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Brussels, 10-11 October 2007

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CONTENTS

ACRONYMS

APU	Auxiliary power unit
CGH2	Compressed gaseous hydrogen
CHP	Combined heat and power (generation)
CCS	Carbon dioxide capture and storage
DoE	US Department of Energy
EIB	European Investment Bank
ERA-NET	Project to coordinate European national and regional R&D programmes in hydrogen and fuel cells
ETAP	Environmental technologies action plan
ETS	Emissions trading system
FP6	6th Research And Development Framework Programme of the EU (2002-2006)
FP7	7th Research And Development Framework Programme of the EU (2007-2013)
GHG	Greenhouse gas
HFP	European hydrogen and fuel cell technology platform
HTE	High temperature electrolysis
ICE	Internal combustion engine
IDA	Innovation and development action
IG	Industry grouping
INTAS	International association for the promotion of co-operation with New Independent States
IP	Implementation plan
IPHE	International partnership on the hydrogen economy
ISO	International organization for standardization
JTI	Joint technology initiative
JU	Joint undertaking
LH2	Liquid hydrogen
MCFC	Molten carbonate fuel cells
MEA	Membrane electrode assemblies
OEM	Original equipment manufacturer
NMP	Nanosciences, nanotechnologies, materials and new production technologies
PEMFC	Proton exchange membrane fuel cells
PBI	Polybenzimidazole (membranes)
PFSI	Perfluorosulphonate ionomeric (membranes)
RCS	Regulations, codes and standards
RG	Research Grouping
RSFF	Risk sharing financial facility
SDO	Standards Development Organizations
SME	Small and medium enterprises
SOFC	Solid oxide fuel cells
SRA	Strategic research agenda
TPS	Thermoplastic starch
UPS	Uninterruptible power supply

EXECUTIVE SUMMARY

Background to the review

The 2007 European Hydrogen and Fuel Cell Review Days were held on 10-11 October in Brussels. The event was organised by the European Commission with the logistic support from the European Hydrogen and Fuel Cell Technology Platform Secretariat. The main objectives were to promote information exchange, review the achievements of the project portfolio and provide orientations for future actions.

The review took place against at the same time as the Community made a critical advance in the management of its research in fuel cell and hydrogen. Under the 7th Research Framework Programme (FP7), the bulk of funds for fuel cell and hydrogen research will be entrusted to the Joint Technology Initiative (JTI). On the day before the conference, the Commission adopted a proposal for a Council Regulation to set up a Fuel Cells and Hydrogen Joint Undertaking (JU), which will be the legal entity entrusted with the coordinated use and efficient management of the funds committed to the JTI.

This report has been compiled mainly from the proceedings of the Conference, its purpose is:

- To identify how fuel cell and hydrogen research can contribute to important policies in the EU
- To present a critical review of the FP6 portfolio of research in fuel cells and hydrogen
- To distil some lessons for the future priorities of the JTI

Considerable preliminary work has been accomplished to guide the JU in its work. Key studies are the Strategic Research Agenda, to guide community and national programmes in a concerted manner, the Deployment Strategy, to move technology from the prototype stage through demonstration to commercialization and the Implementation Plan – Status 2006, that is a strategic plan to facilitate and accelerate the development and deployment of cost-competitive, hydrogen and fuel cell technologies.

The potential contribution of fuel cells and hydrogen to important EU policies is analysed in this report. The most important impacts are on sustainable development, energy, transport and the Lisbon Agenda for competitiveness and growth. The analysis concludes that the fuel cell and hydrogen research can provide significant support to all these policies. The analysis draws attention in particular to the need for the external costs of transport, especially relating to climate change, to be internalised fully and effectively by appropriate policy interventions.

The main body of the report comprises a detailed review of the project portfolio. The strategic approach in FP6 was to support selected fuel cell and hydrogen technologies across the spectrum of RTD, from basic research – to demonstration projects, complemented by projects on cross cutting issues. Around 75% of the hydrogen and fuel cell research projects are funded under the thematic priority on “ Sustainable Energy Systems” of FP6, but other thematic priorities and FP6 programmes have contributed.

There is a strong increasing trend in EU funding to fuel cell and hydrogen research over successive FPs. Under FP2 (1986-1990) it was 8 M€; by FP5 (1999-2002) it was 145 M€ and in

FP6 it was around 320 M€, matched by an equivalent amount of participating stakeholder investment. Under the new arrangements, FP7 will provide a budget of 470 M€ and the private sector will contribute matching funds of at least 470 M€.

The detailed review of the projects concludes that they constitute a good portfolio, well balanced between and among applications and technologies. Projects are broadly on track and of satisfactory quality. It is important that the results of these projects are systematically validated and assessed according to a common framework. Unless this is done, it will not be possible to set sensible targets and design sensible programmes for the future.

The review confirms the logic of a more focused approach that underlies the JTI. The EU in this field is estimated to lie broadly five years behind that of the US and Japan. In part at least this arises from the more focused programmes of research management that are difficult to achieve in the dispersed EU research environment. The Joint Undertaking can help redress this weakness.

Lessons for future priorities

It was noted that some of the performance targets set out in the Implementation Plan are challenging. The JTI needs continually to assess the contribution of projects to meeting these targets through an agreed and effective framework of technical validation and assessment.

The Implementation Plan envisages large demonstration programmes in transport with several thousand vehicles and linked sites. This is appropriate, but doubt was expressed whether in itself this would be enough to stimulate a mass market. There will be parallel programmes that will contribute to demonstration, but it is not clear what the cumulative impact will be. Thought needs to be given and possibly funding developed for a more prolonged pre-commercial activity.

There are significant external costs associated with transport. A supportive and preferably harmonised system of policy intervention to internalise these costs is essential if the demonstration projects are to have impact. The JTI should lobby for policy regimes of member states and cities that reflect the benefits from reducing external costs. More socio-economic research is needed of the policy options, the relationship between policy options and adoption of technology and the economic effectiveness of various options and market behaviour.

A strong emphasis on commercialisation and market opportunity is needed in future research, whilst at the same time recognising the areas where market success still needs fundamental research. Future projects should show clearly how their planned activities would help achieve the targets in the HFP strategy or whatever targets the JTI may later establish.

International standards will eventually materialise for hydrogen and fuel cells and it is important that the EU should establish a common position and exert its influence. Work on regulations, codes and standards should be organised as a crosscutting support activity in the JTI-structure.

The JTI should be proactive in working with national governments to achieve central coordination of strategy, supported by a central validation and assessment exercise from which all can learn. The desire of national governments to preserve commercially confidential information for national companies is likely to be an obstacle, but some arrangement should be found. Collaboration with national governments is also important in the development of a common position on regulations, codes and standards.

Local government has an important part to play as host to demonstration projects, as planner and perhaps as owner of equipment. This is recognised and measures are in place to develop some light partnership arrangement that would let regions and municipalities participate in the work of the JTI.

The large-scale demonstration plants preceding spontaneous commercialisation will be especially demanding of funds. This is an activity where additional funding mechanisms might be envisaged. The Risk Sharing Financial Facility (RSFF) of the European Investment Bank (EIB) is one option, if projects can be structured with revenue flows. Policy to internalise external costs could help generate revenue flows. For later stage projects, there may be opportunities for support under Structural / Cohesion funding schemes and this should be explored in co-operation with the regions.

Some unease was expressed by the research community that the centralisation of funding within an institution strongly oriented towards industrial interests would distort activity and undermine basic research and training. There was also some disquiet about the possible distortion of involvement in favour of big companies from larger countries, as against SMEs and smaller countries. The JTI should introduce procedures internally to make sure that these distortions do not occur, but the Commission must carefully monitor the activities to ensure that the balance is appropriate and corrected if necessary.

European funded research on Hydrogen and Fuel Cells – review, assessment and future outlook

Report from the conference "Hydrogen and Fuel Cell Review Days – 2007"

1. Introduction

The European Community has a long history of supporting research into hydrogen as an energy carrier and fuel cells as a way of converting hydrogen into motive power and electricity. Hydrogen and clusters of technologies that use hydrogen could help the Community improve the security of energy supply and reduce greenhouse gas emissions to the atmosphere. These are critical objectives of policy in the EU. In addition, the development of a dynamic fuel cell and hydrogen industry in Europe can have an important economic impact.

The next twenty years will be critical, both for climate change and for security of supply. In this period, irreversible and catastrophic damage may be done to the climate. Over this period also, the costs of dependence on very few large producers of energy might also become painfully apparent. Europe can meet these challenges only through the application of technology and the adoption of difficult changes to social values and behaviour.

The energy sector is not distinguished by radical technological change. Development in the sector is mainly the product of slow and incremental improvement. The energy technologies that we have to cope with energy security and climate change are known now. The relationship of most of these technologies to existing systems is also clear. They may or may not function as expected, but in general, their characteristics are well established.

This is not true of fuel cell and hydrogen technologies. At present costs, large-scale use of fuel cells and hydrogen is not competitive. Difficult, but achievable, advances could change this. The fuel cell is not a comprehensively disruptive technology; it can be seen as a replacement for conventional power trains, generators or batteries. Only in minor key, within these functions, is it disruptive. Hydrogen distribution is comprehensively disruptive; the relationship to and implications for traditional systems are not yet clear. Many sources of energy can be converted into hydrogen; there are many conversion options; transport options; storage option and options for use. Of all the technological clusters on which we depend to reduce climate change and to improve our security, the hydrogen cluster is the most difficult to characterise and to predict. The potential is important; the challenges are immense. That is why the European Commission has decided to focus and strengthen its efforts in this respect through the creation of the Joint Technology Initiative (JTI) for Fuel Cells and Hydrogen described below.

The portfolio of fuel cell and hydrogen projects of the EU is reviewed periodically. This year, the review took place against the context of a critical advance in the management of research in the EU of fuel cells and hydrogen. Under the new Framework Programme (FP7), the bulk of funds for fuel cell and hydrogen research will be entrusted to the Joint Technology Initiative. On the day before the conference, the Commission adopted a proposal for a Council Regulation to set up a

Fuel Cells and Hydrogen Joint Undertaking (JU)[1], which will be the legal entity entrusted with the coordinated use and efficient management of the funds committed to the JTI.

The 2007 European Hydrogen and Fuel Cell Review Days were held on 10-11 October in Brussels. The event was organised by the European Commission with support from the European Hydrogen and Fuel Cell Technology Platform Secretariat.

- The main objectives of the event were:
- To offer a forum to promote information exchange between EU-funded projects and disseminate results.
- To review the main achievements of the FP6 projects' portfolio in the different technical research areas and provide orientations for future actions.
- To inform stakeholders about the EU state of play in the area.

This report has been compiled mainly from the proceedings of the Conference, supplemented by a review of important policy issues in Europe to which fuel cells and hydrogen might contribute. Its purpose is:

- To identify how fuel cell and hydrogen research can contribute to important policies in the EU
- To present a critical review of the FP6 portfolio of research in fuel cells and hydrogen
- To distil some lessons for the future priorities of the JTI

2. Background to the JTI

The creation of the JTI and the JU were significant steps in improving and extending the management of research in fuel cells and hydrogen, but behind this important decision lies a considerable effort to define the purpose, scale, scope and arrangements for the initiative.

The first attempt at a coordinated strategic planning of research on fuel cells and hydrogen within Europe was undertaken by the High Level Group for Hydrogen and Fuel Cells Technologies. This group was established in October 2002 by the Vice President of the European Commission, Loyola de Palacio, Commissioner for Energy and Transport, and Mr Philippe Busquin, Commissioner for Research. The group produced a report entitled, "Hydrogen Energy and Fuel Cells - A vision of our future"[2]. This report stressed the need for strategic planning and increased effort on research, development and deployment of hydrogen and fuel cell technologies. It recommended a more structured approach to European energy policy and research, for education and training, and for developing political and public awareness and in particular, it recommended the establishment of a European Hydrogen and Fuel Cell Technology Partnership and Advisory Council to guide the process. As a result, the European Hydrogen and

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[1] Proposal for a Council Regulation setting up the Fuel Cells and Hydrogen Joint Undertaking, COM(2007) 571, Brussels, 9.10.2007

[2] Hydrogen Energy and Fuel Cells - A vision of our future, Directorate-General for Research and Directorate-General for Energy and Transport, Brussels 2003

Fuel Cell Technology Platform was established to facilitate and accelerate the development and deployment of cost-competitive, world class European hydrogen and fuel cell based energy systems and component technologies for applications in transport, stationary and portable power.

The HFP produced several strategy papers, of which the most significant were:

- the Strategic Research Agenda (intended to guide community and national programmes in a concerted manner)[3],
- the Deployment Strategy[4] (to move technology from the prototype stage through demonstration to commercialization) and
- the Implementation Plan – Status 2006 (a strategic plan to facilitate and accelerate the development and deployment of cost-competitive, hydrogen and fuel cell technologies)[5].

The Strategic Research Agenda contains a ten-year research, development and demonstration programme, a mid-term strategy until 2030 and a long-term strategic outlook until 2050 (Vision 2050). The Deployment Strategy defines milestones for the market penetration of portable, stationary and transport application by 2020 (Snapshot 2020). These are reproduced in the Table.

Table 1 Key Assumptions on Hydrogen & Fuel Cell Applications for a 2020 Scenario

	Portable Fuel Cells (FCs) for handheld electronic devices	**Portable Generators & Early Markets**	**Stationary FCs Combined Heat and Power (CHP)**	**Road Transport**
EU Hydrogen (H2)/ FC units sold per year projection 2020	~ 250 million	~ 100,000 (~ 1 GWe)	100,000 to 200,000 (2-4 GWe)	0.4 million to 1.8 million
EU cumulative sales projections until 2020	n/a	~600,000 (~ 6 GWe)	400,000 to 800,000 (8-16 GWe)	1-5 million
EU Expected 2020 Market Status	Established	Established	Growth	Mass market roll-out
Average power FC system	15W	10kW	<100 kW (Micro CHP) >100 kW (industrial CHP)	80 kW
FC system cost Target	1-2 €/W	500 €/kW	2,000 €/kW (Micro) 1,000-1,500 €/kW (industrial CHP)	< 100 €/kW (for 150,000 units per year

[3] Strategic Research Agenda, European Hydrogen and Fuel Cell Technology Platform, Brussels, July 2005

[4] Deployment Strategy, European Hydrogen and Fuel Cell Technology Platform, Brussels, August 2005

[5] Implementation Plan – Status 2006, January 2007, European Hydrogen and Fuel Cell Technology Platform, Brussels

The concept of Joint Technology Initiatives (JTIs) was included in the Council Decision on the 7th Framework Programme. They were envisaged to manage research areas where Technology Platforms have achieved a scale that requires large public and private investments as well as substantial research resources to implement important elements of their Strategic Research Agendas. Fuel cells and hydrogen were identified as one of six areas where a JTI could be effective; this was confirmed by the Competitiveness Council. The Commission services have since developed a proposal for a JTI in fuel cells and hydrogen and as noted this has now been adopted by the Commission. The proposal will be presented to the Council and to the Parliament. Adoption by the Council is foreseen for early 2008 and the first call for proposals should be made around the same time. A bridging structure has been put in place under a Coordination and Support Action of FP7 to ensure continuity and a quick start once the approval of the Council has been obtained.

The rationale for the JTI is to provide a more sustained and focused programme for fuel cells and hydrogen research than could be achieved within the proposal-driven structure of FP7. It is expected that the greater predictability and continuity of research will give confidence to industry and enhance still further the volume of research spending in the field. The scope covers basic science through to large-scale demonstrations.

The JTI will be managed by a Joint Undertaking (JU); this is a public private partnership and a Community body established under Article 171 of the EC Treaty. Private industry is represented by the European Fuel Cell and Hydrogen Joint Technology Initiative Industry Grouping, established under Belgian law, generally known as the Industry Grouping. The function of the JU is to support research, development and demonstration in the fields of fuels cells and hydrogen. The founding members are the Industry Grouping and the European Community, represented by the Commission. This is reflected in the governance of the JU; the Governing Board will be composed of six representatives from the industry and six from the Commission. The research community is expected to establish a representative body that will become a member of the JU and their representative will eventually replace one of the EC members of the board. The EC reserves the right of veto on certain matters, relating to finance, statutes and coherence with FP7.

The JU will operate from 2008 until 2017; FP7 will provide a budget of 470 M€ and the private sector will contribute matching funds of at least 470 M€. It will develop its own annual and multi-annual programming cycle. It will select and evaluate proposals based on procedures that are open and transparent and will be responsible for dissemination of information on results and its activities in general. The JU will make open calls for proposals according to its work programme. Consortia will require at least three independent legal entities from different member states. In the proposal for the Regulation, it is suggested that at least one legal entity must belong to the Industrial Grouping (IG) or to the Research Grouping (RG) and the consortium leader will normally belong to one of these two Groupings.

The main reference documents for beginning the work of the JTI is the Implementation Plan (IP) – Status 2006 developed by the HFP. The Plan is built upon four Innovation and Development Actions (IDAs) that group the actions necessary to achieve the "Snapshot 2020" targets of the Deployment Strategy. The IDAs are:

- IDA1: Hydrogen vehicles and refuelling stations

- IDA2: Sustainable hydrogen production and supply
- IDA3: Fuel cells for CHP and power generation
- IDA4: Fuel cells for early markets

Each IDA covers technology development and market-enabling activities. They are assigned priorities according to how important they are in realising “Snapshot 2020” and the 2050 vision. Supporting activities are also specified that cut across the IDAs. These are the promotion of SME participation, regulations codes and standards, socio-economic analysis, training, finance and stimulating awareness.

3. Horizontal policies

There are four horizontal policies where fuel cells and hydrogen may have especial relevance. They are sustainable development, energy, transport and to the Lisbon Agenda for competitiveness and growth. There is considerable overlap within these categories, but the separation is a useful starting point for review.

3.1 SUSTAINABLE DEVELOPMENT

Sustainable development is at the core of the European Union’s policy objectives. In 2001, the Göteborg European Council launched the EU strategy for sustainable development, seeking an integrated approach to policy making in which economic, social and environmental objectives can all be achieved. It complements the Lisbon strategy (see below) that deals with economic growth, jobs, competitiveness and social cohesion.

Technology creates synergies between environmental protection and economic growth. In recognition of this, in 2004, the Commission approved the Environmental Technologies Action Plan (ETAP) intended to encourage the choice of advanced environmental technologies in all investment and purchasing decisions[6]. The objectives of the Action Plan are:

- to remove the obstacles to tapping the full potential of environmental technologies for protecting the environment while contributing to competitiveness and economic growth;
- to ensure that over the coming years the EU takes a leading role in developing and applying environmental technologies;
- to mobilise all stakeholders in support of these objectives.

The Fuel Cells and Hydrogen Joint Undertaking clearly contributes to the implementation of the Environmental Technologies Action Plan (ETAP) and is consistent with the policies on sustainable development. It is helpful to reflect that the policy of sustainable development is conceived as coherent with growth and competitiveness. These should be goals also in the work of the JTI.

An immense challenge of sustainable development is climate change. At the spring meeting in 2007, the Council accepted the need to limit worldwide greenhouse gas (GHG) emissions to a

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[6] Stimulating Technologies for Sustainable Development: An Environmental Technologies Action Plan for the European Union
COM(2004) 38, Brussels, 28.1.2004

volume that would restrict temperature rise to 2°C compared to pre-industrial levels[7]. The Council recognised that developed countries should take the lead and proposed that they should reduce emissions by 30 % by 2020 compared to 1990, with a later target of 60 % to 80 % by 2050[8]. It endorsed an EU objective of a 30 % reduction by 2020 if other developed countries should do the same and if the bigger developing countries should make a significant effort, but in any case, agreed to reduce emissions within the EU by 20 % by 2020 compared to 1990.

Energy accounts for 80% of all GHG emission in the EU; reducing energy use and reducing the carbon emissions from energy use is fundamental to managing climate change. Fuel cells and hydrogen can reduce carbon emissions from the energy sector, because they allow carbon-free production of fuel. Total CO2 emissions from transport are expected to more than double in the period to 2050, making it the second-fastest growing sector after power[9]. Not only is demand for transport growing, but there are few options for removing carbon from transport fuels. Electric vehicles using carbon-free electricity is one option, but battery technology has disadvantages in terms of weight and cost. Fuel cell vehicles using hydrogen from carbon-free sources meet the challenge. Very high external costs for carbon are cited in the literature. The Stern report suggests an average figure for 2010 of around $80 / tCO2.

3.2 ENERGY

Energy policies in Europe are not sustainable. This has been recognised by the Commission and Member States and a major revision of policy was recently undertaken following the Hampton Court (UK) informal meeting of the European Heads of State. The Commission published on 8 March 2006 a Green Paper[10] and, following public consultation the strategy document, An Energy Policy for Europe[11] that included a target-based Action Plan. The Council adopted this Plan and endorsed ambitious targets for use of renewables, specifically:

- a 20 % share of renewable energies in overall EU energy consumption by 2020
- a 10 % minimum target to be achieved by all Member States for the share of biofuels in overall EU transport petrol and diesel consumption by 2020, with some qualifications relating to the sustainability of production.

Most expert opinion is that the renewable targets will be difficult. If fuel cell and hydrogen technologies were to make a significant commercial impact then they would help reach those targets. Hydrogen production offers some advantage to renewables that, as sources of electricity, are penalised by their intermittent nature, because storage of electricity is extremely expensive. In producing hydrogen, the fuel can be stored more easily and this is an advantage.

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[7] Limiting global climate change to 2 degrees Celsius The way ahead for 2020 and beyond, COM(2007) 2, Brussels, 10.1.2007

[8] Presidency Conclusions – Brussels, 8/9 March 2007

[9] The Economics of Climate Change, Nicolas Stern, Cambridge University Press, 2007

[10] A European Strategy for Sustainable, Competitive and Secure Energy - COM(2006) 105, 8.3.2006

[11] Communication from the Commission to the European Council and the European Parliament - An Energy Policy for Europe,
COM(2007) 1, Brussels, 10.1.2007

The EU is the world's largest importer of oil and gas. It imports 82 percent of its oil and 57 percent of its gas. Imports are projected to rise to 93 percent of its oil and 84 percent of its gas over the next 25 years. More seriously, reserves of hydrocarbons are strongly concentrated in a few countries and access to these reserves is restricted. Hydrogen can contribute to a more secure supply by diversifying sources and routes. It offers the potential for a wider use of nuclear, renewables, biomass and coal. These fuels can enter power generation, but fuel cell and hydrogen technology makes them available in more applications and especially in transport.

The spring meeting also recognised the need to strengthen energy research and to accelerate the development of renewables and low carbon technologies; it requested the Commission to prepare a Strategic Energy Technology Plan. The Plan was published in November and places significant weight on fuel cells and hydrogen[12]. In order to meet 2020 targets for reductions in GHG emissions it identifies a need to "*bring to mass market more efficient energy conversion and end-use devices and systems, in buildings, transport and industry, such as poly-generation and fuel cells*". Among the key technology challenges for the next 10 years to meet the broader 2050 vision it foresees a need to "*develop the technologies and create the conditions to enable industry to commercialise hydrogen fuel cell vehicles"*.

The SET argues that the Community framework programmes for R&D should be better used to catalyse the actions of Member States and the private sector, through a paradigm of steering and co-financing joint programmes rather than individual projects. This change, it concludes, requires a corresponding change in the way the programmes are implemented. It identifies the Fuel Cell and Hydrogen Joint Technology Initiative as a good example of such a change.

The SET also indicates that the Commission proposes to initiate in 2008 an action on energy infrastructure networks in Europe and systems transition planning. The intention is to help optimise and harmonise the development of low carbon integrated energy systems across the EU and its neighbours, including CO2 transport and storage and hydrogen distribution.

3.3 THE LISBON STRATEGY

The Lisbon Strategy is intended to improve the perceived low productivity and stagnation of economic growth in the EU. It was adopted in Lisbon, Portugal by the European Council in 2000. It aims to "make Europe, by 2010, the most competitive and the most dynamic knowledge-based economy in the world". The strategy has evolved over time and taken a complex character that informs almost all activities of the Community. It was renewed in 2005 and the Barcelona objective for the EU to invest 3% of its GDP in research and development by 2010 was endorsed[13]. At the 2006 Spring European Council, Heads of State and Government agreed four priority areas for more growth and jobs[14]:

- Investing more in knowledge and innovation

[12] A European Strategic Energy Technology Plan SET-Plan, COM(2007) 723, Brussels, 22.11.2007
[13] Working together for growth and jobs: A new start for the Lisbon Strategy COM (2005) 24, Brussels 2005
[14] Renewed Lisbon Strategy for Growth and Jobs: "A Year Of Delivery", COM(2006) 816, Brussels, 2006

- Unlocking the business potential, especially of SMEs
- Greater adaptability of labour markets based on flexibility and security
- Energy and climate change

The JTI has the potential to contribute under all these headings. It should stimulate spontaneous R&D expenditure on fuel cells and hydrogen above the presently envisaged levels. It needs to involve SMEs effectively in its work. It can contribute to high quality jobs if it succeeds in creating an EU based manufacturing industry and of course, it can make a major contribution to mitigating climate change.

3.4 TRANSPORT

The objectives of EU transport policy, from the transport White Paper of 1992 via the White Paper of 2001 are broadly consistent[15]. They aim to provide efficient, effective transportation systems that:

- offer a high level of mobility to people and businesses throughout the Union.
- protect the environment, ensure energy security, promote minimum labour standards for
- innovate in support of the first two aims of mobility and protection by increasing the efficiency and sustainability of the growing transport sector

In reviewing progress with urban transport, the Commission recognized that many problems remained unresolved. About 80% of Europeans live in an urban environment. Urban transport accounts for 40% of CO_2 emissions of road transport and up to 70% of other pollutants from transport. The EU has few direct possibilities for intervention, but can promote the study and exchange of best practice. The Commission indicated it would prepare a green paper on urban mobility. This was adopted on 25 September 2007[16]. It is intended to open a debate on urban mobility and an urban transport that is accessible, safe and secure. This green paper makes only one reference to hydrogen. There may be an opportunity here for the JTI. It is important that member states and cities create sympathetic policy regimes for hydrogen vehicles. Fuel cells and hydrogen will not be cost-competitive without internalisation of external costs and the green paper offers a chance to make this point.

3.5 CONCLUSIONS

This review generally shows how important is the potential of research in this area to support Community policies in sustainable development, energy, economy and transport. There are large external costs from transport, arising from greenhouse gas emissions and local pollution that can be set against the high costs of the technology. An effort is warranted to design robust policy options that can internalize external costs of climate change and air pollution, and maybe security of supply, in order to encourage demonstration projects and facilitate their funding.

The review also indicates the importance of recognising the goals of the Lisbon strategy during the implementation of programmes of the JTI, especially in relationship to SMEs, training, innovation (basic research) and jobs.

[15] European transport policy for 2010: time to decide. COM (2001) 370, Brussels2001
[16] Green Paper: Towards a new culture for urban mobility, COM(2007) 551, Brussels, 2007

4. Review and assessment of the FP6 programme

The strategic approach in FP6 has been to support selected fuel cell and hydrogen technologies across the spectrum of RTD, from basic research – to demonstration projects. The Commission also funds projects on cross cutting issues (including socioeconomic research, prenormative research, pathways and roadmaps and coordination of EU activities with national and regional programmes). Around 75% of the Hydrogen and Fuel cell research projects are funded under the thematic priority "Sustainable Energy Systems", but many other thematic priorities and FP6 programmes have contributed. The instruments used in FP6 covers the full range of available project forms.

There is a strong increasing trend in EU funding to fuel cell and hydrogen research over successive FPs. Under FP2 (1986-1990) it was 8 M€; by FP5 (1999-2002) it was 145 M€ and in FP6 it was around 320 M€, matched by an equivalent amount of participating stakeholder investment

The FP6 projects under Hydrogen and Fuel Cells are classified in the following main research areas, shown with the percentage of the budget allocated to each area[17].

Hydrogen production and distribution	19.3%
Hydrogen storage	8.1%
Fuel Cell basic research (low & high temperature)	14.6%
Stationary and portable applications	8.0%
Transport applications (including hybrid vehicles)	19.3%
Safety regulations codes and standards	4.9%
Pathways and socio-economic analysis	8.8%
Technology validation and demonstration	16.8%

The European Commission is a partner in the International Partnership for the Hydrogen Economy. This was established in 2003 to help organize and implement effective, efficient, and focused international research, development, demonstration and commercial utilization activities that advance the transition to a global hydrogen economy. Partners include several individual member states, China, India, Japan, the Russian Federation and the USA. It is intended that coordination through the IPHE will leverage scarce international RD&D funds and reduce overall costs.

As a way of stimulating high quality research, the IPHE recognizes each year a set of leading and innovative pre-competitive international hydrogen and fuel cell research projects. European projects have received several recognitions; these are identified in the text below.

The following sections review the projects completed and in progress according to the information provided in the conference "Hydrogen and Fuel Cell Review Days" held in Bruxelles on the 10th and 11th of October 2007 . It attempts to judge their performance and the extent to which the

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[17] European Fuel Cell and Hydrogen Projects, 2002-2006, Directorate General for Research, 2006- http://ec.europa.eu/research/energy/pdf/hydrogen_synopses_en.pdf

match the ambitions of the JTI as expressed in the Implementation Plan and the Innovation and Development Actions.

4.1 HYDROGEN PRODUCTION

4.1.1 Review

Hydrogen from Renewable Energy Sources

This session comprised two distinct pairs of projects, one pair using high-temperature sources of solar energy to drive processes and the other depending on enzymatic or bio-mimetic processes.

The two projects using solar energy at high temperature are HYDROSOL-II (2005-9) and SOLREF (2004-7). HYDROSOL-II is the continuation of a successful FP5 project and it aims to develop a novel high-temperature redox system to generate hydrogen from water; in the first step, the oxide is reduced by thermal decomposition at ca. 1200^{o}C and in the second, the reduced oxide is re-oxidised by water producing hydrogen. In this second stage of the project, the aim is to produce redox metal oxide/ceramic support systems capable of giving long-term, multi-cycle water splitting and regeneration. The project is progressing well and the hydrogen yields are improving. The second project, SOLREF, following on from a previous project SOLASIS, is more conventional and concerns the steam reforming of natural gas using a solar furnace as a source of the energy for the endothermic reforming process. The aim is to improve the steam reforming catalysts used and to improve the solar reformer cell. There has been a delay of about a year in supply of the reformer so the project appears not yet to have produced significantly new results. Both these projects are well in line with the IP and IDA2.

The two projects using enzymatic and bio-mimetic processes are HYVOLUTION (2006-10) and SOLAR-H (2005-7). The former very large project examines two consecutive enzymatic processes for the production of hydrogen from biomass at room temperature; hydrogen is concentrated with a membrane contactor. A range of different types of biomass has been studied: sugar-beet pulp, carrot press cake, potato steam peels, wheat middings, spent brewers' grain and miscanthus. The reactors are large and fermentation times are of the order of days. The hydrogen costs quoted in the project are reasonable, but further work is needed to confirm economic competitiveness with the use of heterogeneous catalysts at high temperatures. The second project, SOLAR-H is very innovative; it is an attempt to develop synthetic materials that mimic the operation of photosynthetic microorganisms (green algae and cyanobacteria). This is a very fundamental project and it has long-term objectives. While it has in common with the previous project the drawback that any materials developed will probably require large reactors and long residence times, such research is still worthwhile. The work might have shorter-term prospects if more funding was devoted to shorter-term strategic basic projects, enabling the employment of larger teams.

Hydrogen Production and Delivery

This session comprised seven presentations covering four different approaches: two using conventional technology; two looking at high temperature routes for water-splitting; two looking at electrolysis methods at low and high temperatures; and one looking at hydrogen transport.

Of the projects using conventional technology, DYNAMIS (2006-9) was presented also in the infrastructure workshop and is described later. The second project, NEMESIS (2005-8), aims to develop a small-scale, fuel flexible hydrogen generator capable of working with liquid and gaseous hydrocarbon feedstocks. The project is based on the use of an existing natural gas reformer and is largely concerned with improving efficiency and integration of all the components of the system. This is an important area of research and development, clearly indicated under Actions 1 and 2 of the IDA2. The single project within the FP6 portfolio is rather isolated and further parallel projects with different approaches (e.g. the use of micro-reactors) would be justified.

The splitting of water at high temperature is studied within HYTHEC (2004-7) and INNOHYP (2004-6). HYTHEC compares the Sulphur-Iodine thermochemical cycle with the Hybrid Sulphur cycle, also known as the Westinghouse thermochemical cycle, these being driven by solar power and/or coupling with a nuclear reactor. The partners have identified the sulphuric acid step as being critical for the operation of both cycles and are currently working on the optimisation of process steps and the development of new catalysts for this reaction that are cheaper than the noble metal materials currently used; further work in this area is desirable. Experiments have also been carried out on the decomposition step using a solar furnace. HYTHEC has been recognized by the IPHE as a leading international project. The Coordinated Action, INNOHYP, has been completed. This work provided a survey of all the high temperature cycles that have been reported (some 400). It identified the processes that are close to demonstration including the Westinghouse and sulphur-iodine cycles referred to above, as well as the redox cycles of the type described previously (HYDROSOL). There was a plea for the establishment of a European platform to allow facilities for testing the most promising high-temperature schemes. It was also pointed out that there is a need to develop high temperature materials, particularly those based on SiC, for use in such cycles.

GENHYPEM (2005-8) examines the electrolytic production of hydrogen using proton exchange membrane-based electrochemical generators. The use of non-noble metal electrodes is studied and plants with capacities up to 50kW are being designed. The reversibility and stability of the electrodes are important and safety aspects of the operation of the systems are of top priority. The project HI2H2 (2004-7) has studied a high-temperature water electrolysis (HTE) system for hydrogen production, the so-called 'Solid Oxide Electrochemical Converter' (SOEC). Such cells use solid oxide electrolytes similar to those used in Solid Oxide Fuel Cells (SOFCs); however, because the reaction is carried out between 1V and 2V (compared with less than 1V for the SOFC) the materials problems are different. The advantage of such cells is that they can be operated thermo-neutrally and that noble metal electrodes are not necessary. The project has been successful in achieving high durability and performance of single cells. However, some problems have been encountered with degradation of the cells, probably due to sealant problems. It has been concluded that heat management is a difficult problem and requires more work, particularly in relation to scale-up to MW scale plants. It was suggested that there should be a large HTE project in the forthcoming JTI and that there was a need for more strategic basic research on the materials used as electrodes.

A single, but very large project, NATURALHY (2004-9), including national gas companies, deals with the distribution of hydrogen. It aims to determine the conditions under which the existing natural gas system can be used safely to transport mixtures of hydrogen and natural gas and to develop innovative technologies for the separation of hydrogen from hydrogen/natural gas mixtures. The approach would allow the use of the existing natural gas grids and avoid the need to develop new hydrogen pipelines; at least until the hydrogen economy is well established. It has been shown that up to 25% hydrogen can be added to natural gas without making the mixture markedly more dangerous than 100% natural gas, but a limit of 10% is preferable. Hydrogen permeation of existing steel pipelines is five times higher than that by methane, causing gradual degradation. There is negligible permeation or degradation of the more modern polyethylene (PE) pipelines. Progress is being made on the improvement of Pd membranes to be used in the separation process (giving 100% purities) while carbon molecular sieve membranes have also been produced which give 80% purity of the hydrogen. The project has good interactions with other consortia working on similar projects and with the US Department of Energy (DOE). There is a need for a modification of the existing Regulations, Codes and Standards to allow the transportation of natural gas/hydrogen mixtures.

4.1.2 Assessment

The portfolio of projects within FP6 dealing with production is generally well balanced and most projects appear to be meeting their objectives. The projects under way are generally in line with the Implementation Plan, and in particular with IDA2. This is not the case for the production of hydrogen from biomass, where the current portfolio of FP6 projects presented did not reflect the aims of the IP and IDA2. These actions relate mostly to pyrolysis and gasification processes and address the co-processing/gasification of biomass with coal and fossil fuels. In this area, a major problem is the treatment of the tars resulting from the gasification processes and the gas-cleaning processes and there is room for significant work in this area. Surprisingly, the actions proposed in the IP do not appear to include other routes for the production of hydrogen from biomass such as the gasification of the residual biomass chars left over after the production of valuable chemicals by biorefining processes or the steam reforming of products such as glycerol or formic acid formed by bio-processing. The use of biomass directly in pyrolysis and gasification processes is a potential waste of valuable raw materials and an approach using the unwanted by-products would seem to be more prudent. This type of work might be approached in collaboration with the European Biofuels Technology Platform. Work of this sort is planned within ERA-NET projects and some is being carried out in the last round of funding from INTAS (the International Association for the promotion of co-operation with scientists from the New Independent States of the former Soviet Union).

Only one project addresses small-scale on-site production of hydrogen, yet there might be useful parallel approaches with different technologies.

There are some concerns that arise from the concentration of research within the JTI and the leading role of industry. One such concern is the diminishing training component of projects. Scientists and engineers with the necessary experience and expertise to manage and perform research and will be needed over the next few decades to support the large-scale deployment of fuel cells and hydrogen. Training at this level is not a priority or competence of industry and there is a risk that it may be neglected in an arrangement lead by industry. Many projects do involve universities and include PhD and post-doctoral researchers, but some are mainly carried out by commercial companies. The need for fundamental research should not be neglected and this should be combined with the training of future technologists. Suitable topics include:

- components and materials for steam reforming, for the removal of tars and other contaminants from the syngas and for sulphuric acid decomposition;
- new and more stable ion-conducting electrolytes for use in high temperature electrolysis cells, as well as new components and materials for advanced electrolysers;
- materials for high temperature reactors (also in relation with thermochemical cycles).

4.2 HYDROGEN STORAGE

4.2.1 Review

In order to enable industrial commercialization of hydrogen fuel cell vehicles, safe, efficient and cost effective on-board hydrogen storage systems are mandatory. In spite of considerable R&D efforts in most industrialized countries, in particular the EU, the US and Japan, such systems still do not meet all technical requirements and cost targets. This is due to the difficulties in meeting the system targets set up in the various countries and the fact that, at present, no system anywhere in the world meets the on-board requirements as defined by industry. Current on-board hydrogen storage technologies rely mainly on classic approaches such as compressed hydrogen gas (CGH2) and cryogenic (liquid) hydrogen (LH2), whereas solid hydrogen stores (metal hydrides) are comparatively neglected because progress on the materials side is considered slow. Compared to current fossil fuel technologies all three storage approaches suffer from technical and economic shortcomings and this situation will continue until new breakthroughs are achieved.

Hydrogen storage is addressed as a priority in the Implementation Plan within IDA1 (Hydrogen vehicles and refuelling stations) and IDA2 (Sustainable Hydrogen Production and Supply). The hydrogen storage portfolio comprises five projects that address both on-board and off-board hydrogen storage systems. The projects are centred on hydrogen storage systems for automotive applications (STORHY, 2004-9), complex solid-state reactions for energy efficient hydrogen storage (COSY, 2006-10), hydrogen storage in carbon cones (HYCONES, 2009-09), novel efficient solid storage for hydrogen (NESSHY, 2006-11), and a hydrogen research-training network (HYTRAIN, 2005-9). Four projects cover solid hydrogen storage whereas one project covers all three hydrogen storage routes (liquid, gaseous, and solid). The portfolio ranges from basic-research oriented projects aiming at finding new and/or improving existing materials, to more application oriented projects aiming at the cost effective production of hydrogen storage materials. All benefit from participations by SMEs and/or have industrial advisory boards. The portfolio cuts across different thematic priorities of the EC research, including Sustainable Energy Systems and Nanosciences, Nanotechnologies, Materials and New Production Technologies (NMP), and different instruments of framework programmes FP6. NESSHY has been recognised by the IPHE as a leading international project.

4.2.2 Assessment

From the results presented, it is clear that hydrogen storage has made significant technical progress. Considering system capacity, ~4.5 wt.% (~2.4 kg H2/100 l) are achievable for CGH2 storage and ~14 wt.% (~4 kg H2/100 l) for LH2 storage (STORHY), whereas for reversible solid storage at room temperature ~1.8 wt.% (alanates) is state of the art (NESSHY), and higher values are achievable for temperatures of interest for FC applications (80°-100°C). However, in spite of this progress, none of the storage routes investigated (liquid, gaseous, and solid) meets the targets necessary for successful commercialisation, neither for on-board nor for off-board storage applications.

Major bottlenecks include system capacity, safety, storage losses, permeability, energy losses, tank design, heat management, recycling of materials and last but not least costs. Clearly, what type of hydrogen storage method is most suitable for what particular application it still an open question. While progress for LH2 concerns mainly the design of compact, light and free-form tanks, the issues of energy penalty (liquefaction), storage losses (boil-off, permeability) and costs need to be addressed in more detail. Compressed gas tanks reaching 700 bar hydrogen pressure appear to be state of the art, but concerns persist concerning safety (aging, fatigue, failure, burst, permeability of liners), energy loss (compression needs energy, cold filling needs instalment of an heat exchanger), environment (recyclable materials), costs (in particular for composite structures) and certification.

Solid storage, which is the safest and most energy saving method, does not yet meet technical and economic criteria, in particular for mobile applications (weight, cyclability, operation temperature, kinetics, material cost). As to environmental issues, only few projects addressed them explicitly during the presentation (for example STORHY: recycling of high-pressure tank materials). Finally, crosscutting issues such as training and education were well covered, while other issues such as safety, regulations, dissemination were covered to a lesser extent. The Marie-Curie actions appeared to be particularly successful, although some concern was voiced about problems in recruiting (and keeping) young and promising scientists. Once again, in an industrial-led environment, training in future technologies might be neglected, together with the need for fundamental research. The JTI may wish to reconsider this issue.

The portfolio covers well IDA1 (Hydrogen vehicles and refuelling stations) and IDA2 (Sustainable Hydrogen Production and Supply). Hydrogen storage is not mentioned within IDA3 (Fuel Cells for CHP and Power Generation) or IDA4 (Fuel Cells for Early Markets). Given the importance of hydrogen storage for FC applications, this omission is puzzling, as is the low profile of "solid storage" in the IP document. The JTI may wish to review this decision.

A good balance has been struck between applied and fundamental research. Theoretical calculations were used for screening potentially interesting hydrogen storage materials, but among those suggested only few were found to be of practical interest, in particular with respect to hydrogen content and thermodynamics. Theory was less commonly used to solve engineering issues such as tank design. The potential of theoretical simulations for finding novel materials and addressing engineering tasks has not yet been fully explored.

The presentations indicate that the lack of a basic understanding of materials properties is limiting progress. Examples include ways to reduce aging and associated failure in compressed gas cylinders, the search of insulating materials for decreasing the boil-off rate of liquid hydrogen, and the improvement of the hydrogen sorption properties of carbon cone materials through a better understanding of the hydrogen-carbon interactions. There is a need for a deeper fundamental understanding of materials properties, and therefore for basic research.

Some performance targets in the IP document need to be revised and others introduced. In IDA1, no targets are given for liquid and gaseous hydrogen storage. These technologies are only expected to “improve”. In IDA2 only density targets are given for tank systems; weight is not a sufficient criterion to guarantee success for off-board storage systems, but thermodynamics, price, kinetics, etc. must also be considered. Furthermore, the different energetic efficiencies of the various hydrogen storage technologies need to be an assessed and compared.

The project portfolio under FP6 has created a relatively dense European research network in the field of hydrogen storage, but there are opportunities for wider collaboration. Coordination with national programmes appears to be weak. The JTI needs to elaborate a strategy better to coordinate the efforts of the EU and member states.

4.3 HYDROGEN INFRASTRUCTURE BUILD UP

4.3.1 Review

There are many references to infrastructure throughout the Implementation Plan; creation of a sustainable infrastructure is almost the guiding principle of the Plan. The extent to which topics contribute to this goal is the main criterion for the assignment of priorities within the IP. High priority levels are assigned to critical elements that help to build up sustainable hydrogen infrastructure across the EU. Medium priority levels are assigned to actions needed to consolidate this infrastructure and low priorities to actions that bear on components of the hydrogen fuel chain that are already well established.

The Implementation Plan envisages within IDA 1 a substantial programme of demonstration for infrastructure. In the first phase, running to 2010, this will comprise 13 demonstration sites for road vehicles, focusing on captive fleets and comprising around 200 vehicles and nine hydrogen-refuelling stations. The objective is to bridge the gap between the isolated prototype demonstrations operating now and future mass-market installation. Technically, it is intended to demonstrate refuelling at 700 bar. This group of demonstrations is planned to be in place by 2010. Larger scale demonstrations are planned for the second phase covering 30 sites with 3000 vehicles and the linking of clusters of users of hydrogen. It is expected to achieve a delivered cost for hydrogen of 2.5 €/kg, excluding tax.

The IDA 2 aims to achieve a portfolio of sustainable hydrogen production, storage and distribution processes. It identifies strategic planning and in-depth assessment of infrastructure development as of “paramount” importance in this endeavour, requiring integrated socio-economic decision support models. The second objective of this IDA is to develop the components of a mass delivery infrastructure beyond 2020-30. The outcomes of IDA 2 are intended to inform the large-scale demonstration activities within the other IDAs. IDA 2 envisions the continued improvement of decision support tools for the assessment of hydrogen systems using the real data acquired from the demonstration activities. It also includes R&D work to advance the technology of hydrogen delivery in support of the demonstration projects.

The projects from FP6 presented in the workshop addressed or are addressing many of the needs identified in the Implementation Plan. The only completed project is HyWays (2004-07). This project has been recognised by the IPHE as a leading international project. It aimed to map the geographical potential for hydrogen production and the location of early users and to combine this with an assessment of the technical potential of various hydrogen delivery chains to assess how hydrogen infrastructure might develop. The focus was on transport. The methodological approach is based on sustained dialogue with national teams, modelling of their revealed preferences and deduction of the implications for infrastructure. The modelling assumptions were selected to reproduce the market penetrations specified in snapshot 2020 and vision 2050. The results were combined into a Road Map that identified the critical steps along the way to large-scale use of hydrogen and an Action Plan that identified necessary policy measures.

The Road Map is a useful document that elaborates the idea of clusters of early users joined by a supply network developing from these clusters. It identifies a particularly promising corridor from North West Italy through the Rhine-Ruhr into Benelux countries. The Action Plan analyses and recommends policy measures, but it is at a high level of generality and further work is needed to provide a sound basis for the design of specific policy instruments. This is important for the adoption of fuel cell and hydrogen technologies and needs to be addressed within IDA 2.

Roads2HyCom (2005-8) arose from the "Quick Start Programme", endorsed at the European Council of December 2003, designed to stimulate economic growth through infrastructure. This programme included the HyCom concept, in which the assessment of hydrogen penetration is made starting from the needs of communities. The broad scope is similar in some ways to HyWays, as the project seeks to understand how hydrogen resources, technological capability and user demand will interact to define the way hydrogen penetrates the economy. The innovative element of Roads2HyCom lies in its focus on the needs of communities and the mechanisms to engage the political institutions that represent local communities. One of the most important outputs of the project is its support to communities through information and training. The project investigates infrastructure build up by mapping existing projects, the availability of "surplus" hydrogen and analysing the motivation of communities to be involved. The project has created a substantial database of existing demonstration projects, hydrogen production and distribution facilities; it concurs with HyWays in detecting a strong corridor from Benelux to NW Italy via the Rhine-Ruhr.

A third FP6 project, DYNAMIS (2006-9), started in March 2006 and will run for three years; it aims to conceptualize HYPOGEN, another concept of the "Quick Start Programme" this for the large-scale production of hydrogen and power from fossil fuels with the sequestration of CO2. An important aspect of this project is the transport and storage infrastructure for hydrogen. DYNAMIS should deliver specifications for practical operation by 2012 together with feasibility and site studies for demonstration plants. These targets relate to power generation from hydrogen-fuelled gas turbines (400 MW electrical output plus 50 MW of hydrogen), flexibility of hydrogen production and standards for the effectiveness and cost-efficiency of carbon capture. The project addresses the infrastructure implications of disposing of the CO2 and of making hydrogen available for use; it has determined 10 pairs of existing production sites and potential disposal sites, suitable for demonstration. The need to develop legal frameworks for the use of aquifers for CO2 storage is a significant issue. The study shows that bus fleets are the most appropriate market and that a fleet of some 200 buses is optimum (such as would be needed in a city the size of Hamburg). A large-scale site of the type envisaged could produce hydrogen for 1000 buses, i.e. five cities. The build-up of infrastructure from large-scale facilities will be difficult; to amortise the investment requires a rapid build up of demand and no organisation is likely quickly to buy 200 buses, because of the cost and the state of the technology.

Various FP6 projects that were not presented in the session were recognised as having made (or as making) significant contributions to the understanding of how, where and why infrastructure might develop. These include HyLights (2006-8); this is a coordination action to prepare European demonstration projects for hydrogen and fuel cells in transport, PREMIA (2004-7) -a project to assess policy measures in support of transport demonstration and infrastructure - and earlier demonstration projects (HYFLEET:CUTE and ZERO REGIO).

The USA also has a programme to assess hydrogen pathways and this was presented at the workshop. The approach is rather different to that in Europe and is more commercially focused. The presentation of the DoE showed a logical, progressive model structure within which clear solutions could be defined based on specified criteria. This contrasts with the more diffuse, consultative approach being undertaken in Europe. The difference might be explained by the greater authority of the DoE within its jurisdiction compared to that enjoyed by any body within Europe. The complex political structure of Europe does not permit simple solutions. The strength of the European approach lies in its diversity and the sensitisation of communities of users. Within the IPHE project, HyWays has worked with the US DoE to compare approaches and results. Some technical differences emerge; there is in the US some scepticism over pipeline infrastructure and a view that compressed hydrogen on trucks would be the initial technology for moving hydrogen. The early markets appear to have been identified as middle-class car owners seeking novelty and environmental credit rather than urban bus fleets. The technical and commercial aspects of analysis predominate in the US scheme, whereas in Europe there is more attention paid to social aspects – consensus building, regional development, employment.

The Implementation Plan envisages a total expenditure over the period to 7.4 bn € - much more than the resources available to the JTI. Bridging this large gap is critical to the execution of the Plan. It will be necessary to seek innovative financial instruments to cover this funding need. A possible candidate is the Risk Sharing Financial Facility (RSFF) an instrument jointly developed by the Commission and the European Investment Bank (EIB). The aim of this facility is to increase private investment in research by improving access to EIB loan finance. It will permit the financing of risky, but bankable research projects, providing that they have a financial profile that will support a loan. The RSFF is theoretically available for corporate and project finance, but given the nature of hydrogen infrastructure projects and the multiple partners, the appropriate format is likely to be project finance to a distinct legal entity that owns and operates the infrastructure. The facility presents an interesting option to fund later stage projects, providing that they can be established as a legal entity with a revenue stream adequate to support the loan. Guidelines for demonstration projects should recognise these requirements at an early stage in the identification and design of projects.

4.3.2 Assessment

The road mapping activities within FP6 have made a substantial contribution at the technical level to understanding how infrastructure will develop, but there are missing elements. More work is needed to establish how large-scale penetration of hydrogen will affect energy prices and how other technologies would react, taking into account that if hydrogen is available in large volumes it can also be used to refine low grade hydrocarbons that may be available in large volumes. Potentially these tools can help identify how and when public authorities should intervene to establish codes, standards, regulations and market-based incentives. The tools cannot yet provide reliable guides to policy – this is an important deficiency. More work is needed to examine the optimal design and depth of policy interventions, the costs and the welfare benefits.

The road mapping activity needs to be refined to deal more sensitively with practical issues of market penetration, for example, there is a need to develop business plans for the conversion of bus fleets to hydrogen dependent upon the age profile of the existing capital stock and the financial possibilities. There is also a need to consider the sociological aspects of early adoption and the manner in which it may be stimulated. To some extent, this could be addressed in Roads2HyCom, but probably will need further attention subsequently. It could help to extend the modelling work to include business scientists, economists and sociologists.

The link between the demonstration stage and the early market is not well understood. It is unlikely that spontaneous replication will occur based on the demonstration sites envisaged within the JTI. A much larger programme of publicly supported work is likely to be needed between the large-scale demonstration plants and the early market and the funding of this is not evident. The RSFF offers an interesting option for funding. It requires that projects be run within a distinct legal entity and with an adequate revenue stream, but by then this should be possible to achieve. The facility may also be useful for partial funding of the demonstration projects specified in the Implementation Plan. Guidelines for the design and support of demonstration projects should seriously consider this option and the requirements.

Collaboration with countries outside the EU in technology assessment, validation and road mapping is likely to be beneficial; it has been initiated with the US, but should be strengthened. Differences in policy, economic and social structure will limit the direct transfer of techniques, but bench marking of data and comparison of methodologies is valuable. The activity is not costly and sufficiently far from market to avoid concerns over commercial confidentiality and competitive advantage.

4.4 BASIC RESEARCH ON FUEL CELLS

4.4.1 Review

In the two sessions on “Fuel cell basic research”, eight FP6 projects were presented: five deal predominantly with road transport applications, two with stationary applications and one addresses generic fuel cell modelling.

Road transport applications

In the HFP Implementation Plan (IP), road transport comes within Innovation and Development Action 1 (IDA 1). Three major fuel cell applications (passenger cars, buses and auxiliary power units) are mentioned with the following 2015 targets:

	Efficiency (%)	Fuel cell system cost(€/kW)	Lifetime (hrs)
Cars	40	100	5 000
Buses	40	100	10 000
APU	35	500	5 000 (for passenger cars) and 40 000 (for lorries)

For these applications, hand-made low- temperature (LT) PEMFC systems operating at 80 ^{o}C are currently used costing around 2000 – 3000 €/kW. Fuel cells are in general suitable for cheap mass production because they have few different parts. Studies in the US have demonstrated that with the current state of the art, mass-produced hydrogen fuelled PEMFC may cost around 300 €/kW. Major barriers for further cost reduction are the high cost of the electrolyte membrane and of the platinum catalyst. The cost of currently used Nafion membranes alone ranges from 50 to 100 €/kW, where the thickness of the membrane (and related lifetime) is an important cost factor. The cost of the platinum catalyst per kW is around 50 € (assuming a power density of 0.6 W/cm2 and a platinum load of 1mgPt/cm2). RTD aiming at cost reduction for electrolyte membranes and catalysts is key to achieving the IP cost target of 100 €/kW.

Five projects seek to reduce cost by developing high temperature (HT) PEMFC operating at 130-200 ^{o}C. With LT PEMFC, it is hard to reject the heat in car applications; the higher operating temperatures of HT PEMFC will mitigate this problem. The research effort is focused on cheap non-noble metal catalysts and on very cheap electrolyte membranes, e.g. polybenzimidazole (PBI), that have lower system costs because they do not require humidification, yet that have power densities comparable to those of LT PEMFC. In previous research, it has been shown that a cheap PBI membrane with phosphoric acid in HT PEMFC can achieve power densities of 0.3-0.5 W/cm2 at 150 ^{o}C with a CO tolerance of 3%, allowing for a cheaper reformer (the tolerance for CO in HT PEMFC is 1000 times higher than in LT PEMFC). At 0.35 W/cm2, 150 ^{o}C and a Pt load of 0.6 mgPt/cm2, a lifetime of 5000 hours with 140 thermal cycles has been demonstrated in 2002; with a voltage degradation 01%/1000 hours.

The integrated project FURIM (2004-8) is building a 2 kW HT PEMFC for APU applications in cars, operating at 170 ^{o}C with a reformer using diesel oil (consistent with the action clusters of IDA1). This fuel cell application has the advantage that the IP cost target for APUs is easier to achieve than that for car propulsion. HT PEMFC APUs therefore present an early market opportunity; they may also have other early market applications and stationary applications (IDA 3 and 4). After these promising results the FURIM project began development of a 2 kW HT PEMFC unit in April 2004. In view of mechanical stability problems with PBI membranes, new blend PBI/SFS membranes has been developed with better mechanical stability. The progress of stack and reformer development was not presented in detail.

APOLLON - B (2006-9) is developing cheap HT electrolyte membranes and low cost noble metal catalysts. The work concentrates on car applications, but is also relevant to IDA 3 and IDA 4. After a broad search for HT electrolyte membranes, research focused on a new aromatic polyether, TPS, containing polar pyridine units in the main chain. TPS has excellent film forming properties, a high thermal and chemical stability and can be doped with phosphoric acid, leading to a high ion conductivity (>10-2 S/cm) in the temperature range 130-200 0C. Lifetime tests with the TPS polymer membrane containing phosphoric acid have been carried out for 1700 hours at 180^{o}C, 0.5 V, 0.5 - 0.6 A/cm^{2} and with a Pt load of 1 mgPt/cm^{2}. No decrease in efficiency due to degradation was observed; in fact the current density (and efficiency) at a constant voltage of 0.5 V, increased 20% with time; this requires further investigation. Research for cheap catalysts was aimed at non- or partly noble metal cathodic catalysts Fe/C and Pt/Cu-CeO2/C. Fe/C showed insufficient catalytic activity; Pt/Cu-CeO2/C is promising, but has the drawback that it still contains platinum. Collaboration with AUTOBRANE and CARISMA (see below) should be encouraged

AUTOBRANE (2005-9) also aims to develop low cost noble metal catalysts and new, cheap HT (130 °C) electrolyte membranes, with a high thermal and chemical stability, for use in high power density (> 1 W/ cm2) HT PEMFC. The project has examined a variety of membranes and will shortly select membranes for further investigation. Catalyst research within the project has identified catalysts with enhanced stability compared to benchmark catalysts (at 80°C). Model Pt and Pt/alloy thin film catalysts were synthesized and practical Pt and Pt/alloy catalysts have been fabricated on treated and new supports. Equipment for the testing of catalysts at 130°C has been set up and tests at these temperatures will start soon. An important objective of the project is to develop Membrane Electrode Assemblies (MEAs) suitable for automotive high temperature operation. MEAs with the three of the best-investigated membranes are being prepared, namely polybenzimidazole (PBI), hybrid, and perfluorosulphonate ionomeric (PFSI). A first test with a MEA of PFSI gave only 0.07 W/ cm2 at 120°C. Substantial improvements will be needed to achieve the target of 1 W/ cm2 at 130°C. There is a close collaboration with the CARISMA coordination project and IPHE-GENIE, which started in 2006.

CARISMA (2007-9) is a coordination action to network research in Europe on membrane electrode assemblies operating at high temperature and their components. Activities cover: membranes, catalysts and high temperature MEAs; the impact of high temperature operation on degradation of MEA components and MEA durability; proton transfer mechanisms operating in water free conditions, and technical specifications for high temperature PEMFC applications. CARISMA established contacts with the US High Temperature Membrane Working Group (HTMWG) group and a joint meeting was held in the US on October 10th 2007. A meeting with a similar group in Japan is envisaged. CARISMA and AUTOBRANE have both been recognised by the IPHE as leading international projects.

FCANODE (2007-10) aims at the development of cheap non- or low noble metal catalysts (< 25 €/kW) for the hydrogen oxidation reaction at the anode of HT PEMFC in a temperature range of 130-200 °C. Such innovation would reduce the cost of fuel cells and bring them closer to commercialisation. The research falls within IP actions IDA 1 on catalysts and IDA 3 on generic fuel cell research; it is also relevant for stack development for different applications in IDA 4.There are no results yet. Collaboration with APOLLON-B, AUTOBRANE and CARISMA could lead to synergies

SOFC for stationary applications

In the HFP Implementation Plan (IP), stationary applications are dealt with in IDA 3. For residential and industrial applications, the following 2012 targets were set in the IP.

	Efficiency (%)	Fuel cell system cost (€/kW)	Lifetime (hrs)
Residential	40	6000	>12 000 hours (10% degradation)
Industrial	40	1500 - 5000	>30 000 hours (10% degradation)

The projects Real-SOFC and SOFC600 address these issues within FP6; both deal with planar SOFC for stationary applications, operating between 600 and 800°C. Major problems are voltage (and efficiency) degradation (1-3 % per 1000 hours) and sealing, particularly because of high temperature operation, slow start-up of up to 10 hours, limited number of thermal cycles and carbon deposition in the case of reforming. The projects both engage in systematic material research to reduce degradation in planar SOFC operating at 800 and 600 ^{o}C respectively. At 800 ^{o}C, degradation is faster than at 600 ^{o}C, but the cost per kW is lower due to a higher power density. Both projects address the IP topics under IDA 3 and IDA 4 and are relevant to IDA 1 for on-board APU applications, where SOFC is not currently included.

Real-SOFC (2004-8) aims to develop cells with a degradation rate <0.5% per 1000 hours, a stack life of >10000 hours and >100 thermal cycles. It is also envisaged to develop two proofs of concept, including laboratory equipment tests, for pressurised operation of SOFC stacks (5 to 50 kW range) coupled with gas turbines. To reach these targets for SOFC operating at 800 ^{o}C (including reforming of dry methane), a systematic materials research was made on the bipolar plate, the anode (e.g. carbon deposition), cathode and new electrolyte materials and in general micro-structural analysis (for sulphur and chromium poisoning). In a first test, a stack of three cells at 800 ^{o}C with hydrogen and oxygen and a power density of 0.25 W/ cm2 operated for 3500 hours with a degradation rate of 3.5% per 1000 hrs; this high degradation may be caused by chromium poisoning. With this disappointing performance, much work is needed to achieve the targets. It will be challenging to do this before the end of the project and the preparation of proofs of concept for pressurised 5 and 50 kW SOFC stacks with gas turbines may be premature. Collaboration on standardisation of testing conditions is going on with the projects SOFCNet, FCTESQA and SOFC600. There is also an interaction with the IEA Advance Fuel Cells Implementing Agreement.

SOFC600 (2006-10) has been recognised by the IPHE as a leading international project. It investigates planar SOFC at lower temperatures (600 ^{o}C), where degradation may be expected to be slower; the target is a stack degradation rate of < 0.1% per 1000 hours. The cost target of 2500 €/kW is well below the IP cost targets. Intermediate performance targets have been met for anodes and cathodes and for the electrolyte. Progress has been made in developing a process for manufacture on non-sintering substrates, but cost is a concern. HT glass seals for 600 °C have been identified to meet sealing targets and metal-metal seals are being investigated. The integrated cell performs close to intermediate performance target, but shows excessive ohmic losses and a higher than expected degradation. Endurance tests showed a very high degradation immediately after starting the tests; a possible cause could be the measuring system. Further research will be needed to achieve the project targets. There is collaboration with REAL-SOFC, FlameSOFC, BIOCELLUS and Green Fuel Cell; test procedures developed by FCTESTQA are used by SOFC600.

Generic fuel cell modelling GENFC

GENFC (2007-10) should provide a generic modelling tool for fuel cell and fuel cell systems developers making fuel cell modelling expert knowledge available to all of them. This project addresses IP actions within IDA 1, IDA 3 and IDA 4. Existing and future models and hardware for different types of fuel cells on all levels from system integration, via stack and cell down to electrode processes, are integrated in the tool and interfaced with a common database for process and design parameters. A first model will be ready in March 2008. For PEMFC testing protocols developed within the FP5 Thematic Network FCTESTNET will be used.

4.4.2 Assessment

After many years of research, there are hardly any commercial applications of fuel cells. The results presented during the Review Days indicate the obstacles. In road transport, the IP targets for fuel cell applications in private cars are a cost of 100 €/kW and a life of 5000 hours. Whereas the lifetime is achievable with present day LT PEMFC, the cost target can only be achieved if the cost of the membrane and the platinum load can be severely reduced. The focus on HT PEMFC with cheap membranes and non-noble catalyst is therefore appropriate, but progress will be difficult. Progress in the projects reported, was either described in too little detail to be assessable, or appeared slow. In the FURIM project, insufficient information was given on the progress and performance of the stack. HT membrane research in AUTOBRANE has not yet resulted in promising options; APOLLON-B identified an interesting membrane, but still much work is needed to develop a stack. It appears that research on cheap noble catalysts has not yet resulted in promising options. A variant approach is to develop PEMFC with a low platinum load of fine nano-particles. The US DOE aims to reduce the current Pt load of 1 mg Pt/ cm^2 to 0.1 Pt/cm^2 in 2010. The lack of published data on stack performance will make it difficult to establish targets for the next round of research.

Planar SOFC suffers from voltage (and efficiency) degradation (1-3 % per 1000 hours). REALSOFC has not been able to improve on historic performance; first results of SOFC600 are also not promising. Major degradation problems in planar SOFC are have been noted in the US DOE SECA programme where the degradation rate in five planar SOFC systems of 3 kW, varies between 1 and 3% per 1000 hours. In this trial, the only project with tubular SOFC demonstrated a very low degradation in 100 kW systems (0.1% per 1000 hours) and did not have sealing problems (sealing occurs here at the low temperature part of the fuel cell). Tubular SOFC has a high cost partly due to a low power density; 0.15 W/ cm^2 as compared to 0.5 W/ cm^2 for planar SOFC. There is some indication that power densities could be increased and therefore costs reduced; this option may deserve more attention in the EU HFP program.

Although advanced concepts are important, their commercial development may be delayed by slow progress in the basic research. The JTI on hydrogen and fuel cells should therefore continue to work on LT PEMFC, which is closer to the market. Applied R&D, including industrial research on series and mass production of fuel cell systems and components, will be needed to scale up applications and to meet cost and performance targets. Basic research is still needed to reduce the Pt load and prolong life by reducing corrosion and degradation.

4.5 TRANSPORT APPLICATIONS

4.5.1 Review

The Transport Session was mainly relevant to IDA 1 on Hydrogen Vehicles and Refuelling Technologies; it included three fleet demonstration projects, namely HyFLEET:CUTE (2006-10), HYCHAIN-MINITRANS (2006-10) and ZERO REGIO (2004-9) which are partly oriented also to IDA 4 on Early Market Initiatives. It included also HYICE for internal combination engines. HyFLEET:CUTE (and a predecessor CUTE-ECTOS) and HYCHAIN-MINITRANS have all been recognised by the IPHE as leading international projects.

Fleet Demonstration projects

HYFLEET:CUTE is a follow-up to CUTE-ECTOS, these projects involved Chinese and Australian partners and operated thirty hydrogen fuel cell powered buses in nine cities. This experience provided substantial familiarity of fuel cell vehicle and hydrogen infrastructure applications in day-to-day operations and helped to raise the expectations in the public domain including the city and transit authorities. HYFLEET:CUTE will introduce further innovations and extend the scope of operations. It will operate hydrogen internal combustion engine buses in regular public transport in Berlin and demonstrate on-site hydrogen production. The knowledge will allow a comprehensive life-cycle assessment of all advanced public transport technologies currently on the market under real life conditions. The project aims to reach a price for hydrogen ICE vehicle operation close to the price for current vehicle operation. It will continue to develop fuel cell technology, to increase the fuel cell lifetime and to reduce the fuel consumption. Hybridisation will be used to increase lifetime, reliability and efficiency and automotive fuel cell systems will be applied in order to reduce costs, weight and volume. Fuel cell and ICE hydrogen buses have to be considered and designed as one modular family concept and both should aim at using common platforms for the on-board hydrogen systems and related safety and certification concepts.

Diesel buses (and in future diesel hybrids) are the benchmark for costs and efficiency. The goal of HYICE (2004-7) is to develop an engine concept with the potential to surpass the performance of diesel engines at reasonable cost. HYICE is optimising combustion with direct injection, cryogenic port injection concepts and plasma spark ignition. Best point efficiencies of up to 42-46 % for the MAN 200kW Bus engine and power densities of up to 17 % higher than modern gasoline engines seem to be feasible. In combination with ULEV- and Zero-CO2- capabilities and the potential of using regenerative fuel as basis, the Hydrogen-ICE concept has progressed to move to a significant and a valuable building block of the IDA 1 strategy.

The objective of HYCHAIN-MINITRANS is to manage an early market entry approach in four European regions by deploying portable hydrogen storage units (clip-in-and-drive) along with a logistic and distribution concept for them. As first step, it aims at niche market applications in the transportation segment mainly in form of equipping battery-electric vehicles with a fuel cell and hydrogen system. ZERO REGIO (2004-9) aims to develop and demonstrate infrastructure systems for hydrogen as a motor fuel. This includes 700 bar refuelling technology, deployment of by-product hydrogen, pipeline transport of hydrogen and the development and test of an ionic liquid compressor. The demonstration programme is foreseen with five vehicles from Daimler and three vehicles from FIAT in Frankfurt and Mantova.

Fuel Cell applications in transport

The systematic approach covers four areas: hydrogen and fuel cell technologies (HYTRAN, 2004-9); fuel cell vehicle system components (HYSYS, 2005-9); power electronics (HOPE, 2006-9); fuel cell power trains and clustering (FELICITAS, 2005-8).

For bus and heavy duty applications, twin cluster concepts for PEMFCs were developed and demonstrated in FELICITAS. The possibility of clustering modules to reduce product and development costs seems to become an important element in the fuel cell business. In the long-run, it can be seen as an inherent advantage of fuel cells compared to ICEs, which always require a multitude of engines to cover the required vehicle portfolio of a company. FELICITAS demonstrated that the clustering concept is valid and that combined with hybridization, the lifetime and efficiency of the FC engine can be increased significantly. The results will be applied directly in HYFLEET CUTE aiming at about 4-5000 hrs lifetime and efficiencies above 50 %.

HYTRAN`s approach is to improve the performance and cost of fuel cells by integrating components into two innovative, fully integrated fuel cell systems. One is a direct hydrogen PEM fuel cell system of 80 kW, with innovative stack and balance of plant (BoP); the other is an APU diesel reformate, PEM fuel cell system of 5 kW, including a micro - structured steam reformer, clean-up reactor, stack and BoP. The 80 kW Stack is completed; it will be integrated in a vehicle and validated at the end of 2007 and in 2008. The JTI needs to compare the performance of the HYTRAN vehicle with the next generation of FCVs from car manufacturers, which are expected to be available at the end of 2008, to determine the base line for follow-up programmes in IDA1.

HYSYS aims to improve cost and performance in specific aspects of the FC-system and the hybrid drive train, e.g. air supply modules, humidifiers, hydrogen sensors, Li-ion batteries, power electronics, and electric motor components. Synergies with ICE Hybrids are identified to enable a broader application platform with the expectation of reducing costs in this way. The “validator vehicles” of the HYSYS programme are delivery vans. Fleet applications with delivery vans using central fuelling stations and serving customers mainly in urban areas are suited for early ZEV-FCV applications. There is at present no demonstration programme of this technology; the JTI might consider using the results of HYSYS to stimulate such a programme with orientation to pre-commercialisation in 2015.

HOPE is evaluating high power electronic technologies with respect to the reliability requirements and high temperature operating conditions in automotive power trains: i.e., active and passive components, sensors and substrates, SiC devices with integrated passive elements, joining and interconnection technologies, advanced cooling techniques. These are fields where fundamental application oriented R&D work is needed because power electronics are crucial components in the automotive environment and they are contributing significantly to problems of reliability, safety, costs and packaging.

CELINA (2005-8) investigates the technical capabilities of an existing fuel cell system under aircraft operation conditions. It is intended to characterise the differences between the current fuel cell systems and an airworthy design and to identify the requirements of an airworthy design. The project has developed a certification specification for fuel cell power systems in large airplanes and has worked with the aviation industry to establish relevant rules and regulations. It has investigated the overall system and interaction of the system components under aircraft conditions and partly validated its simulations with experimental tests.

MC-WAP (2005-10) is a project to investigate molten-carbonate fuel cells for waterborne application. The main objective is to give to the maritime industry a benchmarking based on real-life and real-size tests on board of MCFC performance. In the period under review, it successfully identified the state of the art in MCFC, desulphurisation and fuel reforming for marine applications. It has identified expected power profiles and operating conditions and has prepared preliminary designs.

4.5.2 Assessment

To cover all the transport applications and, at the same time, to achieve a meaningful portfolio of relevant fuel cell and reformer technologies with the limited resources available under FP6 is an ambitious objective. The approach within FP6 was to complete a matrix of technologies and applications and the result is as good as could be reasonably expected. A good balance has also been achieved, between focused and application oriented programmes like MC-WAP (maritime) and Celina (airplane) and broader programmes like the product cluster concept in PEMFC and SOFC technology.

The principle topics of IDA 1 are well addressed in the Research and Development part with clear priority to the development of PEMFC technology for the drive train. The portfolio of programmes covers the spectrum of vehicular components, sub-systems and systems with only small overlap between the projects. The main road transportation segments are covered in the programmes and vehicles for validation purposes of pre- commercialisation readiness in all those areas will be built up. Demonstration programmes for urban buses are being implemented.

Some gaps can be identified:

- A dedicated program for delivery van fleet applications equivalent to that for urban buses is needed.
- The progress in PEMFC stack and BoP technology seems insufficient to bring Europe in a leading position or to close the gap with the state-of-the-art in North America and Japan.

IDA 1 addresses as well, with lower priority, APU and reformer technology and the utilisation of PEMFC, SOFC and MCFC in other transportation segments. Both areas are covered in the FP6 Transportation Programme Portfolio:

- HYTRAN - 5 kW Diesel Reformate PEMFCS- APU
- CELINA – (up to) 65 kW Kerosene Reformate PEMFC-APU for Airplanes
- MC-WAP – (up to) 500 kW Reformate MCFC-APU for maritime applications
- FELICITAS - PEMFC and SOFC- APUs (and propulsion systems) for trucks, buses, light and heavy rail and marine applications.

The objective of IDA1 is “to kick-start the mass production of hydrogen vehicles by 2015 and permit their ensuing market deployment”. It is likely that a much stronger approach for demonstration programmes has to be prepared. FP6 is a first step but the total scope of existing demonstration programmes may not to be enough to stimulate users and manufacturers to invest seriously. This constitutes a serious gap between the objectives of the IP/IDA1 and the status achieved up to now in FP6.

North America and Japan have very active programmes; about 300 fuel cell vehicles with fuel cell drive trains have been tested in these countries in the last 5 years. About 2500 are planned for a market introduction programme in US/California within the next 5 years. Without a comparable market introduction programme in Europe, the gap to the North-American and Japanese industry will become bigger and perhaps un-recoverable.

4.6 STATIONARY APPLICATIONS

4.6.1 Review

Five projects were presented in this session: BICEPS (2007-11), Flame SOFC (2005-9), NextGenCell (2006-8), LargeSOFC (2007-9) and MOREPOWER (2004-7). The last of these had been completed and the others were in progress.

BICEPS (2007-11) is focused on the development of MCFC technology for large-scale commercial and industrial applications. The objective is to design, build, test and operate two MCFC power plants running on biogas from sewage gas (Italy) and landfill gas (Spain) and finally to demonstrate the cost-effective use of biogas for high-efficiency energy production. The project has begun recently and there is as yet little progress to report.

Flame SOFC (2005-9) aims to develop a robust, stationary micro-CHP for domestic application using SOFC and operating on a range of fuels, including natural gas, LPG and fatty-acid methyl ester. The targets are a 2 kWe net output with a modulation > 1:4, an electrical efficiency > 30% (up to 35% seasonally); > 90% total CHP efficiency and durability > 30,000h. Cost target is < 1950 €/kW for the complete system. A prototype has been constructed and preliminary tests are being made. Detailed simulation tools for the component development and optimization have been developed. The 3D integration studies for the system layout of the second generation of plants are underway.

NextGenCell is a joint EU and US collaborative effort within the framework of the existing EU-US Cooperation Agreement on fuel cells. The project has been recognised by the IPHE; it aims to develop a PEM fuel cell for domestic CHP. The goal is a 1 - 5 kW HT PEM fuel cell prototype micro CHP system with modular designs. The project responds to the IP IDA3 on fuel cells for heat and power generation, for efficient, distributed and diversified energy production. It expects to reach or exceed IP targets for efficiency and cost.

LargeSOFC is preparing concepts for large-scale SOFC fuel cell systems for commercial and industrial applications. It addresses the basic problems of scaling up from kW to MW size plants, focusing on technologies with a potential for low manufacturing cost. Performance targets are electrical efficiency 60%; total efficiency (CHP) 90%; system cost 1000 €/kW; lifetime 50,000 h. The project is relevant to IDA3.

MOREPOWER was intended to develop a low cost, low temperature, portable direct methanol (or ethanol) fuel cell of modular design with an output of 500 W, operating at 40 A and 12.5 V and temperatures up to 60^{o}C. Applications envisaged include weather stations, medical devices, signal units, APU's, gas sensors and security cameras. The project achieved a fuel cell stack for 350 W operating with 1molar methanol solution at 60^{o}C. It achieved 90 % of the single cell target for methanol and 70 % of the single cell target for ethanol using PtCo/C or PtFe/C catalysts at 80oC and 1 bar and practically 100% was achieved operating at 2 bar.

4.6.2 Assessment

These projects demonstrate the range of technologies available for stationary and portable applications, from domestic CHP systems of several kW electrical outputs to large-scale fuel cells from 50kW up to 1MW for commerce and industry. Work comprised a mix of basic and applied research with demonstration in the sense of technology validation, but no large-scale demonstration activity. The collaborations include research institutes and universities, businesses, large and SMEs, fuel cell developers and end users across Europe.

The projects show ambition in the overall project objectives and deliverables, both in their technical and economic targets. Progress is being made in technology development and knowledge creation, and there are clearly opportunities of learning by doing which increase the breadth and depth of knowledge within Europe.

There is a growing appreciation and understanding of the need for knowledge development and creation in Balance of Plant as opposed to simply cell and stack. The BoP, e.g. fuel processing, power electronics, air and fuel movement and circulation and heat exchangers are fundamental to creation of successful systems, as is the system development itself. It is the system and the system components and sub-systems which create and maintain the conditions in which the cell and stack operates. These projects have shown that without effective systems cell and stack issues such as degradation are exacerbated.

More support is needed for developing BoP and systems integration expertise. Off-the-shelf components that are not designed to operate under the challenging conditions of fuel cells create weakness in fuel cell units. The emphasis in the past of basic research projects on cell and stack development has created an imbalance in the European knowledge and capability. Without a body of expertise and experience in these fields, Europe will fail to create successful stationary and portable fuel cell systems. Creating opportunities for European entities specialising in these areas is a priority for the activities under FP7.

European based fuel cell developers are preparing for technology validation and demonstration efforts over the period of the FP7; both at the small residential and the commercial/industrial scales. Europe is well placed to benefit from these activities, but only if it is possible to engage further developers through an expanded programme of activities under FP7 and the JTI. The European Public Sector must play its role in supporting European businesses in this high-risk development stage, and the efforts of not merely the European Commission, but Member States and Regions must be harnessed if the benefits of fuel cells are to become available to the communities of Europe. Without substantial increase in support, there is a real opportunity that the benefits of Europe’s expertise will diffuse outside of Europe towards the larger support programmes available in Japan and the USA.

Future projects need to show greater awareness of the market opportunities and link their efforts to the needs of the market and the particular technology challenges these entail. The HFP strategy sets out key technical targets and milestones to guide technology development from basic research to demonstration and lighthouse projects. Projects must show how their planned activities will help achieve these targets. Projects moving towards demonstration field trials will need to ensure that they incorporate end users in their activities to demonstrate the linkage with market.

5. Institutional and regulatory aspects

5.1 TECHNOLOGY VALIDATION AND ASSESSMENT

5.1.1 Review

Validation is taken here to mean the testing of hardware and systems according to their technical specifications and assessment means the evaluation of impacts and cost-effectiveness. The Implementation Plan identifies a need for integrated assessment of research and demonstration to support continuous review of technology progress and priority setting. The JTI should ensure good communication of results between applied research and demonstration, so that technological strengths and weaknesses can be identified early, and appropriate actions implemented to reduce time to market.

Common measurement standards and data analysis are required, as is the integration of modelled and experimental data; this facilitates benchmarking and forward extrapolation of performance - having regard to the latest technological developments – without always having to build extensive and expensive fleet demonstrations. Benchmarking progress against competing technologies is equally important – both for research and demonstration. This requires a comprehensive technology assessment framework for effective exchange of data.

The JTI can help facilitate the development of a comprehensive techno-economic assessment framework. It should provide performance and cost data for the benefit of both public and private stakeholders alike – both to benchmark progress against competing technologies and to provide continuous update to programme managers for priority setting.

Many projects of the Framework Programme have an element of technology validation and assessment and several of these projects were presented to the workshop on this topic. The EC presented the general approach they envisaged for the Sustainable Assessment of Technologies (SAT), based in dynamic life cycle assessment, using similar boundaries and functional units and a range of indicators. The Technology Platform for LCA has specified such an approach that is intended to be mandatory for projects with significant environmental impact. The dynamic nature of the SAT is captured by learning curves to anticipate technological change. An Integrated Project to develop the approach will be included in the 2008 programme of FP7.

The approach adopted by the US DoE in its assessment of electric hybrid vehicles was presented, stressing the value of integrated analysis and testing. The approach provided for an integrated analysis of policy and vehicle design so that the precise impacts of policy could be anticipated at an early stage and policy designed to be effective. The topic is suitable for EU-US cooperation at it has few direct commercial implications, but the caveat was noted that joint projects generally have low priority within any programme.

The Joint Research Centre (JRC) at Ispra has been a partner in the Eucar/Concawe/JRC Well-to-Wheel study on alternative fuels. This study aims to establish, in a transparent and objective manner, a consensual well-to-wheels energy use and GHG emissions assessment of a wide range of automotive fuels and power-trains including a range of hydrogen options. The work shows hydrogen to be non-competitive under present conditions, but with good potential in the longer term. The team is preparing forecasts for 2020 and 2030.

The purpose of Roads2HyCom (2005-8) is to assess and monitor hydrogen and fuel cell technologies for stationary and mobile energy applications. As a part of this work, it conducts validation based on the capability of the technology, current and future hydrogen infrastructures and energy resources, and the needs of communities that may be early adopters of the technology. It has developed eleven metrics of characteristics that affect adoption and though these metrics has begun to create a profile of early adopters.

PREMIA (2004-7) is an SSA (specific support action) that investigates the effectiveness of demonstration and incentive programmes to facilitate the introduction of biofuels and hydrogen in the transport markets of the European Union. The project developed an assessment framework for demonstration of hydrogen and biofuels use in transport. The common methodology is intended to help compare project outcomes and to build consistent conclusions. The framework comprises a technical part and a socio-economic part. The socio-economic evaluation covers awareness-raising, acceptance, energy security and socio-economic impact. There is an extensive list of performance indicators.

HyLights (2006-8) is a coordination action. Its objectives are to compile lessons from past and ongoing demonstrations, to agree an assessment framework to be used for the forthcoming large demonstration projects, to develop guidelines for planning demonstration projects and to improve the visibility of the hydrogen option. The consortium has found that progress is impeded by reluctance among implementers of demonstration projects to reveal detailed results. Clearly, the closer a technology gets to market the more valuable such information becomes and this may impede the development of a common framework.

$FCTEST^{QA}$ (2006-10) builds upon an FP5 project FCTESTNET and aims to establish a formal European procedure for validating and benchmarking fuel cell technology. It has developed test procedures and is now in the process of validating them. Critical in validation are the requirements that operating conditions can be reproduced and that testing cycles represent the real world. There has to be widespread agreement on criteria. Both HyLights and $FCTEST^{QA}$ have been recognised by the IPHE as leading international projects.

HYFLEET:CUTE (2006-10) was described in the Section 4.5 on transport applications. It operates buses in several cities and needs a common framework to assess and compare performance. It found it difficult to impose a common framework on multiple partners with their own approach. Lessons learnt were to develop the framework at the beginning of the project and to involve partners, to define data requirements before ordering hardware and to impose clear lines of responsibility with strong communication links.

5.1.2 Assessment

Ongoing assessment and validation of technology is important in order to check that the state of the art from research is advancing as required and to check that demonstrations are delivering the expected results in the real world. In a Public-Private Partnership, there is also a need for public accountability; ongoing assessment and validation activity supports this goal.

Work needs to be done to establish and agree a framework, as an early task for the JTI. Many tools and much data exist already in the EU and outside, but work is needed to pull these building blocks together. This is a significant task. The point was made several times that as technology approached commercialisation so the willingness to part with information decreases. The JTI will fund research and has technical capacity so it is in a favourable position to establish protocols and develop techniques for aggregate and, where appropriate, non-attributable benchmarking. As core functions, it needs to call for and negotiate demonstration projects, monitor and assess their performance and readjust project and performance goals. It therefore has legitimacy and a duty to ensure that the work is well done to a satisfactory and common framework.

An assessment and validation framework needs to be:

- Simple and easily understood, communicated well to all stakeholders
- Sophisticated enough to be useful, capturing key technical issues correctly
- Transparent, using agreed, open tools and databases
- Compatible with requirements for energy, environmental and economic impact assessment at policy level
- Capable of soundly based forward projection and analysis of future potential

In some instances, there are established tools or processes, in other cases these need to be developed more; in all instances, the approach needs to be agreed. Good baselines are needed, along with understanding of how these baselines or competitive benchmarks will evolve with time Assessment and validation measures need to be structured so that feedback across sectors and back into more basic research (including identifying component issues from system performance) is facilitated. Holistic life-cycle analysis and cost-benefit analysis (including externalities) is becoming increasingly important. Finally, there is a strong need to cooperate internationally Sharing tools and data for assessment and validation is less subject to commercial rivalry than other aspects of cooperation and not expensive.

5.2 REGULATIONS, CODES, STANDARDS AND SAFETY

5.2.1 Review

The preparation of regulations, codes and standards (RCS) is contained within the IP as a supporting activity that cuts across the IDAs. About 70 M€ is provisionally allocated to RCS, distributed across the IDAs. The topics envisaged are:

- Supporting the relevant directive initiatives
- Road vehicle logistics
- In-door use of H2 and fuel cell devices
- Grid-interconnect RCS
- Aerospace RCS development
- Maritime transport RCS development
- Rail transport RCS development

Preliminary work has been done by the Technology Platform Initiative Group, that undertook a Gap Analysis to determine what RCS existed already in Europe and what desirable. The objectives were to:

- Provide an overview of status
- Identify urgent initiatives in Europe for RCS
- Prepare an EU Action Plan to bridge the identified "gap"

Similar work is currently being undertaken by the CEN Mandate M/349 " Feasibility study on hydrogen and fuel cell", which also presented preliminary results at the conference. The results of such gap analysis revealed a wide range of opinion on what has to be done and how to organize the work within Europe. The issues concern how to harmonize standards, how to improve or better coordinate standardization work within Europe, and how to better and more strongly contribute in international RCS work. There was general agreement that the goal was international standards, achieved by a harmonised EU position within international bodies such as ISO.

HyApproval (2004-6) aims to develop guidelines for the approval process for hydrogen refuelling stations in order that infrastructure companies can propose cost-efficient standardised designs for refuelling stations. There appears to be a developing consensus among the partners in the project on the main elements in such a process (described in a handbook), it is now necessary to formalize the process through a Directive or Regulation, which clearly brings in many political considerations. The HyApproval project proposes an establishment of a "Hydrogen Refuelling Station Industry Grouping" as an instrument in the new JTI. To follow up the implementation plan for hydrogen vehicles will require about 1000 hydrogen-refuelling stations within the timeframe 2010-2015, rapidly increasing thereafter.

HYPER (2007-11) is aimed at developing fast-track approval for small stationary hydrogen and fuel cell systems, by providing a comprehensive agreed installation permitting process for developers, design engineers, manufacturers, installers and authorities. The strategy seems to follow the approval route for Natural Gas installations, and eventually will propose changes or revisions for use of hydrogen.

The JRC implements two projects with RCS implications. One is $FCTES^{QA}$, for fuel cell testing, safety and quality assurance; the other is FCTEDI for fuel cell testing and dissemination. $FCTES^{QA}$ is described in Section 4.1.1; FCTEDI is an SSA under FP6 that aims to disseminate $FCTES^{QA}$ results to IPHE member states and to international bodies including the IEA, IPHE, ISO, and IEC. It is also making a meta-gap analysis on RCS for FCs intended for stationary applications. It aims to provide support to Standards Development Organizations (SDOs) and several practical examples of this were given. The presentation argued that it is necessary to establish a semi-permanent body to collate data and testing materials and to interface with SDOs. The relevant knowledge cannot be accumulated and maintained effectively in a series of projects.

HySAFE (2004-9) is a Network of Excellence with the goal to contribute to the safe transition to a hydrogen economy. It collects, evaluates and organises global experience from use of hydrogen and seeks to transfer knowledge and build competence by education and training, interface with bodies responsible for regulations, codes and standards and hydrogen developers. HySAFE is a valuable source of facts about hydrogen behaviour and the risks associated with the use of hydrogen in energy systems. HyApproval. HYPER, FCTES^{QA} , FCTEDI and HySAFE have all been recognised by the IPHE as leading international projects.

Standards for safety have implications for cost and these can be high. Hydrogen storage solutions in commercial production must be based in concepts that permit high volume production and extensive use. The cost and weight of storage systems is a big hurdle to cost-effective solutions. StorHy (2004-9) aims to develop safe and efficient on-board storage systems. The project is of the view that the cost/weight hurdle arises from regulatory requirements. As a basis for approval, the StorHy project proposes a probabilistic process and consideration of real risk, implying some fundamental changes in modern safety philosophy.

HYCHAIN-MINITRANS (2006-10) will allow testing of a group of 150 small urban vehicles, with feedback from passengers. The project has experience of approval process, and acceptance in different European regions. It covered several distinct applications: cargo bikes, wheelchairs, scooters, utility vehicles and mini-buses. For motorbikes, utility vehicles and minibuses there is a regulatory roadblock and a need to adapt the existing EU approval framework for 2 to 3 wheeled vehicles to include hydrogen. The project suggests a European legal framework for hydrogen refuelling stations. Further, the project proposes a permanent structure within the JTI to coordinate RCS strategy and to liaise with international bodies.

HyFLEET:CUTE gave an overview of failure modes and frequencies in running demonstration projects for hydrogen buses. Most failure relates directly to the refuelling station and the interface in between the refuelling station and the vehicle. Many incidents are caused by malfunction of computer systems. The interface between the vehicle and the refuelling station should be evaluated as one issue for further development of RCS. The project team argued that the technology is not yet mature, so that comprehensive standardisation is not desirable, although for some components it might be feasible.

ZERO REGIO, for which the transport aspects are described in Section 4.5 of this document, also has relevance for RCS and well demonstrates the challenges of introducing hydrogen into European countries. What is relatively easy to in one country may not be at all possible in another. National (or even regional laws within a country) create severe hurdles. Some countries do have sufficient flexibility within the national laws for new technologies, whilst other countries may lack the necessary depth of technical experience. The experience of ZERO REGIO showed that in Germany it is possible to make a 1000 bar transport pipeline for hydrogen and to build and operate a 700 bar refuelling station. In Italy, it has been difficult to get permits because there is no relevant national legislation and only a refuelling station for hydrogen at 200 bar has been possible. Refuelling was approved to 350 bar, but cars are approved only to 200 bar.

5.2.2 Assessment

There is a reasonable level of progress in RCS under FP6, but now there is a need to develop a strategy and an action plan to ensure successful implementation of hydrogen in the Europe. This will give Europe a better and stronger influence on the international development of RCS. Today Europe is very fragmented with respect to participation and voting within SDOs.

Global standardisation and global regulation work will take time, and existing national laws in European countries will continue to be obstacles. There may be resistance at country level to change existing national laws, as long as there is no EU regulation/directive or any other international acceptable references available. A European initiative would help harmonise European opinion and foster a better and stronger contribution on the global level. For road vehicles, there is already such an initiative in progress. Europe is now in a situation, where all vehicles can be type approved within reasonable time (1-2 years from now), but the refuelling stations will still struggle with single approval from local authorities and high cost. The same is also valid for general use of fuel cell stationary applications, piping of hydrogen and bulk haulage of compressed hydrogen.

Europe will need about 1000 refuelling stations in the period 2010-2015. An important factor governing decision-making is related to the analysis of risk and cost in negotiating exemption with national authorities. Having a harmonised EU regulation or directive in place will give a significant cost saving and smooth the introduction of Hydrogen.

The workshop showed consensus on the need for more work on RCS. This could be organised as cross cutting support activity in the JTI-structure. Such an activity will require strong support from key stakeholders of the JTI (including the Commission). Functions could include maintenance and updating of regulations in accordance with further development of technology, knowledge and product availability, harmonisation with the development of RCS in other continents (US, Japan) and contribution to Global Technical Regulations where applicable.

Continued development of knowledge on hydrogen behaviour is important to provide input to regulatory bodies and SDOs. Further, continued development of tools for simulation of hydrogen behaviour and evaluation of risks associated with introduction of hydrogen in the community is needed. This will most likely contribute to less need for high cost experimental tests in the future.

5.3 COORDINATION OF EUROPEAN REGIONS AND MUNICIPALITIES

Local authorities have an important influence over the adoption of hydrogen and fuel cell technologies, especially in transport. The nature of this influence varies greatly across the EU, reflecting the wide variety of forms and powers of local government in Europe. They will generally plan the development of transport services, may specify technology or may own and operate buses. They may subsidise routes and can create or lobby for zero emission zones. It is essential that they coordinate their interests and that these interests be represented within the JU.

At the Conference, a workshop was held to discuss the possibility of creating a partnership of European regions and municipalities committed to or interested in the development and deployment of fuel cell and hydrogen technologies. The preliminary discussion recognised the need to involve regions and municipalities in the design of demonstration programmes, definition of RCS and funding; the advantages of cooperation in, for example, joint procurement of buses were recognised. Regions and municipalities will compete for the siting of demonstration projects, but that did not preclude some cooperation. It was recognised that participation would require some financial commitment, but it was also observed that a steady financial contribution would depend upon the perceived success of the venture. This is consistent with a recent written declaration of the European Parliament[18].

The system operating in Germany was described. The disbursement of funds for hydrogen research is made with the help of an advisory board with regional representation. There are sixteen regions in Germany and only two representatives from the regions in the board. The views of the regions are determined in periodic meetings that come to binding decisions to be put before the board by the representatives.

Representatives from Lombardia / Piemonte (Italy), Nordrhein-Westfalen (Germany), Aragon (Spain) Greater London Authority (UK) and the Scandinavian Hydrogen Highway Partnership (Norway) were asked to comment on:

- Why coordination is important? What are the expectations?
- Are there any similar initiatives internally in your country? If so, what is the experience?
- Is a light "Partnership" or "Association" the best model for this coordination?
- Is your Region/Municipality ready to devote resources to this?
- How do you see the role of Regions/Municipalities in the future structure of the JU?
- Do you see the JU as a "source of income" or as a potential instrument to align your RTD&D programmes with the JTI strategies?
- How do you see the role of the Commission in this process?

The presentations confirmed that many European Regions and Municipalities are already funding growing and important activities in RTD&D projects on Hydrogen and Fuel Cells and that there is a significant potential for them to contribute to the European development and deployment of these technologies. Although there exist differences in their strategic priorities, approaches and goals all of them share the common goal to prepare for a new and promising market development.

The potential to contribute at European level is not effective at present, because the regions and municipalities lack a common and coordinated position, which could allow them to act as a single, distinguishable (and influential) voice in the process. Only in a few Member States (e.g. Germany, Italy and Scandinavian countries) there seem to be well established coordination mechanisms at a national level.

The expectations of the Regions and Municipalities include both political and operational aspects. Politically, they include:

- Direct dialogue with Commission, industry, Member States and other key actors
- Interfacing with the JTI: direct feedback/possibility to influence in the RTD&D programme (e.g. consultative or advisory role)

[18]European Parliament: Written Declaration on establishing a green hydrogen economy and a third industrial revolution in Europe
through a partnership with committed regions and cities, SMEs and civil society organizations, 12.2.2007

- Alignment, organization, continuation and/or enlargement of Regional initiatives within a European and international context
- Open forum for all European regions interested in Hydrogen and Fuel cells including those with incipient activities
- Better access to funding, open to all regions/municipalities

Operationally, they include:

- More rapid inception of common codes and standards for the safe, efficient use of hydrogen and the homologation of products and applications
- Common public procurement strategies, e.g. for early market applications, following existing examples such as the "Bus Alliance"
- Benchmarks for economic and environmental evaluation of projects in order to secure political acceptance and sustainability
- Coordination among regions as likely promoters of incipient markets (fleets, infrastructure)
- Clustering and benchmarking projects at European level and generating critical mass
- Better cross-communication of issues and solutions/sharing and learning from experience

There was agreement that the best approach for the coordination of the Regions/Municipalities would be a light partnership. A legal entity is excluded by the large differences between the political and legal systems applicable to the different Regions and Municipalities. There was also discussion if the membership "criteria" should include a certain degree of commitment of resources and funds for hydrogen and fuel cell activities.

It was agreed to establish a Task Force to follow up the workshop and prepare the creation of the Partnership. The regions/municipalities that made presentations in the workshop together with Abruzzo and Trentino in Italy, and the North East in the UK expressed their readiness to commit resources for the launching of the "coordination" initiative and to constitute the Task Force. The Commission offered to continue as a "facilitator" of the process so that the leadership could soon be assumed by the partnership of the regions/municipalities, with the assistance of the two EU funded projects HyLights and Roads2Hycom that will participate in the Task Force as associate members. Representatives of the European associations for hydrogen (European Hydrogen Association) and fuel cells (Fuel Cells Europe) were also invited.

The mandate of the Task Force will be to:

- Prepare Terms of Reference, including membership rules and organisational structure of a future partnership,
- Prepare a foundation meeting (or assembly) of the partnership by march 2008 and
- Communicate with European regions and municipalities interested in fuel cells and hydrogen during the preparatory phase up to the launch of the partnership at the foundation meeting.

6. Lessons for the JTI

The creation of the JTI and the JU to manage it is an important contribution to the successful development and future deployment of hydrogen technologies. There remain huge challenges. Some interesting themes emerge from the Conference and from the review of horizontal issues.

- FP6 has provided a good basis for future work, but it needs systematic validation and assessment
- Performance targets in the IP are challenging
- The intervening period between large-scale demonstration and mass-market application is unclear
- The nature of optimal policy support and its depth is uncertain; regulatory regimes are embryonic and vary between countries
- International standards are necessary and will emerge – the EU must be institutionally and technically prepared to be a forceful participant
- The funding available under the JTI is less than what is needed
- Effective collaboration of the JU with national and local government is essential
- There is concern in the research community over the future of basic research and training and that the JU could become exclusive

These themes are examined individually below.

The portfolio of FP6

The projects funded within FP6 were generally acknowledged to constitute a good portfolio, well balanced between and among applications and technologies. Projects are broadly on track and of satisfactory quality. It is important that the results of these projects are systematically validated and assessed according to a common framework. Unless this is done, it will not be possible to set sensible targets and design sensible programmes for the future. There may be some resistance from project consortia to revealing sufficient data for proper assessment. The requirement to submit adequate data in a form suitable for validation and assessment might be a contractual obligation in future.

The US and Japanese programmes have well-developed processes for technology validation and assessment that are difficult to achieve in the dispersed EU research environment. The Joint Undertaking can redress this lack; it is the only European entity capable of exercising this function of validation and assessment on the scale needed. It must ensure that suitable frameworks are in place and are used. Considerable effort has been spent in developing various frameworks for components and demonstration projects. They need to be evaluated and possibly refined. The EU Commission is developing a comprehensive approach to sustainability assessment, based in dynamic life cycle analysis. This is intended for the analysis of policy and regulations and is not be directly suitable for the JTI, but the spirit of that approach should be maintained. It was noted that continuity is a virtue in this endeavour and arguments were made for a permanent body. This should be small and kept within the JU; analytical work should be commissioned by tender.

Targets are challenging

It was noted by rapporteurs in several sessions that some of the performance targets set out in the Implementation Plan will be challenging. The target for lifetime for LT PEMFC is achievable with available cells; the cost target can only be achieved if the cost of the membrane and the platinum load can be much reduced (Section 4.4). To achieve the targets in the IP for 2012 for stationary applications will also require solution to serious problems, including degradation of voltage and efficiency, weaknesses in sealing (particularly because of high temperature operation), slow start-up, insufficient thermal cycles and carbon deposition in the case of reforming (ibid). Performance targets for storage of liquid and gaseous hydrogen are not given in the IP, but the cost and weight penalties of hydrogen storage are still significant and this is not expected to change dramatically in the short-term (Section 4.2). The scope of existing demonstration programmes may not be sufficient to stimulate commercialisation (Sections 4.3 and 4.5). Projects dealing with stationary applications seemed generally more confident of meeting cost and performance targets in the IP (Section 4.6). An agreed validation and assessment framework still needs to be developed (Section 5.1). A strong basis for policy design, scrutiny and evaluation is needed especially for transport (Section 5.3). The evidence from short presentations of complex projects is clearly not an adequate basis on which to jump to judgement, but the JTI needs to assess these challenges fully in the framework of the technical validation and assessment activity described above.

Demonstration projects and commercialisation

The Implementation Plan envisages in a first phase to 2010, thirteen demonstration sites for road vehicles, comprising around 200 vehicles and nine refuelling stations. Larger scale demonstrations are planned for the second phase covering thirty sites with 3000 vehicles and the linking of clusters of users of hydrogen. It is debatable whether this will be enough to stimulate a mass market. Evidently, there will be parallel programmes by national, regional and municipal governments that will contribute to demonstration, but it is not clear what the cumulative impact will be. Thought needs to be given and possibly funding developed for a more prolonged pre-commercial activity.

There are significant external costs associated with transport. It is the most intractable and growing source of greenhouse gas emissions; it is almost entirely dependent on oil, so is a critical contribution to energy insecurity and it is still the most important source of local pollution for most people. Demonstration of urban transport fleets is an important activity within the Implementation Plan and its finance at the scale required will be problematic. A supportive and preferably harmonised system of policy intervention and support is essential if the demonstration projects are to have impact. The JTI should lobby strongly for policy regimes of member states and cities that reflect the benefits from reducing external costs.

There is a growing appreciation and understanding of the need for knowledge development and creation in Balance of Plant as opposed to simply cell and stack. Off-the-shelf components that are not designed to operate under the challenging conditions of fuel cells create weakness in fuel cell units. Creating opportunities for European entities specialising in these areas is a priority for the activities under FP7.

The HFP strategy sets out key technical targets and milestones to guide technology development from basic research to demonstration and lighthouse projects. Projects must show how their planned activities will help achieve these targets. Projects moving towards demonstration field trials will need to ensure that they incorporate end users in their activities to demonstrate the linkage with market.

Policy support

Policy support is essential, but the basis for good intervention does not exist. There is insufficient systematic analysis of the policy options, the relationship between policy options and adoption of technology and the economic effectiveness of various options and market behaviour. Existing national regulations are often confusing and may constitute unnecessary obstacles. The JU needs to be proactive in promoting adequate and appropriate policy support. This is essential if demonstration projects are to spark genuine spontaneous replication. Policy instruments to consider include zero emission zones, capital subsidies and payments for carbon avoided. Planning regulations need optimisation and harmonisation. This needs to be done in collaboration with national and local governments and the Commission.

International standards and regulations

International standards will eventually materialise for hydrogen and fuel cells and it is important that the EU should establish a common position and exert its influence. Work on regulations, codes and standards should be organised as a crosscutting support activity in the JTI-structure. Functions could include maintenance and updating of regulations in accordance with further development of technology, knowledge and product availability, harmonisation within Europe and internationally.

Funding

The tasks of the JTI are onerous. Its function is to execute a programme of R&D to accelerate the time to market of fuel cell and hydrogen technologies. It has to conduct large-scale demonstrations, whilst maintaining adequate activity in other fields, managing crosscutting activities and promoting fuel cells and hydrogen to stakeholders.

The resources available to JTI (considering EC support matched by an equivalent amount of private funding) will be 0.94 bn €. The large-scale demonstration plants preceding spontaneous commercialisation will be especially demanding of funds. Fortunately, this is also an activity where additional funding mechanisms from other sources might be envisaged.

Increases in the total of available funds can come from several sources. The first requirement is that the JU should be and should be seen to be successful. If the future of hydrogen research looks bright then companies and users will invest in research, in manufacturing facilities, infrastructure and in appliances, of their own volition. A source of funding that is suitable for the expensive demonstration plants is the Risk Sharing Financial Facility (RSFF) of the European Investment Bank (EIB). The facility creates an option to fund later stage projects, providing that they can be established as a legal entity with a revenue stream adequate to support the loan. Guidelines for demonstration projects should recognise these requirements at an early stage in the identification and design of projects. If achieved, this would free up core funding for other functions for which loan finance is not suitable. Furthermore, for later stage projects there may be opportunities for support under Structural / Cohesion funding schemes and this should be explored in co-operation with the regions partnership.

The other important source of funding is reductions in external costs achieved in demonstration projects. These are not normally a source of funds for research, but if properly internalised they can become a revenue stream that will secure the loans under the RSFF or some similar commercial agreement. Internalisation requires strong and well-designed policy, as was described earlier. In theory, the external costs of GHG should be internalised by the Emissions Trading System that credits them to the original production of hydrogen, but in practice this may not work and in any case the prices for carbon prevailing under the ETS are well below the majority of estimates of its true value and are very volatile. There need to be long-term arrangements at a reasonable level. This involves both national and municipal governments. There is therefore a close interrelationship between policy design and funding with big synergies through the mobilisation of loan funds for demonstrations.

Collaboration with national and local government

HyLights estimates that the EU is 5 years behind Japan and North America in the demonstration of fuel cell vehicles. The US and Japanese programmes are strategically managed by central government. Central management is not possible within the EU political structure. It is unrealistic, at this stage, to expect national governments to put substantial funding behind the JTI. The dispersed European effort has evident disadvantages, although it may also have some advantages in that allows a more diverse offer of technical solutions. What is important is not so much central management, but central coordination of strategy, supported by a central validation and assessment exercise from which all can learn. The JTI should be proactive in working with national governments to achieve this level of collaboration. The desire of national governments to preserve commercially confidential information for national companies is likely to hinder this collaboration, but some arrangement needs to be found. Collaboration with national governments is also important in the development of a common position on regulations, codes and standards. The Commission has authority in this field and can support the JTI.

Local government has an important part to play as host to demonstration projects, as planner and perhaps as owner of equipment. This is recognised and measures are in place to develop some light partnership arrangement that would let regions and municipalities participate in the work of the JTI. The restricted membership that is likely from those regions and municipalities with a direct and immediate interest in developing hydrogen technologies may limit the effectiveness of the solution for wider issues such as RCS. It will be necessary to work with other representative bodies of local government, but the partnership should provide a good bridge to those. Certain regions may enjoy special status for benefiting from structural funds.

Basic research and training

Some unease was expressed by the research community that the centralisation of funding within an institution strongly oriented towards industrial interests would have some serious disadvantages. One concern is a possible tendency to prefer immediate commercially interesting options to basic research and training that are important in the long-term. There is reasonable grounds for this unease, especially given the immense challenges of getting hydrogen technologies to market that are likely to dominate the thinking of the JTI. There was also some disquiet about the possible distortion of involvement in favour of big companies from larger countries, as against SMEs and smaller countries. Again, in the absence of experience of its operation, this disquiet is understandable.

The JTI should introduce procedures internally to make sure that these distortions do not occur, but the final sanction will be the regulation by the Commission. The performance of the JTI will be monitored and it is the responsibility of the Commission to ensure that the balance among its activities is evaluated and corrected if necessary.

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