) the co-financing of basic materials and technological research, or iii) a contribution to the creation of a favourable selection environment, for example in certification and legal issues.

Conclusion

We will conclude this chapter by focusing on two broad issues for the next ten years : 1) the nature of commitment from public authorities and the new collaborative emphasis with private firms; 2-the different policy challenges for the three poles of the Triad.

1- An increased commitment of public funds and collaborative emphasis with private firms

When looking for a comparative assessment of public interventions, and the resulting coordination requirements between public and private actors, within usual-incremental innovations, and radical ones, one may find the following differences (see graph n°3).

Stage 1- Basic Research- Longer and larger basic research are involved, because radical innovation implies the creation of a new body of scientific knowledge, which may leads to the creation of new scientific disciplines or sub-disciplines

Stage 2-Applied Research- The applied research stage is also longer and more expansive because the requirement to imagine new practical devices, new artefacts with likely insufficient performance at the beginning, and the need to come back on the first prototype in order to improve their key characteristics

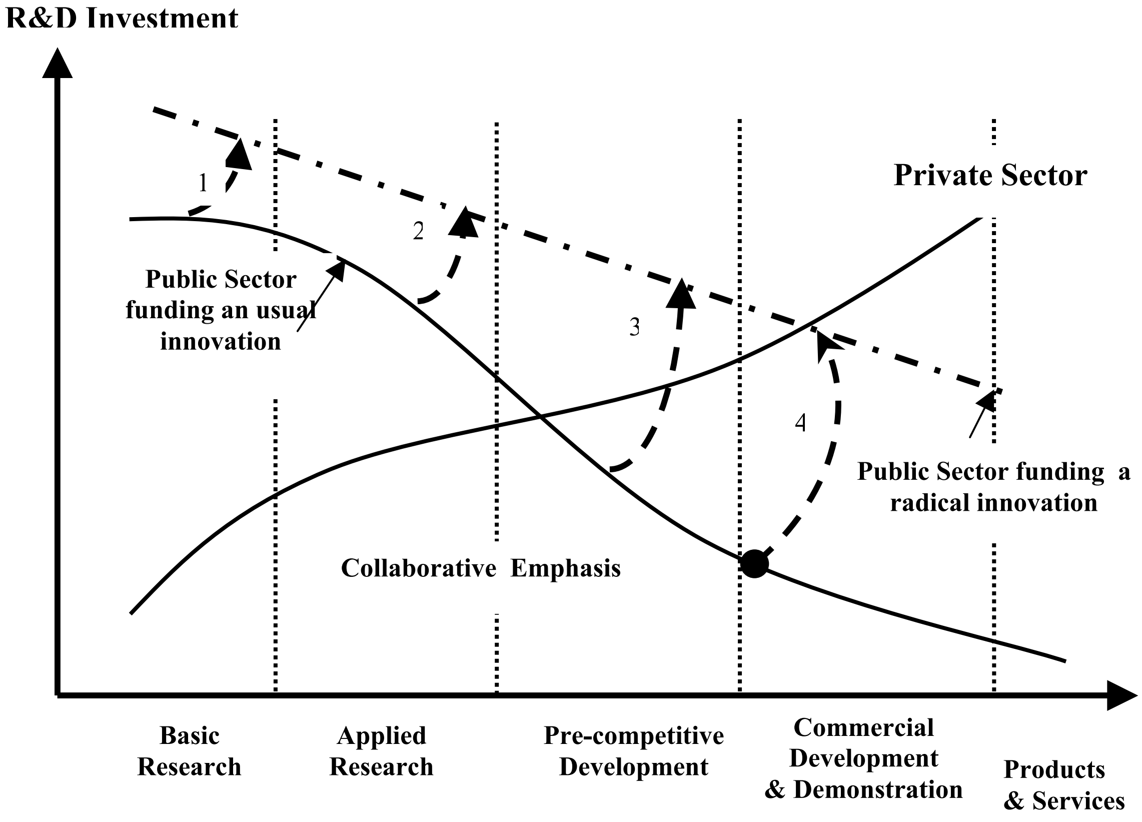
Stage 3 –Pre-competitive Development- and Stage 4-Commercial Development & Demonstration- The main differences are concerning these stages, because high public support is required in demonstrations/purchase, market entry-support, investment in infrastructure (hydrogen networks and storage), while generally these activities are entirely supported by private investment in the case of usual innovation. During this stage, public/private partnerships may be necessary to speed-up the cost reduction process by accelerating early market development and so decrease lead time to commercial operation and so crossing the " valley of death" with decreased risks

These required public support lead to two consequences which differentiates radical and usual innovation :

- the volume of public support is much higher and has a longer duration, which obviously may cause crowding out effects for the other technologies supported by public funds,
- the length and the intensity of "Collaborative emphasis" between public and private actors are much higher, which addresses the coordination competences of public institutions.

In the fuel cells case, scope and complexities of "collaborative emphasis" address on the one side the coordinating abilities of public authorities, and on the other side a minimum communication of information by the private sector about its product specificity fuel cell system and vehicle or power plant development activities.

Graph n°3 : Coordination requirements between public and private funding during innovation process : the fuel cells case



Source : Authors, and EPRI, 1999, Electricity technology Roadmap,-Powering Progress, 1999 Summary and Synthesis, Internet site : http://www.epri.com

There is no doubt that fuel cells technology may be included in the "radical innovation" category, and like such could benefit from higher than usual public supports. But should all (potential) radical innovations benefit from public supports ? We will not tackle that issue, but we will argue that if a major environmental innovation may drive a likely transition between the "old" energy systems mainly based on carbon fossil energy resources and a "new" one mainly based on renewable, nuclear and hydrogen energy sources, then fuel cells technology is among the major forthcoming innovations to be supported. This type of innovation is obviously much more than an "ecological modernization" : in that case the more focused market instruments are likely the fittest policy instruments[30]. Within the case of a "*technology transition*", N.A.Ashford with many other scholars may reasonably argue that " *more radical and far-reaching institutional changes are needed within the framework of command-and control environmental governance*". We will not try to develop in that chapter all the consequences of this statement and the new relevant policy instruments mix within that perspective. But we would assume that without this new public and society representation, technological advances while necessary would be insufficient to overcome the still inferior overall performance of fuel cells in respect to the mainstream existing ones.

-2-The different policy challenges for the three poles of the Triad

A precise identification of the different policy challenges should begin by an in-depth study to assess the overall effectiveness of the innovation system in the fuel cells case, by bench-marking the fuel cells programs in the different involved countries at world level. Due to the absence[31] of a such study[32] one may use the following partial assessment criteria of public policy supporting FC. Our survey of existing TC highlights the following dimensions in their implementation :
-the high intensity of public/private partnership mainly between big oligopolies and states,
- the partial internationalization of fuel cells R&D and mainly of fuel cells field tests (learning by using)
-the links between FC developers and big Original Equipment Manufacturers,
- the likely existence of a minimum size in the programs and a world quality research and development facilities and human resources.

-Our statement on relevant policies to implement, under the previously mentioned caveats, is based on a basic assumption : due to their still very uncertain and long lead times before marketing stage in energy markets, and the very high up-front costs which are involved in the demonstration phase, it appears that the relevant decision space for developing fuel cells technologies seems to be at least the level of the triadic poles. For these three poles, some challenges to face in the next ten years are common, and others are specific.
Among the common challenges, many familiar issues are to be solved :
1) What are the most effective organizational ways in implementing and steering the essential hybrid cooperative devices : the private /public partnerships?

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[30] "use of economic instruments, exploiting industry's potential to engage in technological innovation, encouraging more voluntarism and stakeholder participation in governance and promoting demand-side policies focused on green consumer behaviour" Ashford (2002, p.1417)

[31] Despite the existence of numerous studies or reports such as the Galley and Gatignol (2001) one.

[32] A working group of OECD- TIP Case Study On Innovation In Energy Technology- should bring conclusions at the end of 2003 about an international comparison of several energy innovations, including the fuel cell one.

2) What are the best arrangements to solve the collective intellectual property rights?
3) What is the appropriate level of cooperation between one pole and the two others of the triad?
4) To what extent common codes and standards are to be decided between a three poles discussion?

We then highlight rather the competitive dimension than the cooperative one at that level. Among the so called "specific" challenges, we think that appropriate policies should be probably differentiated between on the one side for the two "leaders" – Japan and North America (USA+ Canada), and on the other side for the current "follower"(European Union).

In this last case, new initiatives are at present identified within a broad political process discussion (the so-called "High-Level group"), in order to define a kind of "European Research Area in fuel cells" : conclusions are expected for the mid 2003. Taking into account the accumulated lags, and the willingness to be not totally absent from the F.C. world competition, the most feasible perspective would be to look for a good balance between a pure follower policy and a too much voluntary catching-up policy. The usual nationalistic reluctances to delegate to European level the technology initiatives may decrease in a near-future, because each member-state can no longer finance in a purely autonomous way the required budget for FC development. The most important difficulties seem to lie on the firms side : the major European industrial players are already involved with north-American partnerships[33]. So the main issue could be to identify the correct incentives which could promote industrial European partnership at the required level.

For the USA-Canada, the main stake is quite different. On one side US diplomacy has proven a determined opposition to the Kyoto protocol and to any kind of stringent agreement within natural environment. But on the other side, Department of Energy and other Federal administrations are simultaneously mobilized to speed up the American firms performance within a clean technology innovation race at a world level. Very recently the US Secretary of Energy, S.Abraham, was arguing in favour of " a *leapfrog*[34]" policy to switch towards an hydrogen economy, at least in the personal transportation of future. Assuming that these very constraining new objectives would be effectively pursued, several issues are open. To overcome the enormous gap between the carbon civilization of north America and the implementation of an hydrogen economy, two kinds of difficulties are to be solved. A such "leapfrog" policy requires long and costly public support, and a societal adhesion. The first requirement do not challenge the possibility of a sudden shift in financing new public expenditures in R&D and diffusion of fuel cells and hydrogen technologies, but rather its persistence possibility in medium term (10 to 15 years): the volatile compromise between different lobbies and Congress support will likely be a threat to this persistence requirement. Society adhesion is the other issue : the traditional and deep reluctance from US citizens to pay more for new clean energy supplies, while the cheap oil era will likely last the next fifteen years, will create a barrier to market diffusion process.

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[33] According to European Commisssioner P. Busquin,(2002): "*These two examples (biotechnology and fuel cell technology) show that industrial policy should take account of the quantity and quality of knowledge which nurtures growth and competitiveness. Without taking into account researchers and public and private investment, industrial policy will become empty, ignoring the knowledge which constitutes its motor*".

[34] During the last Global Forum on Personal Transportation in Dearborn, (Michigan, 12 th of November), Spencer said " *Whether it is fusion, a hydrogen economy, or ideas that we have not yet explored, I believe we need to leapfrog the status quo and prepare for a future that under any scnenarion requires a revolution in how we produce, deliver and use energy*".

In the Japan case, our knowledge of the fuel cells programme is still too incomplete and partial to attempt a such assessment. Our impression, based on other contributions (see for example Avadikian chapter ?? in this book), is that the very determined position for a national “quasi-autonomy” by public Japanese authorities may conflict with the much more open cooperation attitude of Japanese firms with their foreign partners and competitors, and indirectly put into question the necessary public/private partnership. This may become an obstacle when technical development leads to a fuel cells pathways selection (PEMFC and SOFC) which has not mainly been developed at home. But the voluntarist catching-up policy which has been launched in the recent years by Japanese government in PEMFC show important reactive abilities when this nation is facing such situations.

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