European Hydrogen & Fuel Cell Technology Platform

Deployment Strategy

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DISCLAIMER

The Advisory Council of the Hydrogen and Fuel Cell Technology Platform endorsed the Foundation Report for the Deployment Strategy at its meeting on December 16th, 2004. While development and refinement work will continue throughout 2005, this Foundation Report provides a broadly supported body of knowledge, conclusions and recommendations. The Panel thanks all those who have contributed in generating, reviewing and enriching this report and seeks for continued involvement and support from the Hydrogen and Fuel Cell Technology Platform community in its efforts to consolidate its work.

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Deployment Strategy

0 EXECUTIVE SUMMARY

In January 2004, following the recommendation of the High Level Group, the European Commission (EC) initiated the European Hydrogen & Fuel Cell Platform (HFP). Its aim is to prepare and direct an effective strategy for developing and exploiting a hydrogen-orientated energy economy for the period up to 2050.

An Advisory Council was set up to guide the activity, together with a number of subsidiary bodies, each charged with examining a particular aspect of the task. This included a Deployment Strategy Steering Panel (DSP)[1] appointed to identify the scale and scope of a programme, including recommendations for a supporting framework necessary to:

a) Promote commercially viable hydrogen & fuel cell applications
b) Initiate an appropriate hydrogen infrastructure

Hydrogen: energy carrier of the future
The high-level policy objectives driving this initiative are (in no particular order of importance) to:

- ***Optimise security of energy supply***. Hydrogen offers new options for the ***generation***, storage and distribution of energy which is considered vitally important – especially in reducing oil dependency in the transport sector and increasing the diversification of supply.

- ***Reduce greenhouse gas emissions*** (GHG). In the long-term, this means attaining zero carbon emissions; but practical, shorter term options are also urgently required in order to reduce the current carbon burden on a 'source-to-user' basis. Improving local air quality is also of major importance.

- ***Create new opportunities for the European economy*** by establishing a leading position in hydrogen & fuel cell (FC) technologies and strengthening its global competitiveness.

Bringing the future closer
This foundation report therefore addresses the technical, socio-economic and political challenges of deploying world-class, competitive, hydrogen technology & fuel cell applications (transport, stationary and portable), the scale and scope of the task, and recommended courses of action. This includes not only how we can support efforts already underway, but also how to create powerful new initiatives.

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[1] The recommendations of the DSP also depend on the actions proposed by the other bodies of the HFP, including the Strategic Research Agenda Steering Panel (SRA) and the following Initiative Groups: Business Development & Financing, Regulations, Codes & Standards, Public Awareness and Education & Training.

It aims to answer the following key questions:

1) Where do we stand today?
2) Where do we want to get to?

   Targets are suggested for the long-term (2050, as outlined by the High Level Group); but intermediate milestones (the so-called 'Snapshot 2020' and deduced from it R&D milestones for 2015) are also recommended in order to promote a sense of urgency and priority.

3) What do we need to do to move effectively from 1) to 2)?

The DSP used the following sequential steps to arrive at its recommendations:

- Developed and described an intermediate milestone ("Snapshot 2020").
- Identified the SRA (Strategic Research Agenda) milestones necessary by 2015 to enable a mass market roll-out by 2020 at the latest.
- Made a technical and market assessment of hydrogen & fuel cell technologies, including hydrogen production, storage and distribution.
- Assessed the social and political implications.
- Proposed a Deployment Strategy.
- Aligned the strategy with the goals and timelines of the SRA.

'Snapshot 2020'

By 2050, conventional oil supply is unlikely to be able to meet demand. Certainly, Europe's oil import dependence will be far higher than it is today - and the same will probably apply to natural gas. Hydrogen is therefore expected to become an important alternative energy vector. However, any major change in the energy industry is likely to require several decades to implement effectively, owing to the high capital intensity and long asset lives involved.

The transition process towards hydrogen therefore needs to be initiated without delay.

In pursuit of the long-term goals, a set of milestones – 'Snapshot 2020' - is suggested for effective target setting and coordination of first steps. 2020 has been chosen because it encourages challenging targets, whilst helping to test for practicality and feasibility. It also reflects requirements on the applications side, corresponding with the findings of the SRA. Accounting for a lead-time from research to mass market roll-out, 2015 has been chosen for the SRA milestones, allowing 5 years for serial development and commercialisation activities.

The Table below indicates the deployment status for applications by 2020, expressed in numbers of sold units per year and cumulative sales projections respectively. (These projections are based on the findings of the DSP and other sources, as detailed in chapter 1.4.)

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

	Portable FCs for handheld electronic devices	**Portable Generators & Early Markets**	**Stationary FCs** Combined Heat and Power (CHP)	**Road Transport**
EU H2/FC units sold per year projection 2020	~ 250 million	~ 100,000 (~ 1 GW_e)	100,000 to 200,000 (2-4 GW_e)	0.4 million to 1,8 million
EU cumulative sales projections until 2020	n.a.	~ 600,000 (~ 6 GW_e)	400,000 to 800,000 (8-16 GW_e)	1-5 million
EU Expected 2020 Market Status	**Established**	**Established**	**Growth**	**Mass market roll-out**
Average power FC system	15 W	10 kW	< 100 kW (Micro CHP) > 100 kW (industrial CHP)	80 kW
FC system cost target[2]	1-2 €/ W	500 €/kW	2.000 €/kW (Micro) 1.000-1.500 €/kW (industrial CHP)	< 100 €/kW (for 150.000 units per year)

The characteristics of the various sectors are summarised as follows:

Portable FCs
Micro-FCs (1-20 W) are alternative power sources for handheld electronic devices. The market is potentially very large and market entry should be easier than for other FC applications, as it is likely to be driven by ordinary commercial considerations (therefore requiring less governmental support).

Portable Generators & Early Markets
Portable generators (typically up to 10 kW_e) are often based on power modules using a common architecture that can be adapted for a variety of applications, e.g. backup power, specialist vehicles and Auxiliary Power Units (APUs) for recreational vehicles.

Stationary FCs
Two main FC applications are expected to achieve substantial market penetration from now until 2020:

- Residential and small commercial systems will be a promising market for FC-based combined heat and power (CHP) generation systems below 50 kW_e , with a focus on small systems of 1 to 5 kW_e. This sector is mainly covered today by conventional boiler systems (for heat generation) and grid connection (for electricity supply).
- Industrial, large-scale commercial and district residential applications and Tri-generation (combined Heat, Power and Cooling). This sector offers important opportunities for high temperature systems of 200 - 500 kW_e.

Road Transport
Transport applications for hydrogen & fuel cells – mainly road vehicles – will probably take longer to achieve mass market roll-out (as indicated in the High Level Group Vision Report). In 2020, hydrogen & fuel cell vehicles are likely to account for only a few percent of the overall vehicle fleet (which today is c. 215 million units, of which

[2] The primary reasons that automotive fuel cells are expected to be produced at a significantly lower cost than stationary fuel cells are discussed in chapter 2.4

passenger cars 190 million). Other transport applications, e.g. maritime, are also expected to come to market by 2020, albeit in small numbers.

For 2020, the primary objective is confined to achieving EU-wide availability of a significant choice of hydrogen & fuel cell vehicles, with an appropriate coverage of fuelling infrastructure. The best case estimate for hydrogen fuelled vehicles in 2020 is in the range of 0.4 million - 1.8 million[3] units sold per annum. This reflects uncertainties in the rate of technical development and mass market roll-out.

Even at the lower end of this estimate, a few thousand hydrogen filling stations will be required to service cars sold, probably in clusters around the most populous European cities.

Conclusions from 'Snapshot 2020'
The DSP expects fuel cells in portable applications - especially in computers and generators - to have achieved established market status in 2020. The market for stationary fuel cells will still be growing and road transport applications will be at the threshold of mass market roll-out.

It is useful to compare these conclusions with the published market goals of two major competing nations, Japan and the United States:

- Direct comparison between Europe and Japan is possible only for stationary fuel cell systems and transport applications. In 2020, The Ministry of Economics Trade & Industry in Japan expects 5 million hydrogen vehicles on the road and a cumulative installed capacity for stationary fuel cell systems of 10 GW_e. These numbers are comparable with figures in this report.
- The US Department of Energy has adopted a different approach. It is committed to a 10 year research, development and demonstration programme in order to achieve demanding performance and cost targets which will enable industry and government to commit to a full commercialisation decision in 2015. The milestone for 2012 is to deploy around 100,000 units / 500 MW_e capacity.

In both the US and Japan, firm plans are supported by substantial public funds (Japan 2005 budget ~€260 million; US 2005 Federal Appropriation ~€235 million plus significant State funding). China has also now entered the race.

Over the next few years, manufacturers will make investment choices based largely on where public support is available to mitigate the risks of development. In the absence of a fully-fledged development and deployment strategy in Europe, there is a high risk that the investment, skills and - ultimately - the economic benefits, will migrate elsewhere.

To reach the targets outlined in 'Snapshot 2020', the main requirements are a considerable reduction in the cost of fuel cell systems and a significant improvement in lifetime. Today, all fuel cell systems, regardless of application, cost in the region of 10.000 €/kW. This is influenced by the available technology and, in particular, low production volumes.

[3] Further details are discussed in chapter 1.4.4

Although it can be assumed that general cost reductions will be achieved - in particular for key components - there is likely to be a wide range of learning curve reductions in different applications. Further R&D is required to meet performance and cost targets, as defined in the SRA report.

But this must be integrated into an iterative, synergistic process with long-term, step-by-step demonstration and deployment programmes. This will give the technology developers and suppliers not only the confidence to invest in the manufacturing processes, but the facilities to produce economically viable products.

Where do we stand today?

(1) Technical assessment of hydrogen pathways

A successful Deployment Strategy requires a sound knowledge of the technological state-of- the-art and any gaps, obstacles, barriers and opportunities. The DSP has analysed the current situation as follows:

Hydrogen Production

Choosing the right route for large-scale hydrogen production is crucial. Bearing in mind the different regional characteristics and preferences of the Member States, a broad portfolio of different hydrogen production pathways is anticipated. In the period between now and 2020, hydrogen is likely to be produced from conventional energy sources.

However, it must be remembered that energy and GHG balance of hydrogen is strongly dependent on the supply pathway. These issues are debated in the 'HyNet' Roadmap Report which concludes that, at first, hydrogen should be produced from either natural gas or electrolysis. The development of hydrogen production systems is expected to progress as shown below:

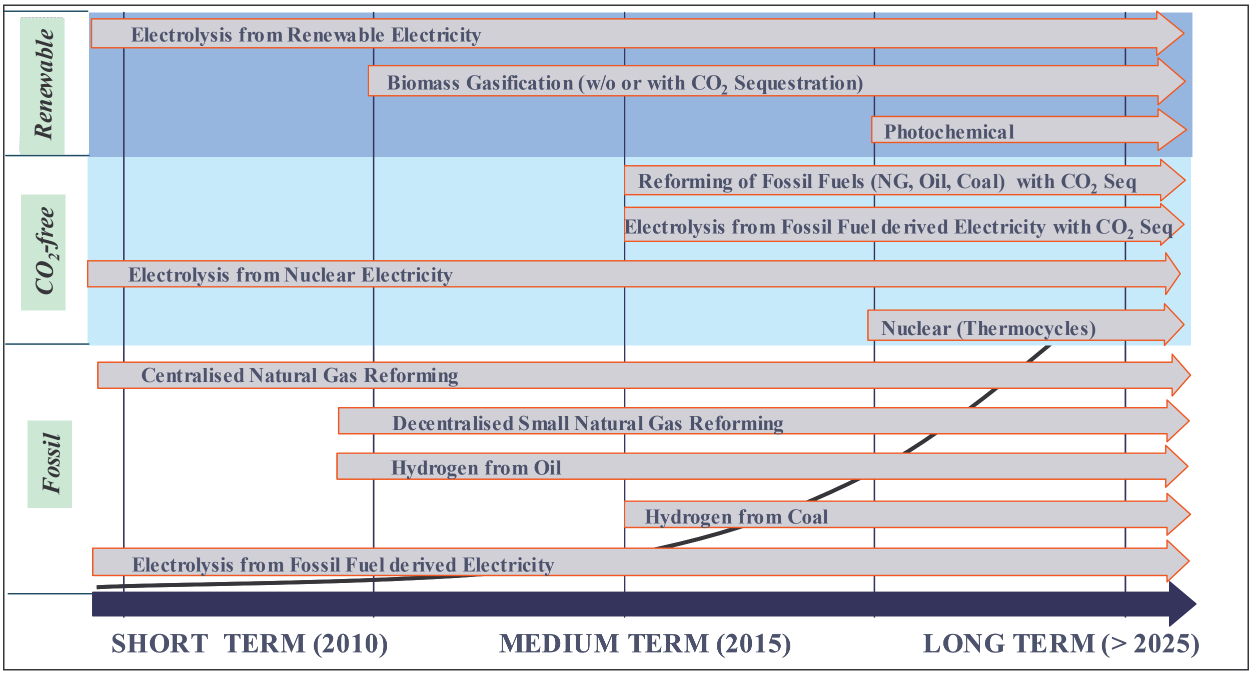

Figure I: Maturation of hydrogen production pathways from "HyNet" Roadmap Executive Report

It is suggested that three hydrogen pathways be further developed in an initial phase, with the aim of increasing reliability and economic performance:

1. Hydrogen derived from refineries and chemical plants, to take maximum advantage of existing low cost hydrogen sources.
2. In parallel, on-site hydrogen production based on different technologies (electrolysis, reforming) and sources (natural gas, biomass, electricity and, in particular, renewable) to stimulate these industries to develop the necessary technologies.
3. Large-scale, centralised hydrogen-production, based on natural gas or other available fossil resources, with future options for CO2 capture and storage.

Hydrogen Storage and Distribution

This section addresses the infrastructure required to support stationary and transport applications.

For stationary applications, the following issues have been considered:

- Connections to the natural gas grid for installations of fuel cells in the range of up to some 100 kWs.
- Fuelling via hydrogen (from reforming) or direct use of natural gas.
- Pipeline transport for the use of by-product hydrogen, or mixtures of natural gas and hydrogen, from chemical plants and refineries.
- Installation of hydrogen-microgrids to supply networks of stationary fuel cells.

For transport applications, the following options have been considered:

- Central hydrogen production with pipeline transport to the filling station (only compressed gaseous hydrogen - CGH2 fillings possible).
- Central production and liquefaction of hydrogen with tank trailer transport to the filling station (CGH2 and liquid hydrogen - LH2 fillings possible).
- On-site production of hydrogen with optional buffer storage for load levelling (only CGH2 fillings possible). At large fuelling stations, we propose to evaluate the possibility of adding LH2 storage supplied by trailer to provide a buffer/ backup capacity for the on-site reformer.

Regarding hydrogen distribution and storage, the following issues require early attention:

- An infrastructure for portable applications (notebook computers, telecommunication devices) with hydrogen (hydrides, cartouche) or direct methanol.
- Small generators, back-up power systems etc. The system may comprise hydrogen distribution via cylinders and should be developed in close collaboration with the gas industry and application developers.
- Improvements in LH2 and CGH2 storage systems (and possible alternatives). Industry standards need to be agreed by 2010.

- Centralised hydrogen production and distribution mechanisms to provide a flexible service for early and time critical demonstration purposes.
- The deployment of on-site pathways to lay the foundation for the commercialisation decisions expected to be required around 2015.

Where do we stand today?

(2) Strategic and socio-economic factors

Technology is by no means the only factor that will influence the transition from traditional to new energy systems. Left to its own devices, the transition will respond to market pressures, probably favouring the maximisation of short and mid-term profit, and the most readily available technologies.

Indeed, the pursuit of 'disruptive' innovation requires thought and imagination, and market forces alone are unlikely to provide the incentives required to bring about the desired changes. The Deployment Strategy therefore considers various ways of dealing with the competing demands of short-term profits and long-term benefits.

The key issues are:

- Identifying the incentives required and making the transition towards hydrogen a matter of rational boardroom decision.
- Identifying early markets and developing the appropriate market strategy.
- Establishing large-scale integrated demonstration programmes to validate functionality and prepare for market entry and commercialisation.

Political commitment will be a key factor in fostering the required technical development, as well as managing public awareness and acceptance. In fact, Government inaction would have a negative not a neutral effect. Various policy issues (at several different levels throughout the EU) requiring attention therefore include:

- General vision of Governments and consensus on the need for sustainable development.
- Public funding policies covering the related, but separate, needs for (1) research and (2) deployment.
- Harmonised fiscal and economic incentives for hydrogen, fuel cells and other hydrogen conversion technologies to give manufacturers, infrastructure providers and buyers the confidence to invest in them.
- Education and public awareness, including investment in large-scale demonstrations, e.g. in public transport and municipal vehicle fleets.
- Establishment of regulations, codes and standards, and removal of regulatory barriers.
- Removal of institutional and regional barriers, e.g. enable the use of hydrogen as a fuel and facilitate access to grid for efficient cogeneration systems.
- Safety concerns associated with hydrogen usage.

The Table below summarises the major barriers to progress and actions required to overcome them:

Table II: Gap Analysis for the Commercialisation of Hydrogen & Fuel Cells

	Today: Main Barriers & Characteristics	***Targets & Required Actions***
Framework	▪ Insufficient EU-wide regulations, codes & standards for transport and stationary applications ▪ No EU-wide fiscal incentives for hydrogen, FC and other hydrogen conversion technologies in place ▪ Legal liability and insurance issues for hydrogen & fuel cell applications wide open ▪ Safety concerns	▪ Develop a Proposal for a EU Hydrogen Support Regime
H2 Production & Distribution	▪ Cost of renewable hydrogen 3-8 x higher than conventional fuels (total supply cost) ▪ Distribution costs a major proportion this increased cost ▪ No low cost, on-site production available	▪ Support demonstration activities with innovative distribution solutions
FC Supplier Base: material, components and subsystem	▪ Low temperature FC membranes: weak EU supplier position ▪ Lack of investment in manufacturing facilities for low-cost production	▪ Develop proposals for attractive investment/financing regimes (in collaboration with IG FBD), based on political support for a comprehensive deployment strategy
Stationary Applications	▪ Increase in FC lifetime and durability needed by factor 2-5 (based on a target stack lifetime of 40.000h) ▪ FC system cost decrease needed by factor up to 10	▪ Cost-of-ownership comparison of stack change (cheap & lower lifetime) vs. higher lifetime targets during large-scale demonstration programme (that also need to generate volume to drive down cost)
Transport Applications	▪ FC system cost decrease needed by factor up to 100 based on actual prototypes ▪ FC lifetime and durability increase needed by factor 2 - 5 (based on a target stack lifetime of 5.000h) ▪ Compressed hydrogen storage: weak EU supplier position	▪ Decrease FC system cost by more than an order of magnitude based on volume production ▪ Parallel deployment of cost-learning curve effects and SRA cost & performance targets ▪ Increase ICE efficiency ▪ H2 Storage density needs to be increased by factor 1.5 - 2

How can these goals be achieved?

The Deployment Strategy requires close collaboration between private and public entities in order to bridge the gap between the present research/prototype demonstration stage and the full-scale, commercial introduction of hydrogen & fuel cell technologies.

Phases and Timings

While different priorities exist for the transport, stationary and niche markets, we recommend the following general approach:

1. *Prototype development:* this first phase is about proof of concept and requires only a limited number of units/vehicles (about 10).
2. *Demonstration projects:* requires some hundreds of units/vehicles.

The aim of both these phases is to develop guidelines, establish best practice and encourage technical development through the rapid transfer of early experience. The preparation and validation of industry standards also begins in parallel.

3. *Pre-commercial phase:* the number of units/vehicles is extended to some thousands. The influence of demonstration experience is lessening and validated industrial standards are expected to be in place at the end of this phase.
4. *Production phase:* Products are ready for market introduction and being produced and delivered in large quantities. However, market entry support is still needed in the early years.

The Deployment Strategy needs to focus on actions required in the immediate future (say up to 2010), without neglecting the longer term issues. While the later pre-commercial and production phases are at least as important as the earlier ones, there is less urgency to define fully the actions required. These will be elaborated during the course of 2005 in close collaboration with the Initiative Group Financing and Business Development.

Next Steps

The Steering Panel recommends the following steps, to be undertaken in parallel:

- A concerted campaign to promote comprehensive large-scale demonstration projects, as proposed under the European Initiative for Growth (HYCOM - HYPOGEN)[4]. This includes the Lighthouse Projects to launch small scale production. In view of the highly integrated nature of these projects, some elements may be at the R & D stage (justifying government and/or EC funding), while others may already be in the commercial phase. Government and industry must move forward together in a carefully coordinated campaign, providing clear signals to the general public that this development is both serious and realistic.
- Develop market introduction and cost reduction programmes (in close collaboration with the initiative group on Business Development and Finance).
- Establish regulations, codes and standards to allow the deployment of components and systems in field tests and early markets (in close collaboration with the initiative group on Regulations, Codes and Standards).
- Develop a Policy Framework that (1) encourages the deployment of hydrogen & fuel cell technologies necessary to meet the high level objectives; (2) encourages private and public investment; (3) provides guidelines for developing integrated, coherent national and regional agendas.
- Develop early and niche markets as the bridge between demonstration activities and full commercialisation. The development of commercial products for early premium price markets will also help significantly reducing the cost of key components.

A clear commitment by public bodies to provide financial and other support to these activities is vital to encourage technology developers and suppliers to make the substantial investment in manufacturing processes, facilities and human resources required for full-scale commercial deployment.

[4] A European Initiative for Growth, COM(2003)690

Early niche and stationary applications will help initiate the build-up of a manufacturing and supply base that can then form a basis for the later commercialisation of fuel cell vehicles. For every field of application, we need an analysis of the relevant issues faced and specific conditions required. These include technology gaps; identifying the most promising early markets; the economic threshold levels for market entry; and any possible synergies.

Schedule for a deployment strategy (Action Roadmap)
Successful deployment requires high priority attention within the energy and transport policy of the European Union if hydrogen & fuel cells are to achieve the desired impact on the security of energy supply, GHG reduction and economic opportunity between now and 2050.

On the basis of today's evidence, early markets (including certain portable applications and specialist vehicles, e.g. forklifts) can be established in the time frame 2007 to 2010. Stationary applications can achieve the commercialisation stage by 2015; transport applications by 2020.

The following actions are recommended in response to issues identified in the gap analysis (see Table II):

- The launch of a 'Design Phase' in 2005/06 to develop proposals for a coherent European Hydrogen Policy Framework. This should consider fiscal incentives and the development of a legal framework, as well as an in-depth analysis of the proposed large-scale Integrated Demonstration Programme, based on public-private partnership (PPP) structures.
- An 'Implementation Phase' in 2006/07, aimed at:
  - Launching the Integrated Demonstration Projects for all hydrogen & fuel cell applications in 2007.
  - Implementing the proposed European Hydrogen Policy Framework.
- Inclusion of existing R&D and demonstration projects will be crucial in gaining technological learning and operational experience.

Lighthouse Projects will be developed in certain Pilot Regions across the EU. Each of the deployment phases needs to support the transition towards commercialisation, aiming at (no later than) 2010 for early markets and 2010 to 2015 for stationary applications. The transport sector, which faces the greatest economic and technical challenges, is expected to achieve commercial viability after 2015, leading to mass market roll-out of all types of hydrogen vehicles by around 2020.

The recommendations are summarised in Figure II below:

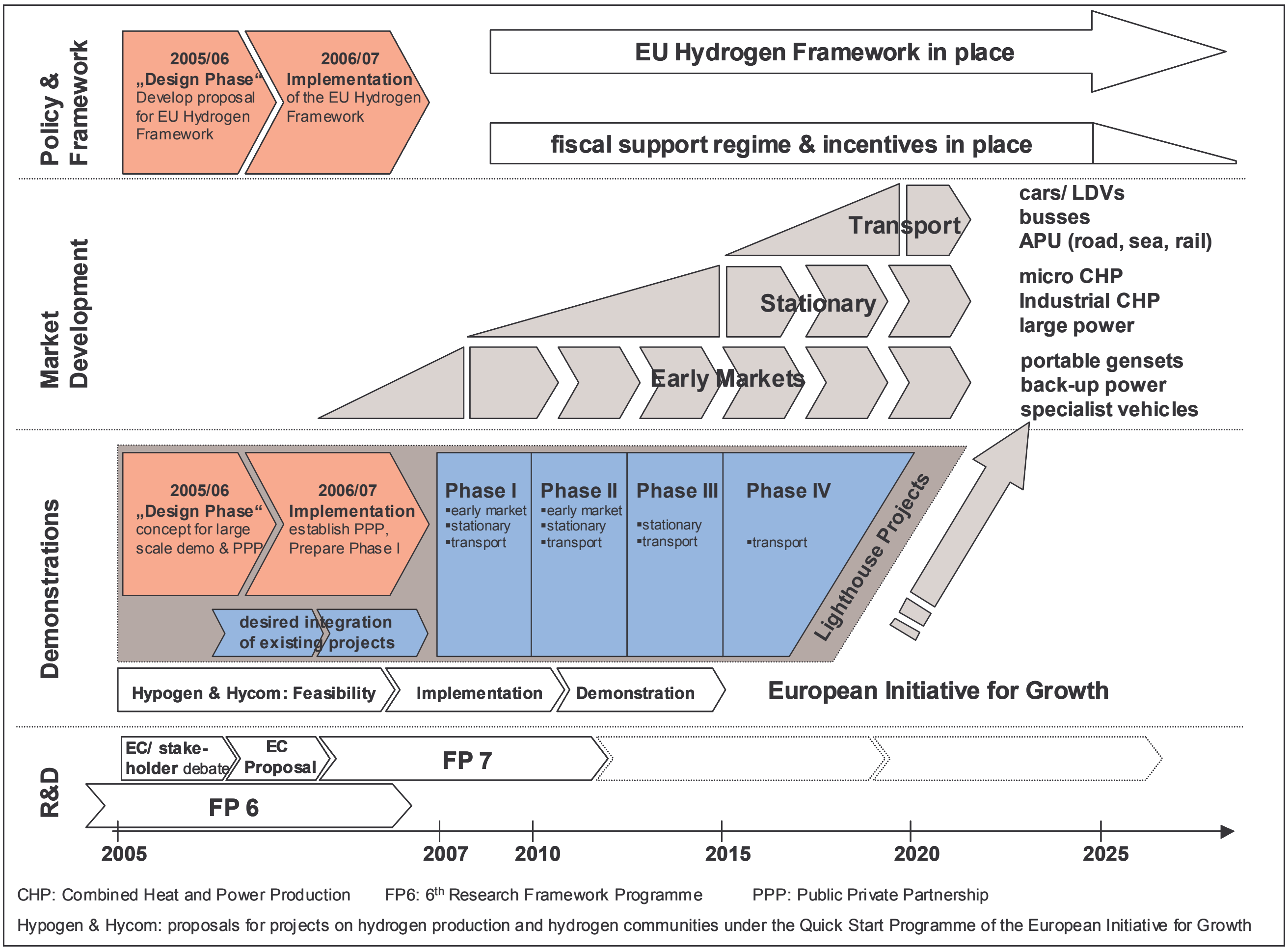

Figure II: Schedule for a Deployment Strategy on Hydrogen & Fuel Cells

Recommendations

The following recommendations are made to the Advisory Council of the HFP and the European Commission (EC):

- Financial planning for comprehensive Lighthouse Projects should be initiated by the EC by mid 2006, under the direction of a body which includes broad stakeholder representation.
- The Deployment Strategy Steering Panel should continue to promote the development of hydrogen & fuel cell technology at a European level and prepare detailed proposals for the structure and content of the proposed, large-scale integrated demonstration programme by the end of 2005/06.
- The Deployment Strategy Steering Panel should also be engaged to provide further proposals on commercialisation strategies - in particular, how to use Lighthouse Projects to help stimulate a European support regime for hydrogen & fuel cells and establish viable markets.

1 Scope and Ambition of a Deployment Strategy

1.1 Introduction

Within the European Union and worldwide there is a general consensus on the long term need for a transition towards sustainable energy systems due to limited fossil resources and the necessary reduction of green house gas (GHG) emissions. The political emphasis has been placed on the security of energy supply and the strengthening of the European economy by acquiring and maintaining a leading position in hydrogen and fuel cell technologies as well as hydrogen conversion technologies in general. Equally important the reduction of green house gas emissions has been addressed as a major concern by the EC[5] highlighting also the important role of renewable energies. On this background all potential measures have to fully be aligned with the overall criteria of:

- Security of energy supply
- Reduction of green house gas (GHG) emissions
- Strengthening the European economy and global competitiveness

Based on this the Steering Panel "Deployment Strategy" shall illustrate possibilities and propose feasible transition pathways for the establishment of hydrogen and fuel cell based energy systems for early market, portable, stationary and mobile applications in the medium term. This deployment strategy needs to be developed, considering the European energy framework illustrated in the Green Paper on the Security of the Energy Supply and in close alignment with the SRA Panel and relevant Initiative Groups such as "Business Development and Finance" and "Regulations, Codes and Standards".

1.2 Outline of a Deployment Strategy

The long term vision regarding the potential of hydrogen and fuel cells was compiled by the High Level Group[6] and illustrates the final goal of a hydrogen orientated economy by 2050 that relies mainly on renewable production pathways. For the purpose of developing a deployment strategy in addition less distant supporting points are required for guiding the transition towards hydrogen and fuel cells. Hence a target scenario for 2020 is envisaged that describes the anticipated (likely) status quo for stationary and mobile applications as regards the fulfilment of a threshold of an economical viable market entry. A backward approach based on the different industrial development cycles leads to the definition of specific interim milestones and structures the transition towards hydrogen into manageable sections. At the same time the developments of stationary, mobile as well as early & niche market applications need to be aligned and potential synergies will be captured through close collaborations with the SRA Panel. Regarding niche applications it is crucial from a deployment view that these applications are on a clear pathway forereaching the end goal of mass markets since a "niche - hopping" is not fostering the broad penetration of hydrogen and fuel cell technologies. Properly planned and thought through, the niche market applications may however constitute a strong enabler of

[5] Green Paper: „Towards a European Strategy for the Security of the Energy Supply“ COM (2000) 769
[6] EUR 20719 EN – Hydrogen Energy and Fuel Cells – A vision of our future

technology consolidation, infrastructure build up, cost reduction, and public acceptance.

Acknowledging that portable, stationary and mobile hydrogen and fuel cell applications need to be analysed individually before developing an integrated European deployment strategy that should ideally utilise synergies between different markets it is necessary to define common boundary conditions. Regarding market development and penetration rates over time in general an S-Curve model is assumed as a first order approach. Three phases are often distinguished as described below[7]:

- **Innovation Phase**: Prior to the market introduction the technical and economic viability need to be validated. At the end of this phase first series model are available and introduced to first customers.
- **Growth Phase**: in this phase products are introduced to a broader public and high growth rates can be observed. At the very beginning progressive individuals (so called early adopters) are accounted for most sales but soon also mainstream consumers are addressed.
- **Maturity Phase**: the final run of the S-Curve is characterized by the maturity phase in which the market share converges slowly to the final saturation.

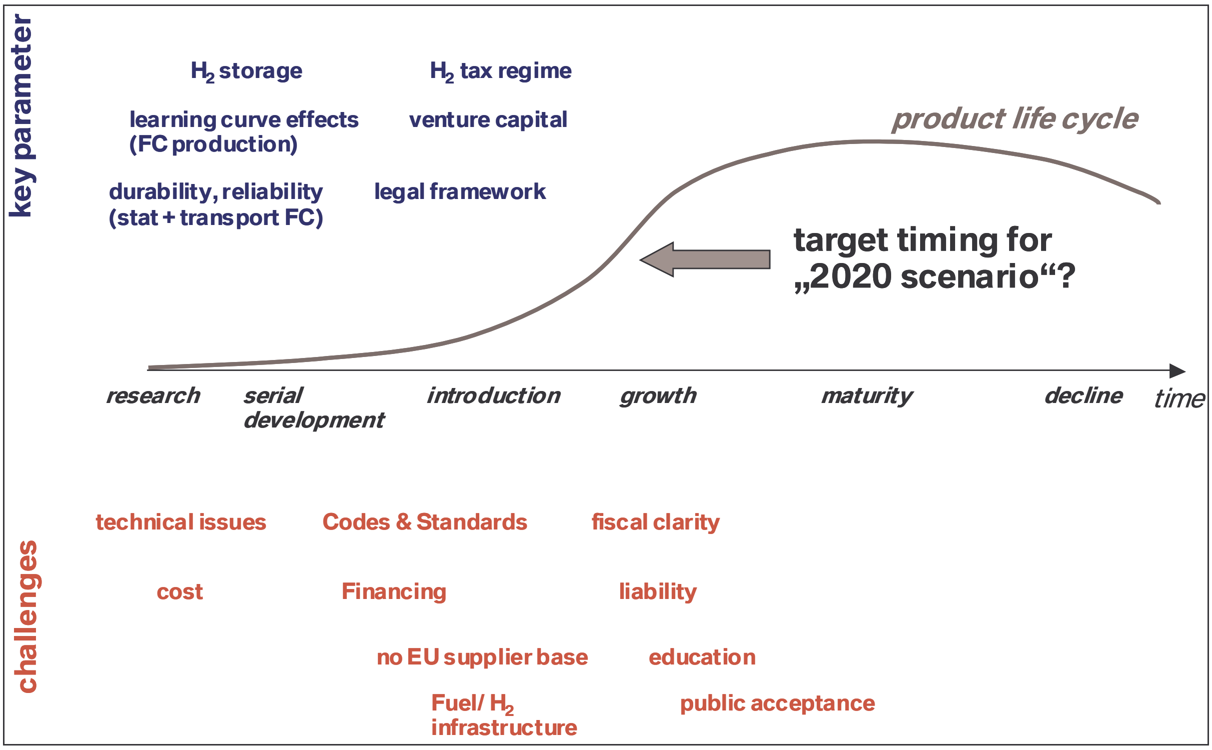

Figure 1: Challenges and Key Parameters for hydrogen and fuel cell application along an extended product life time (Steering Panel Deployment Strategy)

A first analysis has shown that a deployment strategy for hydrogen and fuel cell applications requires a more detailed approach in order to address all relevant issues

[7] According to HyNet Annual Report 2003, TWG 4 Report

from first research results across large-scale demonstration projects towards the final goal of mass-market penetration. Figure 1 highlights that the phases of research and serial development are crucial for the later successful introduction and therefore a major portion of the deployment strategies for all segments will address these questions. It has to be taken into account, that the timing of the three phases of the S-Curve will be different for different applications. Portable will start earlier than stationary and transport will reach maturity last.

Regarding the differentiation between research and the beginning of a serial development process relevant input and criteria for the technological maturity (minimum technological, socio- and economic performance levels) of critical components such as fuel cell components, fuel cell stacks and systems or hydrogen storage devices will be derived as an input from the Strategic Research Agenda Report.

Figure 1 refers to a product life cycle under stable market boundary conditions. In the light of the discussions on security of energy supply and climate change hydrogen and fuel cell technologies may need to follow not only mechanisms of a traditional business case. Besides pure economical drivers these technologies are needed in transportation and stationary applications since they will contribute significantly to the political goals mentioned above. Based on present industry practise for the evaluation of business plans, however, investment in hydrogen and fuel cells involves at present a high economical risk and development times that may be too long for a secure return of investment. Hence, public benefits of hydrogen and fuel cells such as the security of energy supply, the economic growth and competitiveness or green house gas emission reductions can only be timely materialised if public funding contributes to accelerate the commercialisation process.

1.3 Transition Steps and Milestones

The desired process towards mass market penetration of stationary and mobile hydrogen related applications was further structured assuming it as a logical sequence of subsequent development steps (stair-case) as described below. For portables, early and niche markets these steps could in some cases be logically applied by replacing the large scale demonstration by a market introduction supported either by public incentives or by an extreme market environment that allows the (limited) commercialisation by free market forces:

- Prototype development by the manufacturers (ongoing for early/ niche market, stationary and mobile applications for more than 10 years).
- Establishment of single demonstration projects (under way, e.g. CUTE, CEP, Virtual Power Plant, etc.).
- Realisation of comprehensive large-scale integrated demonstration projects such as proposed under the European Initiative for Growth[8] or "Lighthouse Projects" that enable the start of pre-, early commercial small series productions; due to fully integrated nature of these projects in which some elements may be in the research and demonstration phase (and justify governmental and/ or EC funding), whilst other elements may already be in

[8] A European Initiative for Growth COM (2003) 690 final

the commercial phase (and do not justify government and/ or EC funding) the industry will move forward in a focussed way and provide clear signals to the general public that this development is serious and realistic.

- In parallel the development of market introduction and cost reduction programmes (assessment in close collaboration with the Initiative Group on Finance and Business Development).
- Parallel establishment of regulations, codes and standards to allow the deployment of components and systems in field tests and early markets.
- Also in parallel development of a political / policy framework that encourages the deployment of technologies that meet policy objectives, encourages private investment in new technologies and provides guidelines for the definition of national and regional policies, in order to have strong coherence between the European vision and the local support strategies.
- Finally mass market penetration commencing post 2010 for stationary applications and later for hydrogen vehicles.

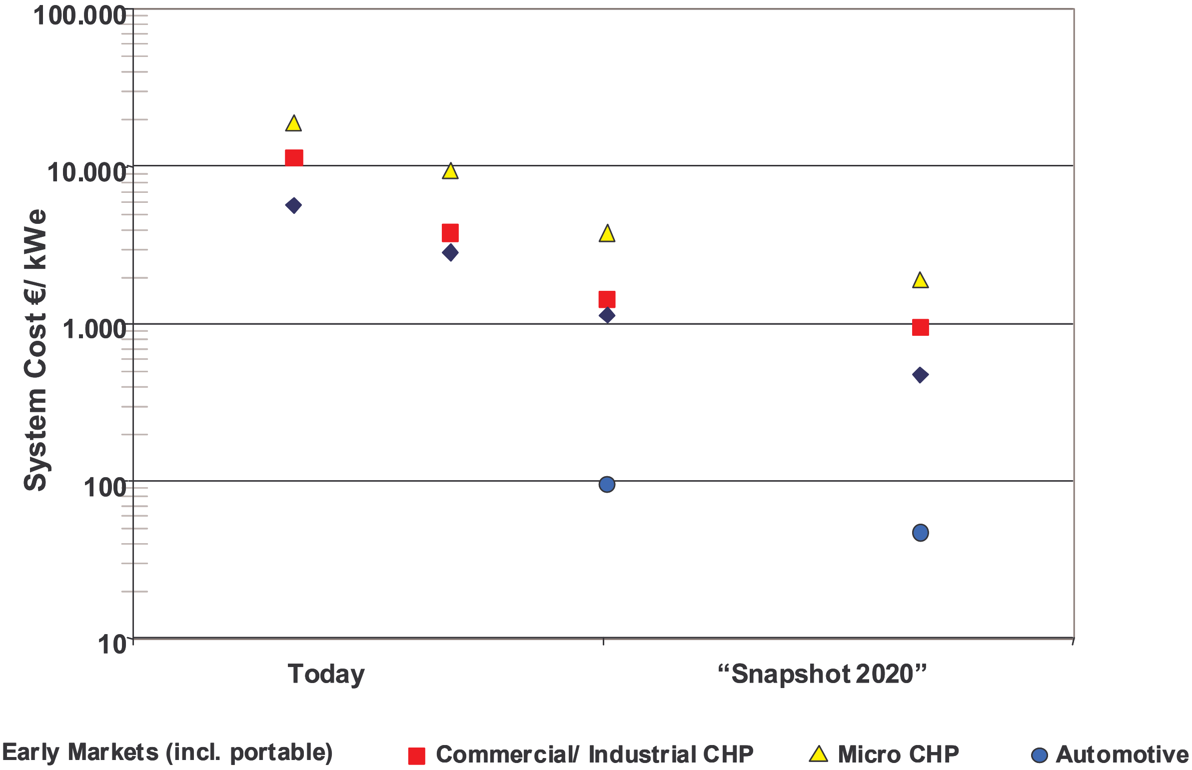

Figure 2: Fuel Cell Markets Timing and Industry Cost Curve illustrating how early markets could contribute to cost reduction of mass market H2 and FC technologies (from the Strategic Research Agenda Foundation Report and Fuel Cell Europe)

The deployment strategy focuses within the time frame until 2020 especially on the definition of comprehensive large-scale demonstration projects such as lighthouse projects and the initiation of first series productions of hydrogen and fuel cell energy systems. A differentiation regarding the technological maturation, the existence of early and niche markets, possible synergies and the application specific determination of economical threshold levels for market entry needs to be undertaken. An outline illustration of how the different markets could develop in a

synergistic way is shown in Figure 2. This cost reduction scenario is based on the learning curve on the supplier side. It has to be noted that different system development and integration activities need to be performed for each respective market in parallel, which may result in a slightly different outcome from that depicted in Figure 2.

Since the success of comprehensive large-scale demonstration projects concerning the establishment and stimulation of early markets is expected to determine the quality and speed of the whole transition process towards hydrogen and fuel cells, precise criteria for the set-up and selection are needed such as:

- Number of projects and a focussed project management structure.
- In the first phase start with a few clusters, preferably in densely populated areas, to concentrate the limited resources, optimise risk sharing, and achieve a maximum benefit regarding synergies, experience, and knowledge increase.
- Focus on the introduction of hydrogen and fuel cell technologies in early markets, in order to cut the costs, help establish a supply chain and pave the way and accelerate the entry of stationary and mobile applications in the market.
- Focus on technologies that have met pre-defined deployment criteria related to technical performance and economic merits (which differentiates deployments from R&D).
- In parallel further development and demonstration of stationary and mobile applications as well as identification of potential synergies. Technical synergies are expected in real-life operational experiences and the respective feedback into the development processes as well as in manufacturing processes. The deployment of stationary fuel cells will help to build a manufacturing base and production volume as well as a robust supply chain (e.g. for key components and closed material loops for critical raw materials like Platinum) all of which should contribute to the development of technically, even more important, cost-wise more demanding fuel cells for automobiles. It should be noted that economies-of-scale achieved through the supply chain that are necessary to meet demanding cost targets, are a result of fuel cell systems cumulatively built rather than by manufacturing capacity installed at a given point in time. In addition the technology deployment delivers also required technological learning as further input for future R&D activities that are necessary to meet future targets, too. However, it is recognised that the successful deployment of hydrogen as an automotive fuel is the major driver of public policy in terms of environmental (reduction of GHG and local pollutant emissions), energy security, international competitiveness and employment benefits and as such public support for the deployment of early market and stationary applications should be based on a clearly defined and synergistic pathway (see chapter 2.1).
- Criteria for establishing a more competitive position for the EU compared to North America and Asia, especially Japan[9]. These regions lead fuel cell development. It is essential that Europe establish a strong competitive position in the emerging global hydrogen and fuel cell industry.

[9] Japanese government targets (2004): 50,000 FCVs by 2010, and 5 million FCVs by 2020 as well as 2,200 MW of residential and commercial fuel cell generation by 2010 and 10,000 MW by 2020 (source K. Nakui, NEDO, FC Europe)

- Criteria for the selection of potential regions considering national preferences for hydrogen production technologies and the root of optimal pathways.
- Sustained political support for the deployment of large-scale demonstration projects.
- Financial requirements require long-term stability in the magnitude as proposed in the Growth Initiative (2.8 bn €).
- Usage of existing hydrogen infrastructure including “excess capacities” (e.g. from refineries, chemical industry, gas industry); besides the actual potential due to yet not fully utilised plants there should be the feasibility of having these “excess capacities” available within the next 10 to 15 years; in parallel the basis for hydrogen pathways realising a broad energy portfolio as well as showing well-to-wheel advantages over existing technologies need to be established.
- Possibilities of linking single lighthouse projects after an organic growth in a later phase into “hydrogen corridors” allowing an area-wide operation of mobile applications.

In addition existing demonstration projects should be monitored and their integration or extension under the frame of comprehensive large-scale demonstration projects should be considered. Furthermore, commitments from the industrial stakeholders as well as from public funding authorities are needed regarding the necessary actions and the resulting financial requirements accompanied by the preparation of the legal framework.

1.4 Description of a “2020 Snapshot”

The overall goal of the 2020 Snapshot is the description of a desired situation in 2020, hence deriving interim steps of a deployment strategy by a back-casting approach. Since the overall time frame of a deployment strategy for hydrogen and fuel cell technologies has been set towards 2050 by the High Level Group the need for a less distant supporting point as major milestone has been addressed in chapter 1.2. Two main objectives have been discussed for the scope and ambition of such a scenario:

- Description of a desired situation for portable, stationary and transport applications at a given time – testing for practicality and attainability.
- Choosing an appropriate time window reflecting the requirements of all applications, matching it with the analysis of the SRA report.

Regarding the first topic the possibility of forecasting the penetration of hydrogen and fuel cell technologies has been refused due to too many uncertainties. Crucial sub-systems such as fuel cell stacks or hydrogen storage systems but also key components like catalysts and membrane-electrode-assemblies have already achieved significant progress but require further breakthroughs on their way towards mass commercialisation so that a more evolutionary based forecast is not within the scope of this work. The description of a desired situation also introduces the possibility to illustrate feasible transition gradients towards hydrogen and fuel cell technologies on the basis of a sufficient support from society, policy and industry. In addition by using a backward approach important milestones can be derived for each market. The issue of choosing an appropriate time window is a difficult one since the

expected maturity of portable, stationary and mobile applications is strongly varying and the existing research and policy framework of the EC has different time schedules. Based on the expectations of the EC on the substitution of alternative fuels as expressed in the "Biofuels Directive"[10] or in the report of the Contact Group on Alternative Fuels[11] a time horizon of 2020 was chosen as an interim milestone for the deployment strategy. This time frame for market targets on hydrogen and fuel cell applications (not research targets!) is furthermore supported by the recommendations of the Strategic Research Agenda. Since the SRA report provides detailed information on expected technical performance and cost data on all relevant conversion technologies for hydrogen with special emphasis on fuel cells (component and system level) as well for storage systems for portable, stationary and mobile applications in 2015 it corresponds with the 2020 time frame for the deployment strategy allowing the transition from the research and development level to commercialisation.

Table 1: Snapshot 2020: Key Assumptions on Hydrogen and Fuel Cell Applications for a 2020 Scenario

	Portable FCs for handheld electronic devices	**Portable Generators & Early Markets**	**Stationary FCs** Combined Heat and Power (CHP)	**Road Transport**
EU H2/ FC units sold per year projection 2020	~ 250 million[a]	~ 100,000 per year[a] (~ 1 GW_e)[a]	100,000 to 200,000 per year[b] (2-4 GW_e)[b]	0.4 million to 1.8 million per year[e]
EU cumulative sales projections until 2020	n.a.	~ 600,000[a] (~ 6 GW_e)[a]	400,000 to 800,000[b] (8-16 GW_e)[b]	1 – 5 million
EU Expected 2020 Market Status	Established	Established	Growth	Mass market roll-out
Government Targets (for Comparison)				
Japan METI cumulative sales targets 2020	n.a.	n.a.	10 GW_e[c]	5 million[c]
US DoE sales targets 2012	n.a.	0.5 GW_e[d]	n.a	n.a.

[a] Portable electronic devices market data taken from "Fuel Cells for Portable Power: Markets, Manufacture and Cost", Jan. 2003, Darnell Group Inc. Corona, CA, USA
[b] Sales projections for Portable Generators / Early Markets and Stationary FCs are based on a consultative process undertaken by Fuel Cell Europe including industry workshops in: Frankfurt, December 2003; Brussels, March 2004; meeting with German Fuel Cell Alliance (BZ-Bündnis), September 2004
[c] Japanese FC & H2 Programmes and Initiatives, Koji Nakui, Director General New Energy and Industrial Technology Development Organization, Japan, presented the official Japanese fuel cell commercialisation and diffusion scenario during the H2FC Based Energy Systems Conference in Vienna, 31.03.04.
[d] Fuel Cell Report to Congress, US DOE, February 2003
[e] H2-fuelled vehicle projections were adopted from the HyWays Project (interim results, unpublished)

Furthermore the "2020 Snapshot" shall describe a desired situation as a major milestone transitioning towards the HLG vision the three markets portable, small and large scale stationary and mobile applications. In addition early and niche markets that help either the market introduction of mass products or positively influence public awareness have been identified too.

[10] Proposal for a Directive, COM(2001) 547 final, 7.11.2001
[11] Market Development of Alternative Fuels", Report of the Alternative Fuels Contact Group, Dec. 2003

The major definitions for portable, stationary and road transport applications are summarized in Table 1. It has to be mentioned that turbo machineries driven by hydrogen or hydrogen rich gases will be available for the use in central power stations above 50 MW_e.

Assuming that technical performance and cost targets (as defined by the SRA) can be achieved and that a clear public commitment is made to a deployment strategy, it is believed that European industry will be in a position to achieve significant sales and take a strong position in the emerging global market for fuel cell equipment by 2020:

- European based companies have already started to introduce direct hydrogen PEMFCs that can be adapted to a number of early market applications, including portable power. The US and Japanese governments are focussing their development and support activity (R&D and market introduction) in the sub-5kW_e segment on fossil-fuelled FCs that will take some years to achieve technical maturity.
- Europe is believed to have a leading position in the Industrial and Large Commercial CHP segment (200-500 kW_e) and given an effective deployment strategy it could dominate this segment.

In order to achieve the ‘’Snapshot 2020’’ publicly supported, extensive demonstration and field trial programmes are required to facilitate investment in high volume, low cost production processes and facilities to help bridge the financial gap between high cost, low volume prototype production and high volume commercial production and are critical to the commercialisation of all new/disruptive technologies. Large-scale demonstrations are required in order to:

- First, demonstrate how the entire fuel cell system works in real life operating conditions, to determine what improvements are needed and the system’s suitability for the specific application. Demonstration programmes must be integrated with an iterative R&D programme.
- Larger demonstrations and field trials are then required to demonstrate the benefits, applicability, reliability and durability to a number of potential users, government, other stakeholders, the media and general public.
- Gain manufacturing experience and build up production volume.
- Identify ‘showstoppers’ e.g. regulations and other impediments.

1.4.1 Hydrogen Production

For 2020 it can be estimated that the main objectives of hydrogen production – diversification and CO2-reduction – will be fulfilled. Hydrogen will be produced from a variety of sources like carbon-free electricity (renewables like wind, nuclear and based on fossil fuels with CO2 capture and sequestration) or directly from fossil fuels with coal gasification processes or natural gas steam reforming including CO2 capture and sequestration. In addition, biomass gasification is expected to be technically feasible in 2020. Two main technologies will be in place: high efficient and low cost electrolysers and gasification processes. If employed at that moment, a substantial reduction of GHG emissions for the fossil pathways.

Hydrogen generated from electricity will be mainly produced on-site at the filling station; in this case the existing energy distribution system (electricity grid) can be

used. Exception is large-scale generation in large (off-shore) wind farms with no appropriate access to an electricity network. Coal gasification or natural gas steam reforming requires large scale production units in centralized plants, the hydrogen will be mainly distributed as liquid with trucks, and a few first pipeline distribution systems in areas with high consumption will be installed. On-site steam reforming – a well-established and necessary technology in the transition phase – may decline due to the lack of applicable technologies for capture and sequestration of CO2 in small quantities.

It cannot be stated today which technology or pathway (including distribution) will be the 'winner' in 2020. On the one hand economics doesn't differ to a large extent and on the other hand quite a few technical and economical uncertainties exist and have to be solved in the upcoming years. It is assumed that there will be a variety of different competing supply paths in 2020; thereby competition will support the development to achieve economically sound and reliable production of hydrogen.

1.4.2 Portable and related Applications

The portable category is made up of two distinct segments:

- Micro-FCs (1-20W), as alternative power sources for handheld electronic devices is potentially a very large market in terms of unit volume. In addition, market entry is expected to be easier than other FC applications and is expected to require little governmental support.
  Although substantial technical barriers have yet to be overcome and for reasons described in section 2.5, including Asian technical leadership, it is believed that micro-FCs may not warrant significant attention in the Deployment Strategy.
- Portable generators (typically <0.5 to 5kW) make up the other segment. However, these generators are often based on power modules using a common architecture that can be adapted for a variety of applications such as backup power, specialist vehicles and APUs for recreational vehicles.

A common approach for these various applications is recommended in the Deployment Strategy. Products are now entering the market and the early implementation of demonstration programmes to assist market entry may effectively act as a bridge to future full-scale deployments of hydrogen and fuel cell technologies.

An issue for the realisation of these goals is the build-up of an at least European wide infrastructure for supporting these applications with either pure hydrogen or a liquid fuel such as methanol. In accordance with the Strategic Research Agenda[12] metal hydride cartridges or methanol for DMFC (direct methanol fuel cell) stacks have been identified as appropriate solutions that could be developed to mass-market maturity beyond 2010. Furthermore a EU wide hydrogen infrastructure for metal hydride cartridges could be realised at all major points of interests such as airports, large shopping centres or filling stations; the distribution system for CO2-bottles used for home soda makers can be used as an example for the general technical feasibility of such an hydrogen infrastructure build-up for portables.

[12] Strategic Research Agenda Foundation Report, chapter 2.5.3.1

Table 2: Snapshot 2020: Market targets for low power portable fuel cell applications

	Portable FCs for handheld electronic devices	**Portable Generators & Early Markets**
Mass Market Introduction	≥ 2008	≤ 2010
EU FC units sold per year projection 2020	~ 250 million[13]	~100,000[14] (~1 GW_e)
average power FC system	15 W	10 kW
FC cost target[15]	1-2 €/W	500 €/kW
Estimated EU added value due to FC system manufacturing (2020 estimate)	probably low due to foreign competition	~ 500 million € per year

Larger portable and other early applications will require a similar fuelling infrastructure although the primary requirement is expected to be for refillable hydrogen canisters. In the event that solid oxide fuel cells (SOFC) are developed for portable applications (backup/remote power, etc.) other available "packaged" fuels such as LPG, propane and methanol could be used.

1.4.3 Stationary Applications

For the segment of stationary fuel cell systems two main applications have been identified as suitable for larger penetration rates of fuel cell systems in the time frame until 2020. First the residential and small commercial segment, today covered mainly by conventional boiler systems for the heat generation and grid connected electricity supply will be a promising market for fuel cell based CHP (combined heat and power generation) systems below 50 kW_e with a main focus on small systems in the range of 1 to 5 kW_e. Another segment where (mainly high temperature and combinations of high and low temperature systems) can create additional values to industrial customers are CHP systems in the range of 200 to 500 kW_e.

For industrial and commercial users but also potentially for residential applications tri-generation (Combined Heat, Power and Cooling) can be an additional feature where the high temperature heat can also be used for cooling purposes.

Following market targets are recommended for a 2020 scenario:

[13] Portable electronic devices market data taken from "Fuel Cells for Portable Power: Markets, Manufacture and Cost", Jan. 2003, Darnell Group Inc. Corona, CA, USA.

[14] Based on consultative process undertaken by Fuel Cell Europe (FCEu) including: workshops held in Frankfurt in December 2003 and in Brussels in March 2004; meeting with German Fuel Cell Alliance (BZ-Bündnis) in September 2004.

[15] Strategic Research Agenda Foundation Report Table 2.5-1

Table 3: Snapshot 2020: market targets for stationary fuel cell applications

		Micro CHP (<50 kW_e)	**Industrial CHP** (200 -500 kW_e)
Mass market introduction	-	≥ 2010	≤2010
EU FC units sold per year projection 2020[16]	GW_e/a	(~ 0.4 GW_e)	(~ 3 GW_e)
average power FC system	kW_e	~ 3	~ 350
FC cost target[17]	€/kW_e	2,000	1,000 – 1,500
Estimated EU added value due to FC system manufacturing (2020 estimate)	€/a	~ 1 billion + installation and energy services	~ 3 billion + installation

Total projected annual production of approximately 3 GW for the residential, commercial and industrial CHP market would represent <1% of the expected gross installed generating capacity in EU15 in 2020.

For a 2020 time frame it is assumed that most of the stationary fuel cell systems will run on natural gas[18] or syngas that can be supplied at reasonable cost and therefore do not need a new and costly infrastructure. However for industrial applications also "pure" hydrogen systems without fuel processor with gas purification are foreseen as niche product for the chemical industry where larger hydrogen volumes occur as by-product such as in the chlorine-alkaline electrolysis. Furthermore a smaller fraction of systems could be connected to hydrogen micro-grids that use either renewable feedstock such as biomass, municipal solid waste or natural gas that could utilise synergies between stationary and mobile applications due to a large-scale production with better economies.

Where significant quantities of hydrogen or hydrogen rich gases are available at very low cost alternative technologies such as hydrogen fuelled gas turbines and combined cycle power plants should be considered given that efficiency and cost are superior to fuel cells. The Strategic Research Agenda should assess the relative benefits of the competing technologies.

A long term or niche market aspect on stationary applications is the use of fuel cells in combination with an electrolyser (or ideally having large scale reversible fuel cell systems) for the net balancing of renewables such as for future large wind offshore installations. However since today the share of intermittent renewables of the EU power production is very small this issue will not have a significant impact on a 2020 scenario.

1.4.4 Transportation Applications

1.4.4.1 Road Transport

In comparison to portables and stationary applications transport applications for hydrogen and fuel cell – mainly road vehicles – will probably perform later the transition from early applications towards mass markets. Based on the present development status a broader market introduction is expected to start 2015 leading

[16] Fuel Cell Europe
[17] Strategic Research Agenda Foundation Report chapters 2.3.3.6 and 2.3.3.7
[18] For remote applications without connection to the natural gas grid propane could be used instead

to a market share of a few percent in 2020. Still in the 2020 scenario there will be no significant contribution of hydrogen and fuel cell vehicles to the overall vehicle fleet of today roughly 215 million units in operation (passenger cars ~190 million)[19].

Therefore early applications play an important role for the preparation of the beginning mass-market penetration of hydrogen and fuel cell vehicles around 2020. The following segments have been identified:

- Inner city traffic such as public transport (buses), light duty fleets for passenger transport and delivery services, city vehicles (4 and 2 wheels) for private or fleet users.
- Industrial material handling such as forklifts, cargo handling.
- Airport apron vehicles such as passenger transport, VIP shuttle, cargo handling, delivery services.
- Auxiliary Power Units (APU) running on conventional fuels for trucks, boats and recreational vehicles or premium cars.

The Contact Group on Alternative Fuels concluded in it's report[20] that a slower mass market introduction of hydrogen and fuel cell vehicles can be expected than anticipated by the EC in 2001 when the 5% target for EU motor fuel substitution in 2020 was set. However there is a big gap between the market potential of the markets mentioned above and the goal of ensuring a visible contribution of hydrogen and fuel cell vehicles to the total alternative fuel substitution target of the EC of 20%. Therefore the target of having "hydrogen cars in the showroom" in 2020 has been translated into a EU-wide availability of both a significant choice of hydrogen and fuel cell vehicles and an area wide hydrogen-filling infrastructure. Based on this ambition an upper range of 5% of all new vehicles sales being hydrogen fuelled has been assumed as the best case for the 2020 scenario. Even if this scenario might be too optimistic a fleet of several 100,000 hydrogen cars is needed to ensure that until 2020 at least a few thousand hydrogen filling stations will be built as basic infrastructure in larger clusters around the biggest European cities. Hence for a 2020 snapshot a range of 360,000 up to 1,825,000 vehicles sold per year being hydrogen-fuelled vehicles has been adopted from the HyWays Project[21].

This bottom-up approach does not reflect processes that will be needed once a radical change in the EU energy supply due to the lack of economically viable (compared to today's market conditions) fossil resources (oil and gas) occurs. Today's dependency on fossil fuels especially in road transport may lead to a need for hydrogen and fuel cell technologies before 2020. This might significantly change the above-mentioned scenarios. In addition unforeseeable technology leaps of a disruptive nature could also lead to earlier than anticipated market development. It is important that the deployment strategy is robust against such unexpected timing variants.

One key aspect of a successful deployment strategy is the proper management of the transition from early applications and the build-up of an adequate hydrogen infrastructure. To be successful, hydrogen and fuel cell vehicles must draw upon the lessons of battery electric vehicles, which lacked acceptance in part due to low

[19] Source: ACEA, Japanese and US targets for home market share are more aggressive
[20] Market Development of Alternative Fuels", Report of the Alternative Fuels Contact Group, Dec. 2003
[21] HyWays Workpackage 3 (interim results, not published)

autonomy, long refuelling time, and low passenger space, and compressed natural gas vehicles, which lacked acceptance mainly due to lack of refuelling infrastructure.

1.4.4.2 Other Transport Applications

Fuel Cells used as auxiliary power units (APU) will in extension to their potential for road transport applications also be used for maritime, air and railway transportation. Furthermore niche markets for fuel cell driven applications such as trams, commuter trains or boats and water taxis could develop, especially in environments with strong local emission restrictions. Also, significant synergies are expected between APUs and small stationary niche and mass-market applications in the same power range, such as remote power and CHP systems.

Industrial material and cargo handling is also an interesting niche market for fuel cells and hydrogen (e.g. battery replacement). However, in the literature the vehicles are often cited as “non-road transport” since they are only used in closed areas and not on public roads.

2 TECHNICAL AND MARKET ASSESSMENT OF HYDROGEN AND FUEL CELLS

Since a major goal of the deployment strategy is the acceleration of the commercialisation of hydrogen and fuel cell technologies by building a positive business case for different markets, a detailed analysis of the expected technical development is needed as well as an assessment of anticipated market requirements. Research and technological development of hydrogen and fuel cell systems have been documented extensively over recent years. Much less attention has been given to analysing the impact of their introduction on industrial value chains. Such an assessment facilitates the definition of balanced marketing strategies. Within this general framework suitable methodologies and tools to examine organisational and market changes related to the use of hydrogen and fuel cells could facilitate recommendations for suitable market strategies. The IG Financing and Business Development suggested the creation of a European Hydrogen and Fuel Cell Market Observatory, as a collaborative effort of economic departments of Universities, industries and public entities active in this field, to guarantee structural and regular updates including the analysis of the European competitive strengths, weaknesses and challenges versus the US and Japan.

These tasks lead to a close alignment with the Strategic Research Agenda since it combines the appraisal of research topics and their expected market maturity with the overall market potential of hydrogen and fuel cell technologies. In this context also possibilities for bridging the initial gaps between market requirements and product performances need to be evaluated in order to support the preparation of appropriate recommendations.

2.1 Hydrogen Production

Policy Objectives and Boundary Conditions regarding the hydrogen production and the distribution towards the consumer are often neglected in comparison to the applications that draw most of the attention. However concerning the targets for a future European energy policy the right choice of the primary energies as feedstock for large-scale hydrogen production is a crucial issue. Keeping in mind the regional specificities of the Member States a broad portfolio of different hydrogen production pathways is foreseen. Recognizing that in the period between now and 2020 a feasible stepping stone would be to produce hydrogen from conventional energy sources, it may not be forgotten, that hydrogen is as sustainable as the primary energy carriers and the process hydrogen is produced from.

These issues have been examined within the Contact Group on Alternative Fuels [22], incorporating findings from various sources including a Well-to-Wheel analysis[23] and cost calculations for a European hydrogen infrastructure from the industrial partners co-operating in the European Thematic Network on Hydrogen (HyNet). Based on this work the following key findings can be derived:

[22] Market Development of Alternative Fuels“, Report of the Alternative Fuels Contact Group, Dec. 2003
[23] „Well-to-Wheels analysis of future automotive fuels and powertrains in the European context“, 2003;EUCAR/CONCAWE/ JRC

- In order to realize advantages in terms of energy efficiency and GHG emissions compared to conventional technologies –under the assumed conditions and ignoring economic aspects- the Well-to-Wheel analysis shows the striking advantage of hydrogen derived from renewable energies in general with a good European potential for biomass and wind energy in combination with hydrogen powered vehicles.
- As a bridging solution hydrogen derived from natural gas in combination with fuel cell powered vehicles offers savings in GHG emissions of about 30% at a slightly lower energy consumption compared to conventional technologies; in combination with hybridised internal combustion engines it would offer similar GHG emissions that conventional technologies on a well-to-wheel base.
- In the initial phase on-site reforming of natural gas, on-site electrolysis and central production with liquid delivery could be considered for deployment. Based on different project assumptions each technology could offer advantages and hence all three possibilities should be assessed in large-scale demonstration projects.
- The integration of mobile and stationary applications, i.e. onsite co-production of hydrogen, heat and power, could support the development of economically viable decentralized systems in the initial phase.
- Hydrogen production based on gasification is process (e.g. biomass, coal, residues) efficient and economically viable only in larger, regional installations. However, fuel cells operating on biogas (primarily from waste such as water treatment plants, landfill sites and food industry) are in demonstration and provide the opportunity to utilise biogas in relatively small installations (~250kWe). The ability to use these systems to co-produce hydrogen and electricity should be assessed.
- Pipelines could be considered in an advanced phase of market uptake of hydrogen.

In addition, electrolysis from off peak nuclear power or fossil power in combination with carbon capture/ sequestration needs to be examined more close in collaboration with the Strategic Research Agenda Panel. In addition a future long-term potential of thermolysis from nuclear or solar heat could be exploited.

Since hydrogen is an energy carrier a strong relationship and in some cases also strong competition with electricity exists. In addition electrolysis and fuel cells as well as other hydrogen conversion technologies offer a bi-directional link between both energy carriers as displayed in Figure 3. In the short to medium term the production of electricity and also hydrogen will mainly rely on conventional fuels and thus the hydrogen production from fossil generated electricity is less efficient than the direct use of fossil fuel. However in the long term (beyond 2020), assuming an increased share of renewable electricity generation, the strong relationship between those two energy carriers offers a wide variety of energy pathways. One example is large-scale hydrogen gas turbines that could balance a large amount of non-intermittent renewable energies like wind energy.

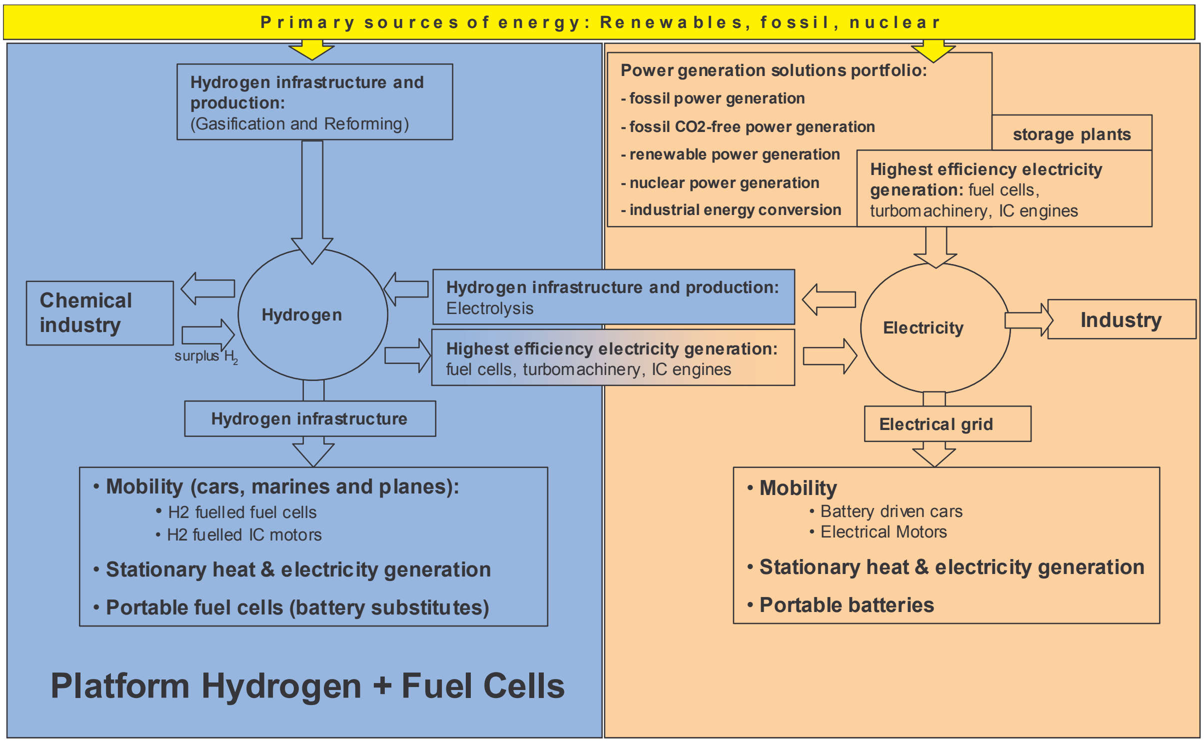

Figure 3: Electricity and hydrogen as complementary energy carrier (from Siemens Power)

2.1.1 Experience from Existing Demonstration Projects

Pilot project experiences with various hydrogen production and distribution technologies are gathered in the EU-funded such as CUTE and ECTOS Projects. Although these projects are still ongoing it has become obvious in the first year of operations that further development in refuelling technologies is necessary to assure a reliable use of hydrogen as a fuel in commercial markets.

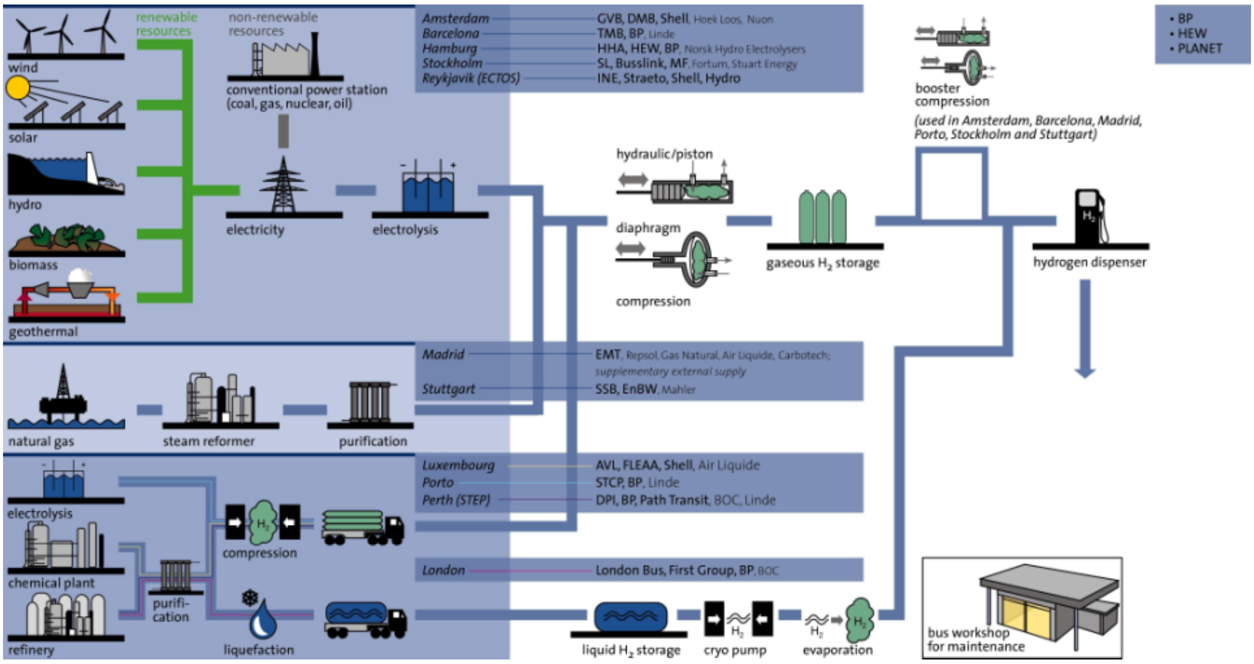

Figure 4: CUTE Project: Hydrogen pathways demonstrated at the CUTE sites (from CUTE)

These and other demonstration programs, like the Virtual Power Plant project in the stationary sector, will provide a valuable input into the DS in terms of identifying barriers towards a commercialisation of the respective technologies.

2.1.2 Assessment of Hydrogen Pathways until 2020

It is expected that renewable hydrogen will play an important role in the long term future in addition to other carbon free or low carbon production pathways. The design of the transition process towards renewable hydrogen will be strongly influenced by the initial infrastructure that will be required to allow a beginning mass-market penetration. As discussed in chapter 1.4 by 2020 for all relevant segments mass market penetration of hydrogen and fuel cell application has already taken place or will be likely to happen which also requires appropriate production and distribution services by than. Due to a typical plant lifetime of at least 20 years for key equipments such as electrolysers, filling stations or large scale steam reformers the pathways that will be chosen now for large-scale demonstration projects and the following market introduction phase will have an impact beyond 2030. Hence a future European energy policy needs to address the question of the preferred use of renewable energies considering that (comparatively cheap) renewable resources within the EU are limited and there is already a strong competition between stationary users in some Member States due to feed-in laws for “green” electricity. On the basis of a political desire for renewable fuels for transport renewable hydrogen pathways should be part of large-scale demonstration projects as well.

These considerations have also been expressed in the HyNet Roadmap Report that leads to a suggested entry scenario for hydrogen production from either natural gas on a centralised base and electrolysis from renewable electricity (Figure 5).

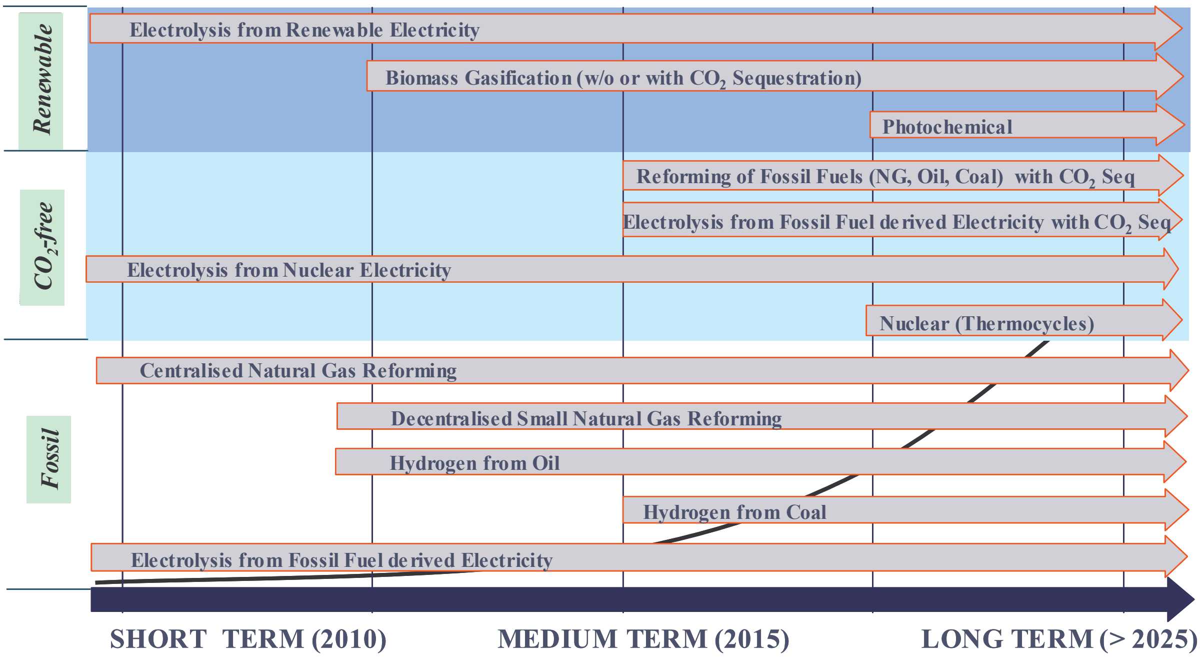

Figure 5: Maturation of hydrogen production pathways from HyNet Roadmap Executive Report

With regards to further recommendations of preferred hydrogen pathways besides economical criteria also the potential support of energy policy related issues needs to

be taken into account. In order to allow for a medium term impact only pathways that have been identified to mature before 2015 in accordance to the Strategic Research Agenda and the HyNet Roadmap[24] have been considered.

Table 4: Assessment of relevant hydrogen pathways until 2020

	Natural Gas[1] (SMR)	Grid Electricity[1] (electrolysis)	Wind (electrolysis)	Biomass (gasification)
Hydrogen cost (excl. distribution)	1.00 €/kg[2] (8.3 €/GJ)	3.75 €/kg[2] (31,3 €/GJ)	6 –8 €/kg[3] (50-67 €/GJ)	3-4 €/kg[3] (25-33 €/GJ)
Positive impact on security of energy supply	modest	high	high	high
Positive impact on GHG emission reductions	neutral – modest[4]	negative-neutral[4]	high	high

[1] Current EU-Mix including distribution, in combination with nuclear/ CO2-free power a high positive impact on GHG emission reductions could be reached
[2] Strategic Research Agenda Report, Table 2.1-1 (large scale conversion, electrolysis 1000kg/d)
[3] Report of the Contact Group on Alternative Fuels, 2003
[4] Depending on the hydrogen conversion efficiency of the applied application

One additional pathway to provide hydrogen is proposed e.g. in the Zero Regio project, which is funded by the EC 6th Framework Programme. In this project it is planned to use hydrogen as an alternative fuel, which is produced as primary or waste stream in chemical plants, to be demonstrated in the Rhine-Main-Area in Germany and in Lombardia Region in Italy. Similar to this, large scale reforming of natural gas, e.g. at oil refinery sites offers hydrogen that is available today. In comparison with decentralized on-site reforming, central production has the additional potential for use in combination with CO2 sequestration options. This central production of hydrogen via gasification (coal, biomass, residues or waste[25]) would generate the required additional capacity.

2.1.3 Conclusions on Hydrogen Production

In an initial phase – for the near and mid-term future - three hydrogen pathways should be deployed:

- Hydrogen derived from refineries and chemical plants[26], to take maximum advantage of already existing lowest cost hydrogen sources.
- In parallel on-site hydrogen production based on electrolysis or natural gas reforming, to stimulate the respective industries to further develop the necessary technologies and
- Large-scale centralised hydrogen-production based on natural gas (see also chapter 2.2.5), with future options for CO2 sequestration.

[24] HyNet Roadmap Executive Report, www.hynet.info
[25] Local remediation of urban waste could offer between 15-20% of a community's energy needs (source: Initiative Group Financing and Business Development).
[26] Since in many cases today the by-product hydrogen is used thermally (e.g. heat generation) this hydrogen could by replaced by other fuels suitable for process heat generation and used for hydrogen demonstration projects instead.

The additional environmental impact of hydrogen production from each of these pathways should be carefully considered: aspects such as land use and NO_x emissions should be evaluated.

In parallel the following activities should start today, to have the respective technologies available. Furthermore if positive research results have been achieved, these pathways should be also demonstrated under the frame of large-scale demonstration projects:

- Hydrogen production based on gasification (biomass, residues or coal) should be further assessed, to lay the basis for a broader feedstock for hydrogen as well as for a dramatic reduction of GHG emissions. In this context the general distribution of biomass to stationary and transport markets needs to be addressed on a political level. Similarly CO2-capture and sequestration need to be evaluated for fossil feedstock in order to broaden the range for low carbon pathways.
- Potential sources for power based on renewable energies should be assessed on their availability for the production of hydrogen. In this context offshore wind, geothermal and solar thermal pathways need to be considered and their down-side of being often at remote locations should be weighted against the demand of hydrogen in the envisaged highly populated regions for deployment projects, since by 2015 significant research progress can be expected[27].

Biomass gasification and renewable energy sources have also to be discussed in the context of regional opportunities, potentials and restrictions. As one example could serve large centralised wind farms remote from consumers for hydrogen production, which are generating surplus power that cannot be fed into the electrical grid. Overall, within the timeframe of the Deployment Strategy a broad primary energy portfolio for the production of hydrogen must be established.

A more detailed roadmap including the potentials of the various energy sources for hydrogen-production (e.g. biomass, which is also used for liquid fuels) is expected from the activities in the frame of the HyWays project which is currently funded under the 6th Framework Programme and the HYPOGEN project as proposed under the Initiative for Growth, the results of which will be a valuable input into the deployment strategy.

The key issue in the context of a deployment strategy is to ensure that an appropriate, environmentally compatible and economically viable infrastructure is made available in conjunction with the introduction of applications (e.g. vehicles). The best long-term technologies will finally be determined by commercial factors.

2.2 Hydrogen Distribution and Storage

This section examines the supply chain between the centralised and decentralised production of hydrogen towards the consumer (up to large scale consumption), including eventual storage at the demand site for portable and mobile applications or stationary applications with volatile load profile such as filling stations. Furthermore, the production options of “central” versus “decentralised” that require different

[27] Strategic Research Agenda Foundation Report chapter 2.1.3.1

distribution systems are considered against the various user-induced storage requirements.

2.2.1 Hydrogen Distribution and Storage for Portable Applications

At present two technologies are competing for portable low-power applications such as notebooks or other electronic gadgets. The DMFC (direct methanol fuel cell) significantly simplifies the fuel distribution and storage issues[28]. However, the deployment of portable DMFC based applications is strongly dependent on R&D results for increasing the power densities within the next years whereas the bottleneck for the market introduction of portable PEMFC applications is cost issues the provision of an appropriate infrastructure. Regarding the storage of pure hydrogen for portable low power applications none-refillable cartridges either being CGH2 or metal hydrides have been proven to be the most suitable technology regarding cost, ease of handling and safety issues[29]. The gas industry has been distributing since more than 50 years high pressure cylinders (steel, 200 bar) to customers with a relatively small hydrogen demand, in the order of some 1 to 10 kg per week. There is already a European wide hydrogen supply network in place that gradually could be expanded with the growing demand for hydrogen fuelled portables. For a deployment strategy the following two points are of interest:

- Creating an interface with the customer: the process chain from recycling empty cartridges at existing sites of the gas industry and delivering them to “filling centres” (e.g. at big shopping malls or airports) where consumers can exchange their empty cartridges with new ones.
- Preparing the legal framework: the usage of these hydrogen cartridges at all public places including their air-transport needs to be ensured. Detailed proposals are expected by the Initiative Group RCS.

Finally synergies should be sought with other early markets or niche applications such as light traction (wheelchairs, micro cars for inner city traffic, power tools) that could be tied up with the same infrastructure in order to increase utilisation and sales volumes.

2.2.2 Hydrogen Distribution for Stationary Applications

Most demonstration projects and field tests for pre-commercial stationary fuel cells in the range between some kW_e to some 100 kW_e are connected to the natural gas grid and produce hydrogen via reforming of natural gas and an integrated gas purification unit. Especially for high temperature fuel cells with their simplified reforming and good resistance against impurities this solution is very cost effective. Decentralised H2-production based on the existing NG-network allows a fast build up of early markets for a broad range of stationary hydrogen and fuel cell applications long before a competitive H2 infrastructure is built up.

For the usage of by-product hydrogen from chemical plants or from a refinery a pipeline transport over short distances is the most efficient way if the utilisation is high right from the beginning. This applies to most industrial fuel cell installations in contradiction to the supply of hydrogen in filling stations where the slow ramp up of vehicles causes a lower utilisation over a longer period.

[28] The actual volumetric and gravimetric density of PEMFC with metal hydride storage is FC 55 W/l and 95 W/Kg, a DMFC system achieves 40 W/l and 30 W/Kg (Strategic Research Agenda Foundation Report chapter 2.5.3.2)
[29] Strategic Research Agenda report, chapter 2.2.3.3.1

A mid-term option is the installation of H2-microgrids to supply stationary fuel cells and filling stations with hydrogen. The advantage would be the synergies of hydrogen demand patterns from stationary and filling stations, thereby an optimization of the hydrogen production and storage facility. Of course, in this case stationary fuel cells running on pure hydrogen (PEM) have to be developed. The operation of hydrogen pipelines has been performed by the chemical and gas industry since the 1930s as the example of the Leuna site (Germany) manifests.

2.2.3 Hydrogen Distribution for Transport Applications

For transport applications three different pathways and distribution regimes are generally considered as viable options (taking into account the long term potential for CO2 emission reduction and economic considerations):

- Central hydrogen production with pipeline transport to the filling station (only CGH2 fillings possible).
- Central production and liquefaction of hydrogen with tank trailer transport to the filling station (CGH2 and LH2 fillings possible).
- On-site production of hydrogen with optional buffer storage for load levelling (only CGH2 fillings possible). An option that should be evaluated at large fuelling stations would be to add LH2 storage supplied by trailer to supply LH2 vehicles and cover peak loads and a buffer / backup supply for the on-site reformer.

The first option is often seen as the ideal long term option when high penetration rates of hydrogen will have been reached for example as suggested for a 2050 scenario[30]. However this would imply a radical shift in technology at a point where a fairly high market penetration has been already reached. An example may be referred to for the post 2020 time frame from the HyNet Roadmap Report, assuming that more than 10,000 hydrogen filling stations would exist in the EU and therefore should need to be linked with a new hydrogen pipeline network. Based on the results of the Transport Energy Strategy[31] a rough estimate on the additional investment for the pipeline network in the order of 10 billion € can be made. The initial investment on the other hand for these 10,000 hydrogen stations using either an on-site production or a centralised liquid supply is in the order of 7 to 14 billion € (see Figure 6).

Regarding the investment figures given in Figure 6 it needs to be stated that the ground area costs for the filling station including the area for on-site generation have not been included. Therefore, depending on the location the actual investment can differ from the figures given above since on-site production requires a significant larger footprint than pipeline supply or liquid underground storage[32]:

[30] Strategic Research Agenda Foundation Report chapter 2.2.1
[31] Transport Energy Strategy, 2nd interim report to the Steering committee, June 2001 (not published)
[32] Presentation by J. Wolf (Linde) at the First General Assembly of the HFP, January 2004

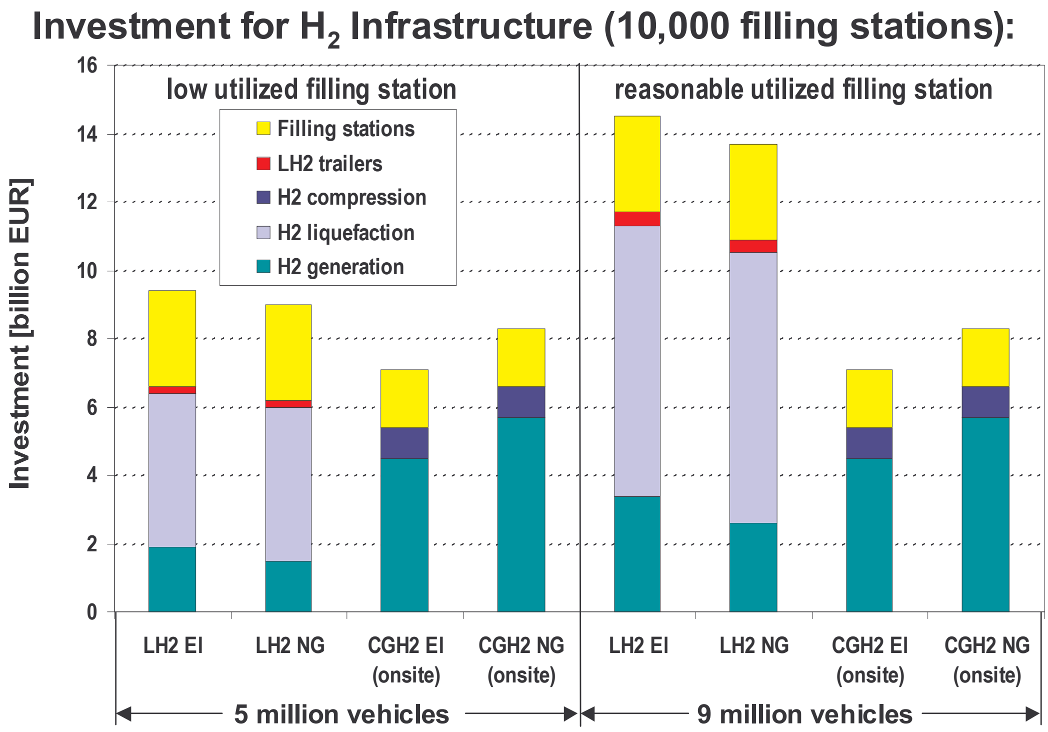

Figure 6: Investment for a transport hydrogen infrastructure from: Report of the Contact Group on Alternative Fuels, Annex 4 (compiled by HyNet)

Hence an optimised distribution system will likely require an intelligent mix of technologies reflecting the following issues:

- Flexibility and transition friendliness
- Footprint requirements
- Cost issues
- Emissions and energy balances
- Safety and permitting issues

However this shall not prejudice a certain onboard vehicle storage technology since all three potential storage technologies (liquid, high pressure compressed, low pressure technologies like nano-tubes) can be supplied by a filling station using a liquid storage tank.

2.2.4 Hydrogen Storage

Regarding hydrogen storage there is a necessary distinction between mobile applications and stationary ones since for stationary users weight and volume of fuel supply storage devices either for load levelling purposes or as source for remote systems are less critical than for vehicles.

2.2.4.1 Hydrogen Storage for Stationary Applications

For stationary applications, in general, two different basic requirements need to be considered. First of all the hydrogen storage for island or remote applications requires the storage of high energy contents over a long period of time and requires external hydrogen delivery. Second for load-levelling requirements that could occur

for instance at a hydrogen filling station with onsite production the hydrogen is stored internally at the plant for a short time only.

For remote applications due to the need for delivery either by road or by ship a liquid distribution and delivery system is most likely the most economical solution. State of the art technology uses cylindrical tanks that can either be mounted above ground (standing, lying) or under ground having usually volumes from some m³ up to around 100 m³. Refilling of such tanks via trailer adds a transport cost in the range of 0.2€/kg[33] and is a standard operation in the gas industry, based on standard cryogenic equipment used also for the delivery of liquid nitrogen or oxygen.

Regarding the need for having intermediate buffer storage in most cases compressed gaseous hydrogen storage is foreseen. Smaller installations can utilise either commercial pressure cylinders that are mass-produced today for the gas industry (200 bar, steel) and maybe in future also for the automotive industry (350 or 700 bar, composite). Larger installations can also utilise tailored tube storage systems based on steel piping tubes that are produced for instance for large gas pipelines and commercially available for pressures up to 100 bar and diameters up to 1,400 mm. Very large scale storage of hydrogen (in the order of 10.000 m³ at about 1.000 bar) would be required at sites near large wind farms to store fuel for centralised power stations to provide grid stability. In addition it is recommended to examine whether the design pattern of town gas-meters could be used for new hydrogen storage facilities.

2.2.4.2 Hydrogen Storage for Transport Applications

Since conventional cars offer ranges between 500 km to around 1000 km the range of today's available semi-commercial storage solutions hinders the market success of hydrogen-powered vehicles. Due to the physical properties of hydrogen even liquid hydrogen, which offers the best physical storage, density (fuel property only!) needs roughly four times the volume than the same energy equivalent of gasoline. Furthermore cryogenic or high-pressure vessels also reduce the gravimetric advantage of hydrogen in comparison to gasoline, which is in theory (fuel property only!) 3 times better.

However existing liquid or compressed hydrogen storage vessels deliver today gravimetric densities far below 10% which means that more than 90% of the weight of the full tank system are related to the containment whereas today's plastic gasoline tanks have roughly 10% of the weight of the stored fuel.

The following hydrogen storage solutions are recognised to be available for serial development in 2015 and therefore relevant for market introduction strategies in 2020 and beyond:

[33] Transport Energy Strategy, 2nd interim report to the Steering committee, June 2001 (not published) for a transport distance of 150 km

Table 5: Hydrogen Storage Performance expected by 2015

	Usable H mass fraction (2015 perspective)[a]	Remarks
LH2	12%	Ongoing fleet tests
CGH2 700 bar	9%	First fleet test (ongoing with 350 bar)
Complex metal hydrides (alanates)	7%	Laboratory phase
Chemical hydrides ($NaBH_4$)	9%	Demonstrator in USA, requires not only refilling but also draining of hazardous chemical liquid; recycling process not reasonable

[a] Strategic Research Agenda Foundation Report Table 2.2-1

Table 5 indicates that for the frame of a deployment strategy only LH2 and CGH2 storage systems can contribute to large-scale vehicle demonstration programmes and preparatory activities of a market introduction in the time frame until 2015. It also needs to be stated that the "onboard vehicle storage problem" is also related to the fact that all automotive companies use up to now for their hydrogen development programmes, due to cost reasons, a converted conventional body, which is designed for a flexible mouldable gasoline tank rather than for accommodating a more bulky hydrogen storage system. Hence one task for a deployment strategy and in particular for Lighthouse Projects is the creation of an initial demand that is big enough to allow the automotive companies designing first small series of some thousand dedicated units each. With these dedicated hydrogen cars having a range in the order of 400 to 500 km and the full functionality of conventional cars the demand of fleet and private customers will be stimulated much better than with today's converted vehicles.

For some heavy duty vehicles such as public transport buses the hydrogen storage problem has already been solved regarding range requirements with actual available liquid or compressed systems. Most common solution for buses are roof mounted compressed tanks where even the commercial available 350 bar tanks offer a range capable of about one day's service or more. Hence for this segment the most urgent issue for a deployment strategy is reducing the cost for storage systems by utilising economies of scale in the production,

2.2.5 Recommendations on Hydrogen Distribution and Storage

In an initial phase – in the near and mid-term future – the following activities regarding hydrogen distribution and storage should further be deployed:

- An infrastructure for portables (mainly notebooks and telecommunication devices with < 100W) and early or niche markets applications (power generators, forklift trucks, back-up power systems, …) with hydrogen cylinders needs to be developed in close collaboration with the gas industry and application developers.
- The ongoing improvements of LH2 and CGH2 storage systems as well as eventually other available alternatives need to be further deployed under large

scale demonstration programmes such as Lighthouse Projects with the aim to agree on industry standards in the 2010 time frame.

- Large-scale hydrogen-production and liquefaction and subsequently trucking of liquid hydrogen to the re-fuelling stations, to offer flexible hydrogen supply for early and time critical demonstration purposes should also be tried out. In this case the delivery of liquid hydrogen and the demand side need to be well synchronized in order to avoid boil-off hydrogen. Re-liquefaction units or concurrent operation of stationary heat and power production could be used to overcome this problem.
- In parallel to the large-scale liquid production build up, the deployment of on-site pathways should be performed with the same intensity in order to prepare the ground for final commercialisation decisions around the 2015 time frame.

2.3 Stationary Applications

Within the stationary energy market in Europe the following trends can be observed:

- Power plants in the order of several hundred GW have to be replaced/expanded in the next 2-3 decades in Europe.
- Centralized power production will remain the main source and backbone for electricity generation in the coming years and as such will remain the benchmark.
- The share of decentralized energy solutions will increase (reduces T&D losses, reduces/defers need for investment in T&D upgrades, reduces peak power, etc.).
- More and more renewable energy sources, e.g. offshore wind power will be introduced in the energy system.
- Centralized power stations with higher dynamic and operational flexibility (used also as balancing and reserve power for renewables) will also be introduced.

In this context the discussion on fuel cell and hydrogen is focused on:

- The use of fuel cell systems in de-centralized power stations to convert energy directly into electricity and heat (CHP).
- The use of gas turbines in decentralized and centralized power stations to combust hydrogen for the production of electricity.
- The use of reversible fuel cells (still in the R&D phase) in combination with large wind installations (especially offshore) for grid balancing.

2.3.1 Small-scale stationary applications using fuel cell systems

Due to its limited output the small-to-mid-scale fuel cell systems are well placed in de-centralized energy systems with output up to 1 to 10 MW_e (has to be developed). The fuel of choice for stationary fuel cell applications is - depending on the technology deployed, i.e. high-temperature or low-temperature fuel cells - natural gas or a hydrogen-rich synthetic gas derived from various feedstock like biomass, waste, etc. If hydrogen is more centrally produced and supplied in micro-grids, fuel cells fuelled with pure hydrogen are also an option. With pure hydrogen the fuel cell system is much less complex by avoiding the fuel processor.

For the deployment of fuel cell technologies in the de-centralized stationary sector today's most prominent two concepts are being discussed below:

2.3.1.1 Micro CHP

Natural gas fuelled micro-CHP systems are expected to become one of the first major mass markets for fuel cells. The product can be described as a mass produced appliance targeted at residences (single and multi-family) and small commercial users as a replacement for conventional gas boilers. Power produced will be used preferentially within the building with top-up and backup power supplied from the grid; where practical, excess power will be exported to the grid. In most cases a supplementary boiler will be included in the system to provide for peak heat requirements. Most systems will be sized between 1 and 5kWe; small commercial units may be as large as 50kWe. Micro-CHP units can be handled and certified under the regime of the European Gas Appliance Directive (EU 90/396/EWG), which covers nearly all safety issues for domestic installation.

Utilities and Local Authorities believe that there is a significant opportunity to provide a complete energy service, including combined heat and power supply, to residential and commercial customers. In addition to the advantages of decentralized power systems mentioned above this would provide the following benefits:

- Increased energy efficiency: micro-CHP with fuel cells can reach overall efficiencies up to 90%.
- Integration of multiple sources including fuel cells and renewables into a virtual power plant.
- Job creation and development of SMEs: "energy services are a job machine" and encompasses supply, installation, financing, operation and maintenance.
- Increased efficiency potentially yields energy cost savings to users and may reduce fuel poverty for low-income households.

As of mid of 2004 more than 100 Fuel Cell Heating Appliances (4.6 kW_{el}, PEM and 1 kW_{el}, SOFC) are in operation in multiple family houses, hotels, shops and small business sites in Europe. Issues identified to-date are system complexity, insufficient durability and costs. Next generation systems with improved system architecture and higher integration are expected from 2005 onwards. (A tri-generation option should be evaluated as the inclusion of chilling technology reduces electricity peaks in summer and improves commercial business case.)

Based on the SRA targets[34] preliminary suggestions for publicly supported demonstration programmes the need of which has been argued previously, combining hundreds of fuel cell CHP units (1-10 kW_e) in centrally controlled Virtual Power Plants can be summarized as follows:

- 2006/08 1 MW_e installed capacity, system cost target 12,000 €/kW
- 2007/10 5 MW_e installed capacity, system cost target 6,000 €/kW
- 2009/12 200 MW_e installed capacity, system cost target 4,000 €/kW

[34] Strategic Research Agenda Foundation Report Table 2.3-2

These steps are considered the optimum to demonstrate the systems to the point of technical readiness and bring about costs to approaching commercial levels for early high-value applications.

It should be noted that many of the current residential fuel cell demonstrations in Europe include core components using foreign technology, mainly from North America. In terms of future employment and GDP in Europe, it is crucial that the EU carefully analyse its competitive position regarding fuel cell technology in order to provide a fair and reasonable benefit from the establishment of a global fuel cell industry to its Member States. Nevertheless, worldwide co-operation is necessary to open the global markets for the EU industries. Therefore, co-operation with non-EU partners worldwide, should be part of the deployment programme (e.g. Lighthouse Projects) to encourage the building up of global alliances with a strong EU-part in it.

2.3.1.2 Decentralized CHP Power plants

Large fuel cell systems (>200kW$_e$) based on high temperature fuel cell technologies for de-centralized power/cogeneration have been developed. These fuel cell systems offer higher efficiency and high-grade heat suitable for large commercial and industrial applications. Since they can operate with various feedstock like natural gas, biogas, landfill and water treatment gas (coal gas is in development) they contribute to the goal of fuel diversification. Tri-generation should be evaluated in lighthouse demonstration projects. These systems also offer all the benefits of distributed / decentralized generation.

High temperature fuel cells like the Solid Oxide Fuel Cell (SOFC) and Molten Carbonate Fuel Cells (MCFC) are ideal for distributed energy supply systems which operate today with natural gas. This makes the development and use of such a technology independent from the establishment of a hydrogen infrastructure. Demonstrations have shown operability of high temperature fuel cell systems over more than 20,000 hours. This technology can contribute to realising the reduction in Greenhouse Gas Emissions by more than 50% with virtually zero acid rain emissions (NOx, SOx). Highest electrical efficiency of any small power system at 53% fuel-to-electricity can be achieved with high temperature fuel cells[35]. There is even more potential when it is utilized in the hybrid configuration with a Micro-Turbine to achieve an electrical efficiency of higher than70%. Further developments are going on for the use of methane rich gases, alternate fuels and coal gas utilization. Today the major challenge for the commercialisation is the cost reduction and product standardization.

First generation units are in demonstration in Europe and 2nd generation technologies are expected in 2005. To serve larger power demands 1 MW$_e$ and hybrid fuel cell / turbine systems are in development.

Based on the SRA targets[36], preliminary suggestions for publicly supported demonstration programmes deploying high temperature fuel cell systems sum up to the following capacities:

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[35] „Fuel cells for distributed power: benefits, barriers and perspective"; 2003; a study for WWF and Fuel Cell Europe

[36] Strategic Research Agenda Foundation Report Table 2.3-2

- 2006/08 3 MW_e installed capacity, system cost 12,000 €/kW
- 2007/10 20 MW_e installed capacity, system cost 10,000 €/kW
- 2009/12 400 MW_e installed capacity, system cost 3,000 €/kW

As mentioned earlier these steps are considered the minimum needed to demonstrate systems as technically ready and economical for commercial early high-value applications.

These systems could be integrated into Virtual Power Plant demonstrations and their use at co-production sites producing hydrogen and power should be evaluated.

2.3.2 Large-scale stationary applications

One example for early market opportunities in the stationary sector is the use of hydrogen recovered from industrial plants, for example electrochemical processes such as chlorine-alkali and chlorate plants, by fuel cell systems to save energy in the plants themselves. Hydrogen produced from some industrial and chemical plants in Europe is of high purity and abundant (> 200 MW). Modular fuel cell systems would allow an increasing power output over time, i.e. as next generation technologies become available based on experiences from the previous generations and as investment costs decrease with a growing manufacturing volume, a multi-MW stationary fuel cell system can be developed. Safety codes and standards for use of hydrogen in industrial applications are already in place, lowering barriers to market introduction. The opportunity to exploit on-site recovery of industrial hydrogen needs to be assessed versus the opportunity to deliver industrial hydrogen to on site re-fuelling stations for fuel cell cars or stationary units. This needs to include an assessment of the investment needed for large on-site fuel cell systems including the reduction in cost per kW for every MW produced.

Centralized power stations will still be the backbone of Europe's energy supply in the next decades. The introduction of hydrogen or hydrogen rich gas driven turbines would give more flexibility to the system and serve as a bridge between the energy system of the renewable sources like wind with its high fluctuation and the back-up power stations. The fuel independent driven gas turbine could be used as micro turbine in a decentralized energy system - also together with a fuel cell – and in big, centralized power stations.

In a step-by-step introduction of hydrogen into the energy system the use of gas turbines could be transposed from the use of pure natural gas over a mix through to pure hydrogen driven technology. Although there is development to be done to adapt gas turbine technology to a pure hydrogen fuel, it could be made available in a few years time in parallel with the introduction of a hydrogen production facility.

2.4 Transport Applications

2.4.1 Road Transport

At present hydrogen powered vehicles with PEM (Polymer Electrolyte Membrane) fuel cell powertrains and somewhat less with internal combustion engines are being demonstrated in ongoing projects worldwide. Moving ahead, the Roadmap outlined by the High Level Group proposes the following four steps concerning the introduction of fuel cell powered vehicles with the perspective that this will be the dominant technology in transport by the middle of this century:

Table 6: Transition steps for fuel cell vehicles towards mass market penetration from: High Level Group, A Challenging European Hydrogen Vision

Step	Timing	Vehicle Maturity
1	Today until 2010	Demonstration of fuel cell powered vehicles in controlled fleets
2	>2010	Series production of fuel cell powered vehicles for fleets (1st generation on board hydrogen storage)
3	>2020	Series production of fuel cell powered vehicles in broad application (2nd generation hydrogen on board storage and low-cost high-temperature fuel cell systems)
4	>2030-2040	Fuel cells become dominant technology in transport

In the above mentioned steps 1 to 4 the development of fuel cell components and hydrogen storage technologies is crucial. Especially the transition from step 2 to 3 requires close collaboration and feedback between basic research on components and fuel cell stacks on the one side and the technical validation of integrated systems under demonstration programmes that allow an organic growth in dependency of the technical and economical progress. In this context to prove that cost reductions for critical sub-systems such as fuel cell stacks or hydrogen storage tanks are feasible more and more units need to be demonstrated leading to fully developed large scale demonstration projects such as Lighthouse Projects in the 2010 to 2015 time frame. In order to allow an organic growth of the existing projects and their successors such as the proposed Hypogen and HyCom Projects of the Initiative for Growth or activities of the 7th research Framework Programme under the umbrella of one large-scale comprehensive hydrogen demonstration programme technical and economical criteria should also be devised. A starting point for fuel cell vehicles can be obtained from the Strategic Research Agenda comparing the fuel cell targets for 2015 with the actual status as given in Table 7.

In terms of barriers not only technical issues need to be resolved, but also industry development cycles in terms of timing need to be considered. The automotive industry is committed to develop hydrogen-powered cars and a lot has been achieved within the last decade. However, it will take more test-fleet generations to develop complete new technologies like fuel cell systems up to the point where they are competitive to conventional drive trains in terms of reliability, lifetime or costs. Clearly the number of demonstration vehicles in Europe within the first step will be limited and has to be aligned with other worldwide activities.

Table 7: Comparison of the actual status with 2015 targets for fuel cell systems for passenger cars[37]

		Actual Status	2015 Target
Power density	l/ kW	3.0	1.5
Cycle Efficiency (NEDC)	-	37%	> 40%
Life time	full load hours	< 2,000	> 5,000
Specific cost	€/ kW	> 4,000	< 100 (> 150,000 units/ a)

Vehicles with hydrogen fuelled internal combustion engines (ICE) are viewed as a possibility to provide a faster pathway to a broad market introduction of hydrogen vehicles as reported by the Contact Group on Alternative Fuels (AFCG)[38]. Based on the Well-to-Wheel analysis the AFCG concludes however, that a larger market introduction of hydrogen ICE vehicles should only be considered on the basis of low-carbon hydrogen production. Hybridisation helps to increase the efficiency of ICE vehicles and lead on the basis of hydrogen from natural gas to a neutral effect on GHG emissions on a well-to-wheel base, whereas fuel cell vehicles offer a 30% reduction in comparison to the conventional gasoline vehicle[39]. Furthermore the AFCG study concludes that fuel cell driven engines for passenger cars are not likely to reach the power level of high power internal combustion engines above 100 kW in the near future.

In terms of fuelling options it is crucial for the success of the introduction of hydrogen as an alternative fuel that commercially viable hydrogen in terms of costs, safety and public acceptance will be available starting with the first fleet applications (step 2). Hence the vehicles as well as the hydrogen infrastructure need to be developed in parallel starting today. In this context a clear set of governmental regulations is crucial for the acceleration of the commercialisation of fuel cells and hydrogen.

Besides reducing the costs of electric fuel cell drive trains and hydrogen storage systems it is also necessary for a successful market introduction to have vehicle concepts on the market that are specifically designed for hydrogen as discussed under the storage section. Therefore a deployment strategy also needs to address schemes that allow secure planning concerning the future demand development for automotive companies, infrastructure providers and political bodies such as the EC or the Member States. An appropriate answer on this issue could consist of a public private partnership structure for an integrated European large scale demonstration project, which is linked to other hydrogen and fuel cell markets such as stationary applications and commonly used hydrogen production and infrastructure components.

2.4.2 Other Transport Applications

In addition to mass-market passenger cars, hydrogen powered micro electric vehicles with a fuel cell powertrain (sub class A and so called micro-cars, quadri-cycles or neighbourhood vehicles) may offer early demonstration of small controlled

[37] Strategic Research Agenda Foundation Report chapter 2.4.3.1
[38] „Market Development of Alternative Fuels“, December 2003; The Alternative Fuels Contact Group (AFCG) represents the stakeholders of the transportation sector in terms of alternative fuels and alternative powertrain vehicles.
[39] „Well-to-Wheels analysis of future automotive fuels and powertrains in the European context“, 2003;EUCAR/CONCAWE/ JRC

fleets. This would provide early experiences in hydrogen and fuel cell technologies and offers a high-profile presentation to encourage public support and to build awareness.

Besides the vehicle applications as described in chapter 2.4.1 there are other transport applications of interest for the scope of a deployment strategy until 2020 such as

- APUs for commercial airplanes/ jets, mainly fuelled with kerosene.
- APUs for maritime applications in the range of 0.5 to 1 MW_e.
- APUs for railway applications, either direct hydrogen fuelled or in combination with conventional fuel (mainly diesel) and fuel processor technology.

Hydrogen or fuel cell propulsion for airplanes, ships or railways is only expected to become – if at all – a niche application and therefore treated separately under early and niche markets in chapter 2.6.

Especially for large-scale maritime fuel cell APUs synergies with onshore stationary applications are expected. The project "Fuel Cell technology for SHIPs" (FCSHIP) is the first major attempt of the European Commission to establish a roadmap for the marine industry to adopt this sustainable technology. According to the FCSHIP final report[40] there is a strong demand for full-scale demonstration to validate and promote the potential of marine application of fuel cells. In order to create production synergies with stationary applications the development of (high temperature) fuel cells systems with a module size in the order of 0.5 to 1.0 MW_e should be considered. A set of one or more of these modules could be used either as APU, preferably with fuel processor technology, for large seagoing merchant ships (EU owned fleet ~ 9,800) and large ferries commuting within the EU (EU fleet ~ 500) or for propulsion purposes of smaller vessels such as fisher boats. Here also direct hydrogen fuel cell systems for ships that are able to return to port/ refuelling depot frequently should be considered for demonstration activities.

2.4.3 Conclusions on Transport

Regarding the overall energy policy goals on security of supply, strengthening of the European economy and reduction of GHG emissions (see also chapter 1.1) H2 and FC technologies in the road transport sector in general and passenger cars in particular will have the highest long term impact. Hence, regarding transport applications first priority is given to hydrogen powered cars and linked large-scale demonstration activities. In addition the required infrastructure should also be used for the commercialisation of early market transport applications as described in the Early Markets chapter. Pursuing the deployment strategy until 2020 therefore, the following actions are recommended:

- Create a stable frame for large, long-term fleet demonstration projects and aim to commercialise fuel cell vehicles in 2015.
- Focus on highly populated, urban areas to implement hydrogen clusters.

[40] FCSHIP final report (FCSHIP G3RD-CT-2002-00823 DTR-5.2-06.2004)

- Support the infrastructure build-up in an early phase by funding additional hydrogen vehicles and by implementing various actions e.g. public-buy programmes in a later phase.
- In parallel support APUs with reformer technology as “door-opener” for the fuel cell technology by utilising synergies with stationary FC applications such as Micro-CHP and small back up power systems.

2.5 Portable Applications

The portable category is made up of two distinct segments:

Micro-FCs for handheld electronic equipment

Micro-FCs are considered as alternative power sources for electronic devices such as cellular phones (<10W), laptop computers (~15W), and PDAs (~5W). The total annual European Premium Battery Market applicable to these applications could be in excess of ½ million units by 2020 and provides the largest unit volume potential for FCs and the highest allowable cost per kW. Given the strong consumer benefits of longer run time and ease of refuelling their market entry is expected to be easier than other FC applications and it will require little governmental support.

However, substantial technical barriers have yet to be overcome. It is believed that Asian, but especially Japanese manufacturers lead technical development and have announced their intention to launch products in or shortly after 2005 with solid growth thereafter being likely.

The deployment of these micro units will not directly provide manufacturing synergies to larger FCs nor will they contribute to GHG reduction or to energy security. They are however expected to increase consumer awareness and promote acceptance of H2 and FC technologies. For the above reasons it is believed that micro-FCs will not warrant significant attention in the Deployment Strategy. However, input from the SRA should be requested to identify emerging European technologies so as to define specific deployment needs and strategies. For example, in the micro range of less than some Watts medical applications such as FC implants for powering peacemakers could be an interesting marketing opportunity.

Portable Generators / Power Module (<0.5 to 10kW)

A number of fuel cell companies are developing, and some have already commercially launched, power modules using a common architecture that can be adapted for a variety of applications such as: backup power and uninterruptible power systems; specialist vehicles (forklifts, micro, airport tugs, industrial vehicles) and APUs for recreational vehicles and boats. These applications, especially in battery hybrid configuration, are less demanding than mainstream applications in terms of performance, durability and cost.

The urgent implementation of demonstration programmes to, in the first instance, prove performance and then assist market entry may effectively act as the first step and bridge to future full-scale deployments of hydrogen and fuel cell technologies

It should be noted that the US DOE is planning to fast-track commercialisation of a solid oxide fuel cell (3-10 kW) that can be mass-produced in modular form. Used individually or in clusters, depending upon the amount of energy required, these fuel

cells will be able to power a broad array of applications. By 2010 they intend to demonstrate the fuel cells at $400/kW with target efficiencies of 40-60%.

2.6 Early Markets and Niche Applications

The selection and support for deployment of early market and niche applications could be key to the implementation of a market driven deployment strategy, accelerating the introduction of stationary and transportation applications. Although the specific early/niche markets have been discussed in the relevant sections (transport, stationary and portable) it is recommended that the Deployment Strategy adopt a common strategy to ensure optimum synergies.

Early markets will help build manufacturing volume and operating experience and provide a near-term incentive to fuel cell developers and component suppliers to invest in technical development and production facilities to provide the base from which low cost production of mass-market stationary and automotive applications can be established. Additional benefits of supporting the development of early markets are seen as follows:

- Short-term introduction in the market of H2 & FC technologies will test and optimise the whole production chain, from raw materials to components and systems assembling; in this way the H2 & FC sector will shift from a today R&D approach to a more industrial and manufacturing oriented structure; this process is expected to cut the costs all along the value chain, allowing stationary and transportation applications to get closer to the cost target for market introduction.
- Gain manufacturing and operating experience providing feedback into development and manufacturing processes for mass-market applications.
- In terms of competition towards US and Japan, the support to niche market opportunities will create the first real business opportunities for H2&FC technologies, thus attracting foreign investments, skilled people and boosting internal development in R&D.
- Support for niche applications that can generate economic return in the short-term will assist the H2 & FC industry to become much more financially self-sufficient; this could be an efficient way to invest public money and maximise the return; a self-funding industry will be more likely to increase investments in R&D, reducing in this way the technological gap with US and Japan; this is seen as critical for Europe in order to catch up with those areas of the world that have taken a lead in fuel cell technology today.
- A European competitive advantage is the FC materials and components industry; if the deployment strategy manages to bring the first niche FC products to the market, the required industry investments in manufacturing will more likely happen in Europe.
- The creation of a profitable FC&H2 industry in the short-term, though relatively small, will create jobs in Europe, most of which would be high-skilled.
- Build recycling capability. Managing material loops for critical raw materials like Platinum and other precious metals that, despite being sufficiently available in principle, needs to be established in closed loops for economic and supply of security reasons.

- Provide an early market for hydrogen and facilitate the early build-up of a hydrogen infrastructure. Gain operating experience with hydrogen and help establish codes, standards, and regulations.
- Build public awareness and acceptance of hydrogen and fuel cells.

In comparison with automotive targets in terms of system cost and durability (50-100 €/kW; 5,000 hrs) and in comparison with the stationary targets (1000-1500 €/kW; > 40,000 hrs) early market applications can be found where cost barriers exceed 2 - 3,000 €/kW and durability starts at 5,000-7,000 hrs. Under these conditions the following applications are being discussed as early market opportunities:

- Backup power and uninterruptible power systems (UPS)
- „Non-road“ transport applications such as forklifts or specialist vehicles
- APUs, hydrogen fuelled or with fuel processor technology
- Large FC power plants fuelled by by-product H2
- Home care applications (back up; mobile tools)
- CHP remote island supply
- Net balancing for intermittent renewables (such as wind power)[41]
- Defence applications

2.6.1 Premium Power Generation

One prime example for a small market niche where hydrogen based fuel cell systems can today compete against other technologies is back-up power supply for telecom systems. Today’s most often used back-up systems using lead acid batteries do offer a lower invest against other alternatives; however, on the basis of a 10 years time frame a fuel cell system could offer the best economics as displayed in Table 8.

Table 8: Power supply sources for a 5 kW back-up system for telecom installations[42]

	Estimated cost for a 5 kW_e plant	Remark
Lead acid batteries	11,000 – 15,000 $	Battery replacement after 5 years, does not include O&M
H2 Fuel Cells	15,000 – 20,000 $	Estimated life time 10 a, includes maintenance
Microturbine	> 35,000 $ (30 kW)	Mainly used for prime power
Photovoltaic	>25,000 – 40,000 $	Requires additional batteries

2.6.2 Non-Road Transport and other specialist vehicles

Forklifts fleets with centralized hydrogen production are expected to have significant customer advantages over conventional battery-run models. The total market for battery-powered forklifts in 2010 is estimated at 350,000 units. Since hydrogen

[41] due to the efficiency losses of the pathway electricity → electrolysis → hydrogen storage → fuel cell → electricity this niche application will only be feasible for remote locations where no sufficient balancing capacities via grid connection are available

[42] „Telecom networks: the new rules of power“, William Ernst and Jim Nerschook, The Fuel Cell Review, Volume 1, Issue 1, 2004

fuelled forklifts do not require time consuming battery recharging, even early products could create value for large fleet operators of such forklifts right at the beginning.

Other specialist vehicles can be mentioned (normally in hybrid configuration) such as micro electric cargo vehicles, airport tugs, industrial vehicles (sweepers, aerial platforms, booms etc) and marine applications.

APUs for recreational vehicles and boats can initiate the APU market of later commercial applications with higher expected sales volumes (such as long distance hauling trucks) since for leisure applications convenience matters more than pure cost of ownership.

2.6.3 Power Generation and Remote Island Supply

In Europe the total available amount of by-product hydrogen (from industrial plants) is between 2 and 10 billion Nm³ hydrogen per year. The majority of this by-product H2 is used for process heating.

The use of a proportion of this by-product H2 for stationary power should be assessed. A multi-MW fuel cell power plant can be built-up over time using a number of fuel cell modules. This would allow for ongoing product improvement and reduced investment costs with a growing manufacturing volume. This would also permit the testing of a large number of high power FC stacks and this experience could be of value for automotive applications.

On-site co-production of hydrogen and power at a refuelling station is another possibility for early market applications with the aim creating synergies between stationary and mobile applications. The AFCG study[43] suggested that in the initial phase, on-site reforming of natural gas is the most economical solution to provide hydrogen at refuelling stations. In addition, co-production of hydrogen, power and heat - especially in an initial phase when the transportation side does not fully utilize the capacity of a refuelling station - could be a highly flexible and cost efficient introductory strategy for the development of a H2 fuelling infrastructure. The potential benefits should be verified by assessing the results of appropriate demonstration activities.

Preliminary suggestions for publicly supported demonstration programmes, incorporating a number of early applications can be summarized as follows:

- 2006/08 Alpha FC prototypes (5 MW_e installed capacity)
- 2007/10 Beta FC prototypes (30 MW_e installed capacity)
- 2009/12 Pre/ Initial commercial FCs (200 MW_e installed capacity)

These steps are considered the optimum to demonstrate the systems to the point of technical readiness and with reduced costs approaching commercial levels for early high-value applications.

[43] „Market Development of Alternative Fuels“, December 2003; The Alternative Fuels Contact Group (AFCG) represents the stakeholders of the transportation sector in terms of alternative fuels and alternative powertrain vehicles.

If the Deployment Strategy could support the successful launch of 4-5 profitable markets for fuel cell and hydrogen applications in the next 3-4 years, this would contribute to make Europe a competitive hydrogen and fuel cell market worldwide.

3 Strategic, Socio-Economic and Technological Appraisal

3.1 Hydrogen in the context of an EU Energy Policy

On the background of a further increasing energy demand worldwide and in Europe with simultaneously decreasing fossil supply from European based sources the Green book of the EC addresses the need of a structural change of the future energy supply chains[44]. The world energy outlook (WETO) assumes as reference scenario an increase in the final energy consumption from 2000 to 2030 by 21% whilst the share of EU's primary energy resources will fall from 65% in 2000 to only 39% in 2030[45].

Since the availability of fossil resources is assumed to be guaranteed until around 2030 according to the WETO the development of oil and gas prices has been predicted to remain below the 40$/ barrel level until 2030 as displayed in Figure 7.

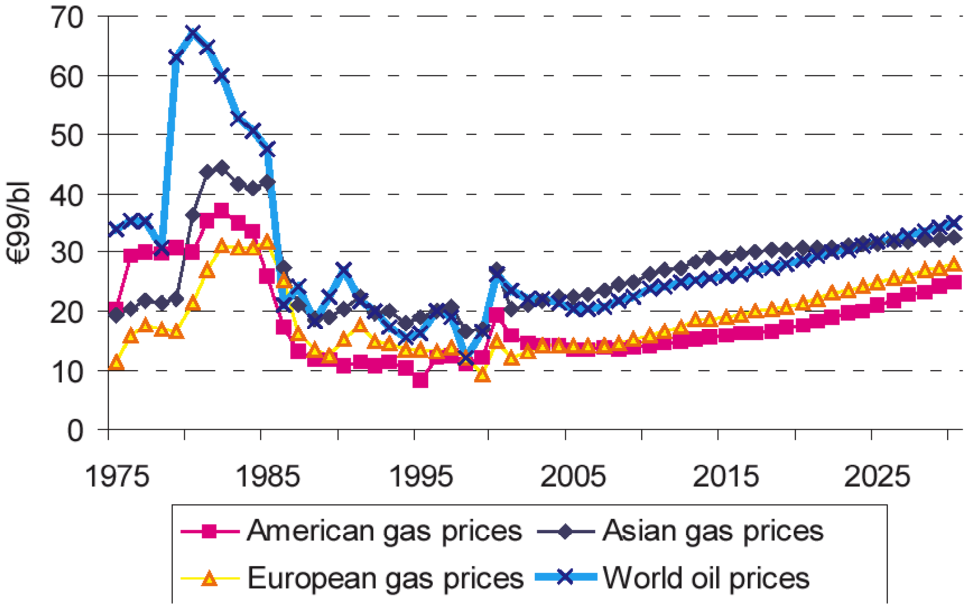


Figure 7: Oil and gas price reference scenario of the WETO

The present development of oil prices leading to price records both for the Nymex and IPE, since the mid 2004 with levels above 40$ per barrel and even reaching 60$ in summer 2005, can be argued on the grounds of the political instability in the Middle East. However, the more relevant question is related to long term price scenarios. The reference scenario of the WETO assumes that the oil production need to (and will) climb up from presently exceeding 80 million barrel per day to around 120 million barrel per day in 2030 in order to meet world's oil demand and price levels well below 40$ per barrel in 2030. Since some experts question whether this drastic increase will be met by conventional oil and predict a "peak" in the oil production before 2015[46] the search for alternative fuels becomes more and more

[44] Green Paper: „Towards a European Strategy for the Security of the Energy Supply“ COM (2000) 769
[45] World energy, technology and climate policy outlook, EU 20366, 2003
[46] The Association for the Study of Peak Oil & Gas (ASPO), www.peakoil.net

important. Probably the most affected sector to oil shortages would be the transport sector since road and air traffic rely to almost 100% on oil based fuels.

Hydrogen and fuel cells are hence seen as key elements for bridging the future gap between the supply of fossil fuels and the demand by using either renewable energy resources or other limited resources with a longer range than conventional oil such as natural gas, coal or nuclear energy. Fuel cell technologies are expected to play a key role in a future economy in which electricity and hydrogen become principal and interchangeable energy carriers. Hydrogen brings important opportunities for the distribution of sustainable energy (e.g. renewables) and for decentralised power generation. One of the main benefits of hydrogen over electricity as an energy vector is also its capacity to store energy, which is crucial for transport applications.

A challenge for Europe is its current fragmentation of activities. While diversity is a stimulus to innovation, it also inhibits the emergence of consensus. The EC seeks to secure industrial leadership in any new technology and to develop and deliver world-class technology meeting the ambitious objectives of sustainability. Liberalisation of the energy markets and the growing integration of European transport and energy networks mean that promotion of fuel cells and hydrogen is a trans-national issue. Increased coordination between stakeholders across Europe and partnerships are therefore encouraged. The Department of Energy in the US and the Ministry of Trade and Industry in Japan have taken such a role for coordinating fuel cell related activities in their respective national economies for many years and it is believed that the gap between Europe and these regions in terms of fuel cell technology advancement partly results from this.

However, hydrogen is not regarded as the only answer for solving the issues of security of energy supply and meeting greenhouse gas emission reduction targets in the Kyoto time frame and beyond. In the "Biofuels Directive"[47] following substitution targets for alternative motor fuels, including hydrogen are outlined until 2020 as given in Table 9.

Table 9: EC's substitution targets for alternative fuels

Year	Biofuels (%)	Natural gas (%)	Hydrogen (%)	Total (%)
2005	2			2
2010	6	2		8
2015	(7)	5	2	14
2020	(8)	10	5	23

3.2 Policy Issues related to Hydrogen and Fuel Cells

It is recognized that in all major technological and socio-economic changes the political commitment is a key factor. The role of the political action is always fundamental in fostering the development of technologies as well as managing public awareness and acceptance in big transitions processes. The public sector becomes

[47] Proposal for a directive, COM(2001) 547 final, 7.11.2001

therefore a reference point under several points of view, and different actions can be performed by Governments and Public Administrations in order to increase the speed of the evolution of innovative processes.

Rapid improvement of hydrogen and fuel cell technologies is nowadays considered as the condition for an effective transition to an new energy system, which can guarantee large availability of the resources as well as their sustainable use. This objective is a primary political issue for Governments, which should support socio-economic development as well as environmental sustainability.

The deployment of hydrogen and fuel cell technologies is therefore strongly influenced by the political framework. The impact of public actions can provide an opportunity or a hurdle: it will hardly be “neutral”. We can consider an example: public incentives for hydrogen production would certainly be an opportunity to accelerate research and applications, whereas the absence of specific incentives would become a barrier to deployment of hydrogen technologies, due to the lack of competitiveness of hydrogen with respect to conventional fuels, in present conditions. In other words, an indifferent policy framework without specific support could be a barrier against the development of a hydrogen-based economy.

As a consequence, a deployment strategy cannot be defined without gauging technological needs, market issues and deployment strategies against the policy framework. The framework can vary significantly between Member States and between different European Regions: it is clear that an effort towards an homogeneous approach should be carried out in order to prevent what we could call ”hydrogen-divide” or “energy-divide” situations.
The scope of this section is to provide the policy-makers with a comprehensive evaluation of the expected effects of different policy framework conditions and public actions on the deployment of hydrogen and fuel cells technologies and relevant market applications. The chapter will analyse:

- The different phases and areas of the policy framework.
- The basic conditions for an effective public support to the deployment.
- The role of energy end environment strategies of governments.
- The public funding policies.
- The fiscal incentives policies.
- The role of public-private partnerships at different levels.
- The effects of actions directly performed by public authorities and governments in hydrogen and fuel cells related projects.
- The impact on education and public awareness.
- The need for a governance of the system.

3.2.1 Phases and areas of the policy framework

The main phases and areas of actions towards a hydrogen economy carried out by public bodies, authorities and Governments can be summarised as follows:

- Strategies in the fields of energy and environment, with evaluation of socio-economic effects of build-up of a hydrogen economy in the relevant context.
- Laws and rules, at national and regional level.
- Direct support to research and pre-commercial development.
- Support to facilitate market development.
- Participation in demonstration projects.
- Policies for the creation of new industrial districts and of new jobs.

- Definition of codes and standards.
- Education and dissemination of knowledge about hydrogen to improve public awareness.

3.2.2 Basic conditions for public support

Effective support of the public system to the deployment requires some pre-conditions following two main directions:

- General commitment of Governments.
- Definition of the most adequate government level and dimension.

Commitment of Governments is an essential factor in developing a positive framework. It is required on all government levels: European Union, Member States, Regions and local level. It is influenced by several factors, which can vary significantly throughout Europe:

- The general *vision* of the Government: a long term strategy is obviously much more helpful than a short term vision. In this respect, Member States should generally have a better approach than lower government levels, but it so happens that Regions have sometimes a longer term vision than States.
- The consciousness of the *need for a sustainable development*, together with a clear idea of the potential of hydrogen and fuel cells technologies in this context.
- The capacity of *evaluating potential socio-economic impacts* of the hydrogen economy in each different situation: this is strictly connected to a medium-to-long term vision, but it also requires specific analysis and studies.
- The *capacity of* building *networks*, at national and regional levels: this factor also depends on the general strategic vision, and it is influenced by the involvement of governments in Trans-European or regional networks. This could also include a global perspective.
- The visibility of the action supporting the development of hydrogen and fuel cells, also in a short term perspective: this factor is essential for the political consensus, and it must be based on a strong communication strategy.

The definition of the adequate *government level* and dimension for managing the build-up of a hydrogen economy is crucial for an effective deployment strategy. *Member States* are the natural reference points for an appropriate strategic vision. They should be engaged in a coordination effort and network building activities. *Regions* are important political actors as they are closer to citizens and aware of regional and local problems. They can more easily strengthen the regional assets, also promoting public-private partnerships in an effective way; regions are usually involved in important networks; they have the possibility of putting additional resources to support research and development, as well as creating the conditions for industrial policies and districts and the creation of districts and jobs; finally, regional policies are very often a driver for national strategies.

If Regions are strongly committed to cooperate to the deployment of hydrogen and fuel cells technologies, they can facilitate the creation of regional or local seed communities for a hydrogen economy. To achieve this result, it will be necessary to implement large projects covering all the aspects of hydrogen and fuel cells technologies; such projects shall have a double level of coordination and networking, both inside the Region itself and with other Regions. The so-called "Lighthouse

Projects" could then, over time, gradually expand to "*Lighthouse Regions*" or "Pilot Regions" thus yielding a greater "*Hydrogen Community"*. A Lighthouse (or Pilot) Region could provide deployment clusters of medium size projects in the regional context, establishing a network, which would then present the aspect of a coherent large project of regional dimension.

Based on the above considerations, *direct links* between the European Commission and important European Regions are recommended, in agreement with and under supervision of the Member States, possibly using the new European governance tool of Tripartite Agreements.

3.2.3 Energy end environment strategies

Recognising the development of hydrogen and fuel cells technologies as a strategic priority is a matter of interest for Member States and Regions. While the European Commission has defined a clear strategic approach towards hydrogen and fuel cells technology development, including them among the enablers for the future competitiveness of Europe it appears that so far only a few Member States or Regions have expressed a strong commitment in the same direction. Larger efforts are necessary in view of the international context with USA, Japan, China, Canada etc. having also defined clear strategies and roadmaps.

In order for the Governments to recognize hydrogen and fuel cells as a strategic issue for the sustainable development of national and regional systems, it is necessary that a combination of at least four factors occur:

- *Energy policies* suitable to support economic development.
- *Environment policies* particularly attentive to sustainability.
- *Innovation policies* oriented to promote medium-to-long term research as well as short term demonstration projects.
- *Industry policies* able to recognize the possibility of development of new *opportunities* in terms of market evolution and job creation.

The adoption of hydrogen and fuel cells technologies as a *strategic objective for National and Regional Governments* is an important signal for the research community and the market players to increase their efforts in fostering the development. Lack of such an action priority by governments appears to imply a negative consideration on the hydrogen economy. *Again, a non-choice is not a neutral situation, and inaction generally becomes a hurdle to the deployment*.

Besides steering the evolution towards a hydrogen economy as an essential issue in their strategic vision, Governments have another great possibility to support the deployment, related to the legislative activity.

National and Regional laws for the energy sector, as well as for environmental protection and for research have a great potential impact on the development of new energy technologies. Such approach has been necessary to support renewable energy sources in European, National and Regional contexts. The use of renewables has been greatly improved after specific laws have been adopted at different government levels throughout Europe and worldwide. It will not be different for hydrogen and fuel cells. As an example, the Italian Parliament has approved in July 2004 a new law for the energy sector, which includes a specific article providing the extension of the incentives granted to the energy produced from renewables (the so-

called “green certificates”) to the energy carried through hydrogen. It is evident that such an approach is an important signal to the market in two different aspects: on one side, it is an indication of a clear political will, on the other hand the combination of grants for the hydrogen energy and the high cost of oil is strongly raising the interest of the research and market players towards hydrogen and fuel cells. If other countries move in the same direction, a new trend supporting hydrogen at a legislative level will be established in Europe. A *homogeneous approach* is anyway recommended, in order to avoid unbalances: a coordinating action by the European Commission is key to reach such an important objective.

Of course many issues remain open, like the discussion about “clean” versus “conventional” production of hydrogen. As an example, a possible time-phased strategy could include a short term strategy providing first incentives to hydrogen use without any reference to the way it is produced, in order to create attention to the issue, initiate market driven activities and increase private investments. A medium term strategy could then in a transition period set-out a progressive decrease of the incentives for “conventional” hydrogen and a simultaneous increase of the incentives to “clean” hydrogen as well as innovative ways of using it (in particular fuel cells). In the long term, public incentives should be maintained only for “clean” hydrogen and innovative technologies.

3.2.4 Public funding policies

The financial support by Governments and public institutions plays a role of major importance in the deployment of new technologies. Public funding is normally available at different levels: European Union, Member States, Regional and local Governments.

The availability of resources at different levels is, in principle, a good opportunity, but it needs a *coordination* effort in order to *maximize the efficiency and effectiveness* of the interventions. The reasons for this coordination are mainly related to the necessity to:

- Minimise overlapping or duplications of projects.
- Avoid leaving significant gaps which are not covered by proper funding.
- Evaluate the priorities and relationships between the funded projects.
- Concentrate resources on “strong”, strategic projects.

Public funding is obviously of great importance in the area of *research*. The financial resources available today inside the European Union appear to be insufficient to build up a sufficiently strong self-carrying momentum in the field of Hydrogen and Fuel Cell technology development. This is also obvious when compared to other competitive economies like USA, Japan, and China. A significant *increase of resources for research and technological development* is highly recommended by all governments. The European Commission is strongly engaged with the 6th Framework Program, and it is expected that the 7th Framework Program will provide an increase of resources to support the development of hydrogen and fuel cell technologies. National and Regional governments are expected as well to enhance their engagement in this field.

Public funding of *demonstration projects* is another key factor to give strategic indications to the market, also helping public awareness and acceptance. Such financial support can have different characteristics, like: *direct funding* of projects of

the public sector; direct participation or indirect support to the creation of *industrial districts* (e.g. through the creation of common infrastructures for enterprises, service centres or industrial parks). In this effort to facilitate the creation of positive market conditions a particular attention should be paid to the *niche markets* and to the *early market applications*.

Governments have also the possibility to support and facilitate the creation of *new financial support strategies and instruments*. A good example is represented by the commitment for the European Investment Bank foreseen in the Growth Initiative of the European Commission; other possibilities are connected with the creation of *venture capital funds*, *revolving funds*, *innovative financial instruments*. Such actions can also be taken at regional level, where it is generally possible and strongly recommended to create partnerships with *local banks* and especially *foundations*: this level of action will probably be a key factor for the creation of regional hydrogen-based systems.

The use of European *structural funds* to support the deployment of hydrogen and fuel cells technologies is a great opportunity. Unfortunately, very often it doesn't match with the real availability of national and regional situations: in fact, structural funds are dedicated to the development of the less advanced European regions, while technological, scientific and environmental conditions are much better in the strong economies. A good way to maximize the effectiveness of such resource could be the promotion of twinning, networking and common projects between Objective 1 regions and the most advanced European areas. Such an approach could maximize the effectiveness of structural funds for the deployment of hydrogen and fuel cells, and in the meantime significantly improve the cohesion policies in the field of energy and sustainability.

The *state aid* issue has to be carefully considered by the European Commission. The possibility for Governments and Public Administrations to support private initiatives in the field of new technologies is often limited by the rules on market competition. The strategic priority of hydrogen and fuel cells technologies as defined by the European Commission should be reflected in some way in the state aid approach: in fact, at present these technologies are clearly not competitive with conventional energy technologies, similarly to the situation with renewable energies. This requires the possibility of public support even in the form of public funding or fiscal incentives in order to speed up the transition from the research and innovation phase towards market introduction, growth and maturity.

Finally, the growth of the hydrogen and fuel cells technologies could be significantly improved if the environmental *external costs* could be included in the cost of the energy produced. This is a very difficult matter that is quite similar to what should be required to increase the competitiveness of the renewable energy sources versus conventional energies.

3.2.5 Fiscal incentives policies

Fiscal incentives have proven to be an important driver for the deployment of innovative technologies. Several sectors of the hydrogen and fuel cells value chain can be considered for the application of fiscal benefits by Member States and Regions.

Hydrogen *production* could gain significant advantages from de-taxation. Such fiscal incentives should be differentiated based on the way of hydrogen production, in order to promote sustainable production systems (from renewables or with carbon sequestration) with respect to conventional systems.

Hydrogen *distribution* networks are of vital importance for the deployment strategy, as they constitute, under certain aspects, the most critical item, due to the need for large investments. Also in this case, fiscal incentives are expected to be an effective contribution in terms of development of such infrastructures.

The supply of hydrogen energy can be improved by fiscal measures as well as by the application of additional pricing of the energy itself. Such policy should take into consideration a flexible approach: in the short term it would probably be very useful to recognize grants or fiscal benefits to energy from hydrogen in a general way. In a medium to long term dimension, such benefits should progressively be restricted to the most innovative hydrogen and energy production technologies. In any case, energy processed via fuel cells should receive higher advantages with respect to other energy production technologies, valuing the efficiency of the process.

Fuel cells are a key factor for an effective deployment and market penetration of hydrogen. Fiscal incentives are advisable especially in the research and pre-commercial development phase.

A particular attention should be paid to the *automotive sector*, where the production of the first generations of hydrogen powered vehicles as well as the realization of the first fleets (public services, taxis etc.) could be greatly facilitated by the presence of fiscal measures.

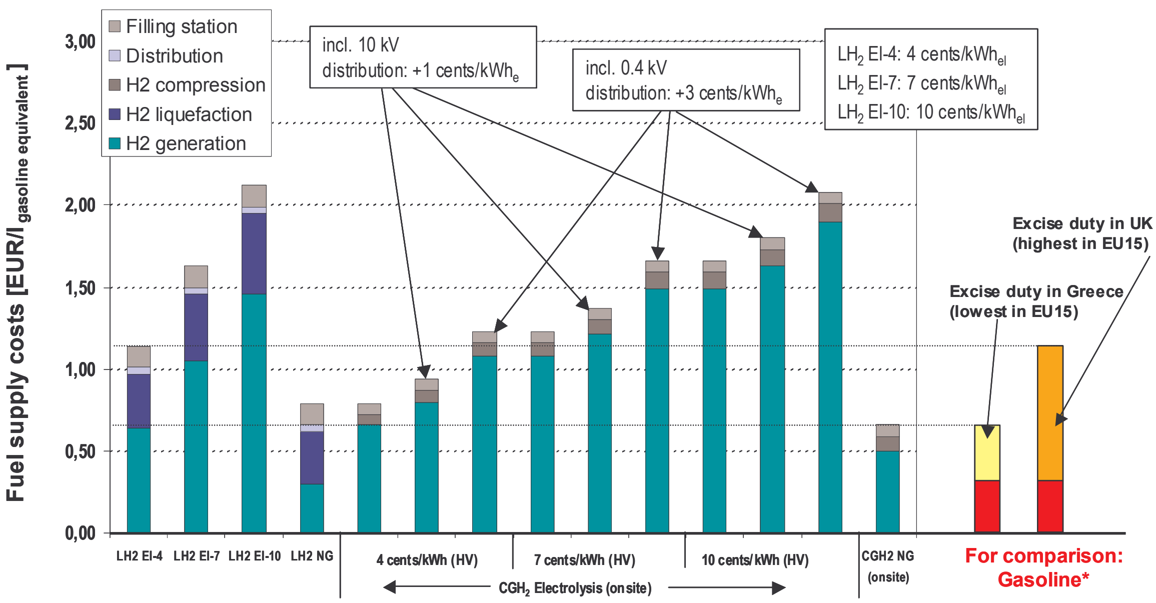
The issue of fiscal policies is complex, and it is strongly recommended that such type of facilitating measures be adopted on a *coherent basis* inside the European Union, in order to avoid the creation of unbalances between States and Regions. Despite the fact that the fiscal sovereignty is a matter of the Member States, the principle guidelines are given by the European Commission and these different kinds of taxes are generally affecting hydrogen and fuel cells:

- Excise duties such as taxes on energy consumption
- Income tax for companies including loss carry forward regimes
- Property tax such as motor vehicle tax
- Value added tax
- Revenue roll-over of emission certificates such as ROCs (renewable obligations certificates)

In order to support large-scale demonstration activities and the market introduction of hydrogen and fuel cell applications especially the first two types of taxes are of high relevance to a deployment strategy. Regarding the public awareness excise duties

on energy, mainly on motor fuels but also on heating oil, natural gas or electricity are well known and tax exemption such as given by most of the Member States on alternative fuels can support early markets.

A comparison with expected untaxed hydrogen prices for different centralised and de-central production pathways with the current taxed (VAT not included) gasoline range in the EU15 shows that natural gas based pathways as well as electrolysis with electricity prices below 4 cent/kWh could compete with gasoline at the upper tax level, as displayed in Figure 8. Hence a first recommendation regarding hydrogen as a vehicle fuel leads to the need of a long-term excise duty exemption within a fiscal hydrogen support regime. In addition the production of renewable hydrogen requires additional fiscal incentives for production and distribution as described below.



* Untaxed gasoline (95 octane) pump price 1st half year 2004: 31,0 ct/ l (German average, source Aral)

Figure 8: Hydrogen pump prices for different pathways (assuming a vehicle fleet of more than 2 million vehicles!) and current gasoline price levels (incl. Mineral oil tax, excl. VAT) in EU15[48]

The field of income taxes offers a broad variety of fiscal incentives concerning the investment and operation of hydrogen production and distribution plants as well as for small/ medium commercial and large scale industrial fuel cell (or other hydrogen conversion) power plants. A rough qualitative analysis recommends further examination of the following fiscal measures:

- Modification of depreciation regimes regarding any commercial or industrial investment in hydrogen or fuel cell technology.
- Prolongation of loss carry forward possibilities for any commercial or industrial investment in hydrogen or fuel cell technology in order to reflect the longer times of capital expenditure in comparison to conventional technologies.

[48] hydrogen data from HyNet, excise duties according to the Directorate General Taxation and Customs Union Policy (http://europa.eu.int/comm/taxation_customs/publications/info_doc/taxation/c4_excise_tables.pdf)

- Where private consumers are the decision makers for technologies straightforward fiscal incentives are required.
- Technology risk guarantees for project financing are required.

3.2.6 Actions of public administrations

The public sector can play an important role in the start-up phase of the hydrogen economy through the direct promotion of initiatives.

The direct involvement in demonstration projects is a possibility not only for National and Regional governments, but very often also for local authorities. Typical projects can be:

- Public transportation prototypes, such as hydrogen buses.
- Public fleets, such as vehicles for waste management or LDVs including passenger cars and taxis[49].
- Fuelling stations for such fleets and prototypes.
- Hydrogen and fuel cells based applications for cogeneration and tri-generation in public buildings or for district heat and power supply.

Public procurement of hydrogen and fuel cells related products is another area where the public administration can give an effective support to the deployment of the technologies.

Finally, it is evident that solutions to the issue of *infrastructures* for hydrogen distribution systems can be facilitated by a direct involvement of the public authorities, both in terms of programming of the development of such infrastructures and in supporting in adequate ways their realization, at least until a market competitiveness is reached.

As far as the Commission is concerned it should continue pursuing its alternative fuels strategy with actions as for the biofuels for other alternative fuels, including hydrogen.

3.2.7 Public-Private Partnership

One of the main possibilities for policy to really help the deployment of hydrogen and fuel cells technologies is by facilitating the building of real public-private partnerships. This method is proven to be an effective and transparent way for stimulating and supporting initiatives where the common interest of public and private players cannot be achieved on the basis of the public action only, or it is not sustainable in pure market logic. This approach needs a *strong commitment on the side of the public sector*, and is currently followed at all government levels, including regional and local authorities. There are several possibilities for such partnership in the field of hydrogen and fuel cells technologies, like:

- *Stimulate joint initiatives* between public administration and private companies in the field of demonstration projects, with a particular attention to the possibility of realizing clusters of coherent and integrated projects.

[49] taxis are mainly private owned but due to licensing by local/regional authorities fleet mandates could be applicable for taxis as well

- Build *synergies* between the *research* efforts and activities carried out by Universities and public research centres, and those independently done by private companies.
- *Create consortia* between private companies and public authorities/institutions, aimed at managing large integrated projects, including research and demonstration phases.
- Develop *public/private initiatives* for the creation and growth of hydrogen and fuel cells *industrial districts* and for establishing public/private thematic industrial parks and service centres.
- Start jointly the *realization* of *infrastructure networks*, especially for the automotive sector.

During the first phase of technological development, such partnerships are expected to be strongly driven by the public sector, both in terms of governance and financial support. Approaching the market phase, public/private partnerships will change their characteristics and assume balanced public and private efforts with increasing progressively the private contribution.

It appears that Regions can effectively support the deployment also acting as *direct partners* in the FP6 – FP7 research projects, as this can be a guarantee of a higher degree of coherence between the projects and the general socio-economic context, as well as the possibility to improve the effectiveness of financial resources from European Commission and from European regions.

3.2.8 Education and public awareness

The education process is a key factor for the management of large socio-economic and technological changes. Particular attention should be paid by the political circles to the *priorities* of the education programs, in order to increase the capacity of the education system to respond in an adequate way to the new challenges. In the meantime, such process would support the *dissemination* of information to the public about the characteristics of new technologies, improving the awareness and social acceptance. The deployment of hydrogen and fuel cells requires a clear political vision of the education issue.

Governments and local authorities should operate to supp*ort the investments in human capital* required by the transition to the hydrogen economy. This objective can be achieved through a suitable organization of education programs related to hydrogen and fuel cells in the schools at every level, as well as a clear orientation of the technological and economic universities to support new specifically suited profiles of scientists, engineers, technicians and economists. Also regarding the education programs funded by *Objective 3* funds from the European Union, new projects dedicated to hydrogen and fuel cells would be strongly recommended. Lighthouse projects can provide a “real life” pilot test frame for the development of educational methods, materials and processes and thus, education should be an integral part of it.

As far as the *dissemination of knowledge and information to the public* is concerned, it appears that governments and public administrations can play a key role, organizing or supporting specific events, seminars and conferences, as well as properly managing the relationships with media.

3.2.9 Governance

The final consideration on the policy framework regards the governance of the complex relational system connected to the development of the hydrogen economy.

A rational approach is needed to optimize the efforts made to support the deployment of hydrogen and fuel cells technologies, which includes several aspects to be covered:

- Coordinate strategies and projects at national and regional and local levels, in order to minimise overlapping or duplication of projects and to improve initiatives to fill the existing gaps.
- Activate a monitoring process of projects, to improve efficiency and maximise effectiveness.
- Create the conditions for an efficient integration of projects.
- Adequate policies to allow funding for industrialisation.

In order to reach the above objectives, structures based on the approach pursued by the European Technology Platform should be promoted at regional and local level, including the creation of *links* among such regional and local governance bodies with the European Platform itself.

The creation and *implementation of networks* at different levels (worldwide, Europe, Member States, Regions) requires a strong commitment of the policy makers and is a major item connected to the system governance. This issue is connected to specific actions needed to *define the infrastructure relationships* between States with Regions.

Promoting the specific assets of each State or Region is an interesting objective for governments, which are usually very active in supporting the marketing of their territories. As a matter of fact, some areas are characterized by specific economic, scientific or technological conditions, which can be particularly suitable for the creation of hydrogen communities, where the build-up of a hydrogen economy can be promoted.

Finally, a strong involvement of governments and public authorities in the strategy for the development of hydrogen and fuel cells is needed to guarantee the necessary balance between the positions of the different stakeholders.

3.3 Possible Barriers and Hurdles for Hydrogen and Fuel Cells

The deployment strategy should address those technical, socio-economic, regulatory and general deployment aspects that could become key hurdles for an efficient and effective deployment and rollout of a Hydrogen-economy in Europe. These hurdles will need to be addressed by a continuous interaction between Research & Development projects (Strategic Research Agenda) and Deployment projects (e.g. Lighthouse projects), and supported and streamlined by the Initiative Group on Regulations, Codes & Standards (IG RCS).

Furthermore the identified barriers and challenges need to be sorted out regarding timing and for the different phases of the next steps towards a commercialisation of

hydrogen and fuel cells appropriate solutions need to be proposed. Beyond technical and cost issues a simultaneous feedback and feed forward between research activities and demonstration projects is advised in order to gain a fast approach on the ideal framework conditions such as legislative, financial and fiscal. While some challenges such as costs and reliability are rather obvious other issues will only occur during larger demonstration projects under realistic day-to-day conditions.

3.3.1 Regulations, Codes & Standards

Under this section are listed regulatory aspects that are currently seen as possible key hurdles in the development of the hydrogen-economy and which need to be resolved as part of the implementation of the deployment strategy.

It is not the intention to give an extensive and complete overview of the status of regulatory aspects in relation to the hydrogen economy. The IG RCS will address this.

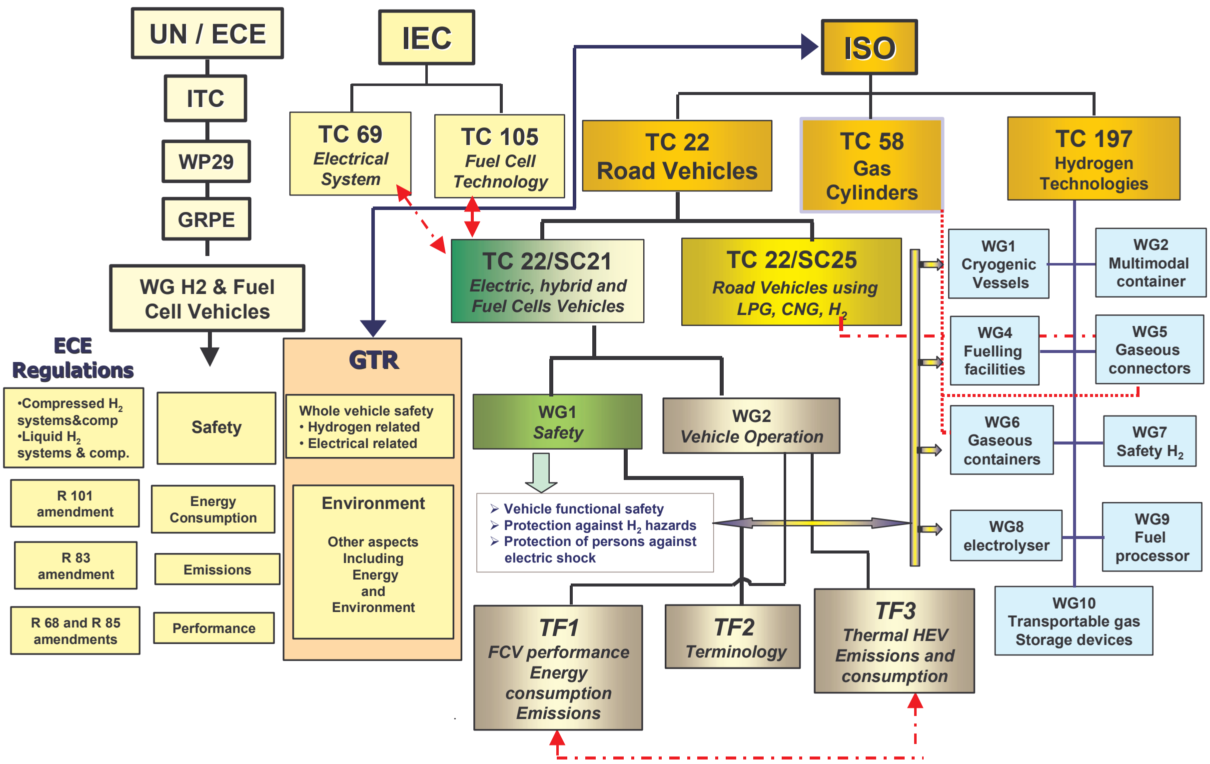
Before stationary fuel cell CHP systems can be successfully introduced commercially the current barriers to commercial introduction must be removed. The current regulatory environment in some countries can severely impede the installation and operation of fuel cell CHP power plants. Changes are required in order to:

- Ensure fair competition between different energy solutions /providers.
- Facilitate access to the grid for CHP units: avoid inappropriate grid interconnection requirements / standards and costs, and ensure a fair price for surplus electricity and top-up power supply.
- Costs and administrative burdens must be reduced to an absolute minimum, in particular for standardised, serially produced micro (<50 kWe) cogeneration units in order to facilitate their use by householders and small enterprises, as for today’s boilers.
- Permit the safe storage and use of hydrogen.
- Supportive, harmonised codes and standards.

3.3.1.1 Summary of the State of the Art

Hydrogen has, compared to Natural Gas specific technical & physical aspects, such as: wide ignition limits, no visible flame, low calorific value, high flame velocity, different Joule – Thompson coefficient, tightness problems with existing gas pipe work materials, and corrosive effects on metallic materials. For this reason specific and tailored regulations and codes and standards for hydrogen transport & distribution, utilization and application (mobile as well as stationary) and hydrogen supply (e.g. Vehicle Refuelling Stations) need to be developed and implemented, in order to ensure a more efficient permitting and approval process than we have today. One example is the lack of European Hydrogen Vehicle Type Approval consisting of guidelines for hydrogen as a fuel (including generation, storage and distribution), regulations for the fuel cell drive and hydrogen fuelled ICE drives. At present in some European countries prototype vehicles may be certified under a complex single vehicle type approval where different regulations from other fields such as chemical engineering are applied to the vehicle logically, while in some countries hydrogen as a motor fuel is still banned.

The landscape in which international RCS for hydrogen and fuel cell vehicles are being developed is therefore complex and involves numerous authorities and stakeholders as displayed in Figure 9.



Source: CRF - VEHICLE - "FUEL CELL SYSTEMS" - JAN 2005

Figure 9: **Complex landscape of international regulations, codes & standards for hydrogen and fuel cell applications for transport (from IG RCS)**

The IG RCS will, as part of their mission, develop an action plan to coordinate, streamline and accelerate processes for implementation of commercially competitive RCS, commensurate with requirements for public safety and use for hydrogen and fuel cell technology in the European Union. This action plan will include:

1) Develop and provide an overview about the current RCS activities.
2) Determine RCS gaps and priorities, and suggest methods to close those gaps.
3) Recommend EU technical experts to key working meetings of RCS setting bodies, incl. regulatory groups (WP.29, GRPE) and key international standards meetings (e.g. SAE, ISO, IEC, CEN, CENELEC).
4) Monitor and publish status reports on RCS activities.
5) Recommend and develop training programs for insurers, state and local officials.
6) Identify, prioritise and recommend critical R&D activities needed for RCS development.

A good, up-to-date overview of the development of hydrogen standards can be found at the web page (http://www.fuelcellstandards.com)) of the US Department of Energy (DoE). The so-called 'Hydrogen Regulations, Codes and Standards Matrix' gives a description of existing standards, standards under revision and areas/topics for which standards are still lacking. The latest version of the matrix dates from August 2005.

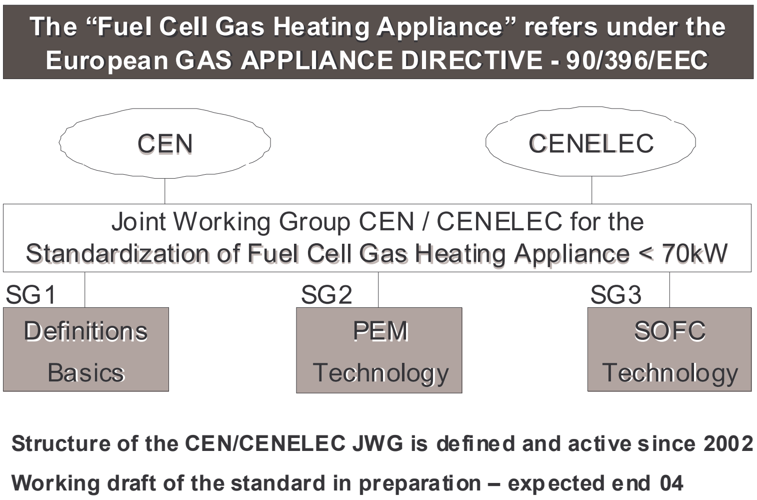


Figure 10: The European standardisation project for Fuel Cell Gas Heating Appliances has been established under the proven structures of CEN/CENELEC

3.3.1.2 RCS related topics to be addressed in the deployment strategy

In order to facilitate a positive environment for hydrogen and fuel cell applications regarding regulations, codes and standards as displayed in Figure 11, following activities are recommended for a deployment strategy:

- Close interaction and involvement of members of the IG RCS as well as members of the Steering panel for the Strategic Research Agenda need to be ensured in setting up and execution of the deployment strategy.
- Close interaction and involvement of local, national and European authorities and jurisdiction need to be ensured during final set-up and implementation of early market deployments, including Lighthouse projects.
- The results of the detailed gaps analysis by the IG RCS should be used, as a starting point to define which RCS need further development and/or are to be tested/evaluated in the Lighthouse projects. Target date for finalizing this gap analysis should be before the end of 2005, to ensure inclusion into the Deployment Strategy. It is essential that the RCS will be applied to realistic situations in line with the roll-out of the hydrogen economy in the future.
- Real life experience from the Lighthouse projects should be used to further improve and optimise regulations, codes and standards (via a feedback mechanism to the IG RCS).
- Subsequently improved regulations, codes and standards should be used also as input to end up with more adequate and efficient permitting and approval processes as well as to lower labour and construction costs of new facilities.
- Regulations for road vehicles should refer to existing ISO/ IEC standards (as legal requirements they do not depend on them).
- Streamlined and international standards permitting process are key to ensure a fast conversion of retail sites. The development of regulations, codes and standards should emphasize on safety, reliability and environmental concerns and assure that the relevant risks are managed in a clear, efficient and consistent way for all application areas.

- Due consideration should be given to the adoption of best practices for management of risks from different industries. Interaction with the EU safety Technology Platform to be ensured.

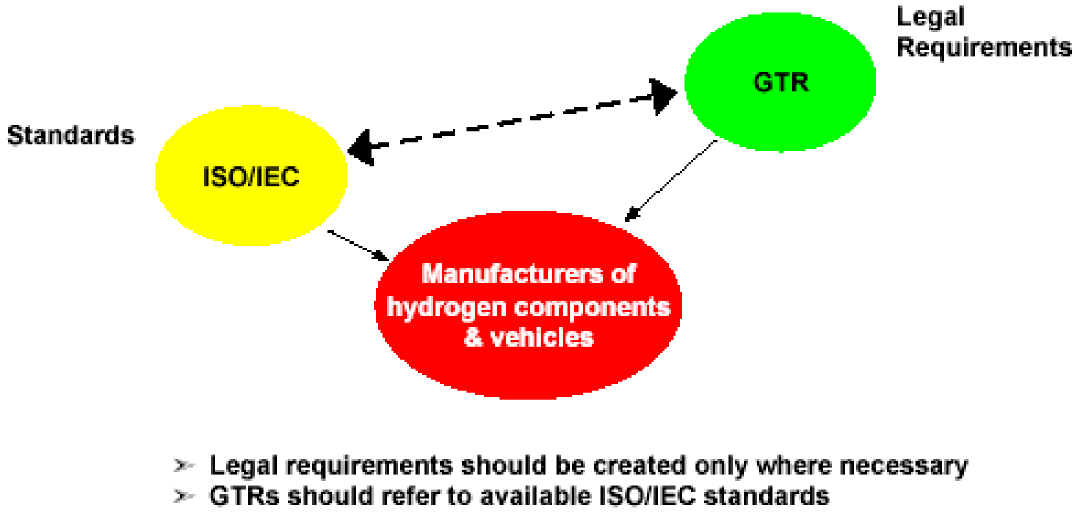


Figure 11: Desired landscape for regulations, codes and standards for hydrogen and fuel cell applications from IG RCS

Trust and acceptance in RCS needs to be built by local communities. Lighthouse activities in publicly accessible locations will help people to get familiar with hydrogen and confident with the governance around the safe use of hydrogen.

3.3.2 Technical Barriers

For all applications the general technical issues are related to fuel cells and their need for further improvements regarding lifetime and durability, membrane production and catalyst loading as well as missing facilities for mass production.

Regarding road transport in addition the need of a dense and lightweight onboard storage of hydrogen (see chapter 2.2.4.2) is seen as a challenge for achieving a driving range comparable to conventional vehicles. In addition for hydrogen fuelled ICE powertrains the achievable efficiencies in the NEDC need to be further increased beyond the 24%[50] for a compact car that could be ready for market in 2010.

The major technical barriers for stationary, road transport and APU applications have been summarised in Table 10. While lifetime and durability is an issue for all fuel mass market fuel cell applications the medium prospects for a begin of the commercialisation are best for stationary high temperature fuel cell applications in the fields of industrial power and heat generation (200 – 500 kW_e range) and auxiliary power unit applications in the transport sector. Other stationary fuel cell applications based on PEMFC need further improvements on the platinum loading of membranes (cost issue!) and more efficient and less costly reformers. However, it must be emphasised that a number of European PEM fuel cell manufacturers are developing power modules for early and niche markets. It is believed that these systems are “fit-

[50] „Well-to-Wheels analysis of future automotive fuels and powertrains in the European context“, 2003;EUCAR/CONCAWE/ JRC

for-use” and early demonstrations are needed in order to provide for the European fuel cell industry a “fast-mover” advantage.

Since most barriers are related to fuel cell vehicles the initial assessment of a 2020 scenario as described in chapter 1.4 seems to be supported regarding the latest mass market entry of fuel cell vehicles in comparison to other market segments.

Table 10: Main technical barriers for stationary and transport fuel cell applications

	Residential CHP (< 50 kW_e)	Industrial CHP (200 - 500 kW_e)	Road Transport	APU (Transport)
lifetime and durability[51]	~ factor 5-10 needed	~ factor 5 needed	~ factor 2-5 needed	~ factor 2-5 needed
Pt loading of MEA	factor 2-5 needed	low cost catalysts (SOFC & MCFC)	factor 2-5 needed	SOFC: low cost catalyst PEM factor 2-5
Power density	sufficient	sufficient	sufficient for smaller cars	sufficient for trucks, boats
Infrastructure issues	solved (NG fuelled)	solved (NG fuelled)	open	solved (reforming of diesel/ gasoline)

3.3.3 Economic Barriers

Under the umbrella of economical barriers both issues on the micro-level such as higher cost of ownership for hydrogen and fuel cell applications in comparison to conventional technology and on the macro-level such as financing and fund raising for infrastructure and production facilities are mentioned.

Regarding the cost of ownership the following categories have a major impact on a qualitative level regardless the application:

- Investment
- Maintenance
- Fuel Cost
- Recycling of precious metals

For industrial and residential CHP applications with high load profile the investment is only a minor share of the total cost of ownership over the life time of the applications. Hence the fuel and maintenance costs are dominating and on the basis of having solved the technical challenges as specified Table 10 a moderate premium on the investment can be justified since the more efficient energy conversion and lower maintenance will payout over the operation time and generate a customer benefit. This is even more true for large centralised power stations. Today the largest energy conversion technologies reach the best efficiency rates. Therefore all stationary applications have to follow the technological development route to increase the efficiency of fuel cell systems as well as of turbo machineries.

Regarding transport applications the allowance of such an investment premium is more difficult to determine for mass market introduction since only in the beginning

[51] Strategic Research Agenda Foundation Report chapter 2.3.3.8 (stationary) and chapter 2.4.3.1 (Road Transport)

the majority of hydrogen vehicles will be fleet operated. In theory high energy savings have been claimed assuming an efficiency advantage of 50% for a fuel cell vehicle in comparison to a conventional ICE energy savings[52]. However this implies that the efficiency of conventional technology would not develop further, which is in fact not true. Based on the outlook of the Well-to-Wheels Study from DG JRC, EUCAR and CONCAWE[53] the energy consumption in 2010 could decrease for a Diesel vehicle by 23% due to hybridisation and further engine improvements. In comparison the energy savings of the fuel cell vehicle could be reduced to around 30%. Hence the 2015 cost targets for fuel cell drive trains suggested by the Strategic Research Agenda below 100 €/kW[54] which would be twice the value for a diesel engine seem to be a reasonable upper level.

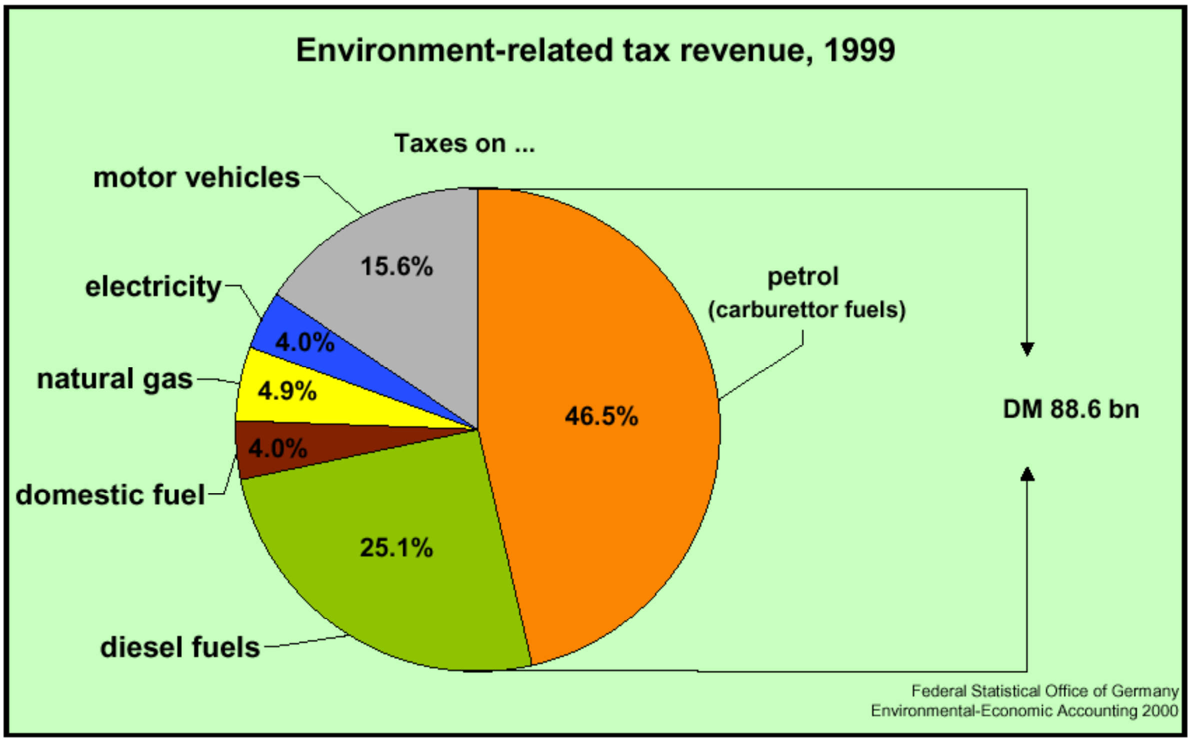


Figure 12: Share of German environment-related tax revenues[55]

All previous assumptions have been made on the basis that the pump price for hydrogen won't exceed the levels for competing fuels such as natural gas (e.g. stationary applications) or gasoline/ diesel (e.g. transport applications). On a pure cost basis excluding any excise duties hydrogen - even from fossil sources such as natural gas – can't compete with gasoline, it exceeds this benchmark by at least a factor of two as been described in chapter 2.1.2. Unless the feasible untaxed hydrogen pump price is not exceeding the taxed gasoline/ diesel prices a tax levy on hydrogen can allow a successful commercialisation. Such a tax exemption for hydrogen as a motor fuel is a desirable entry strategy to overcome the initial cost barriers during the introduction phase. However it needs to be stated that on the long run – when hydrogen has left the "5 to 10% niche" – the hydrogen production and distribution need to be competitive to other energy sources on a cost to cost basis

[52] „Fuel Cell Commercialisation; the Key to a Hydrogen Economy", P. Zegers, 9th UECT, 2004
[53] „Well-to-Wheels analysis of future automotive fuels and powertrains in the European context", 2003;EUCAR/CONCAWE/ JRC
[54] Strategic Research Agenda Foundation Report chapter 2.4.3.1
[55] Environmental-Accounting in Germany 2000, Report of the Federal Statistic Office

since niche market subsidies for alternative fuels can be cross-subsidised but a major shortfall for excise duties from motor fuel would have a significant impact on the Member State financing as exemplified for Germany in Figure 12. In 1999 the overall revenues of energy related tax have been summed up to 45.3 billion € from which more than 70% have been raised through motor fuels.

Another important issue related mainly to transport applications is the slow ramp up of a hydrogen infrastructure resulting in low utilisation rates and poor economies of scale at the beginning. Most cost analysis such as the Transport Energy Study (TES) or the HyNet Roadmap assumed already a market penetration of hydrogen as a fuel in the order of 5% for their cost analysis, leading to the conclusion that fossil hydrogen could compete with a special tax regime (see chapter 2.1.2). Assuming that before 2020 a hydrogen infrastructure for transport applications will hardly pay back it's investment combined measures are needed to overcome the economical barriers on hydrogen production and infrastructure:

- Public Private Partnerships for building up a basic infrastructure, beginning with large scale comprehensive demonstration projects in order to allow a risk share for the initial investment.
- Tailor made financing regimes acknowledging the long pay-back time for capital (e.g. zero interest rate for first 10 years, not pay back for first 10 years).
- Reliable long term tax regime for hydrogen allowing security for infrastructure providers and application buyers, including a determined phase out period after 2020.
- Potential synergies with stationary applications need to be examined: economies of scale for central production could be realised for so called "energy stations" supplying both hydrogen micro-grids and mobile applications. However the danger may exists that high hydrogen prices for mobile applications could be "exported" to stationary users.

However, the major barrier to the introduction of fuel cells is the need to invest in the development of high volume, low cost production processes and facilities, especially for high value key components such as PEM membrane electrode assemblies or the basic fuel cell unit in the case of SOFCs.

The potential size of the fuel cell industry is large, implying significant investment requirements and corresponding job opportunities. The financial markets and fuel cell / component manufacturers will ultimately have to provide the capital required for the necessary production facilities, but they cannot do so until they can be reasonably certain that a market will emerge. In the next few years manufacturers will have to make investment decisions based, in large part, on where public support and its impact on the market are most conducive to the introduction of fuel cells. If present trends are not challenged the US will build on its financial, regulatory and market advantage and attract most fuel cell investment. Manufacturing capacity and human capital will certainly follow up the financial capital.

The financing issues for large-scale comprehensive demonstration programmes need to be carefully analysed in collaboration with the Initiative Group Financing and Business Development. Regarding the deployment of hydrogen powered vehicles the following general financial requirements could be considered:

- **Phase I (until 2010):** start-up of large-scale comprehensive demonstration projects with the focus on initiating a public private partnership equally financed by industry and public authorities for the first infrastructure and hydrogen fleet vehicles (mainly cars and buses).
- **Phase II (2010 – 2012):** extension of demonstration sites with the focus of reaching at least 5 Member States, hence requiring additional capital for the infrastructure investments from structural funds and/or EIB loans.
- **Phase III (2012-2015):** preparation of a commercialisation in major European markets for all kinds of vehicles, mainly financed through private venture capital and EIB loans.
- **Phase IV (2015 -2020):** transition towards mass market commercialisation with a further build up of a hydrogen infrastructure.

An integrated large scale demonstration project will not only deploy transport applications under the phases I to IV as described above but also all kind of stationary fuel cell and hydrogen conversion technologies as well as selected other early market applications. It needs to be stated that for phase I a public co-funding for both hydrogen infrastructure and product development is desired. Further ramp-up of applications such as vehicles with the aim of reaching the commercialisation targets for hydrogen and fuel cells (see chapter 2.4.1) by 2015 should be supported by governmental purchase programmes and other fleet mandates instead of funding of vehicles.

Another economical factor is the strengthening of the European supplier base for some key components of fuel cells and hydrogen technologies, in particular membranes, so that it develops a structured supply chain geared for widespread commercialisation.. Regarding high temperature fuel cells the European industry is leading the technological development in the 200 to 500 kW_e class in comparison to US or Japanese companies. However, most significant development of low temperature PEM fuel cells and components has taken place either in the USA, Canada or Japan with just a few European companies having started solid activities on a system and component level. On the other hand the European industry has a strong position in the development, the manufacturing and the commercialisation of turbomachineries. These systems like gas and steam turbines, internal combustion engines as well as compressors can also play an important role in a future hydrogen economy.

A situation similar to the fuel cell stack development can be spotted for the development and first prototype production of compressed hydrogen storage tanks using 700 bar technology whereas for cryogenic storage systems European suppliers have a leading position. An overview of the general assessment of Europe's suppliers base competitiveness for the whole process chain of fuel cells and hydrogen storage system is given in Table 11 below.

Table 11: Comparison of the competitiveness of European supplier base concerning fuel cells and hydrogen storage systems

	High temperature FC	Low temperature FC	Compressed H2 storage	Cryogenic H2 storage
Material & components supply	strong EU position	modest EU position (weak for membranes)	weak EU position	strong EU position
Subsystem developer (e.g. FC stack)	strong EU position	weak to modest EU position	weak EU position	strong EU position
System provider (e.g. FC CHP system)	strong EU position	strong EU position	not applicable	not applicable

Under the context of economical barriers the overall framework covering all legal and fiscal issues on hydrogen needs to be examined and adapted before a successful mass market penetration of hydrogen and fuel cells can be expected. All issues on regulations, codes and standards have been described in chapter 3.3.1. In addition the term of "fiscal clarity" needs to be addressed since investment decisions, procurement and operating of hydrogen production and distribution facilities as well as filling stations require stable long-term conditions. Also the energy tax allocation to hydrogen as a fuel and a road tax exempt for hydrogen and fuel cell systems need to be fixed on a long-term base. Another issue for framework conditions are the terms of liability for all activities along the production and operation of hydrogen infrastructure and related applications. Since the insurance companies often rely on statistical data for calculating insurance rates especially at the beginning of the market introduction for hydrogen and fuel cell applications the lacking data will eventually lead to a conservative approach involving a "risk surcharge" for hydrogen components. In order not to disadvantage hydrogen and fuel cell technologies appropriate fiscal or policy measures are required.

3.4 Socio-Economic Assessment

In this section, a brief overview of the impact of socio-economic aspects on the deployment of hydrogen and fuel cell technology is given. A very important boundary condition in the transition towards a hydrogen based society is the nature and strength of the drivers for this transition. It is important that all critical actors involved in the key changes in the transition process are to some extend driven towards the direction of the hydrogen transition pathways. If the strength of these drivers is insufficient, the implementation of a successful deployment strategy is very difficult. Moreover, an effective deployment strategy is only possible when it is undisputed that the transition towards a hydrogen based society actually solves the key problems that society is facing; under the condition that it has no inadmissible adverse effects on other important issues such as welfare (GDP, employment, balance of trade etc.).

First, a brief characterisation of the main drivers for transition towards a hydrogen based society is given. Based on these drivers, a possible strategy for management

of the first stage of the transition (deployment strategy) can be developed. A first outline of possible points of action for management of the desired transition is given.

3.4.1 Drivers for the transition towards a hydrogen based society

A transition towards a sustainable energy system through an incremental pathway is a process that does not occur autonomously. If the energy system is left to change on its own, it will follow market mechanisms that are aiming to increase profits on the short and mid-term, using the readily available most profitable technologies. Advanced and radical innovations are typically less profitable in comparison to conventional technology, even if these innovations might lead to more emission reduction or societal benefits on the long term. Radical instant changes are hardly manageable at all. However, radical changes and radical innovations can be introduced successfully with an incremental slow pace, by coordinated efforts of investors and politicians that are motivated by both short and long term (economic and societal) benefits. In general, new incentives have to be introduced in order to steer the autonomous development into a more sustainable direction. Without these incentives, only a radical instead of a desired incremental might be possible at the moment that we have reached a point in time where changes have become unavoidable.

3.4.1.1 Market barriers and opportunities

Hydrogen is considered to be one of the options that can contribute to the transition towards a sustainable energy system. It is however remarkable that in forecasting studies up until 2030 hydrogen plays not a significant role.[56] However, in some back casting studies it is shown that hydrogen can be considered as a sustainable transition pathway.[57, 58]

Apparently, the (expected) market behaviour as simulated in forecasting studies does not lead to a future hydrogen based energy system, even thought back-casting studies show that such a hydrogen based energy system can compete with or is even preferable over other sustainable energy systems. A likely explanation is that, when taking only short (and medium) term profits into account, there are always competing options that are (at that point in time and under those market conditions) cheaper than the hydrogen based technology. This does however not mean that on the long run these options are also to be favoured. This is illustrated with the following example.

In Figure 13, a possible introduction pathway for emission reduction standards is given as an example.

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[56] European Energy & Transport – Trends 2030, http://europa.eu.unt/comm/dgs/energy_transport/gigures/trends_2030/index_en.htm

[57] Van Hilten et al., Report ECN-C—00-020, http://www.ecn.nl/library/reports/2000/c00020.html

[58] The basic challenge remains as hydrogen can only be as environmentally friendly and CO2 free produced as the primary energy carriers and conversion processes are.

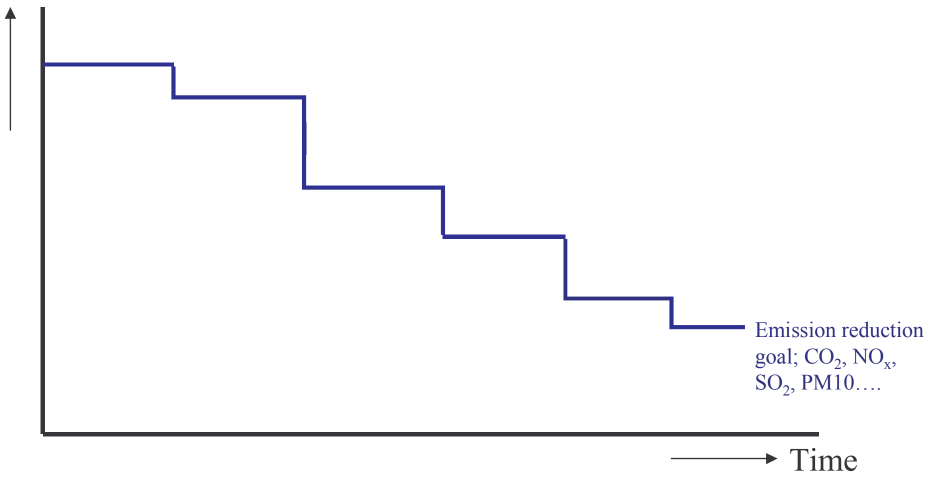

Figure 13: Example of possible development of emission reduction standards in time

The emission level is decreased at certain points in time. Emission levels can be set for several substances, such as carbon dioxide, nitrogen oxides, sulphur dioxide, PM10 and others. Increasing investments have to be made in emission reduction technology, in order to be able to meet these emission reduction targets. Higher investments are needed to meet more stringent emission reduction targets. This is visualised in Figure 14 by the red line.

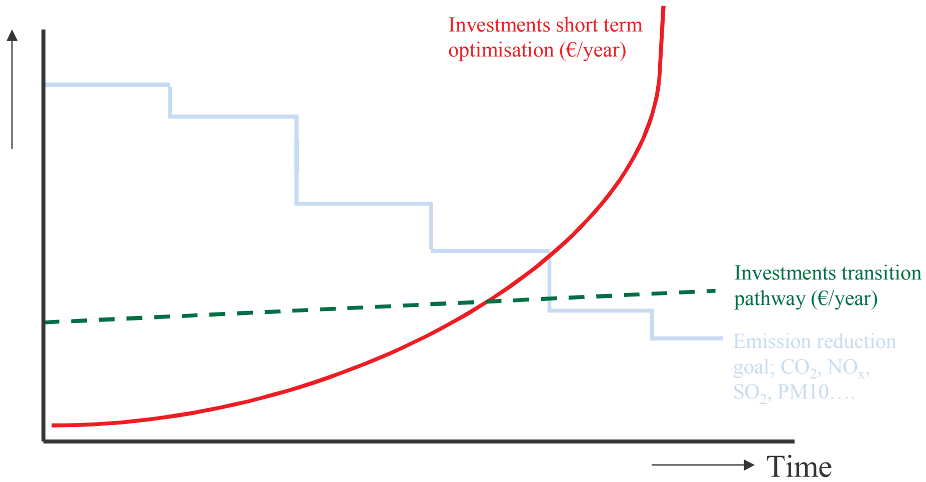

Figure 14: Example of the development of investment costs with decreasing emission reduction targets for a short and long term optimisation strategy

At a certain point in time, the investments will have to increase dramatically as a result of depletion of cost effective (conventional) technology. This depletion of cost effective conventional technology is partly due to the fact that further improvements to the existing technologies have reached their end. As a consequence a decrease of the emission reduction targets above a certain level will only be accessible by the deployment of radically different technologies that do not fit in the current energy system (i.e. since they require new infrastructures). However, the material and economic investments made in the (at that time) current system are so sunk in, that it takes a lot of effort (both in material as in economic sense) to deploy the radical new technological system. It takes for example at least fifteen years to change the whole

stock of cars or boilers. This is the so-called lock in effect. Lock in effects are for example caused by the (lack of) speed in which an energy system can be changed as a result of the average life time of infrastructure and applications. As a result, the introduction of new, advanced technology that does not fit in the current energy system is hindered. However, this new and advanced technology might be able to meet future targets in a more cost effective way than conventional technology.

Independently, one can expect that the energy system will be optimised to the maximum level that is technically feasible and economically acceptable. The energy system will only be changed radically once it can no longer meet new requirements or targets. In that case the awareness of the need to change the system is then visible to all relevant actors. However, if we end up in a situation where mitigation costs (more or less suddenly) go up drastically, it is very likely that emission levels will simply not be reduced beyond a level that is economically acceptable. In practice, this means that due to these economic constraints it may be not feasible to set emission reduction levels at the level necessary to mitigate climate change (e.g. the 550 ppm reduction level), since the autonomous pathway will create lock in effects that will prevent the required introduction of advanced technologies.

By means of an effective transition management, these lock in effects can (partially) be avoided. In this way, the introduction of advanced and radical technology through an incremental transition pathway under economically acceptable conditions is feasible. The red line given in Figure 14 is an example of a cost reduction curve based on a “short term profit” investment strategy, based on current market conditions and near future market expectations. However, if the investment decision is also based on long term market conditions, ambitious emission reduction targets can still be met at reasonable costs since the required changes in the energy system (i.e. infrastructure) are made at optimal points of interaction (during renovation or replacement). This is presented by the green “transition” line in Figure 15. In this new (investment) strategy, an incremental pace of introducing advanced (radical) technology is feasible, whereas the conventional strategy in the end needs a (costly) revolutionary approach in order to meet the same reduction targets.

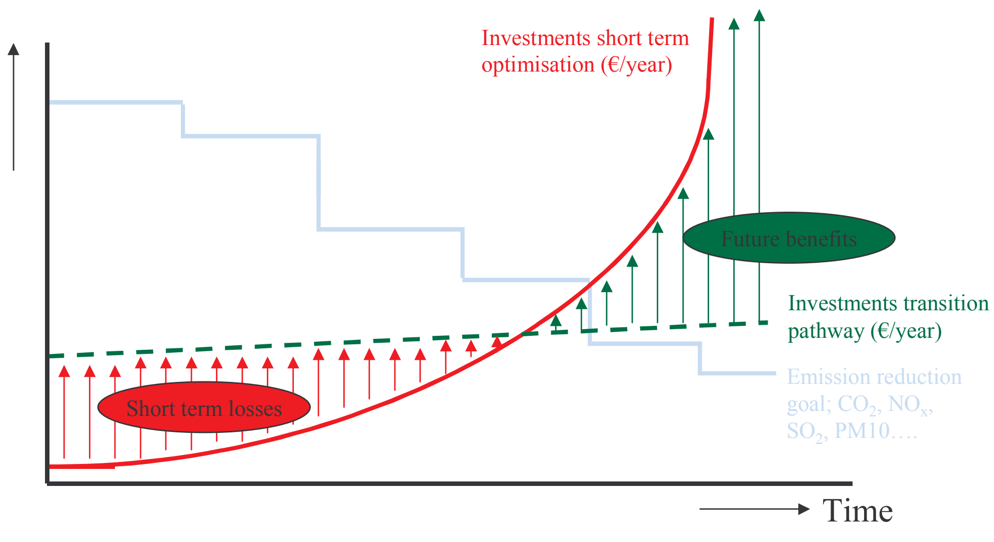

Figure 15: Short term losses vs. long term profits in case of a gradual reduction of emission levels.

The main barrier for this incremental transition strategy is that for a certain period of time the investments exceed the investments following the classic investment behaviour. In other words, the approach that is preferable in the long term leads to short term losses.

Specifically in case the future benefits are uncertain, and usually they are, it is very unattractive to invest according to such a long term optimisation strategy in a fully competitive market. Even if all actors are convinced that this long term strategy is preferable to the short term optimisation, the so called prisoner's dilemma that is introduced might result in a sub-optimal decision process.

Within the HySociety project that is funded under the EU FP5 framework, barriers and opportunities of recent and ongoing hydrogen demonstration projects are identified. Even though most of the demonstration projects are considered to be successful, the required follow up, necessary to make the next step within the transition pathway, is often lacking. The main focus is on the non-technical barriers, i.e. institutional, political, economic and social barriers. The outcome of the project is an action plan which addresses barriers and opportunities that have to be taken into account in order to facilitate the next phases of demonstration projects up to 2010. Within HySociety, an assessment is made of the attitude of actors that were involved in these 'successful' hydrogen demonstration projects. This might however, lead to an overoptimistic outcome, since the actors currently involved in hydrogen at this stage of the transition process are likely to be more motivated than society in general. It is therefore recommended that the scope of analysis of HySociety be broadened to perform an actor analysis that is not strictly limited only to those currently involved in hydrogen demonstration projects. In addition, the key changes (and therefore critical actors) in the next phase of the demonstration projects might deviate from the key changes as identified within the HySociety project.[59]

Among the factors that determine the long term profits of the transition towards a future hydrogen based society are cost reductions and efficiency improvements. However, specifically for the long term (2050), there is little knowledge/consensus on these topics. This complicates the discussion on the future profits of the transition towards a hydrogen economy. These inputs are however crucial in energy models that aim to forecast development of energy use as well as technology deployment on the long run. In general, consensus can be found on cost reductions and efficiency improvements on the short term (e.g. 2010). Cost reductions and efficiency on a medium or long term, e.g. up to 2020 or 2030 or even 2050, require different assessment techniques, e.g. by developing learning curves as well as a less detailed but more conceptual approach of technology deployment.

Whereas the HySociety project focuses on short term barriers and opportunities, the HyWays, and integrated project funded under FP6, focuses on the medium and long term. The aim of HyWays is to develop a fully validated hydrogen roadmap. The analysis as performed in HyWays will have to show to what extent hydrogen can contribute to environmental as well as economical policy goals such as security of supply and economic stability, greenhouse gas reductions, competitiveness of and opportunities for European industry and improvement of (urban) air quality. To give

[59] The focus of HySociety is on recent and ongoing (nearly finished) projects. These projects can be considered as the first phase of demonstration projects. These first phase demonstration projects likely need several follow ups in order to outgrow niche markets and make the step towards (the early phase of) mass market introduction.

insight in the dilemma of short term vs. long term optimisation (see Figure 15) is one of the major motives for developing a hydrogen roadmap. A key aspect in the development of this roadmap is the involvement of all relevant stakeholders. In the first phase of the HyWays project, a country specific analysis is performed for Greece, Italy, Norway, Germany, France and the Netherlands. In the second phase of HyWays, a country specific analysis for another six Member States is foreseen. Based on these country specific analyses, a synthesis at EU-level will be carried out. In order to build a valid roadmap, it is essential to take into account the country specific conditions (political conditions as well as other aspects such as characteristics of the power sector, existing infrastructure, type of energy demand etc.). Therefore, expanding the second phase of HyWays by including some additional Member States (e.g. an analysis of opportunities within the new accession states) in the country specific analysis is strongly recommended.

The dilemma of short term vs. long term optimisation as well as differences in interest of critical actors is one of the key issues in the transition towards a hydrogen based society. A first outline of possibilities for transition management is given in section 3.4.3.

3.4.1.2 Drivers in the transition towards a sustainable energy system

In the paragraph above the dilemma of future benefits versus short term profits is described. These future benefits can be influenced by a various external factors, such as energy prices, security of supply, depletion of fossil fuels as well as emission reduction targets. This is influenced by developments in and outside the EU. On the other hand market factors like market share, financial position as well as image and public awareness are crucial for gaining a leading position in a high competitive world market. Specifically, developments within the US, China and Japan influence technology development as well as the boundary conditions for deployment of hydrogen technology.

3.4.2 Other drivers in the transition towards hydrogen

Besides the need to reduce greenhouse gas reductions, there are also other drivers that support the need for changes in the energy system. Specifically security of supply is expected to increase in importance. At the moment, about 50% of the demand for fossil fuels in Europe is imported. This import dependency is expected to increase significantly to about 70% by 2030.[60] Decreasing the dependency of import of fossil fuels is also a major driver in countries like the US, Japan and China. Hydrogen can be produced from various energy sources and therefore contributes to an increase in security of supply.

If the introduction of hydrogen technology on a world wide scale will also affect the deployment of hydrogen in Europe, technology learning, being a function of total cumulative capacity and the required cost reduction will happen a lot faster in a world wide market. A successful introduction of hydrogen technology in other parts of the world might also convince actors within Europe that are currently sceptic about the value added of hydrogen and fuel cells. Key question is whether Europe should take the lead in this transition process or rather it should try to maintain a comparable implementation level with other key players.

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[60] Green Paper: „Towards a European Strategy for the Security of the Energy Supply" COM (2000) 769

One other major driver for a radical change of the current energy system is the impact of local air pollution. Recent studies have shown that the effects of fine dust are even more severe than previously expected. Specifically in city centres, the air quality leads to significant health problems. This is not only a problem on a European level, but acts in (major) cities all over the world.

3.4.2.1 Main conclusions

Based on the analyses of the previous section, the following recommendations are made:

- Long term benefits need to be taken into account in the investment behaviour of public stakeholders in the transition process to provide long term economic prospective for the private sector.
- Research is needed in order to find out what incentives can steer current investment behaviour into a direction that leads to a sustainable energy system (transition management). A relevant boundary condition is that the value added of the transition towards a hydrogen based society is undisputed e.g. by developing a well accepted and validated roadmap.
- Greenhouse gas emission reduction targets may act as one of the drivers for the transition towards a hydrogen orientated society. However, the strength of this driver is hard to assess, since no limits have been set yet for the post-Kyoto period. However, other drivers, such as security of supply as well as air quality improvement might be of key importance. The deployment of hydrogen technology will also significantly be influenced by developments outside Europe.

3.4.3 Managing the transition towards a hydrogen based society

The purpose of managing a transition is to shift from the present situation, for example an energy system with undesirable high emission of green house gasses, towards a sustainable energy system. To be able to change the present situation, structural and radical changes will be needed such as the built up of a new infrastructure. Up till now these changes occurred gradually, and often followed market demands. However, relying on market mechanisms to create a more sustainable future in which hydrogen has a substantial role to play might not be successful.

3.4.3.1 The actor perspective

As mentioned in the previous section, market mechanisms are unlikely to take into account the societal and long-term (economic and societal) benefits of hydrogen and as such not lead to the creation of the required drivers for hydrogen. One major driver for a successful introduction of hydrogen is the creation of an infrastructure. Implementing hydrogen without the required infrastructure could inherently lead to a loss of functionality in the existing practice. However, developing this infrastructure is a costly undertaking, especially when the required market (end-users) does not exist yet. Hydrogen will need to compete with the dominant and fully functional current mix of energy carriers and energy related technologies and faces problems of cost reduction. Moreover, it is not known to what extend the infrastructure will be used in the future.

The actual situation is even more complicated since the actor that provides the end use applications and the actor that has to develop and exploits the hydrogen infrastructure are in general not the same. However, for a successful transition, efforts have to be harmonised. If one of the actors fails, the other actor will also have to bear a substantial (financial) penalty. High investments are involved and investments have, in comparison to business as usual, a relative high risk. As a consequence a status quo emerges. Investments in a new infrastructure will only be made if there is a demand (end-users), and because of the poorly developed or non existing infrastructure, there are no end-users. This status quo would seriously hamper the introduction of hydrogen. Merging of suppliers of end-use applications and developers of infrastructure as a strategy to overcome this barrier may however introduce the problem of partial monopolies. In the past however, the prospect of being able to establish such a (temporary) market monopoly has served as major driver is successful transitions. One idea of creating such a temporary market monopoly is a specific Buyers' Pools for identified niche or hybrid markets that could facilitate this harmonisation between the actors at both ends of the market: an objective of the Buyers' Pools would be to share experiences with the use of hydrogen and fuel cells and to share technical support management. Key to successful Buyers' Pools is the choice of the right product. As the objective in this case would be to educate the customer and stimulate the knowledge on hydrogen and fuel cell applications, the choice of the right buyers and the inclusion of a broad suppliers' base would be crucial as well. The IG Financing and Business Development is investigating suitable hydrogen and fuel cell systems and the right customers to establish one Buyers' Pool in the public and one in the private sector.

Current dominant market actors in general have a high installed base. Therefore, they are reluctant to invest in competing technological pathways, since it will harm the profitability of their current assets. Possible drivers to invest in competing technological pathways are prospects to be able to dominate the future market. Specifically in a full competitive market, this driver often hardly exists. A second driver for investing in competing technological pathways is the belief that the current technological pathway will lead to a dead end in the near or mid term future. In this case, the uncertainty of being able to obtain an appropriate return on investment is outweighed by the fact that no change at all is likely to lead to a significant loss of market share. This specific situation can be created by e.g. regulating the performance of end-use applications (limitation of specific emissions or energy consumption of cars or boilers). Important boundary conditions are that these targets are realistic and that the critical actors are convinced that they have to be met (reliability).

Finally, some boundary conditions for a successful transition can be identified. End users must have the ability to purchase the equipment. The technology has to be available, reliable and should not be limited in functionality (lacking infrastructure). Moreover, the innovations should be affordable and accepted. For industry, the level playing field as well as the ability to make a (reasonable) profit is key factors. Finally, the result of the transition needs to be in line with policy objectives.

3.4.3.2 Consumer acceptance and preferences

Various factors play a role with respect to consumer acceptance and consumer preferences. Some of these factors, such as pay back time, can be assessed in a relative straightforward way. An acceptable pay back time is an important prerequisite for a successful deployment of new technology, but also factors that are less easy to quantify, such as "feelings" towards the new technology, might play a dominant role. Specifically in case of new complex technology, end-users find it difficult to establish an opinion about whether this new option is desirable or not. In general, they do not have the knowledge to make an appropriate judgement on the advantages and disadvantages of a new and yet unknown technology. Therefore, they have to rely on other mechanisms than 'rationality' in order to be able to form an opinion. Mechanisms that are used to derive an opinion about a new and complex problem are for example to rely on the opinions of other actors that are trusted most (i.e. NGO's, government, industry) or make use of associative images.[61] It is likely that these mechanisms that determine preference and acceptance vary between countries as well as in time, since they likely depend on factors such as world view. Specifically in the first phase of introduction of a new technology, the general public has little information to base their opinion on and their opinion might be vulnerable to changes (either in the positive or negative direction). Specifically in the first crucial stage of technology deployment, it is of key relevance to make sure that there is sufficient support from the general public. How this process of obtaining consumer acceptance actually needs to be organised has to be the subject for further research.

3.4.3.3 Hybridisation

One of the main challenges of in the transition to a hydrogen based energy system is the built up of infrastructure. To overcome this gap, the use of specific hybrid technologies might be useful. In the past, the concept of hybridisation (i.e. sailing boats equipped with steam engines) has been able to conquer barriers related to lacking infrastructure. Moreover, application of the advanced technology within this intermediate period can lead to i.e. the necessary cost reductions, improvement of reliability and performance as well as consumer acceptance.

Hybrids are coupled technologies that function as transitional technologies and that probably will not exist in this coupled form for a long time. The hybrids can either make use of the existing infrastructure or anticipate the creation of a new infrastructure. In case of hydrogen hybridisation can take place in two ways: a new technology is introduced (i.e. fuel cell cars with on board reforming or stationary fuel cell systems with a gas turbine) that does not immediately require a new hydrogen infrastructure, but facilitates the gradual build up of a hydrogen infrastructure. The function of this first form is to create a demand, without the immediate need for a new and costly infrastructure, because the existing infrastructure can be used temporarily. Alternatively, hybridisation can occur by changing infrastructure gradually as a result of flexibility in the end -use technology (i.e. ICE vehicles on that can run on hydrogen and conventional fuels). The hybrid technology does not compete with the existing technological systems, in this case the ICE, but is added to it to enhance its

[61] The public might associate hydrogen with water, which is healthy, pure and safe. Also, the link to hydrogen bomb, the Hindenburg or an exploding Space Shuttle might be made. It is of less relevant whether the associations are, from a scientific point of view, correct or not. The consumers might simply have these 'unexplainable' feelings that can be negative or positive due to these associative mechanisms. These feelings however are of relevance with respect to their attitude towards the new technology.

functionality. This type of hybridisation creates an infrastructure from the onset, that later can be used for other hydrogen-related technologies as well (i.e. hydrogen fuel cell vehicles).

Hybridisation involves the coupling of niche and existing technologies or systems that are either similar or different. The coupling results in a variety of different interactive relationships to offer either an optimised or new functionality. The need for coupling of the new technology is often related to its need for growth (of it's market share), whilst the need for coupling of the existing technology or system is often based on a need for optimisation and stabilization, and need for added functionality (often following a change in user demands the existing practice). In the past, the hybrid concept offered at least the perspective of future advantages to the end-user.[62] In the case of hybrid vehicles, it is society rather than the end-user that profit most from this change in technology. The functionality of the hybrid vehicle is comparable to that of the conventional one. Key issue in the hybridisation concept is that the technologies that are hybridised are interlocked in mutual interdependence, and that both their survival (economy and scale) depends on this coupling.

3.4.3.4 Niche market management

Another aspect of transition management is niche market management. Niches are spaces (demonstration sites, new markets, or even controlled environments) that provide an environment for new and innovative concepts (technologies or technological systems) to develop further in terms of technological optimisation or learning curves.

Two types of niches can be distinguished:

- The innovation creates a whole new market where competition is not an issue either because it adds functionality (i.e. increase in performance or level of comfort) to the new system or because it provides a prior non-existing new functionality.
- The innovation is only applied in a part of the market with deviating characteristics (i.e. condensing boilers were applied first in dwellings with high energy consumption).

Sometimes, policy incentives can create niche markets. By setting targets on noise and emission levels, conventional technology might not be applicable (zero emission or low noise vehicles in city centres). Other nice markets might exist as a result of deviating characteristics where specific technological characteristics are valued differently, such as aeronautics or military applications.

As such, niches are protective spaces where efforts of end-users, industry and government can be directed towards accumulating experiences and learning about issues such as end-users needs and demands, maintenance issues, etc. Innovations can be deployed in more than one niche at the same time or at different times in follow-ups, with the aim to learn as much as possible about relevant issues (that can change in time, in line with the changing existing practice in which the innovation might be deployed). In addition the scale of niches can vary from very small and on a

[62] Consumers were willing to invest in stereo equipment containing both a vinyl player and a CD-player, since the CD-player offered them an increase in performance (improvement of audio quality).

national or even regional level, to large scale and international level. Typically, the more the economic viability of an innovation increases (the more market ready it becomes), the larger the scale of the niche experiment will be.

Taking the above into account, it follows that niche experiments can be used as effective instruments to introduce (radically innovative) hydrogen -related technologies in an incremental pace. However, these niche experiments need to be managed and coordinated carefully, preferably on a EU level. This coordinated management should be the result of active and motivated involvement of all relevant stakeholders. To interest these stakeholders; governments, investors, industry, and the market in hydrogen technologies it should be assessed which large-scale, representative (lighthouse projects) demonstration projects might be created. In order to identify these possible hydrogen “lighthouse projects”, it is necessary to assess in which cases hydrogen based technologies might solve or decrease problems or might fulfil needs in a environment in which solving these problems are of more importance than costs or in which areas the technology could be economically viable. Furthermore, it should be assessed which actors might be motivated to start up these new niches for hydrogen, and what incentives can (positively) influence the success of their demonstration projects.

3.4.3.5 Choosing the right options

A last but very important aspect of transition management deals with the consequences of specific technological choices. It is very likely that many possible niches can be identified for hydrogen, all with their specific technological requirements. Facilitating the creation of a (economic viable) hydrogen niche and the accompanying infrastructure might lead to the lock out of other (hydrogen based) innovations. Taking into account that the average time needed to change an existing (material and economic) infrastructure is approximately fifty years, contemplating on the consequences of certain technological choices is important.

3.4.3.6 Towards an integrated approach

The transition towards a hydrogen based society depends on technical, economic as well as political, social and institutional characteristics. In order to make a valid assessment of the barriers and opportunities, all these aspects have to be taken into account in an integral way. Current assessment methods in general cover only part of the actual barriers and opportunities e.g. by assuming full knowledge and economic rationality at end users. Within the HyWays project, a first attempt is made to integrate the results of a qualitative transition analysis into a comprehensive modelling framework through a number of feed back loops. This has to result into a fully validated roadmap taking into account also non-economic and non-technical barriers. However, more research is needed in order to further improve and optimise this methodological approach.

3.4.4 Conclusion

Transition management can facilitate the assessment of the boundary conditions, requirements and benefits of a successful transition to a hydrogen-based economy, by assessing the incentives to motivate end users, industry and policy makers to support the transition towards a hydrogen economy (by assessing benefits, drivers, requirements and costs). Introduction of hybrid concepts have proven to be viable

options in the past, as a strategy to overcome barriers related to infrastructure built up, performance, costs and social acceptance.

Major research areas as well as points of attention in order to facilitate a successful deployment of hydrogen technology are:

- Identification of main incentives for management of the transition towards hydrogen. By means of transition analysis, a strategy to involve critical actors in the process of achieving key changes has to be developed.
- Identification of niche markets and development of a niche market strategy. Specific attention should be paid to hybrid concepts, since they have proven to be effective strategies to overcome massive barriers in successful transitions in the past.
- Establishing lighthouse projects to demonstrate preparing the market entry and commercialisation.

In addition, some factors that can influence the likelihood of occurrence, direction as well as speed of the transition process can be distinguished as:

- The value added of hydrogen as a transition pathway has (preferably) to be undisputed. This can i.e. be achieved by developing a validated and widely consented roadmap.
- The government should define clear future goals for e.g. greenhouse gas reduction and air quality improvement. This should an ensuing and consistent process so that the market can rely on the policy intentions and take these into account in their medium and long term market strategy.

3.5 Cross-Cutting Issues

A deployment strategy on hydrogen and fuel cells requires input from the whole spectrum from basic research and development towards regulations, codes and standards as well as from a business development perspective. Since the Hydrogen and Fuel Cell Technology Platform is dealing with all these topics either on a Steering panel level or in its Initiative Groups it is necessary to establish links between these groups and ensure a fully integrated process.

For the first sketching of a deployment strategy on hydrogen and fuel cells in 2004 not all relevant issues can be analysed in detail and results, inputs from the relevant groups are not fully formulated yet. However the most urgent actions regarding an exchange of cross-cutting issues have been started in 2004 and first results are available:

- First technical assessment of the Strategic Research Agenda (SRA) on hydrogen production and distribution as well as on fuel cells and other crucial hydrogen components for all identified markets (portable, stationary and mobile).
- Cost targets for fuel cells and other hydrogen technologies in collaboration with SRA for the 2015 time frame, allowing a “readiness for market” at latest by 2020.

- First assessment of the Initiative Group Regulations, Codes and Standards on the most urgent barriers for the deployment of hydrogen and fuel cells

In addition to these activities that will continue in 2005 a closer link to the Initiative Group Financing and Business Development (IG FBD) is advised for 2005 in order to make concrete recommendations for the further developments of identified early market applications.

Table 12: Cross-cutting issues within the Hydrogen and Fuel Cell Technology Platform

	DS	SRA	IG RCS	IG FBD
Hydrogen production	X	X	X	
Hydrogen distribution	X	X	X	
Hydrogen & FC component development	X	X	X	
Hydrogen & FC application development	X	X	x	X
Hydrogen & FC market development	X		X	X

4 Managerial Appraisal

For the further development and consolidation of a deployment strategy on hydrogen and fuel cells it is necessary to keep monitoring the results from other groups outside the Technology Platform and to provide also detailed expert advice on the layout of large-scale demonstration projects beyond the possibilities of the working scope of this Steering Panel. Hence the measures described below are recommended in order to ensure a successful operation of this Steering panel in 2005.

4.1 Coordination and Networking

The cross cutting issues within the Hydrogen and Fuel Cell technology Platform have been described in chapter 3.5 and the major issues have been identified. In addition input from other groups inside and outside the EU is welcome for the ongoing work of this panel. In this context either information from and interactions with initiatives on Member State level such as for example the Clean Energy Partnership Berlin (CEP) or projects in Lombardia and elsewhere is desired in order to incorporate the regional views into a European deployment strategy. Furthermore the progress of international hydrogen programmes such as sponsored from the US Department of Energy (DoE) and by the Japanese New Energy and Industrial Technology Organisation (NEDO) need to be monitored and relevant information to be considered in the work of this Panel. Due to the limited resources the following approach is recommended:

- Include expertise from hydrogen projects supported by European regions through the Steering Panel members who are members of a company/ organisation represented in all relevant programmes.
- Furthermore strongly suggest that under the pending calls of the 6th European research framework programme the issue of global monitoring is considered.

4.2 Funding Instruments

This report arguably points out the importance of the large-scale comprehensive demonstration projects as a bridging function between small prototype scale demonstration and the preparation of a successful market entry of hydrogen and fuel cells. Hence, further considering and designing the possible layout of such demonstration projects is an important task of the next work of this Panel. Expert advice is needed to prepare further recommendations on this front by the end of next years. Under the umbrella of the 6th research Framework Programme of the EC it is recommended that a possibility should be foreseen for establishing a functional link between the work of this Panel and strategic hydrogen and fuel cells research projects funded or to be funded by the EC.

4.3 Human Resources

The DS Panel has agreed to limit its size to 35 members in its first tenure term. This decision has been based on considerations for proper functioning of the Panel, effective management of inputs and for manageable consensus building process. The overall composition of the panel seems to be well balanced concerning a representation of the key sectors, equally between hydrogen and fuel cell technologies and a country specific representation. At present good coverage regarding energy issues, hydrogen production and distribution, components for processing industry, fuel cells (including components) and other hydrogen technologies (e.g. storage), stationary applications and road transport has been achieved.

Under the frame of the planned next activities additional input from other transport providers (e.g. air, rail, maritime) and the view of more end-users would be welcomed, including individuals from the New Member States.

5 Proposition of a Deployment Strategy

The deployment strategy outlines the need for joint actions of private and public entities for a successful bridging between the present research or prototype demonstration stage and a mass market introduction of hydrogen and fuel cell technologies. A time frame of roughly 15 years considered from now needs to be covered with different phases and timing for stationary, mobile and early or niche applications. In general a multi step approach is suggested as displayed in Figure 16 consisting of:

- Large scale comprehensive demonstration projects with different phases
- Preparation of market introduction and early markets

All kind of hydrogen conversion and fuel cell technologies require a supporting and stable political, legal and fiscal framework that is outlined in the chapter 5.1. Since the different applications are expected to have different time to market horizons and the energy supply chains for stationary and mobile or portable applications will use a variety of technical solutions, the desired actions and milestones for stationary, mobile and early market applications are described separately.

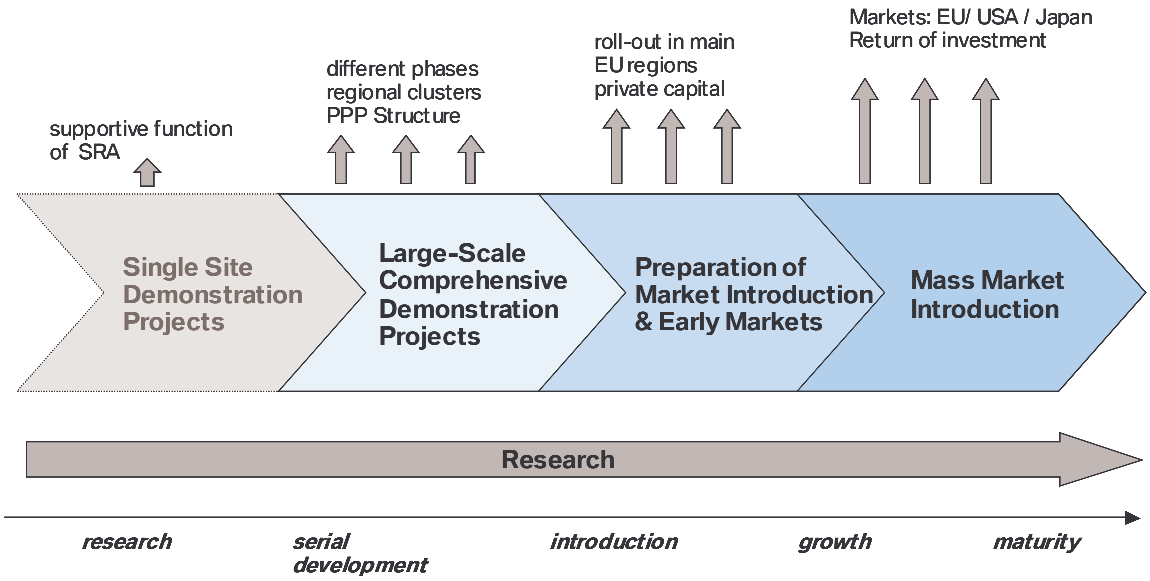


Figure 16: Phases of a deployment Strategy

In the public perception hydrogen and fuel cells are often treated as one entity which is not for all applications the case. An example are natural gas fuelled micro CHPs which can replace residential boilers without requiring a hydrogen supply since they are connected to the natural gas grid like conventional boilers. Hence the deployment strategy must be robust enough to ensure that temporary delays of the commercialisation of certain technologies do not challenge the long term success of hydrogen and fuel cells. A detailed discussion of this issue is given in Annex I. The transition towards a hydrogen economy may not only depend on a successful market introduction of fuel cells and vice versa fuel cells may not need an established hydrogen economy.

An important issue is the transition towards self-sustaining markets that requires mainly a private financed and organised development of commercial hydrogen and fuel cell applications and a corresponding infrastructure. The concept of a public private partnership as an answer to the quest for including public funds for the demonstration phase and the option of a later smooth transition towards free markets will be addressed in chapter 5.6. The structure and chronological sequence for all key activities of the deployment strategy on hydrogen and fuel cells is given in chapter 5.7 whereas for the time frame until 2010 three different stages are outlined in more detail ensuring a successful transition towards commercialisation. A major issue for the next activities of this Steering Panel will consist of the target setting and development of appropriate criteria for the initiation of these proposed next steps including the option of "Joint Technology Initiative" (JTI) as programme office for the large-scale demonstration activities described in chapter 5.6.

5.1 Policy Actions and Fiscal Measures

The objective of a rapid transition towards the hydrogen economy should be a primary political issue for Governments. Their action in building a positive policy framework can strongly influence the deployment of hydrogen and fuel cell technologies. In the meantime, it is also clear that inaction by Governments would not be a neutral choice, as it could easily become a hurdle to the deployment. Therefore, the deployment strategy must include suggestions for a desired policy framework, which should be characterized by a homogeneous approach throughout the European Union, in order to prevent "hydrogen-divide" situations.

The expected effects of different policy framework conditions and public actions on the deployment of hydrogen and fuel cells technologies and relevant market applications have been discussed in detail in chapter 3.2. Recommendations are here summarized.

Basic conditions
A strong commitment of Governments is the pre-condition for a favourable policy framework. Such commitment should be based on a medium-to-long term vision of the energetic, environmental and overall sustainable development strategies and on clear evaluations of the expected socio-economic impacts of the hydrogen economy; in the meantime, the capacity of building networks at national and regional levels is a condition for the effectiveness of strategies and projects. The Governments' commitment should be characterized by a high visibility, which is essential striving for political consensus, as well as for enabling public awareness.

The definition of the most appropriate government level is essential for developing proper action plans. Member States should define clear general policies, strategies and programs while Regions are expected to give an important contribution to the realization of such programs. In fact, they can facilitate the creation of hydrogen communities and develop integrated clusters of coordinated projects of regional dimensions. In this respect, direct links between the European Commission and Regions are advisable, under the supervision of Member States, possibly via enforced cooperation with the regions through tri-partite agreements involving Member States, Regions and the Commission.

Energy and environment strategies

Based on the approach of the European Commission, it is strongly recommended that National and Regional Governments recognize the development and deployment of hydrogen and fuel cells technologies as key factors for the future competitiveness of Europe, establishing proper roadmaps and supporting the participation of all actors and institutions in the European Platform. Hydrogen and fuel cells technologies are an opportunity to be considered in policies for energy, environment, innovation and industry, including the development of new opportunities in terms of market evolution and job creation.

Governments can give a strong support to the deployment with their legislative action: hydrogen and fuel cells as elements for a more competitive and sustainable economy should benefit of special consideration in laws for the energy sector and/or for environmental protection. The case of the law for energy recently approved by the Italian Parliament (extension to the energy produced from hydrogen of the incentives granted to the energy produced from renewables) can be considered as a positive example. In this regard, a harmonised approach is recommended in the European Union.

Public financial support is normally available at different levels: European Union, Member States, Regional Governments and local authorities. Coordination is recommended in order to maximize the effectiveness of funding, avoiding duplications and concentrating resources on significant, strategic viewed projects.

An increase in public resources for research is highly recommended, in order to compete with the major economies worldwide. A particular effort is expected on this front by assigning higher funding in the 7th Framework Programme of the European Commission.

Demonstration projects related to hydrogen and fuel cells technologies need financial support from public administrations at different levels, both as direct funding and indirect financing via the creation of industrial districts. Attention should be paid to demonstrating niche markets and early market applications.

Governments can support the creation of innovative financial instruments, and create partnerships with local banks and foundations. Such actions could foster the creation of regional hydrogen-based systems.

Structural funds are a good opportunity to support the deployment of hydrogen and fuel cells technologies; they could be effectively used to create links between Objective 1 regions and the most advanced European areas, promoting twinning and coordinated projects. This approach can also improve the cohesion policies throughout the European Union.

The “state aid” rules should provide possibilities of financial support to private initiatives in the field of hydrogen and fuel cells from Governments and Public Administrations, when it is demonstrated to be necessary for the deployment. Reflecting on the case of renewables exemptions from the state aid rules can be awarded for the pre-competitive phases of deployment. In this respect H2 can also be treated as RES

Fiscal incentives
Fiscal incentives have proven to be an important driver for the deployment of innovative technologies. Several sectors of the hydrogen and fuel cells chain can gain significant advantages from fiscal benefits granted by Member States and Regions. Again, it is strongly recommended that such type of facilitating measures be adopted on a coherent basis within the European Union, in order to avoid the creation of unbalances between States and Regions.

Actions of public administrations
The public sector should play an important role in the start up phase of the hydrogen economy, promoting demonstration projects in the fields of public transportation and fleets, cogeneration for public buildings, building and setting-up infrastructures. Public procurement of hydrogen and fuel cells related products is another possibility to give an effective support to the deployment strategy.

Public-Private Partnership
Public-private partnership is an effective and transparent way for stimulating and supporting initiatives of common interest. Governments and public administrations are expected to set up such partnerships in order to promote joint projects, common research efforts, funding synergies, consortia aimed at managing large projects; PPPs should also be the basis for the creation of hydrogen-based industrial districts and the development of infrastructure networks. Regions can support strategic projects acting as direct partners in the Framework Programmes 6 and 7.

Education and public awareness
Education is a fundamental element for the development of the new hydrogen including society. The hydrogen and fuel cells deployment requires that Governments and local authorities support the investments in human capital to prepare new technical and socio-economic skills, as well as the dissemination of knowledge and information necessary to foster public awareness.

Governance
Finally, a governance action has to be performed by Governments of Member States and Regions in order to coordinate strategies and programs, monitor and integrate projects, avoid unnecessary duplication and overlapping of efforts by public and private organizations and associations, create links and networks at different levels, and to guarantee the necessary balance between the positions of the different stakeholders.

5.2 Early Markets

Early markets will help build manufacturing volume and operating experience and provide a near-term incentive to developers of hydrogen and fuel cell technologies and component suppliers to invest in the technical development and production facilities. This is in turn required to provide the base from which low cost production of mass-market stationary and automotive applications can be established. The pursuit of these early market border opportunities may effectively act as a bridge to future full-scale deployment of hydrogen and fuel cell technologies.

Early Markets require in first priority appropriate boundary conditions and as second priority demonstration of some key applications. Due to the diverse composition of

these early market applications ranging from micro direct methanol fuel cell handheld applications to hydrogen fuelled specialist vehicles (e.g. forklifts), a deployment strategy can only address activities that lead to a noticeable macro economic impact within the EU.

Regarding early and niche markets applications the demonstration of selected direct hydrogen fuel cell applications within an European large scale demonstration project is recommended on the basis of the validation of synergies:

- Pursue hydrogen production and utilisation synergies with mobile and stationary applications.
- Provide an early market for hydrogen and facilitate the early build-up of a hydrogen infrastructure.
- Gain operating experience and help establish codes, standards, & regulations.
- Search for fuel cell stack and component production synergies with small stationary or APU applications including recycling of precious metals.
- Explore after sales synergies with mobile or stationary applications (e.g. same service team for cars and forklifts).
- Build public awareness and market acceptance of hydrogen and fuel cells.

In this context early and niche market fuel cell applications in the range of some kW_e are recommended for the integration into mobile or stationary demonstration. The following key applications have been identified (see also chapter 2.6):

- Portable gensets, backup power and uninterruptible power systems (UPS)
- "Non-road" transport applications such as forklifts, airport apron vehicles or other specialist vehicles.
- APUs, initially recreational vehicles and boats.
- On-site co-production of hydrogen and power at refuelling station.
- Large FC power plants fuelled by by-product H2 from the chemical industry
- Power supply to remote regions / islands.

A public/private commitment to an extensive demonstration and field test programme is required to help bringing products to technical and commercial readiness. It is anticipated that such a programme would help to achieve competitive market entry prices for a limited number of high-value applications prior to 2012, this would in turn lead to a cost of ≤ 1,000 €/kW_e for the core power module thereafter.

Table 13: Targets for the large scale demonstration of early markets

	Early Markets – All Applications
Cumulative installation 2006/08	5 MW_e
Cumulative installation 2007/10	30 MW_e
Cumulative installation 2009/12	200 MW_e

The demonstration of fuel cell handheld applications is not considered for demonstration activities since hydrogen storage systems or power densities of direct

methanol fuel cells for these applications do not meet present technical targets[63]. Furthermore the application development is mainly driven by non-European companies and hence in this field the support shall focus in the area of research and development assistance for European companies.

Descriptions of generic business plans for essential early market applications such as forklifts or back up power systems [64] are expected in 2005 as a main deliverable from the Initiative Group on Financing and Business Development.

5.3 Stationary Applications

The large scale demonstration of stationary hydrogen and fuel cell applications under the umbrella of a large scale European demonstration programme is aiming at two different strategies for small, medium and large scale applications:

- Fuel cell systems operated with conventional fuels (natural gas, propane) and an upstream reformer unit can be demonstrated under the frame of hydrogen communities (HYCOM)[65].
- Direct hydrogen fuelled applications need to be concentrated around a few regional infrastructures and are ideally combined with mobile applications.

A close link between the two types of demonstration activities are required in order to maximise synergies both for the development and production of applications as well as for the operation and maintenance (O&M). Special emphasis is given to the selection of demonstration sites in order to gain an optimum between distributed hydrogen community applications covering some major European areas and the concentrated direct hydrogen applications. Regarding the technical support of the distributed applications it is likely that the locations of the hydrogen applications will serve as a base for technical and maintenance staff and therefore all demonstration sites could benefit if are within driving distances in order to achieve a minimum of O&M expenditures.

Table 14: Targets for the large scale demonstration of stationary fuel cells

	Micro CHP[66] (< 50 kW_e)	**Industrial CHP**[67] (200-500 kW_e)
Cumulative installation	2006/08 - 1 MW_e	2006/08 - 3 MW_e
Cumulative installation	2007/10 - 5 MW_e	2007/10 - 20 MW_e
Cumulative installation	2009/12 - 200 MW_e	2009/12 - 400 MW_e

A major objective is the realisation of the cost targets expected to be achievable by the initiation of industrial production processes and the utilisation of economies of

[63] Strategic Research Agenda Foundation Report chapter 2.5.3.2
[64] see chapter 2.6
[65] HyCom is a quick start project under the European Initiative for Growth aiming at establishing a number of hydrogen communities within the EU
[66] see chapter 2.3.1.1
[67] see chapter 2.3.1.2

scale. By 2015 a target of 1,000 to 1,500 €/kW for industrial CHP systems (see Table 3) should be feasible and the cost target for residential and small commercial fuel cell systems should follow. A first important step for achieving these goals is the following cumulative installation targets given in Table 14.

In addition to fuel cell applications the introduction of hydrogen driven gas turbines could be considered in the frame of the demonstration of hydrogen applications. Larger hydrogen conversion system up to $50MW_e$ could serve in the long term as a bridge between the energy system of the renewable sources like wind with its high fluctuation and the back-up power stations.

5.4 Mobile Applications

For the scope of a deployment strategy with a minimum time frame until 2020 the road transport will play a dominant role within the transport applications. This is mainly based on the fact that almost 70%[68] of EU's final oil demand is used for transportation of which the majority is for road transport. Therefore alternative fuels and technologies for road transport that meet the requirements of security of energy supply and reduction of GHG emissions are urgently needed. This shall not mean that other transport modes such as "non-road" (e.g. specialist vehicles, railway, air or maritime transport) are not foreseen as target markets for hydrogen and fuel cell applications. In summary road transport applications will play a dominant role because of their exclusive dependence on oil, the first fossil resource to be likely exhausted, and the fact that transport is the most resilient sector as far as GHG emissions reductions are concerned.

However, since mobile applications will have the longest time to market preparation time[69] a major portion of the deployment strategy and the development of a large scale integrated demonstration projects on hydrogen and fuel cells is dedicated to mobile applications and especially to all kind of vehicles. In contrast with the stationary applications that can rely on the existing natural gas grid for fuel supply a deployment strategy for transportation shall focus on hydrogen fuelled vehicles. Furthermore it will target a few demonstration sites to allow a reasonable size and utilisation of the required hydrogen infrastructure. Hence a focussed European demonstration project for hydrogen and fuel cell vehicles is proposed for the time frame until 2015 with a stepwise build up:

- Expansion of hydrogen infrastructure and vehicles in operation per site during a ten years time frame.
- Growing number of sites offering the later possibility (post 2012/15 time frame) of connecting different European hydrogen clusters via corridors.
- Building on existing demonstration sites as nuclei for a quick start.

In this context the existing and future running demonstration projects, the presence of a committed industry and a strong research net work are crucial factors for the selection of potential sites serving as a nuclei for the initiation of a European large scale projects. Right at the beginning a well-balanced consortium is required with a

[68] Green Paper " Towards a European strategy for the security of energy supply" COM(2000) 769 final
[69] see chapter 2.4.3

broad participation of OEMs, utilities, energy and industrial gas companies, fleet operators, suppliers, research institutions as well as public authorities.

Regarding the progression of the vehicle fleet both light duty vehicles (LDV) such as cars or delivery vans and busses need to be considered for the initial phase and the subsequent expansion. Until the 2015 time frame 3 phases are proposed as described in chapter 3.3.3, ideally complemented by a fourth phase that prepares the market introduction in the 2015 to 2020 time frame.

- Phase I (until 2010): start of large-scale comprehensive demonstration projects with the focus on initiating a public private partnership equally financed by industry and public authorities for the first infrastructure and hydrogen fleet vehicles (mainly cars and buses).
- Phase II (2010 – 2012): extension of demonstration sites with the focus of reaching at least 5 Member States, hence requiring additional capital for the infrastructure investments from structural funds or EIB loans.
- Phase III (2012-2015): preparation of a commercialisation in major European markets for all kinds of vehicles mainly financed through private venture capital and EIB loans.
- Phase IV (2015 -2020): transition towards mass market commercialisation with a further build up of a hydrogen infrastructure.

Another important issue is related to the infrastructure build up required for the subsequent vehicle development. In order to achieve synergies and economies of scale also for the hydrogen filling stations a kind of a universal station that can be built and certified around Europe is needed. The following features should be considered:

- Based on urgently required EU-wide harmonised regulations, codes and standards the universal station shall be easily installed and approved within the EU.
- A modular design of tested and certified components shall meet different demand patterns.
- Based on the "market potential" of up to 10,000 stations[70] until the 2020 time frame significant cost reductions shall be realised.

5.5 Synergies

The potential of synergies between different hydrogen and fuel cell applications is the major driver for one integrated large scale demonstration project that shall not only foster the deployment of all hydrogen and fuel cell applications in parallel but shall also analyse and validate the synergies between different markets. The issue of synergies is multi-dimensional since the different layer of activities such as production, operation or legal framework need to be examined:

- Production of "new" components such as fuel cell membranes and stacks: economies of scale in the production process can be utilised especially for PEM fuel cells being used in transport applications, small scale CHP and early market applications (see also Figure 2).

[70] source: HyNet infrastructure analysis (www.hynet.info)

- Hydrogen infrastructure: for direct hydrogen fuelled transport and stationary applications as well as early markets common hydrogen production facilities can be used. The production facilities supplying regional clusters of vehicle demonstrations can supply in addition hydrogen micro-grids and other early or niche markets applications.
- Legal framework: The potential of penetrating mass markets such as vehicles or residential CHP systems are a more powerful driver for necessary changes in European and national/ local legislations and hence, support smaller and niche markets.

The interplay between the two main drivers of transportation and stationary applications with early markets in order to utilise the synergies described above is given in Figure 17. At present these potential synergies can only be described on a qualitative base. Before investment in a large scale demonstration can be envisaged it is necessary to perform first estimates on the quantitative potential of these synergies. Hence it is strongly recommended to consider this analysis under the next strategic hydrogen projects under the next Framework Programme 7 calls (see chapter 4.2).

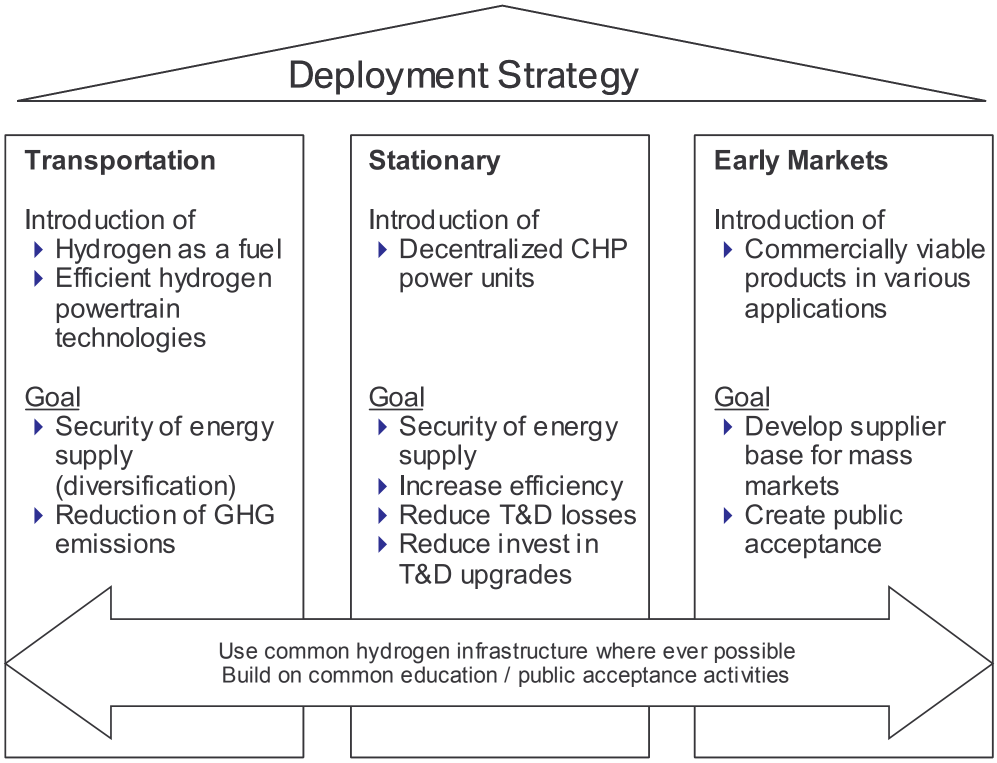


Figure 17: Synergies between transportation, stationary and early market applications

Additional synergies between early markets, stationary and transportation applications could consist of:

- Gain operating experience
- Establishment of codes, standards & regulations
- Fuel cell stack and component production
- Technical training
- After sales

- Build up common supply chain for critical materials, components and sub-systems

5.6 Proposal for Integrated Large Scale Demonstration Projects bridging between Research and Commercialisation

The dynamic step to the deployment of hydrogen technologies by means of a few integrated large scale comprehensive demonstration projects such as a proposed by a “lighthouse project” and under the Quick Start programme under the Initiative for Growth should integrate transport and stationary applications as well as early or niche markets. After the installation of the HFP and the announcement of “Lighthouse Projects” swift, energetic and persistent follow-up actions are required in order not to loose the momentum built up through the recent activities launched by the Commission and in order to see the vision of the High Level Group taking shape during the coming years.

The present Community efforts mainly under framework programme 6 in the order of 250 M€ support research and demonstration projects on hydrogen and fuel cells but are not sufficient for any deployment measures. Hence, new initiatives of a real European dimension, implying billions of Euros have been demanded for large scale deployment projects that should integrate the main components of a hydrogen economy for the transport and energy sectors, in the fields of hydrogen production, distribution and use, and include all relevant actors in the field. Combined funding would be required, with contributions to come from EU, national, regional and/or local resources, together with substantial participation of the private sector. Under this section a preliminary proposal for integrated large scale demonstration projects is briefly outlined, based on following recommendations:

- Different requirements for transport and stationary applications demand tailored demonstration programmes under a common framework.
- For transport applications consider a few integrated large scale projects, covering a few sites in key EU regions.
- Combine at least at one site all different application and production pathways in order to explore and validate potential synergies.
- Include different regions and aim at clusters in order to demonstrate “real world behaviour” instead of single site demonstration.
- Include appropriate existing demonstration sites that support the targets above and allow a quick start and expansion.
- Foster organic growth and expansion to other European regions during the lifetime.

5.6.1 Scope of Large Scale Hydrogen Demonstration Projects

Large-scale demonstration projects such as lighthouse projects should bridge the gap between the present phase of research and development projects and broad commercial market introduction of hydrogen and fuel cell technologies. The main objective should be the development of all key technologies of a hydrogen economy to market maturity, and in parallel the advance of market acceptance, so that decisions on mass production can be taken. The integration of all elements into large clusters should ensure the interaction between the different levels of the hydrogen

chain and particularly between stationary and mobile applications. This should provide the basis for an integrated assessment of market maturity. In this context the additional definition of criteria for the regional and qualitative extension of potential large-scale hydrogen and fuel cell demonstration projects need to be developed under the next activities of this Panel. The performance criteria proposed by the Strategic research Agenda will serve as input for this process as displayed in Figure 18.

It is considered that fuel cell stationary applications fuelled by natural gas and eventually transport APU applications with onboard fuel processor should be integrated in the large scale demonstration projects because they will contribute to bring the fuel cell technology to maturity.

The primary driver for a transition to a hydrogen economy is the transport sector as discussed previously. Projections of car industry and fuel suppliers on building up vehicle production and infrastructure should therefore be used as guideline for time lines and size of lighthouse deployment projects. Large volume production of hydrogen/fuel cell vehicle is expected to start only after 2015/2020 according to the present plans of the major car companies. Therefore demonstration activities for transport applications should be limited to a few sites until the 2015 time frame in order to achieve a critical mass of vehicles per site. Consequently large scale deployment projects could speed up the technological development by providing funds for a rapid sequence of development fleets and ensuring the uptake of the pilot fabrication of a few hundred vehicles from 2010 onwards. The experience of operation in real market conditions can then provide the information necessary for the onset of series production. Vehicle categories such as passenger cars, buses and light duty vehicles should be included from the start; trucks, boats and trains could be possibly addressed in a later phase.

Stationary fuel cell applications should be integrated from the beginning in order to ensure interaction between the key elements of a hydrogen economy. A larger accumulation of hydrogen consumers also provides sufficiently large and stable demand for hydrogen production so that all major technologies can be tested at significant size. The installations should comprise 4 different categories, i.e. in the power range for a family house supply (1 to10-kW level), district/small industrial supply (100-kW level), town supply (1-Megawatt level) and the industrial supply (>10MW). Due to the better availability of stationary applications in comparison to vehicles a broader regional focus for demonstration activities seems appropriate as expressed in the HyCom proposal. Optimisation of the operational link between the hydrogen/fuel cell installations and the power plant duty cycles should be an essential objective. Buffering of excess power production by complementary hydrogen production would be of great interest for both base load power plants facing short-time variations in demand, and fluctuating power production from renewable sources such as wind and solar uncorrelated with demand.

Hydrogen production would first come from existing facilities in order to minimise costs during the introductory phase. A gradual build-up of demand with increasing hydrogen consumption from a larger number of users should allow a cost-effective and emissions reductions useful, step-wise integration of additional hydrogen production from natural gas steam reforming, electrolysis and biomass and coal gasification as described in chapter 2.1.2.

Hydrogen lighthouse projects with transport as main focus should concentrate on a few sites, equipped with specific assets, which allow a cost-effective demonstration of the virtues of a hydrogen economy in full-size tests of all applications. The lighthouse project sites should provide a large customer base for all hydrogen and fuel cell technologies. They should also present the scope for an economically viable utilisation of the major infrastructure installations in a possible large-scale expansion in a subsequent commercial phase of market development. These sites could be located in areas where there is existing hydrogen production capacity available combined with sufficient demand potential. Medium to large cities should be the appropriate size to concentrate the applications.

Operation of key elements of hydrogen lighthouse projects could be envisaged by 2007, with a start of the projects in 2005/06.

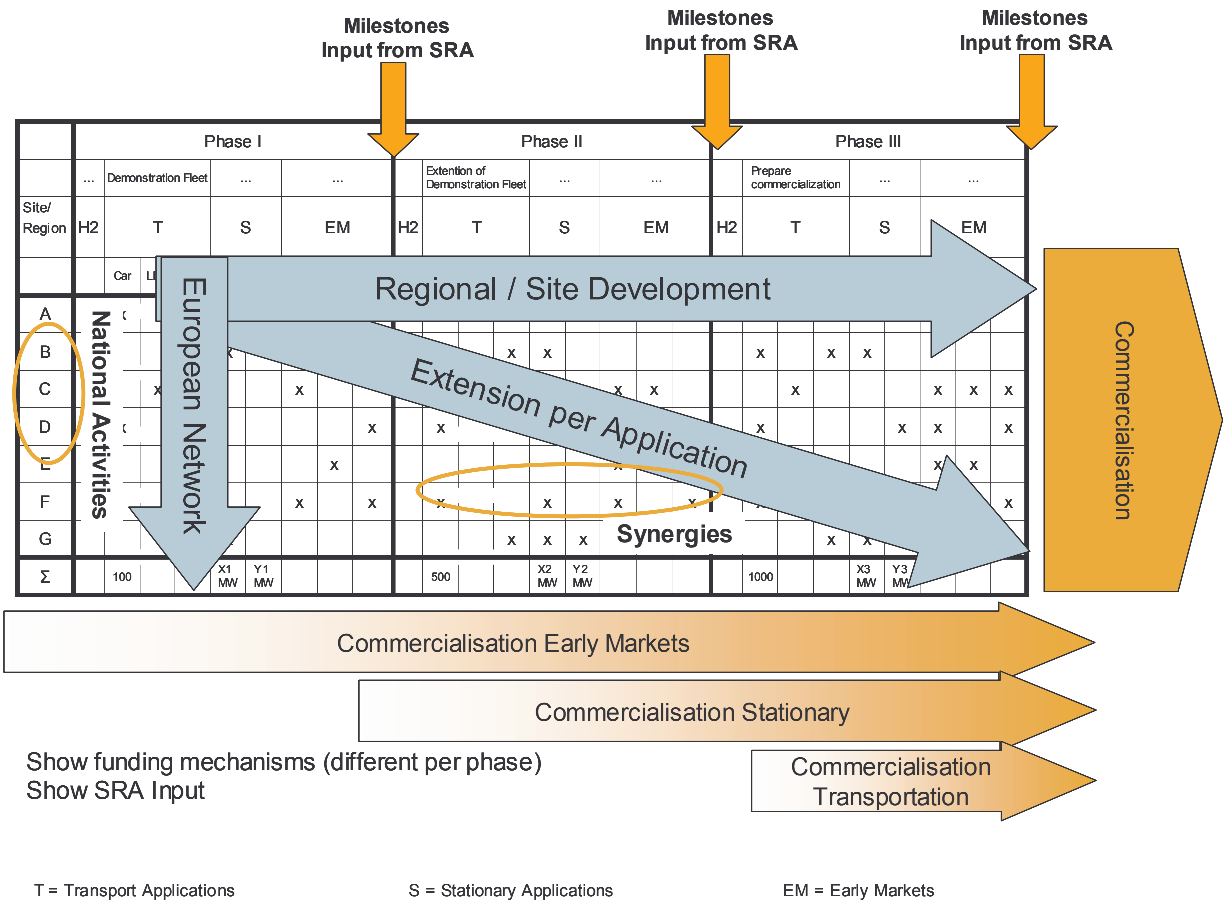


Figure 18: Chronological and qualitative extension of European hydrogen and fuel cell demonstration activities (T: transport, S: stationary, EM: early market)

5.6.2 Outline of Large Scale Hydrogen Demonstration Projects

The general development of lighthouse projects should take place in 4 phases as described below (see also chapters 3.3.3 and 5.4).

- Phase I (2007- 2010): start of large-scale comprehensive demonstration projects.
- Phase II (2010 – 2012): extension of demonstration sites.
- Phase III (2012-2015): preparation of a commercialisation in major European markets.
- Phase IV (2015 -2020): transition towards mass market commercialisation for vehicles with a further build up of a hydrogen infrastructure.

Table 15: Suggested Development of integrated European lighthouse projects

	Phase I (2007-2010)	Phase II (2010-2012)	Phase III (2012-2015)	Phase IV (2015-2020)
Early Markets, Portable Gensets, Backup-Power, Specialist vehicles, etc.	Cumulative installations: 200 MW_e	Transition towards commercialisation		
Micro CHP (< 5kW)	Cumulative installations: 1 MW_e	Cumulative installations: 5 MW_e	Cumulative installations: 200 MW_e	Transition towards commercialisation
Industrial CHP/ large power plants (> 200 kW)	Cumulative installations: 400 MW_e	Cumulative installations: 400 MW_e	Transition towards commercialisation	
Road Transport	~ 100 vehicles	few 100 vehicles	~ 2,000 vehicles	Transition towards commercialisation

Regarding the production and distribution two kinds of pathways could be considered:

- Decentralised hydrogen production and distribution for stationary, transport and early market applications with the option of optimisation of existing facilities.
- Centralised hydrogen production with renewable feedstock or the option of carbon capture and sequestration.

These two pathways are very different and they should be managed in a different way. The decentralised option will concentrate lots of various applications on the same site. In this context it needs to be stated, that the expression “site” could embrace a cluster in which hydrogen and fuel cell applications are demonstrated on large scale. Since stationary applications will mainly use natural gas there is no need

to build up large hydrogen distribution systems such as pipelines under the frame of these projects. In addition decentralised hydrogen production and distribution should be foreseen for vehicles such as buses or captive fleet vehicles including early market applications like forklifts or other light traction. Furthermore around such decentralised hydrogen production units, sometimes named as “energy stations” a local hydrogen pipeline network could supply direct hydrogen fuel cell CHP systems.

In that case of decentralised hydrogen production the site selection process could be disconnected from the applications selections one. The site has to offer the platform to receive applications over the ten years of the planned duration. It requires a strong financial and political involvement of the local authorities.

Depending on the technology choice, centralised hydrogen production is clearly linked with the site. The selection process will include both the application and the site. Considering the cost of hydrogen distribution the production site should be within reach from the consumption sites, however for the liquid H2 delivery a distance of 150 km is not seen as an economical barrier[71].

5.7 Schedule for a Deployment Strategy

To advance with and spread the deployment it requires a high priority within the energy and transport policy of the European Union in order to achieve a significant impact of hydrogen and fuel cells on the security of energy, the economic competitiveness of the EU and the targeted greenhouse gas emission reductions until a 2020 time frame. From a present perspective stationary applications can accomplish the commercialisation stage before 2015, transport applications before 2020 with the prospect of establishing early markets including specialist vehicles and portable applications in the 2007 to 2010 time frame.

As described within the socio economic analysis in chapter 3.4 the transition towards hydrogen and fuel cells is a long-term process. Consequently the investment behaviour of critical actors has to change in a way that also long term benefits are taken into account instead of the common short term thinking. On such a basis the fast transition towards hydrogen is economical right from the beginning as shown in Figure 15.

The following actions in the fields of “policy & framework”, “large scale demonstration” and market development are recommended as displayed in Figure 19:

- “Design Phase” in 2005/06 for the development of a proposal for a coherent European Hydrogen Framework including fiscal incentives and a legal framework, as well as an in-depth analysis of an integrated European large scale demonstration project based on a public-private-partnership structure.
- “Implementation Phase” in 2006/07 aiming at the establishment of an integrated European large scale demonstration project for all hydrogen and fuel cell applications with a project start in 2007. In parallel the implementation of a favourable European hydrogen framework need to be tackled by the European Commission.

[71] Transport Energy Strategy, 2nd interim report to the Steering committee, June 2001 (not published)

- In addition: aim at the inclusion of existing R&D and demonstration projects in order to provide technological learning and operation experience for future activities.

The large scale demonstration project shall aim at the consecutive build up of so called Pilot Regions for hydrogen and fuel cells on a European scale. Each of the four phases needs to support the market development, aiming at an transition towards commercialisation for early markets before 2010, and for stationary applications in the 2010 to 2015 time frame respectively. The transport sector, facing the greatest economical and technical challenges is expected to perform the transitions towards commercialisation after 2015, hence leading to a beginning mass market penetration of all kind of hydrogen vehicles around 2020.

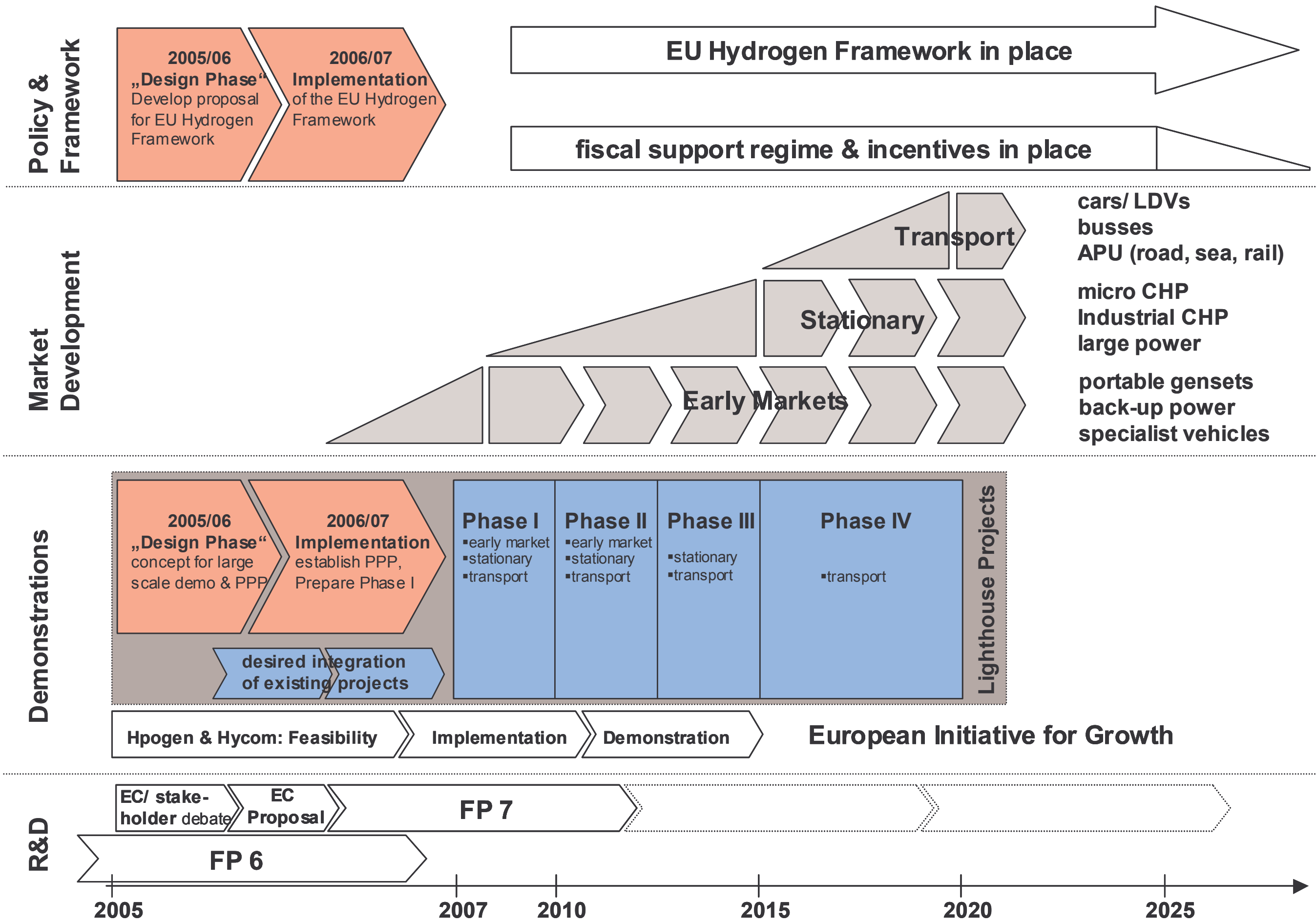


Figure 19: Schedule for a Deployment Strategy on hydrogen and fuel cells

6 Glossary

Definitions:

Demonstration	To prove the viability of a technology at an appropriate scale to satisfy independent evaluation and potential end users prior to commercialisation.
Validation	The stage at the end of the technology development process where it is evaluated to ensure that it complies with the pre-defined requirements set at the beginning of the process.
Deployment	Development action for a given activity from its Market Introduction to its widespread use.
Market Introduction	First step for introducing a new system on the Market. This step follows the Prototype Development Phase and lies ahead of a potential Deployment.
Roll-out	Market penetration and volume growth with time.
Niche Markets	A small area of trade within the economy, often involving specialized products. Markets of limited sizes concerned with specific applications for a given product.
Early Markets	Short-term market for a specific product or application, which satisfies initial business objectives prior to commercialisation.
Cost	Total cost of a product covering labour, overheads, materials, manufacture, marketing, transport & installation, setting to work and warranty
Price	The amount of money a product is offered for sale (it usually but not always covers costs and incorporates a profit margin)
Portable	Product which is designed to be hand held or be easily movable for use at different locations
On-Site	Location at which operation is being carried out. For example, an on-site reformer makes hydrogen at the fuelling site
Lighthouse project:	A large size, long range project of high visibility with the objective to guide development of key hydrogen and fuel cell technologies from the research, development and demonstration stage to a possible start of broad market introduction

Acronyms and abbreviations:

APU	Auxiliary power unit
BTL	Biomass-to-Liquid (Fischer-Tropsch fuel from biomass)
CGH2	Compressed gaseous hydrogen
CHP	Combined heat and power (generation)
CTL	Coal-to-Liquid (Fischer-Tropsch fuel from coal)
DMFC	Direct methanol fuel cell
DOE	US Department of Energy
DS	Deployment Strategy
DSP	Deployment Strategy Steering Panel of the HFP
EIHP	European Integrated Hydrogen Project, http://www.eihp.org/
FP7	Upcoming Framework Program of the European Union (2007-13), the Framework Program is the main instrument for funding research and development
GDP	Gross domestic product
GHG	Greenhouse gas (emissions)
GTL	Gas-to-Liquid (Fischer-Tropsch fuel from natural gas)
HFP	European Hydrogen and Fuel Cell Technology Platform
ICE	Internal combustion engine
IG FBD	Initiative Group on Financing and Business Development of the HFP
IG RCS	Initiative Group on Regulations, Codes and Standards of the HFP
IPHE	International Partnership for the Hydrogen Economy, http://www.iphe.net
IPR	Intellectual property rights
JTI	Joint Technology Initiative, concept of the European Commission (in the 7th FP) of realising public private partnerships
LDV	Light duty vehicle
LH2	Liquefied hydrogen
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
MCFC	Molten carbonate fuel cells
MEA	Membrane electrode assembly
NEDC	New European Driving Cycle, test procedure or the European Union for certifying passenger cars
OEM	Original equipment manufacturer
PEM	Proton exchange membrane
PM10	Particulate matters equal or smaller than 10 μm
PPP	Public Private Partnership
RCS	Regulations, codes and standards
SME	Small and medium enterprises
SMR	Steam methane reforming
SOFC	Solid oxide fuel cells
SRA	Strategic Research Agenda, Steering Panel of the HFP
SWOT	Strengths, weaknesses, opportunities and threats, analysis tool
UPS	Uninterruptible power supply

7 Figures

8 Tables

Annex I: Considerations on the Robustness of the Deployment Strategy

a) Introduction

Within the European Union and beyond the need for a move towards sustainable energy systems is generally acknowledged. The motives include the need to reduce dependency on fossil fuels and reduce greenhouse gas (GHG) emissions, and the EC also emphasises the importance of the economic opportunities offered by establishing a leading position in key technologies such as hydrogen and fuel cell technologies.

In its scenario 'SNAPSHOT 2020', the Deployment Strategy Panel suggests feasible levels of market penetration by 2020 for hydrogen and fuel cells in portable, stationary and transport applications, and identifies the conditions and activities necessary to meet these. The plans take into account the recommendations of the Strategic Research Agenda, which identifies the R&D programme required. The aim is to deliver proven technology, allowing time for the all-important product development and production engineering phases required to meet the market penetration levels outlined in the “SNAPSHOT 2020”.

Early applications opportunities are expected to occur mostly, but not exclusively, in the small portable sector, taking advantage of the added functionality (vs. rechargeable batteries) of conveniently refuellable, high density energy storage. These applications (mainly fuelled with hydrogen) will provide the experience, the culture and manufacturing base required for the market entry of larger portable systems, and by 2010 opportunities are expected to expand to include heat and electricity cogeneration for residential and small commercial premises. Larger stationary fuel cell -based CHP systems, hybridised with gas turbines for increased efficiency and mainly fuelled with natural gas will emerge later – between 2010 and 2015. Mass market roll-out of hydrogen-fuelled road transport is expected around 2015/2020, as displayed in Table 1.

b) Analysis of the Robustness of the Proposed Strategy

The Deployment Strategy is based on the best available knowledge concerning developments in the technology and expected reduction in manufacturing costs. It identifies certain prerequisites for success, of which one of the most important is the constancy of political commitment to the development hydrogen and fuel cells. It is assumed that all the conditions identified will be met and sustained over the period in question.

However, in a volatile environment like the energy one, for a 'disruptive' technology such as hydrogen and, to somewhat lesser extent, fuel cells, the range of possible outcomes is rather wide and with strong linkages with the behaviour of the key parameters of the energy framework. It is therefore important to consider the impact of variation in certain key underlying assumptions. What follows is an appraisal of the robustness of the strategy to some of the variables.

c) How the Deployment Strategy compares with others in Europe and Elsewhere
Direct comparison between Europe and Japan is possible only for stationary fuel cell systems and transport applications. In 2020, The Ministry of Economics Trade & Industry in Japan expects 5 million hydrogen vehicles on the road and a cumulative installed capacity for stationary fuel cell systems of 10 GW_e. These numbers are in good correlation to the numbers of the Deployment Strategy.

The US Department of Energy approach has a different emphasis. It is committed to a 10 year research, development and demonstration programme aimed at the achievement of demanding performance and cost targets. This will enable industry and government to commit to a full commercialisation decision in 2015. The milestone for 2012 is to deploy around 100.000 units / 500 MW_e capacity.

Within Europe, where a common energy policy is missing (unlike Japan and US), there are a number of EU funded projects designed to identify suitable pathways for the introduction of hydrogen. One of these, 'HYWAYS' was used as a benchmark for the Deployment Strategy. HYWAYS is expected to deliver its interim report by the end of 2005, and will include Well-To-Wheel and Source-To-Use analyses for stationary and transport applications for the timeframe 2010 onwards. On the basis of certain results already available to the DS Panel, there is good agreement on market shares and timing. However, the mainly economically oriented models used in HYWAYS do not include predictions of the impact of future policy decisions and / or changing consumer preferences. Neither the acceptance by the public is considered.

The DSP has therefore attempted to identify the parameters that might have a major impact on the outcomes described. Since the overall strategy is concerned with long term goals, short term deviations of single parameters do not weaken the conclusions. However, if the general focus shifts from the need for long term sustainable development towards shorter term gains, for example economic advantage, the conclusions of the Deployment Strategy would be jeopardised.

d) Identification of Key Parameters influencing the Deployment Strategy
The robustness of the Deployment Strategy can be influenced by a wide range of technical, social, national and geopolitical parameters (see section f) of this annex), and each can influence the rate of development of a hydrogen economy either positively or negatively. The primary headings are:

- **Fuel cell development** (technology breakthrough vs. a delay in progress)
- **Competing technologies** (CHP systems based on combustion technologies, hybrid or electric vehicles and highly fuel efficient conventional vehicles or highly improved battery systems for portables)
- **Behaviour of society or customers** (resistance to hydrogen utilisation or strong resistance to nuclear energy facilitated (hydrogen) production)
- **Policy developments** (weaker CO2 reduction policies vs. strong energy efficiency and conservation measures)
- **Major deviations of future fossil energy production capability and prices** (increased political instability in oil producing countries combined with a significant increase in worldwide oil demand vs. an unexpected growth in the

production of oil and in oil reserves; breakthroughs in clean coal technologies and a stable, low market price of coal; role of biofuels)

The potential for significant change under each heading has been identified, and the extent of the impact discussed in each case. To illustrate this, some of the factors considered under 'Competing Technologies' are set out below:

- **The competition of hydrogen with alternative fuels**, especially in the near-term. This includes Fischer-Tropsch fuels such as GTL, CTL or BTL, and the possible widespread exploitation of unconventional oils)
- **The impact of Regulatory and Trading regimes on the development of stationary fuel cell systems** (The progress of de-regulation; Centralisation vs. Decentralisation; CO2 neutral centralised power plants with CCS[72]; new flexible electrical grids; etc)
- **The degree of success in achieving required cost targets for fuel cell systems** for stationary as well as transport applications
- **Timely meeting of 'technical breakthroughs'** for hydrogen and fuel cells, in particular in terms of fuel cell systems production cost .
- **Future developments in road transport** (change in mobility patterns, changing consumer preferences, development trends for hydrogen onboard storage, solutions for the challenges in meeting fuel cell materials demands, including the availability of noble metals)
- **Political Choices** (Fiscal and Regulatory policy on carbon mitigation and energy efficiency)

Changes in these parameters have a different impact on each sector as described below:

Stationary Applications

The exploitation of fuel cells in stationary applications is easier to achieve in the context of further support for CHP generally. However they must compete successfully with other technologies in the market including reciprocating IC engines or micro-turbines. At present the EU and member states aim to achieve a balanced generation mix, and are generally supportive of greater decentralisation of generating capacity. The liberalisation of energy markets will encourage this trend also if strong investments will be required to update the European electrical grid. However, a change of emphasis towards the improvement of centralised capacity based on fossil fuels with CCS or nuclear power could downgrade the prospects for small scale CHP systems in general and stationary fuel cells in particular.

The European CO2 trading system will benefit cleaner energy conversion such as from fuel cells in stationary systems. In the unlikely event of a reverse of this policy the rate of market development for fuel cells would be slowed.

The drive for higher energy efficiency in the buildings environment means that the demand for heat is likely to reduce as a fraction of the overall energy demand. This trend favours the use of FC systems because of their higher power-to-heat-ratio in comparison to other CHP technologies. However the realisable premium for higher efficiency is limited, which highlights the need to reach the technical and economic targets outlined in the SRA and DS.

[72] carbon capture & sequestration

Road Transport
The hydrogen and fuel cell vehicle sales predicted in 'SNAPSHOT 2020' (see Table 1) are based on competitive performance and economics. Certain key assumptions are based on the AFCG[73] Report, which asserts:

- **Fuel costs** per km could become comparable for hydrogen vehicles and gasoline/diesel vehicles if the expected high efficiencies of fuel cell vehicles are reached.
- **Infrastructure investment costs** could be reasonably amortised already in the medium term with a carefully selective market development, drawing upon the principles for successful ‘nucleation’ and ‘growth’. Since the overall investment for a supportive hydrogen infrastructure is within a reasonable reach[74], the key issue consists of an intelligent transition management from 'zero' to maturing markets (also with the help from bridge technologies).
- **Vehicle costs** are the dominant issue and by far the largest cost factor in the transition to a hydrogen and fuel cell orientated economy. The hydrogen internal combustion engine might offer a less expensive fast track route in the initial phase and prepare the wider market for fuel cell vehicles. High efficiency fuel cell systems are essential for the long-term full benefit from a hydrogen economy.

The future competitiveness of hydrogen and fuel cells in vehicles clearly depends on the extent of further development of conventional engines, and also that of alternative fuels such as natural gas or biofuels. The political measures for greenhouse gas emission reductions and higher efficiencies also encourage the further development of gasoline and diesel powertrains (including hybridisation). However, it is believed that the optimisation of conventionally fuelled vehicles will only postpone the mass market roll-out of hydrogen and fuel cell vehicles for a limited period since the problem of finite fossil resources remains and that of biomass use for energy purposes is unfolding.

e) Conclusions
Deployment Strategy[75] and the Strategic Research Agenda deal qualitatively with most of the aspects capable of influencing the outcome of the strategy. A more quantitative assessment requires rigorous technical and socio-economic modelling, and this will be facilitated along with the completion of the HYWAYS project and potentially other European projects in the next couple of years.

Private sector issues and objectives are clearly defined and must be addressed progressively as set out in the HFP Strategy. The recommended next step towards commercialisation involves large scale integrated targeted research with demonstration ('lighthouse') projects, the results of which will provide the means of progressing with and re-adjusting accordingly the strategy. Regular scrutiny of the achievements against the targets of the plan is an absolute and necessary

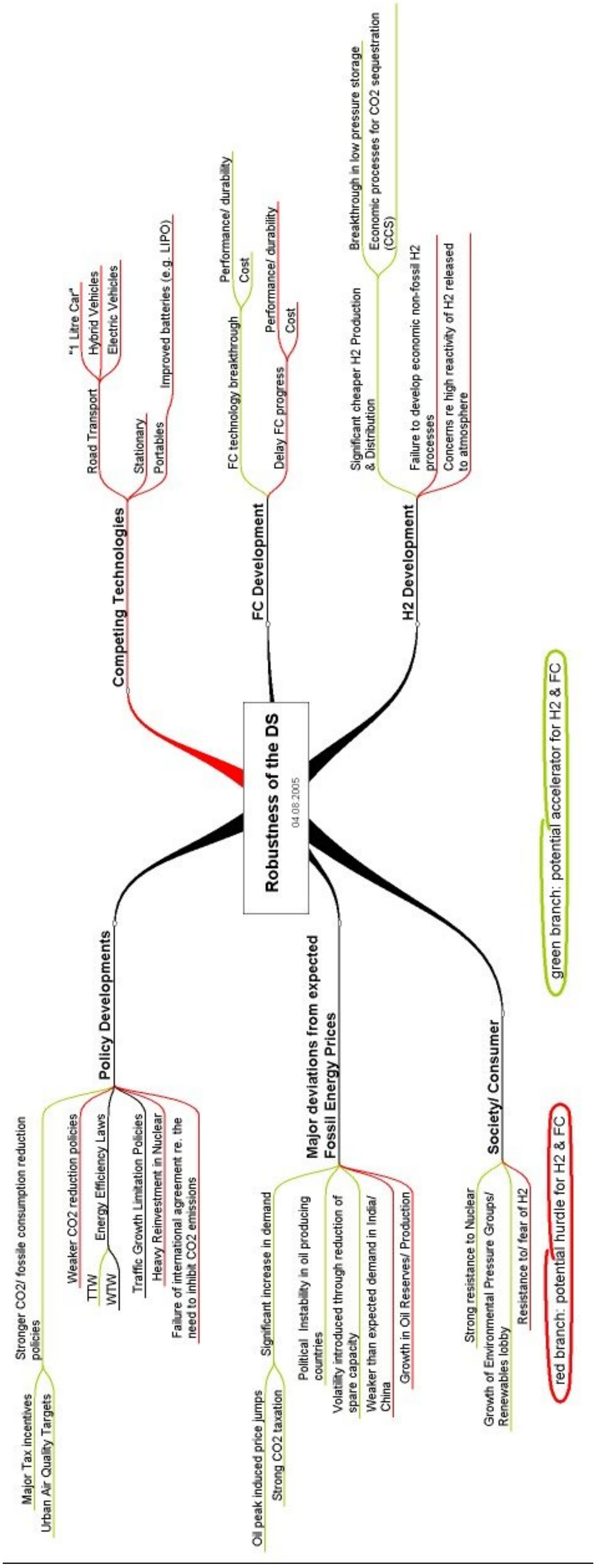
[73] DEVELOPMENT OF ALTERNATIVE FUELS, Report of the Alternative Fuels Contact Group (December 2003)
[74] compare with „DEVELOPMENT OF ALTERNATIVE FUELS, Report of the Alternative Fuels Contact Group” (December 2003), HyNet Infrastructure Analysis (www.hynet.info), ”The economics of a European Hydrogen Automotive Infrastructure”, a study for Linde AG by e4tech (February 2005)
[75] see chapter 3 of the Deployment Strategy Report

ingredient. The DS Panel will in the near future outline in detail the milestones of the development plan.

Technology is by no means the only factor that will influence the transition from traditional to new energy systems. Left to its own devices, the transition will respond to market pressures, probably favouring the most readily available technologies and maximisation of short and mid-term profit. Market forces alone are unlikely to provide the incentives required to bring about the desired changes, and the transition to a hydrogen and fuel cell orientated economy will involve a long term close collaboration of the private sector and public entities.

The key success factor for the robustness of the Research, Development and Deployment Strategy will be **strong and sustained political support** by the EC and the Member States in order to encourage the technical developments required as well as managing public awareness and acceptance. This support will be exhibited in the form of appropriate fiscal and regulatory structures together with stable, long term provision of funds.

f) Mindmap on influencing key parameters of the DS



Annex II: Members of the Deployment Steering Panel of the European Hydrogen and Fuel Cell Technology Platform

Last Name	First Name	Period of Activity*	Company/Organisation
Alli	Paolo		REGIO LOMBARDIA
Baron	Frédéric	since 2005	ELECTRICITE DE FRANCE
Christian	Stoffaës	until 2005	ELECTRICITE DE FRANCE
Berg	Joachim		VAILLANT GMBH
Bode	Michael		MTU CFC SOLUTIONS GMBH
Bonhoff	Klaus		DAIMLERCHRYSLER AG
Burmeister	Roland		UMICORE
Costes	Bruno	since 2005	PSA Peugeot Citroën
Klein	Alain	until 2005	PSA Peugeot Citroën
Curtil	Alain		RATP
Delfrate	Alessandro	since 2005	NUVERA FUEL CELLS EUROPE SRL
Tettamanti	Michele	until 2005	NUVERA FUEL CELLS EUROPE SRL
De Sanctis	Sergio		SAPIO
Frey	Eva	since 2005	SIEMENS AG
Willnow	Klaus	until 2005	SIEMENS AG
Godula-Jopek	Agata	since 2005	EADS Corporate Research Center Germany
Grand	Philippe	since 2005	CITYCELL/ IRISBUS
Bourachot	Jaques	until 2005	CITYCELL/ IRISBUS
Holm-Larsen	Helge		HALDOR TOPSØE A/S
Jeeninga	Harm		ECN POLICY STUDIES
Macey	Kirsten	since 2005	CLIMATE ACTION NETWORK EUROPE
Anderson	Jason	until 2005	CLIMATE ACTION NETWORK EUROPE
Macleod	Duncan	since 2005	SHELL HYDROGEN B.V.
Postema	Adri	until 2005	SHELL HYDROGEN B.V.
Mayo	Ben		THE CENTRE FOR PROCESS INNOVATION
Mulard	Philippe	since 2005	TOTAL
Schulz	Philippe	until 2005	TOTAL
Paulmier	Philippe		AXANE/AIR LIQUIDE
Pedersen	Aksel Hauge		DONG A/S
Perez Sainz	Angel		DG RTD
Scheuerer	Klaus		BMW AG/ CHAIR
Selmer-Olsen	Staale		DET NORSKE VERITAS AS (DNV)
Söldner	Franz Xavier		DG TREN
Stolten	Detlef		CHAIR OF THE SRA PANEL
Trezona	Patrick		FUEL CELL EUROPE
Tsatsami	Vasso	since 2005	BP
Amorelli	Angelo	until 2005	BP
Vandenborre	Hugo		STUART ENERGY EUROPE N.V.
Van Zyl	Arnold		EUCAR
Weinmann	Oliver		VATTENFALL EUROPE AG
Reijerkerk	Jaco	since 2005	LINDE AG
Wolf	Joachim	until 2005	LINDE AG
Wolff	Guillermo		REPSOL
Secretariat			
Peteves	Stathis		DG JRC/HFP Secretariat
Braess	Holger		BMW AG/ Chair Assistant

* Period of Activity: no date indicates members who are active from the beginning in May 2004

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