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European Initiatives for Hydrogen Based Energy Systems

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Background

Europe's energy supply is characterised today by structural weaknesses and geopolitical, social and environmental shortcomings, particularly as regards security of supply and climate change. Energy is a major determinant of economic growth and these deficiencies can have a direct impact on EU growth, stability and the well being of Europe's citizens. Energy supply security, mitigating climate change and economic competitiveness are therefore the main drivers for energy research, within the context of sustainable development.

Hydrogen and electricity together represent one of the most promising ways to realise sustainable energy, whilst fuel cells provide the most efficient conversion device for converting hydrogen, and possibly other fuels, into electricity. The most important aspect of hydrogen is that it can be produced from a variety of carbon-free or carbon-neutral primary energy sources – renewable, nuclear, fossil fuels with CO2 capture and storage. Thus, the use of hydrogen could drastically reduce greenhouse gas (GHG) emissions from the energy sector. Fuel cells are intrinsically clean and very efficient (up to double the efficiency of internal combustion engines (ICEs)) and capable of converting hydrogen and other fuels to electricity, heat and power. They can also be sited close to the point of end-use, allowing decentralised generation.

The European Union (EU) has acknowledged the potential of hydrogen and fuel cells for a long time, both implicitly in its policies and also in its research programmes. However, the past two years have seen an unprecedented number of significant new initiatives not only in the EU, but worldwide, designed to open efficient and clean pathways to a hydrogen oriented economy. Although this will be a long term process the planning needs to start immediately - developing coherent strategic research and policy decisions to face the enormous technical and non-technical barriers this objective implies. This is the mission of the new *European Hydrogen and Fuel Cell Technology Platform* launched in January this year.

Building on the experience of the Fifth Framework Programme (1999-2002)

During the Fifth EU Framework Programme (FP5) research into hydrogen and fuel cells was essentially applications driven with quantified targets compatible with the market segment addressed. Research on new materials, processes, components and system simplification for fuel cells aimed at substantial cost reductions. In addition to the cost challenge, the problem of fuel choice and infrastructure was an important element of the research programme, in particular for transport applications. Socio-economic and pre-normative research was also supported in order to address society issues and to accompany policy and regulatory measures, facilitating the development of stakeholder partnerships and standards.

In FP5 the EU has contributed some 145 M€ to support 70 projects in the field of hydrogen and fuel cells. The budget distribution by technical area is shown is summarised in *Table 1*.

Table 1: EU support (in million €) to hydrogen and fuel cell RTD in FP5 (1999-2002)

	Hydrogen	**FC technology acquisition[1]**	**FC stationary applications**	**FC transport applications**	**FC portable applications**	**Total**
Medium and longer term RTD	**23.6**	**22.4**	**12.1**	**28.0** [2]	**8.4**	**94.5**
Short term (Demonstration and benchmarking)	**6.9**		**16.8**	**26.5**[3]		**50.3**
Total	**30.5**	**22.4**	**28.9**	**54.5**	**8.4**	**144.8**

(1) Includes generic fuel cell development for stationary, transport and portable applications;

(2) Approximately 19 M€ devoted to projects related to fuel processing;

(3) 18 M€ for fuel cell bus demonstration project CUTE;

Specific details on all of these EU funded projects can be found at the following web sites:

http://dbs.cordis.lu/fep/fp5/fp5_projl_search.html

http://europa.eu.int/comm/research/energy/pdf/european_fc_and_h2_projects.pdf

As indicated in Table 1, the main RTD and Demonstration effort in FP5 has been allocated to fuel cell component and system development, as well as fuel reformer/processor development. Fuel cell stack technologies include Proton Exchange Membrane Fuel Cells (PEMFC), Direct Methanol Fuel Cells (DMFC) for small portable, stationary and transport applications. Solid Oxide Fuel Cells

(SOFC) and Molten Carbonate Fuel Cells (MCFC) technologies are also being developed for stationary cogeneration applications up to MW-scale. Hydrogen production (especially from renewable sources such as bio-mass and wind) and hydrogen storage has also been the focus of considerable RTD effort in FP5. For more details of the projects referred to by acronym in the following brief overview of FP5 activities, please refer to brochure "European Fuel Cell and Hydrogen Projects 1999-2002" contained in the second web site mentioned above.

The strategic approach in FP5 was to support a number of key fuel cell and hydrogen technologies across the spectrum of research, development and demonstration. Thus FP5 projects range from basic research on active materials for fuel cells, fuel processors, hydrogen production and storage - through systems integration for stationary, portable and transport applications - to demonstration projects aiming at verifying technology under actual operational conditions. These mainly technical research and demonstration projects are complemented by networking and supporting actions for fuel cell technologies, testing and hydrogen pathway analysis. Pre-normative research has supported the regulatory process, and safety analysis related to hydrogen vehicles, on-board hydrogen storage, and hydrogen fuelling infrastructure has been performed, which has led to the preparation of a draft ECE regulation.

Research on PEMFC includes effort on high temperature membranes and electrode catalysts aiming at reduced cost and improved performance and durability. DMFC systems have also been developed for small portable power and vehicle Auxiliary Power Units. Materials and processes have been researched for lower temperature SOFC, including planar cell technology. In the automotive sector the FUERO cluster of 9 research projects, has developed component technologies for fuel processors for a range of fuels including gasoline (conventional and micro-channel reactors), methanol, and bio-ethanol and carried out "well to wheel" studies for alternative fuels. The cluster also included research on PEMFC and DMFC stack and system components and life-cycle analysis for stacks and other components. FUERO has also developed Fuel Cell-component and system models for computer simulation. Test procedures for performance benchmarking have been developed and verified in component testing. A feasibility study on ammonia as a hydrogen carrier is also underway.

The RTD effort on hydrogen production from renewable sources has been mainly processing different bio-mass feedstocks – often linked to application in high temperature fuel cells. Effort is also devoted to advancing electrolyser technologies and integrating wind and solar to hydrogen/fuel cell systems. Minor work on hydrogen from High Temperature Reactors have also been included.
Achieving sufficient energy density for hydrogen storage is a well-known bottleneck particularly for transport applications and three FP5 projects are researching advanced storage materials, including metal hydrides, carbon nano-structured materials and composites, as well as developing advanced prototype vessels, for on-board storage and also for stationary applications.
Technology demonstration and verification has been a key element of FP5. A virtual PEMFC power plant is being demonstrated, comprising a group of 31 interconnected, decentralised residential micro-CHP systems. FP5 also supports the largest hydrogen fuel cell bus demonstration projects (CUTE and ECTOS)

worldwide – 30 buses operating in 10 European cities. By the end of July 2004, the buses have cumulative service of more than 292.526 km and 22.295 hours, carrying 400.000 passengers. A global study is also performed of public acceptance of hydrogen transport in the EU, US and Australia – based on public reaction to hydrogen bus projects.

Hydrogen and Fuel Cell Projects funded under the Sixth Framework Programme (2002-2006)

The Sixth Framework Programme (FP6), whilst developing the technical concepts and building on results initiated in previous framework programmes, differs significantly in its implementation. A key difference is its role in contributing to the creation of the European Research Area (ERA) in sustainable energy systems. This means that the aim is to assemble a *critical mass of resources*, to *integrate* research and related efforts by pulling them together in larger, more strategic projects and to make this research more *coherent* on the European scale.

For hydrogen, several strategic areas for research are currently being pursued: clean production (development and techno-socio-economic assessment of cost-effective pathways for hydrogen production from existing and novel processes), storage (exploration of innovative methods, including hybrid storage systems, which could lead to breakthrough solutions), basic materials (functional materials for electrolysers and fuel processors, novel materials for hydrogen storage and hydrogen separation and purification), safety (pre-normative RTD required for the preparation of regulations and safety standards at EU and global level), and pathway analysis and road mapping for preparing the transition to a hydrogen energy economy.

In the area of fuel cell systems EU funded research is aimed at reducing the cost and improving the performance, durability and safety of fuel cell systems for stationary and transport applications, to enable them to compete with conventional combustion technologies. This includes materials and process development, optimisation and simplification of fuel cell components and sub-systems as well as modelling, testing and characterisation protocols. The long term goal is to achieve commercial viability by 2020 for many applications.

Hydrogen and fuel cells research cuts across a number of the areas of FP6 such as "*Sustainable energy systems*", "*Sustainable Surface Transport*", "*Nanotechnologies and nanosciences, knowledge-based multifunctional materials, new production processes and devices*", "*Aeronautics and Space*" and "*Nuclear Energy*". Related projects can also be funded under other programmes devoted to Small and Medium Enterprises, new and emerging science and technologies and support for the co-ordination of activities.

Following the FP6 calls for proposals in 2003-2004, projects have been selected with a total EC contribution of up to **100** M€. These are covering the following subareas for hydrogen technologies:

- *H2 production*, eg hydrogen rich gas from biomass, solar steam reforming of methane rich gas, hydrogen thermochemical cycles, high temperature water electrolysis, and hydrogen production from renewable resources
- *H2 storage* for automotive and stationary applications
- *H2 safety, regulations, codes and standards*
- *H2 pathways*, eg pipeline infrastructure requirements for H2 and natural gas mixes, innovative high temperature production routes, hydrogen road map, secretariat for the technology platform, and co-ordination activities
- *H2 end use*, eg H2 Fuel cell fleet demonstration, and optimization of the Hydrogen Internal Combustion Engine

and for fuel cell technologies:

- *High temperature fuel cells*, eg cost effective SOFC systems, biomass fuel cell utility system, SOFC fuelled by biomass gasification gas, new materials and processes for reducing SOFC working temperatures for high power applications
- *Solid polymer fuel cells*, eg hydrogen and fuel cell technologies for road transport, performance improvement and system integration of high temperature PEMFC, novel software-based tools for PEM fuel component and stack designers, intelligent DC/DC converter/fuel cell hybrid power trains, and integration of a PEMFC with ultra-capacitors and with metal hydrates container for hydrogen storage
- Portable applications, eg compact direct (m)ethanol fuel cell for portable application

The portfolio includes the new instruments of FP6, Integrated Projects (IP) and Networks of Excellence (NoE), as well as projects using the more traditional type of instrument used in FP5. This will be reinforced via further calls for RTD and demonstration proposals worth an expected public and private investment of the order of 300 M€, of which about half would be funded by the EU.

A well co-ordinated, strategically selected set of FP6 projects will provide a concerted and essential technical input to the European Hydrogen and Fuel Cell Technology Platform (see section below), as well as to the transport related technology platforms and the Alternative Motor Fuels policy initiative. It will also help establish the definition and detailed planning phase of a substantial and broad ranging hydrogen communities technology initiative designed to stimulate growth and accelerate the move towards the hydrogen economy, under the EU's Growth Initiative

The European Hydrogen and Fuel Cell Technology Platform

Although hydrogen is a bridge to a sustainable energy future, it is a disruptive technology. Exploitation of hydrogen involves creation of new industries and supply chain structures. Major capital investments are required and planned depreciation of existing assets. Complex transition strategies have to be worked through, involving building consensus between key stakeholders.

These issues were considered by a High Level Group on Hydrogen and Fuel Cell Technologies established by Commissioners Busquin and Loyola de Palacio in 2002, which comprised 19 influential stakeholders from industry, the research community and public authorities. The conclusions and recommendations of this Group were set out in their final report (document EUR 20719 EN), "*Hydrogen Energy and Fuel Cells – A vision of our future"*, accessible at http://europa.eu.int/comm/research/energy/pdf/hlg_vision_report_en.pdf .

Building on the recommendations of this report the European Commission has facilitated the establishment of the **European Hydrogen and Fuel Cell Technology Platform** (HFP) with the goal of *"facilitating and accelerating the development and deployment of cost– effective, world class European hydrogen and fuel cell based energy systems and component technologies for applications in transport, stationary and portable power"*.

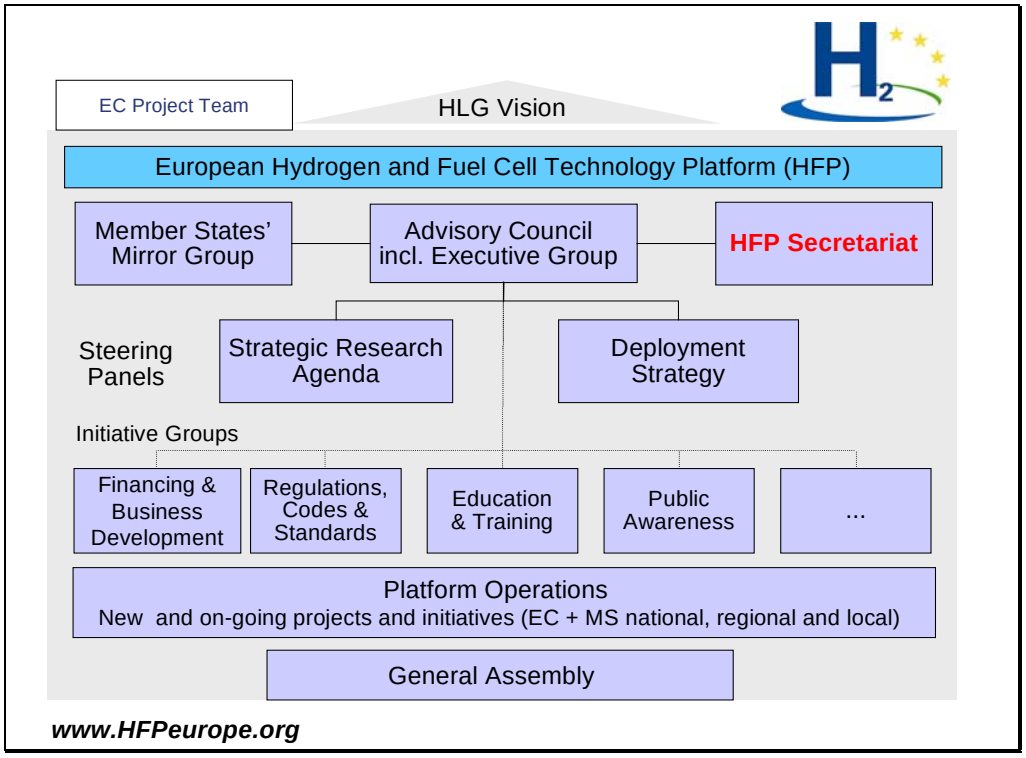

Figure 1: Structure of the Technology Platform

Figure 1 is a schematic of the platform structure. The main body is its Advisory Council, which is composed of 36 senior executives with expertise and direct responsibilities in the field of hydrogen and fuel cells and will set the overall direction, strategy and vision of the HFP. The Steering Panel for preparing a "Strategic Research Agenda" is expected to provide an outline for research and development issues and priorities, including measures and activities for R&D on a 10-year time scale and a long-term strategic outlook until 2050. The Steering Panel for the "Deployment Strategy" will develop a deployment strategy fostering the commercialisation of mobile, stationary and portable hydrogen and fuel cell applications and should consolidate the overall implementation of a European hydrogen vision. Consolidated reports taking account of the comments received from the open consultation will be published for the end of year 2004.

The HFP has also established a number of Initiative Groups to address important specific issues. One will address the necessary regulations, codes and standards for hydrogen vehicles, fuelling infrastructure, and stationary fuel cell systems – to ensure public safety and the development of an open market. The Groups on Finance and Business Development and on Education and Training will address the funding aspects and the need to develop the human capital and resources necessary to effect the paradigm change from today's energy systems.

There is also a *Member States' Mirror Group*, which is actively involving the EU Member and Associated States. The aim of this Mirror Group is to ensure a closer coordination and cooperation between Member States, regional research programmes, high level representatives within administrations and the HFP. It should also act as a forum for exchange of views on the strategic research agenda, the deployment strategy and policy related matters.

Three basic principles govern the participation in the HFP: *commitment, transparency and inclusiveness.* As of July 2004 more than 200 representatives were actively participating in the activities of one of the bodies of the HFP. They represent a balance of expert knowledge and stakeholder interests and typically include:

- Industry (including SMEs) - embracing the whole production and supply chain;
- Users and consumers - to ensure markets for products;
- Research community - public and private; technical and socio-economic;
- Public authorities - European, national, regional, local;
- Financial community - banks, venture capital, insurance;
- Civil society - to enhance public awareness.

The HFP was formally launched with the first "general assembly" in January 2004 in Brussels, which was attended by 400 participants. The conclusions of this assembly identified, in particular, the main technical and non-technical hurdles for the development and deployment of hydrogen and fuel cells in each of their potential applications areas. It is worth mentioning here some of the main conclusions and recommendations related to the principal hydrogen production pathways:

- The current energy mix varies considerably within the EU – transition and long term strategies will differ regionally and nationally
- There are different timelines and levels of maturity for available technologies.
- Currently large scale **methane steam reforming** is the most competitive technology; this is a transition technology; resolving CO2 sequestration will strongly influence its long term potential beyond 2010-2015.
- Large scale de-carbonized hydrogen will be important by 2020-2030: EU interest in **hydrogen from RES** (i.e. wind, solar, biomass) and strong public support; however cost reductions are needed – transition and longer term prospects.
- Long term technologies (2040 -):

  - ✓ High Temperature **thermo-chemical cycles** for large scale carbon-free hydrogen; but they are capital intensive and depend on other developments (e.g. High Temperature Reactors).
  - ✓ Novel ***"Biohydrogen"*** routes (i.e. photo-biological processes) seem theoretically attractive but demonstration will require big efforts;
- For early **wide scale distribution**, use natural gas (NG) pipelines to transport H2/NG mixtures; feasibility now under investigation in EC project "NATURALHY" ; widespread H2 distribution pipelines unlikely before 2025
- Nearer term (2010 horizon)**: on site production** either via electrolysers or compact fuel reforming. Both available, but have significant challenges: the "**energy equation**" for the electrolysers and **CO2 issues** for compact reformers;
- Clusters of local hydrogen distribution grids (e.g. remote communities) 2010-2015
- **Community acceptance** is key to locating infrastructure like hydrogen fuelling stations and pipelines – "Not in my back yard!"
- Distribution medium is linked to storage (e.g. liquid or compressed gaseous hydrogen for vehicles); storage is a key **enabling technology** for hydrogen economy; next generation "conventional" **on-board storage** systems addressed in EC "StorHy" project. Solid storage addressed in EC projects: emphasis on **metal hydrides**. Substantial challenges still remain. Basic research needed;

The presentations, speeches and conclusions of the 1st assembly can be found on the following website:

http://forum.europa.eu.int/Public/irc/rtd/eurhydrofuelcellplat/library

The HFP will be instrumental in structuring socio-economic and technical research on hydrogen and fuel cells at European level. It should stimulate increased public and private investment in research and development and will also help in identifying and promoting deployment opportunities both for energy infrastructure and services. The results of activities, including research and demonstration projects undertaken under the auspices of the HFP will be widely disseminated and communicated to the appropriate policy making bodies. Regular assemblies of the HFP participants will ensure shared ownership and a common vision. Further information concerning the HFP can be accessed at the Platform website: www.HFPeurope.org.

The European Initiative for Growth and Quickstart Programme

The European Commission has recently proposed a European Initiative for Growth aiming at stimulating the performance of the European economy. One of the knowledge and research areas singled out for specific action is hydrogen. In taking the Growth initiative forward, the Commission and the European Investment Bank have identified a "Quick Start Programme" of projects, including actions to benefit the environment.

The proposal for a Hydrogen Quickstart hydrogen project comprises two main initiatives that would be developed over a 10 year period - building on the knowledge and experience gained in the research and demonstration projects funded under FP5 and FP6 and on the research and deployment strategy being developed in the Technology Platform:

The first initiative "HyPOGEN" will explore the limits of using hydrogen as a means of de-carbonising today's fossil fuels and therefore its potential to bridge to a future hydrogen economy. The aim of the project will be to develop and operate a pilot demonstration plant and will prove the feasibility, safety and economics, of carbon capture and sequestration.

The second pillar "HyCOM" will explore the feasibility, safety and economics of managing hydrogen energy communities and hydrogen competence centres. The aim is to research autonomous and grid-connected hydrogen systems exploiting mainly renewable primary energy sources, such as wind, or biomass. Integrated hydrogen and fuel cell energy systems will be developed, exploiting where possible synergies between stationary, and transport applications. Where possible and appropriate, research and demonstration infrastructure will be shared, with the aim of growing local competencies. The Hydrogen Initiative which necessitates strong public private partnerships, is still in its early formative stages.

Hydrogen Production from Nuclear Energy

As explained in the sections above most of the EU research activities related to the hydrogen production, storage and distribution have been undertaken in the frame of the Community RTD Framework Programmes related to non-nuclear energy. Most of these RTD activities are related to the development of cost-effective small and large-scale hydrogen production. In most of the cases they rely on traditional methods such as biomass gasification, reforming of fossil fuels (with and without CO2 sequestration) or water electrolysis for which renewable sources are used to provide the primary energy required. However, other promising methods such as high temperature water splitting using thermo-chemical cycles are also being investigated particularly in the FP6 project 'HYTECH' and the co-ordinated action INNOHYP-CA. However, these technologies are still at an early stage of development and rely on breakthroughs in high temperature materials, cycle simplification and safe handling of materials.

In the Euratom Framework Programme, the different possibilities of using nuclear fission energy to produce hydrogen has briefly been reviewed by MICANET. Nuclear power could play a significant role in the production of hydrogen at a large scale: it could be used either as provider of electricity (or heat) in water electrolysis processes or as supplier of high-temperature heat for both fossil fuel conversion and thermo-chemical cycles. In principle, the electricity produced by the existing nuclear (and non nuclear) power plants during off-peak hours could be already used to produce hydrogen by electrolysis. In the particular case of High Temperature Reactors (HTRs), there is a big potential for the application of the high-temperature heat produced for water splitting using the thermo-chemical cycle. In this cycle the splitting process is subdivided into different partial reactions, each running on a lower temperature level. Although they are inherently

less efficient than conventional processes, the economic competitiveness of some of these cycles might be improved if nuclear heat from HTRs could be used directly for the thermo-chemical cycle. In fact, one of the present research activities at JAERI is to study the coupling of the High Temperature Test Reactor (HTTR) with a hydrogen production system based on the thermo-chemical cycle. Finally, the US DOE is planning to build in Idaho Falls (USA) a prototype high temperature reactor, called "Next Generation Nuclear Plant (NGNP) to produce hydrogen. This will be done in close collaboration with other activities within the Generation IV International Forum.

The EC has supported a number of research actions on HTRs in its 5th and 6th Euratom Framework Programmes. They are aimed at investigating and evaluating the potential of this type of reactors in terms safety, economy, waste management, use of fissile material, less risk of diversion and sustainability. In the next call for proposals the Commission also expects proposals for strategy studies and/or thematic networks for the assessment of applications of nuclear energy other than generation of electricity such as hydrogen production.

International Co-operation and the International Partnership for the Hydrogen Economy

Many of the issues confronting the deployment of hydrogen are of an international dimension. The International Partnership for the Hydrogen Economy initiated by the USA is a welcome, major step forward for building international collaboration on both technical, non-technical and policy related matters – the main elements that will be required to build a global hydrogen economy. The EC has supported its establishment which provides a focal point for developing multi-lateral co-operation on key research and deployment issues.

Anticipating the Seventh Framework Programme

At the beginning of 2005 the European Commission will present its proposal for the Union's Seventh Research Framework Programme (2006-2010). The Commission has made strengthening European research a major objective in its Communication on the future financial framework of the Union, proposing to significantly increase the European Union's research budget. At the Barcelona European Council of March 2002, the EU set itself the objective of increasing the European research effort to 3% of the European Union's GDP by 2010, two-thirds coming from private investment and one-third from the public sector. It is therefore proposed to organise FP7 around six major objectives:

1. Creating European centres of excellence through collaboration between laboratories.
2. Launching European *"Technological Initiatives"* based on Technology Platforms (including hydrogen and fuel cells)
3. Stimulating the creativity of basic research through competition between teams at European level (e.g. a European Research Council)
4. Making Europe more attractive to the best researchers
5. Developing research infrastructure of European interest
6. Improving the coordination of national research programmes

Conclusions

Hydrogen and electricity as energy carriers, together with fuel cell energy converters offer unique opportunities to create clean, efficient "open energy systems" based on sustainable and clean primary sources, with the prospect of dramatic reductions in greenhouse gases. Whilst the main long term emphasis is to move towards a hydrogen economy based largely on renewable sources, new generation nuclear energy represents a potential long term possibility for large scale hydrogen production that may prove necessary to meet energy demand – especially for transport sector which presently accounts for 30% of final energy demand (and growing) and is 95% dependent on oil.

EU funded RTD and demonstration effort in the Framework Programmes on hydrogen and fuel cells has confirmed the huge potential of these technologies. A more strategic, focused approach can be expected to yield breakthroughs in materials and processes needed to improve durability and reduce costs.

A European Hydrogen and Fuel Cell Technology Platform was formed in January 2004, following the recommendation of the High Level Group for Hydrogen and Fuel Cell Technologies. The platform has already mobilised a broad stakeholder base with the express aim of facilitating and accelerating the development and deployment of cost– effective, world class European hydrogen and fuel cell based energy systems and component technologies for applications in transport, stationary and portable power.

The platform includes bodies which will stimulate the building of a European Research Area in the fields of hydrogen and fuel cells, initiatives to support the development of a political framework, and activities to support the establishment of a safe, competitive industry, including standards and regulations and the elaboration of a European Hydrogen "Roadmap".

The ensemble of these activities anticipate new opportunities in FP7, including the establishment of "Technology Initiatives", and the development of hydrogen communities and competence centres as part of the European Initiative for Growth.

The co-ordination of European initiatives under the Technology Platform will form a strong technological and political basis for actively contributing to international activities, including the International Partnership for the Hydrogen Economy. International co-operation is vital to ensure the emergence of globally competitive markets for the hydrogen and fuel cell equipment industry.

