

HYDROGEN AND FUEL CELL ACTIVITIES IN WESTERN EUROPE

T. Alleau¹

Hydrogen as an energy carrier is now considered as a feasible solution to the new challenge of setting up an energy network able to distribute a clean and sustainable fuel free from carbon, source of the increasing CO₂ greenhouse effect. Most of the western European countries are now fully aware of the gravity of CO₂ pollution and are developing technical, economical, political and social strategies to step over that obstacle. Each of the European countries have its way to analyse the situation and therefore carry a strategy depending on its own perception of the energetic and environmental present situation and future evolution.

1. Introduction

Europe, like other continents, is keen to participate in the common drive to reduce environmental pollution within the framework of sustainable development. However, comprising around twenty countries which until recently were still fiercely independent, it offers a certain resistance to the unifying of research resources and harmonisation of the environmental projects which concern these different countries. Under the impetus provided by European Union authorities, harmonisation of European efforts is currently being built up through the framework programmes of the European Research Area (ERA) and networks of excellence. Nevertheless, the efforts are still too scattered and too poorly coordinated for most of the existing programmes to be presented other than by country.

Furthermore, despite the existence of partially or totally European federative structures such as the International Energy Agency (IEA), the Hynet network, the European Fuel Cell Group (EFCG) or the European Hydrogen Association (EHA), there is still no comprehensive database bringing together information on European activities relating to hydrogen and fuel cells. It was therefore necessary to gather information from some of the various players, but this work is unfortunately still incomplete at present, and does not include, in particular, the countries of Eastern Europe; in addition, it has often appeared difficult to distinguish – from the financing point of view – between work specific to hydrogen and work specific to fuel cells, so great is the interaction at times, particularly in terms of system development. In the future, the EHA will have the task of completing this work, which will make it possible to identify the main lines of action on which the various players and the European union will be able to base themselves to orient their development efforts based on better synergy of resources.

For information, all the figures given below are in Euros (€) (~ 0,9 US\$).

2. The European Union

All Framework Programmes which have taken place since 1985 have been aimed at obliging two or more European countries to collaborate. At present, the Fifth RTD Framework Programme (1998 – 2002) is being completed and the invitations for proposals for the Sixth RTD Framework Programme (2002 – 2006) will be sent out in the next few months.

Listed under the Key Action "Energy" in thematic programme 4 "Energy, Environment and Sustainable Development", actions relating to hydrogen and fuel cells are conducted within a clearly identified, consensual programme discussed with European experts in the course of various workshops. Financing in 2001 was as follows:

- R&D on hydrogen: approximately **2.5 M€**

¹ President of AFH₂ (Association Française de l'Hydrogène, <http://www.afh2.org/>) and Member of the EHA Board (European Hydrogen Association, <http://www.h2euro.org/>)

- R&D on fuel cells: approximately **30 M€**

Each Framework Programme co-finances the projects by 30 to 50% depending on the nature of the work (research or demonstration) and the status of the participants. The most significant and most recent ones include:

- EIHP 1 and 2 (*European Integrated Hydrogen Project*): study of the regulations and standards aspects relating to hydrogen energy and fuel cells in Europe, harmonisation of standards in the EU.
- CUTE: production, commissioning and operation of 27 Citaro type DaimlerChrysler fuel cell buses with hydrogen stored under pressure, in 9 European cities and 8 European countries, from 2003 onwards.
- HYPNET : setting up of a European information network on hydrogen.
- ELEDRIIVE : thematic network on electric vehicles including hybrid and fuel cell vehicles.



Figure 1 – The Citaro bus equipped with a Ballard fuel cell (CUTE project)

3. The European associations

There are two European associations concerning hydrogen and fuel cells:

- The *European Fuel Cell Group* (EFCG), a non profit organisation founded in 1989, editing the European Fuel Cell News and organizing workshops. Each European country delegates one or more representatives to this.
- The *European Hydrogen Association* (EHA), founded in 2000, which federates existing national associations² and includes members from countries which are setting up such associations³. Other associations exist⁴ in Europe but are not members of the EHA.

² France (AFH₂), Germany (DWV), Norway (Norsk Hydrogen Forum), Sweden (H2forum)

³ Netherlands, Spain, Greece.

⁴ Italy (FII), Switzerland (Hydropole)

4. Austria

Austria is one of the pioneers of the development of fuel cells in Europe. As early as the 1970s, Professor K. Kordesch of the University of Graz constructed a vehicle equipped with an alkaline fuel cell supplied with pressurised hydrogen at 150 bar.



Figure 2 – K. Kordesch's prototype equipped with an AFC Union Carbide cell (6 kW) (1970)

At present, hydrogen and fuel cell activities seem to have slowed down. The players identified are:

- Public players: Technische Universität Wien, Technische Universität Graz, TU Graz-Inst. für Chemische, Int. Institute for Applied Systems Analysis
- Industrial players: Produktmarketing (storage alloys)

5. Denmark

Denmark does not seem to be conducting a very active policy in the field; indeed, in January 2002, the government – which claims to have attained its objectives in this field – proposed that the "Renewable energies and hydrogen" budgets be considerably reduced, by approximately 20M€ fearing a take-off of energy prices.

6. Finland

The energy policy of Finland – one of the biggest European per capita consumers of electricity – is based on a very low cost per kWh. Consequently, Finland recently decided to relaunch its nuclear programme and limit its financial commitments to alternative energy sources, which are more expensive in the short term.

The players identified are:

- Public players : Helsinki Univ. of Technology/Dept of Technical Physics and Lab. of Polymer Chemistry,
- Industrial players : VTT Manufacturing Technology

7. France

Since the mid-nineties, France has launched a serious, structured programme on renewable energies and new energy technologies, including hydrogen and fuel cells. This policy has shown itself in a financial commitment for several years by government authorities⁵, via a dedicated network (PACo⁶ network) and through the mobilisation of public research resources. Supported and encouraged by this organisation, industrial companies have undertaken R&D actions either within the existing structures or within new structures such as Aréva/Héliion and Air Liquide/Axane.

⁵ Ministries of Research and industry and Ademe (Agence de l'Environnement et de la Maîtrise de l'Energie)

⁶ PACo : **P**ile **A** Combustible (Fuel Cell) network

The subjects dealt with cover hydrogen (production, transport and storage) and PEMFC and SOFC type fuel cells, together with transverse problems such as safety, security, standards and regulations.

The main players are:

- Public players: there are more than 15 public players in the "hydrogen and fuel cell" field. The main ones are: the national PACo network, which co-finances a large proportion of the national projects, the Commissariat à l'Énergie Atomique (CEA), the Centre National de Recherche Scientifique (CNRS), and the Centre National de Recherche Technologique (CNRT/Belfort).
We should add the actions of public or semi-public centres such as Ineris (safety, security), Afnor (standardisation) and the IFP (Institut Français du Pétrole)
The total amount of their investment is estimated at approximately **37 M€**year (2001 figure)
- Industrial players: there are around fifteen industrial players, including: Air Liquide, Alstom Transport, EDF, GDF, PSA, Renault, TotalFinaElf, Snecma, Areva, Irisbus, Sorapec, CNIM. The total amount of their investment apparently came to **35 M€** in 2001.
- Associations :
 - i. *Association Française de l'Hydrogène (AFH₂)*, created in 1998.
 - ii. The "*Fuel Cell Club*"
 - iii. *Alphea*

Acknowledgement of the acceptability of hydrogen and fuel cells by the general public is an important question which must not be neglected; it involves a phase of demonstrations of prototypes, seminars and exhibitions which have not yet been conducted on a sufficient scale, as is the case in Germany. There are few operations of this type in France, but we can underline the following ones which have had a positive impact: the Chelles 250 kW ONSI stationary cell, the PSA fuel cell vehicles, and a "Hydrogen Village" at the Pollutec Exhibition. Several national seminars have recently been organised: we can note that France is organising the "European Hydrogen Energy Conference" in September 2003 in Grenoble.

8. Germany

Germany is the European country which conducts the most active policy in Europe in the hydrogen and fuel cell fields. This situation is due both to the energy policy which has led Germany to take the decision to progressively disengage from nuclear energy and to the dynamism of its industrial companies and research laboratories.

What also distinguishes Germany from other European countries is the autonomy of the Lands and States, which enables them to conduct a strong regional policy which is more dynamic than the federal policy. The main players identified are:

- Regional public players:
 - i. the *Hydrogen Technology Initiative* programme (2002) of the state of Mecklenburg-Western Pomerania
 - ii. Bavaria, which has apparently invested 50 M€ on hydrogen,
 - iii. In April 2002 the State of Hesse founded the *Hydrogen and Fuel Cell Initiative* in Frankfurt-Hoechst, in collaboration with universities, DWV and industrial companies such as Infracore Höchst.
 - iv. In April 2002 the State of the Rhineland Palatinate set up the *Future Technology Fuel Cell Rhineland Palatinate*. That competence network will be a forum for the parties active in the State in this field.

- v. The States of Baden-Wuerttemberg, Hamburg, and North Rhine-Westphalia have taken initiatives of the same kind.
 - vi. Research centres such as Fraunhofer, Max Planck and Garching launched R&D programmes on these subjects
- Federal players:
- i. FEE (Society for the Promotion of Renewable Energy) started (February 2002) a federal task group "Biogenous Gases for Fuel Cells". The project is promoted by the German Federal Ministry of Consumer Protection, Food and Agriculture and scientifically supported by Hahn-Meitner Institute, Berlin.
 - ii. In addition, Germany has set up a system of "Bonus Payments" of 5.11 c€/kWh on fuel cells in co-generation, applicable as of 2002.
 - iii. The TES (*Transport Energy Strategy*) programme, which brings together public and industrial players, must decide before 2005 on the fuel of the future for transport: three fuels are still officially in the running (hydrogen, methanol and natural gas), but hydrogen seems to be increasingly favoured by the majority of decision-makers.
 - iv. *The Clean Energy Partnership Berlin* (CEP) announced June 2002 and supported by the German Federal Government and managed by the German Energy Agency: the goal is to demonstrate that hydrogen is a viable fuel for everyday life.
- Total public financing apparently comes to approximately **100 M€year**
- Industrial players :
- i. DaimlerChrysler, which has made the biggest financial efforts, has brought out a series of light demonstration vehicles (Necar 1 to 5) together with buses, and had decided to invest 1600 M€ in the 2001-2004 period,
 - ii. Opel and Ford Germany, Siemens-Westinghouse (SOFC cells), HEW/HGW (PAFC cells), MTU (MCFC cells), Vaillant/Plug Power (PEMFC cells), Proton Motor (PEMFC buses), BMW (hydrogen engine vehicles), Linde Gas, Messer, RWE, Ballard Power Systems AG, etc.
- Association : *German Hydrogen Association* (DWV/GHA)
- In the area of communication, the Hanover Industrial Fair, the latest version of which, "The eighth Hydrogen and Fuel Cells Group Exhibit", was an unprecedented success with nearly 100 exhibitors on hydrogen and fuel cell technologies, plays an important role.

Work to ensure public acceptance of these new technologies is highly developed in Germany, with numerous demonstrations and surveys:

- NECAR and NEBUS vehicles, BMW vehicles, Ford/Opel Zafira vehicle, Fuel Cell Bus Project (bus undergoing tests since 2000, low-pressure 120 kW cell, hydrogen storage at 250 bar) with the partners LBST, Siemens, Linde and MAN, the Proton Motor bus,
- Munich airport's "Hydrogen" service station,

- stationary fuel cells, small size (Vaillant/Plug Power) and large size (Alstom Ballard/Berlin, MTU/MCFC at the Rhön-Hospital in Bad Neustadt)
- opinion surveys, the widely-advertised results of which are highly favourable to these technologies.

9. Greece

This country does not have any specific "hydrogen and fuel cells" structure or programme. There is little R&D in universities within the framework of European programmes.

There is an Association: the "*Hellenic Hydrogen Association*"

10. Iceland

Iceland is the first country in the world to have decided to abandon fossil energy and set up an economy entirely based on hydrogen, both on land and on sea (12 000 boats), with an objective of "Zero pollution" in 2030.

That's the question Bragi Árnason, "Professor Hydrogen", a University of Iceland chemistry professor set out to answer in his doctoral research in 1970.

"I discovered that we have enough geothermal energy to provide the equivalent of 100 nuclear power stations and enough hydroelectric power to provide the equivalent of 15 nuclear power stations,"

With this objective, the "Icelandic Hydrogen and Fuel Cell Company" was created in 1999 with foreign partners (DaimlerChrysler, Norsk Hydro, Shell International) to introduce hydrogen as the main source of energy, supplied by geothermal resources and hydroelectricity. Numerous other foreign partners have associated themselves with this project: Exxon, BP, TotalFinaElf, Ford, DaimlerChrysler, Renault, PSA, Toyota, BMW, Honda, Nissan, General Motors.

To implement the plan to replace Iceland's public buses with fuel-cell buses, persuade the population to buy fuel-cell cars, and develop fuel-cell technology to power fishing trawlers, the Icelandic government, Shell, and DaimlerChrysler created a consortium called *Vistorka* (meaning eco-energy). *Vistorka* is about to begin the first phase of its ambitious plan: a \$50 million project to replace the Reykjavík Municipal Bus Service's 100 buses with hydrogen fuel-cell buses.

The European Union has also associated itself with this project, investing 4M€ in the 5th Framework Programme.

11. Italy

Italy is one of the most active European countries in the hydrogen and fuel cell field: there has been little work on hydrogen up to now, but a strong increase is planned for the next few years; as regards fuel cells, Italy's interest is centred on PEMFC, MCFC and SOFC type cells. The main players identified are:

Public players :

- public R&D is supported by: the Ministry of Education, University and Research, Ministry of Environment.
- The players are: CNR (National Research Council), ENEA, Universities of Pisa, Cassino and Turin.
- The resources set up by public laboratories amount to around 50 manxyear (which represents an annual investment of around 7.5 M€). The subsidies are 3 M€ for

hydrogen and 5 M€ for fuel cells. In all, this represents a **current annual public investment of 15.5 M€**. From 2002 onwards, the National Research Plan envisages a strong increase in subsidies: 45 M€ for hydrogen and 18 M€ for fuel cells over three years.

Industrial players :

- Ansaldo Fuel Cells, Nuvera, Fiat, Iveco, Sapio, Sol, Aprilia
- The personnel resources set up come to 100 manxyear, **or around 15 M€year**

Work on public acceptability has taken the form of a few demonstrations, such as the Citybus in Turin).

There is an association: the "*Italian Hydrogen Forum*" (IIF)

12. The Netherlands

The Netherlands does not have any national "hydrogen" programme, but conducts actions which are part of the long-term programme for reduction of CO₂ emissions which are included in the NECST programme (*New Energy Conversion Systems and Technologies*) implemented by Novem (*Netherlands Agency for Energy and the Environment*).

The players in these programmes are:

Public players :

- ECN (*Energy Research Center of the Netherlands, Petten*). There is a "Hydrogen Technologies & Applied Catalysis" group which is studying the processing of fuels for production of clean hydrogen (methanol reforming). Another team is working on PEMFCs (1-20 kW) and SOFCs (components and systems). There is also a *Fresco* (fuel cell scooter) project in progress, financed by the E.U.
- Work on the MCFC cell conducted by the *Netherlands Energy Research Foundation*, industrial companies (Stork and De Schelde) and Novem.

The total effort is estimated to **5 M€year** for hydrogen. The fuel cell developments are quite extensive: after 15 years R&D on the National Fuel Cell Programme, high competence has been gained; the fuel cell estimated effort is in the order of **10 M€year**.

Industrial players: the energy industry shows their increasing interest, hydrogen being expected to be an energy vector in a long-term vision. Shell Netherlands is very active in this field.

An association is currently being created: the "*Dutch Hydrogen Association*"

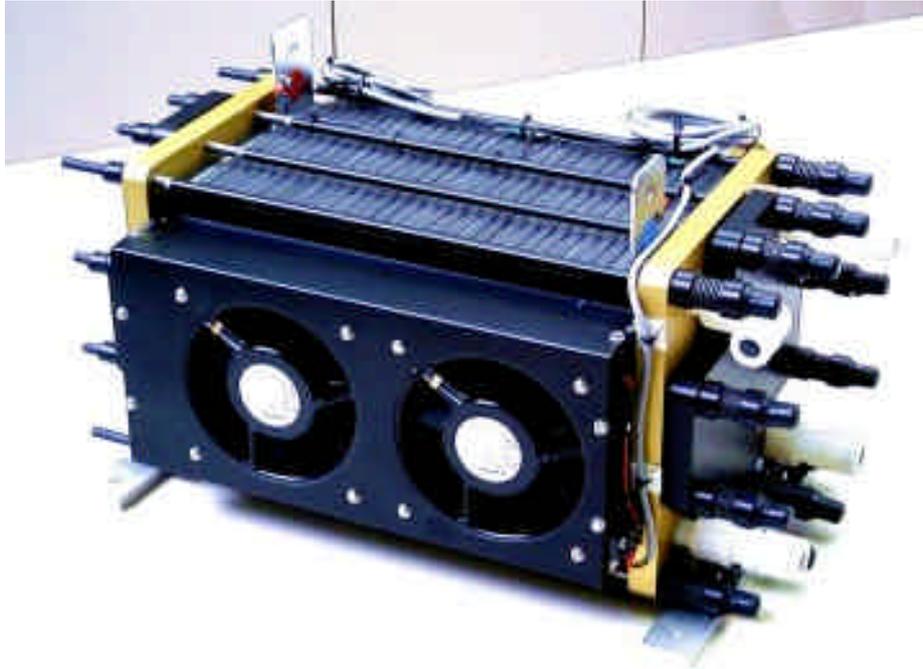


Figure 3 - 1 kW ECN PEM stack working at atm. pressure, no gas humidification, air cooling

13. Norway

The energy situation in Norway is very specific in that 100% of its electricity is of hydroelectric origin. Nevertheless, the deregulation of the energy market and the drive to reduce CO₂ emissions have allowed the launching of studies and demonstrations relating to hydrogen (production and storage) and fuel cells (buses, boats).

The players identified are:

Public players : Universities (Oslo, Grimstad), NTNU, SINTEF, IFE. Their total 2001 budget is estimated at **2.5 M€**. A national plan is currently being developed (National Action Plan).

Industrial players : Statoil, Statkraft, NorskHydro

An association exists: the *Norsk Hydrogen Forum*

14. Portugal

This country is beginning to take an interest in hydrogen and fuel cell technologies and is negotiating a structuring project EDEN⁷ that includes the preparation of the Action Plan for the *Portuguese Hydrogen Society* and fuel cells demonstration, pilot and research activities. The consortium leading the program includes industry, university and research centres, in a total of 11 entities.

Only public players have been identified: the University of Coimbra/Physics Department, Instituto Superior Tecnico, FEUP/Dept de Engenharia Quimica.

⁷ EDEN : Endogenizar o Desenvolvimento das Energias Novas

15. Spain

Studies on hydrogen and fuel cells are included in the *Spanish Plan for Scientific Research, Technological Development and Innovation*. The public and industrial sectors have involved themselves on the following themes:

- hydrogen: production in particular by electrolysis from photovoltaic solar sources, storage, regulations, safety,
- PEMFC, MCFC and SOFC type fuel cells

Public players : Ministry of Science and Technology, CSIC (National Council for Scientific Research), INTA, CIEMAT Centre for Energy, Environmental & Technological Research), ITC/ITER Technological Institute of Canary Islands), Universities (ETS Ingenieros Industriales).

The "hydrogen and fuel cell" activities are piloted by the INTA (Instituto Nacional de Technica Aeroespacial). A total expenditure of approximately **1 M€**year appears to be a realistic figure for 2001.

Industrial players

- ❑ General Services (Utilities): Gas Natural, Gas de Euskadi, Iberdrola, Endesa
- ❑ Car manufacturers: Seat, Iveco
- ❑ Miscellaneous: Abengoa, Aimplast, Expert

Association "*Spanish Hydrogen Association*" under preparation

Public acceptability work has begun with prospective studies, seminars, press articles and demonstrations such as that conducted between 1991 and 1996 in El Arenosillo (Huelva): a solar energy source (8.5 kW photovoltaic generator) coupled with an electrolyser, and a double storage on hydrides and under pressure.

16. Sweden

The "hydrogen and fuel cells" programme consists of a limited number of projects piloted by the *Swedish National Energy Administration*.

The main programmes which have been identified are:

- *MISTRA* (Foundation for Strategic Environmental Research) in collaboration with Swedish industry (Volvo, ABB, Ericsson) and 5 universities on the subject "Lithium Polymer and NiMH Batteries, PEMFC". The first phase was completed at the end of 2001.
- *Green Car* (in progress): co-funded by Vinnova (Swedish Agency for Innovation Systems) and Swedish vehicle industry: part of the project concerns FCHEVs (Fuel cell and Hybrid Vehicles)
- *Stationary Fuel Cells Project* (2002 – 2005): university based research program and applied program. Funded by Swedish National Energy Administration (STEM) and industry (through Elforsk). Programme: SOFC coupled with a gas turbine and MCFC (developments and modelling).
- *Energy Systems for Road-Vehicles*: thermal, hybrid and fuel cell vehicles.
- *E.U. CUTE Programme*: three buses in Stockholm (hydrogen manufactured by electrolysis)

- *H Power's cogeneration fuel cell (4 kW PEMFC) system demonstration: start-up scheduled June 2002, hydrogen produced from solar and biogas (with solar Naps Systems Oy Company)*
- *SOFC Fuel Cell Technologies (5 kW) demonstration: start-up scheduled Autumn 2002*
- *EU-Cryoplane Project: the Arlanda airport participates in the project.*
- *EU Usher Project (Urban Integrated Solar Hydrogen Economy Realisation Project): two fuel cell minibuses on the island of Gotland.*

Other companies involved: AB Volvo, Scania, Vattenfall, Sydkraft, Birka Energi Stockholm energy company), ABB, Opcon, Catella Generics, Catator, Morphic, Cellkraft, EKA Chemical, FMV, JM, NCC, Svenska Bostader, Linde Gas Division.

A "hydrogen association" exists: *H2forum*

17. Switzerland

Switzerland has started developments centred on the production (via solar energy), storage and use of hydrogen (with fuel cells).

Public players : there is a national programme: the *Swiss National Energy Research Program*, financed by the *Swiss Federal Office of Energy*, with a programme line on hydrogen (*The Swiss Hydrogen Program*), together with programmes financed by Federal and Cantonal research institutes. Coordination has been set up with the *Swiss National Science Foundation*.

The work is centred on the production (via solar energy), storage and use of hydrogen (with fuel cells).

The main industrial player is Sulzer-Hexis, known for the development of a 1 kW SOFC flat technology stationary fuel cell, HXS 1000.

A "hydrogen" association was created in 2001: *Hydropole*



Figure 4 – The Sulzer-Hexis 1 kW SOFC cell

18. United Kingdom

Although big British industrial players have long been interested in hydrogen and fuel cells, the British government authorities have not set up ambitious research programmes on hydrogen. On fuel cells, there is the "Advanced Fuel Cell Programme". Efforts appear scattered at present; nevertheless, the situation is evolving and national programmes could emerge soon: thus the government announced in December 2001 the "Green Fuel Challenge", including hydrogen infrastructures for buses (starting in 2002).

Public players:

- Colleges and universities, such as Imperial College and Loughborough University
- The Greater London Authority which announced (May 2002) the formation of a body called *The Hydrogen Partnership* to investigate the benefits of and uses for fuel cell technology in London. It includes BP, Evobus, BMW, Ford, DaimlerChrysler, Merrill Lynch, British Gas, the Energy Saving Trust and the Environment Agency.

Industrial players : Johnson Matthey, B.P., Alstom, Enertech Ltd, Zero-M, CJB Developments Limited.

19. Conclusions

State-funded research on hydrogen and fuel cells in Europe (outside Eastern Europe) varies greatly from country to country, both because of the involvement or otherwise of industrial players and also because of other factors such as the situation with regard to the Kyoto commitments, the energy situation and the energy policy conducted. The amount of money invested for European state-funded research was estimated at **200 M€** in 2001, Germany being the biggest player (100 M€), followed by France (37 M€).

By way of comparison, the US/DoE invested approximately 150 M€ over the same period. Any comparison must nevertheless be made cautiously, because on one side there are 14 nationalities working without coordination and on the other a single country (the United States) which has a structured programme.

The majority of European countries have a rapidly-growing activity in the field of hydrogen (production, storage, transport, safety) and fuel cells in R&D, particularly for PEMFC (+DMFC), MCFC and SOFC type fuel cells, with a determination to provide demonstrations.

European industrial activity is much greater, to cite only DaimlerChrysler which acknowledges an investment of 1600 M€ over 4 years, but it is almost impossible to give an overall figure given the discretion of the majority of industrial companies; it could be at a level two or three times higher than that of state-funded research.

We need to underline the driving role of industry: R&D in new technologies and the opening up of the various sectors of applications (mobile, transport, stationary, chemical and manufacturing industries, etc.).

It is generally thought that the standards and regulations necessary for the diffusion of these technologies should be available around 2005.

We need to underline the active role of the Associations in increasing government awareness and in operations to inform the public, which are necessary for the acceptance of these new technologies.

We should also underline the insufficient level of co-operation between the R&D programmes of the various countries, and hope that the desire of the European Union to federate actions within the framework of the European Research Area (ERA) will allow a better synergy of European potential.

Curriculum Vitae

Thierry Alleau graduated from the Ecole Supérieure d'Electricité and has spent his professional life working with the Commissariat à l'Energie Atomique (CEA, France) in Saclay, then in Grenoble. His activities more particularly covered the energy and thermal fields (thermionics, heat pipes, solar energy conversion, hydrogen and fuel cells). Until September 2000, he was responsible for all the CEA's technological diffusion and non-nuclear energy programmes, including hydrogen and fuel cells. He is now President of the Association Française de l'Hydrogène (AFH₂) (French Hydrogen Association) and a Member of the Board of the European Hydrogen Association (EHA).

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