Towards
a European Hydrogen Energy Roadmap

Preface to HyWays – the European Hydrogen Energy Roadmap Integrated Project

Executive Report

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Prepared by the HyNet partners,

Supported by a group of European hydrogen energy experts and stakeholders
from industry, institutes and consultants

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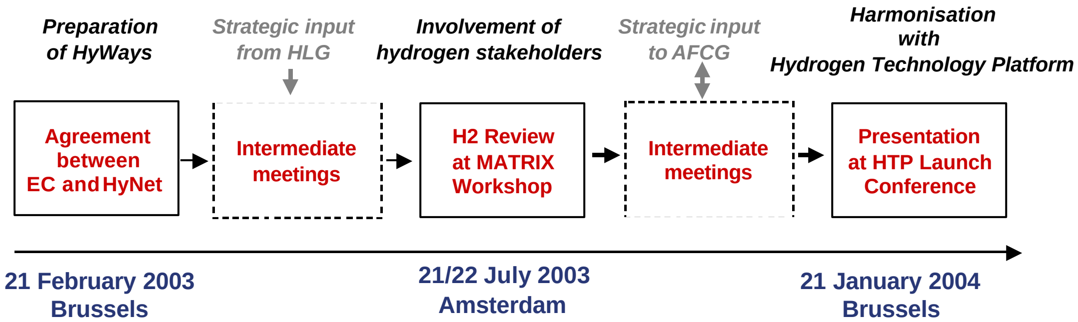
Introduction – History of the Roadmap Activity

In October 2002 the European Commission (EC) established the High Level Group on Hydrogen and Fuel Cells (HLG) involving European hydrogen stakeholders. The aim was to facilitate a high level strategic discussion to develop a European consensus on the introduction of hydrogen energy. HyNet contributed to this process through its partners.

To support this process further, HyNet identified that a European Hydrogen Energy Roadmap would provide a platform to gather the latest perspectives of the key European hydrogen stakeholders. It was anticipated that in contrast to previous international roadmap processes, i.e. in the U.S. and Japan, that the development of a European roadmap could be much more difficult due to the multiplicity of member state perspectives, shaped by issues such as access to natural resources, energy mix and infrastructure, and socio-economic priorities.

The roadmap process began in August 2002 with HyNet developing a proposal for a funded research project, called HyWays, to create a comprehensive European Hydrogen Energy Roadmap, as part of the EC's 6th Framework Programme. In February 2003 the HyNet partners in harmony with the EC decided to prepare a high level so called *0th order* hydrogen energy roadmap to provide expert input to the hydrogen policy activities of the Commission, namely the Hydrogen and Fuel Cell Technology Platform (HTP). HyNet greatly acknowledges EC's contribution to the HyNet Hydrogen Roadmap.

HyNet's approach was to consult widely over a 12-month period with Europe's key stakeholders, through a H_2 review workshop, and gather views from bodies such as the HLG. About 40 hydrogen experts attended the main workshop to collect and harmonise key data for hydrogen technologies, processes, structures and policies. These data produced a "matrix" of information, which forms the basic database of technical contributions and perspectives.



Schedule for the development of the HyNet European Hydrogen Energy Roadmap

An important by-product of the process was HyNet's contribution to the Alternative Fuels Contact Group (AFCG), a strategy and consensus group established by the EC together with industry, to discuss the introduction of alternative transport fuels including hydrogen. The AFCG's Topic Group on hydrogen published the final results of this effort, including HyNet's view on techno-economic aspects of a hydrogen infrastructure, in December 2003.

In January 2004 HyNet presented its roadmap analysis to a group of European hydrogen stakeholders at the Launch Conference of the HTP.

The structure of the roadmap reflects HyNet's five Thematic Working Groups: (i) Hydrogen Production & Infrastructure, (ii) Hydrogen End-Use & Storage, (iii) Hydrogen Codes, Standards & Regulations, (iv) Hydrogen Socio-Economic & Policy Issues and (v) Dissemination and Public Outreach.

Part ONE – Hydrogen Production and Infrastructure

Hydrogen Production

Hydrogen has the ability to act as an energy carrier in both stationary and transport applications, but particularly in the latter sector, where it offers the potential to transition from the world's current reliance on fossil fuels to increased contributions from renewable energy sources. However about 95% of today's merchant hydrogen production is produced from centralised reforming of natural gas. In the medium- to long-term we can anticipate a general shift away from processes that emit CO_2 to the atmosphere. Future options may include CO_2-neutral paths such as hydrogen from fossil fuels with CO_2 capture, electrolysis of water using renewable electricity or nuclear energy, biomass gasification and even more long-term developments such as photochemical/biological or high temperature nuclear thermocycle pathways. We have attempted to capture the technological and market readiness of these options in fig. 1-1. For the technically advanced, but not yet commercially competitive, production technologies, fig. 1-1 implies that intensive short-term R&D efforts may be needed to achieve market readiness.

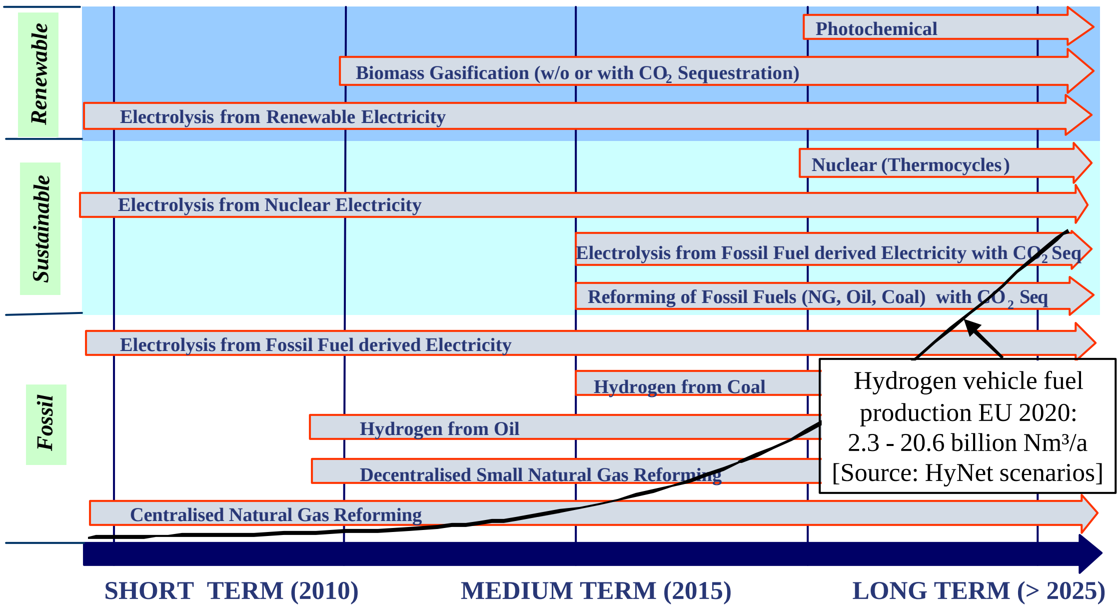


Figure 1-1 Timeline for hydrogen production technologies (The arrows depict the expected earliest commercial introduction of each path, a possible phase-out was not considered)

Considering the current state-of- the-art, electrolysis using renewable power offers the production of hydrogen with zero CO_2 emissions. Electrolysis is also well suited for small scale, high purity hydrogen production and therefore a significant number of hydrogen demonstration fuelling facilities are based on electrolytic hydrogen. The economics of electrolysis are very dependent on electricity prices and better suited for smaller scale applications, therefore historically the technology has not been able to compete with large scale, centralised natural gas steam reforming.

In the medium term other technologies based on fossil fuels and alternative CO_2 neutral pathways are expected to contribute to the hydrogen energy mix. Among the most interesting are small-scale steam-reforming plants, similar to those developed with stationary fuel cells, biomass gasification, as well as more conventional reforming/gasification plants converting oil/coal to hydrogen. In the medium term we may see the introduction of CO_2 sequestration to eliminate emissions to the atmosphere by exploiting local regional conditions e.g. geology and economic incentives. Looking at the very long term, hydrogen production technologies could include photo-biological or photo-electrochemical conversion processes and thermonuclear conversion cycles.

The exact quantities of hydrogen which will be produced from one or other of these technology supply routes will be very dependent on local market factors. These could include the availability of natural resources, the potential for renewable energies, competitive costs between different forms of primary energy production, regional imperatives and energy policy, including fiscal regimes, fuel taxation & carbon taxes.

We also believe that by-product hydrogen from the chemical or other industries may locally play a role in the transition phase, where a distribution infrastructure is already available or developed at low cost. In Europe the total available amount of by-product hydrogen is between 2 and 10 billion Nm^3 hydrogen per year, which would be sufficient to supply 1 to 6 million passenger cars. Today the majority of this by-product hydrogen is used for process heating.

The potential to produce hydrogen from renewable energy sources is significant but dependent on localised resources. The cumulative long-term technical potential of hydropower, biomass, and wind could provide enough energy to supply all transport in Europe, particularly if the energy saving options of future drive systems is taken into account. The necessity to handle intermittent renewable energies, such as offshore wind, may contribute to provide cheap hydrogen fuel from electricity at periods with grid overcapacity. However it should be noted that the competing energy demand for stationary power and the cost and time to develop the renewable infrastructure would have to be considered. Depending on factors such as demand, energy prices and fuel costs the economic viability of individual options may vary widely. So there is unlikely to be a simple or single solution.

Conclusions:

- Steam reforming and electrolysis for the production of hydrogen are commercially available today and can play a vital role in satisfying hydrogen energy demand in the short and medium term. Hydrogen is already produced in significant amounts today and there is likely to be sufficient capacity to meet its initial introduction as a fuel, but not for mass-market demand.

- Today Hydrogen is more expensive than conventional fuels. However we are optimistic that in the future hydrogen could be produced at untaxed costs per km driven which make it competitive with taxed gasoline and diesel fuel in Europe, and even untaxed gasoline and diesel fuel. This assumes that anticipated long-term technology learning curves and economic scaling factors for series production (both for H_2 production and storage and FC technologies) can be achieved.

- With concerns about energy security, resource depletion and reduction of GHG emissions in the medium and long term, a transition to low or CO_2 neutral technologies will be required. This will include hydrogen derived from renewable sources, including biomass, as well as nuclear and fossil fuel pathways that incorporate carbon sequestration.

- Over the long term as technologies develop, we must continually evaluate parameters such as the impact of technology learning curves, the economic benefits of mass production, and importantly the full life cycle analysis of the whole system. We see an important role for member states and the EC to stimulate RD&D for “future” enhanced technologies and to develop positions on market-introduction policies for proven technologies.

- We anticipate that in the transition period, policy measures must be considered to improve the economic viability of CO_2-neutral and CO_2 free hydrogen production. Such measures need to be consistent with the major political goals of the EC and member states, e.g. energy diversity and independence, reduction of greenhouse gases as well as labour market effects and technological competitiveness.

Hydrogen Infrastructure

It is often forgotten that there is already a significant industrial infrastructure for the production of large amounts of hydrogen across the world. As a result industry possesses decades of experience with the safe handling and transportation of hydrogen, both as a cryogenic liquid and as a compressed gas.

Today, centrally produced hydrogen is usually consumed close to the site of production in the petroleum refining and chemicals sector. When distributed from large plants it is transported via liquid hydrogen trucks, hydrogen distribution pipelines or in compressed gas cylinders. In the longer term, we could envisage a global market for hydrogen, with imports via cryogenic marine tankers or dedicated imports of electricity for electrolysers. Ultimately a regional network of H_2 pipelines, similar to today's natural gas system, may be constructed, but this will require hydrogen demand at levels comparable to conventional transport fuels and natural gas for stationary applications.

The two major hurdles for the widespread public use of hydrogen as a fuel are:

- the high costs, relative to conventional fuels, of the distribution of hydrogen to numerous, widely distributed demand centres and
- for transport uses, the high cost of the necessary refuelling infrastructure, including storage and permitting.

Even with growing hydrogen energy demand the economies-of-scale for current distribution technologies are unlikely to achieve the necessary step change even with technological learning curves. We do not expect any major technological breakthroughs and corresponding economic breakthroughs, even through the use of new materials (new metals, ceramics, plastics, composite materials, nanotechnologies) if we were to rely completely on the established logistical pathways.

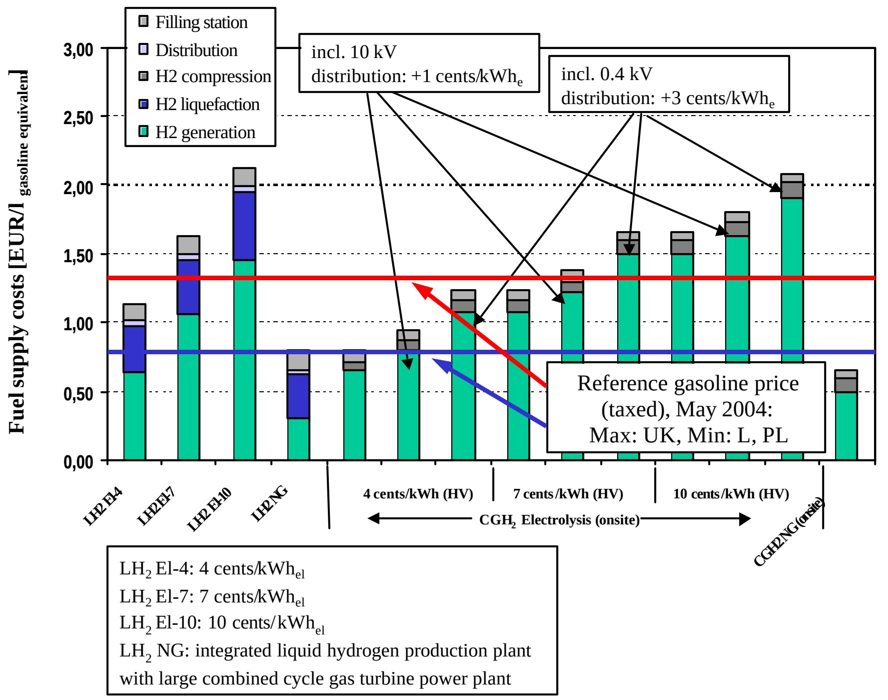


Figure 1-2 Comparative economic analysis of various liquid and compressed hydrogen supply paths (well-to-fuel-station) from electricity and natural gas (HyNet own calculations)

Therefore industry will need to explore innovative solutions, such as the mixing of hydrogen into natural gas infrastructure or decentralised solutions, e.g. on-site retail or home-scale reformers, electrolysers and other novel technologies, to overcome this distribution challenge. Such a distributed approach to the generation of hydrogen would have parallels with current trends in power generation e.g. local CHP and renewables such as photovoltaics. A decentralised approach will also lead to more localised decision-making and therefore a diverse number of solutions. The risk, viewed at a macro level, is then of disjointed development of infrastructure for production, distribution and dispensing, which may hamper its evolution to a mature market. However this risk needs to be weighed against the need to develop hydrogen in the most efficient and economic manner in the early transitional phases.

Fig. 1-2 illustrates this point with an example set of comparative economic data for central and on-site hydrogen energy chains from production to fuelling station. Regional aspects such as electricity price can strongly affect the economy of central natural gas reforming/liquefaction and water electrolysis/ compression pathways. Consequently, based on today's energy prices both central liquid hydrogen and an on-site compressed hydrogen fuel supply options can compete directly with each other.

Investment Costs for the Hydrogen Infrastructure

The creation of any new infrastructure requires massive amounts of financial capital. We can illustrate the potential magnitude of hydrogen infrastructure investment costs by considering initial transition phase scenarios for transport applications with 5,000 and 10,000 fuelling stations representing only 4 to 8% of the 135,000 fuelling stations in Europe. The order of magnitude costs were determined to be:

- 4 – 7 billion € (5,000 fuelling stations supporting 2 – 4.4 million hydrogen vehicles) and
- 7 – 15 billion € (10,000 fuelling stations supporting 5 – 9 million hydrogen vehicles).

These figures are based on some key assumptions about the acceptable utilisation rates for each refuelling station expressed in cars supported per site, cost of the available technologies and the development of appropriate codes and standards. The rationale for investment choices, number of sites, locations, centralised versus decentralised options, will be dependent on such utilisation rates and therefore the local & regional demand patterns for hydrogen. For comparison, the upper utilisation rate used above (800 – 900 vehicles) is still well below today's conventional infrastructure, circa 1500 vehicles per site.

Therefore there are significant financial risks in building the hydrogen fuelling station infrastructure for private vehicles when the number, rate of introduction & uptake, and geographic distribution of vehicles are all uncertain, and yet the consumer rightly expects to travel freely and be able to refuel the vehicle at will.

Consequently there will be a difficult balancing act between the "fuel provider's business case", i.e. the lowest possible fuelling station density to satisfy consumer demand, and the automakers' business case i.e. "fast H_2 vehicle ramp-up" case, which has potentially huge up front infrastructure investment and therefore unacceptable financial risk (see fig. 1-3).

The roll out of H_2 refuelling infrastructure is anticipated to begin in fleet markets, such as public transport, delivery vehicles. Hence early fleet demonstrations could form important components of future EU "Lighthouse Projects" and early market stimulation. The balancing act between lower and upper infrastructure scenarios to meet private vehicle market will likely be influenced by governmental policy measures (e.g. fiscal incentives, accelerated codes & standards, planning policy, public education & outreach), and therefore will certainly require holistic public private stakeholder partnerships to create optimum investment conditions.

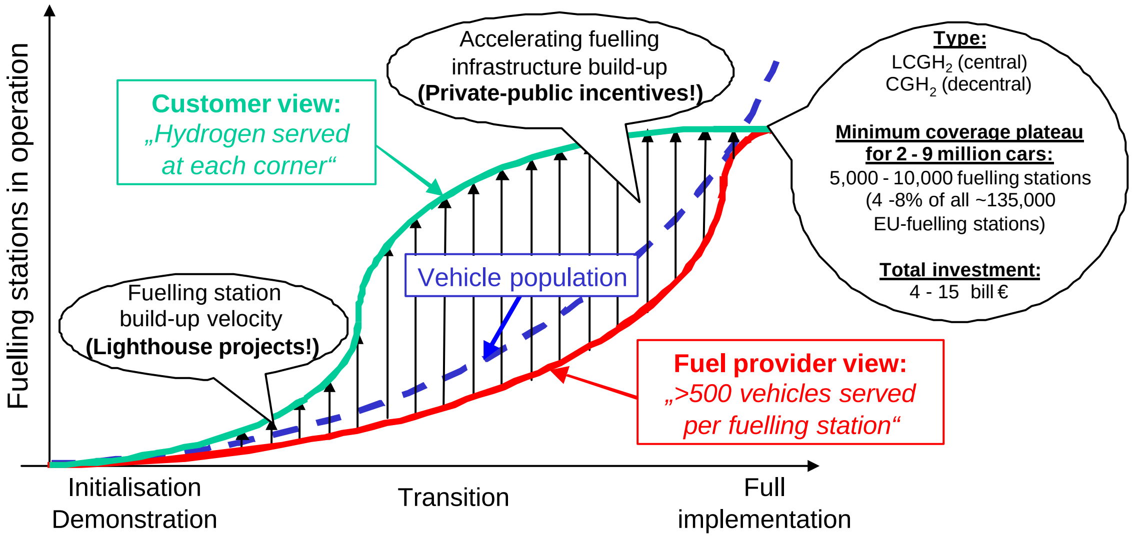


Figure 1-3 Public hydrogen fuelling station build-up strategies between highest customer satisfaction and economic optimum

Conclusions:

- There is a limited but existing industrial infrastructure for the distribution of hydrogen based on cryogenic liquid or compressed gas transportation. This is principally by road but there are also existing pipelines linking large industrial consumers.

- The costs associated with the transport and storage of hydrogen are one of the key hurdles preventing hydrogen from being cost competitive with conventional fuels in the transition phase, requiring innovative solutions such as decentralised production at or close to the point of sale.

- For transport applications, the costs for refuelling sites are also a major hurdle and will require the development of regulations, codes and standards and planning laws that treat hydrogen like conventional fuels and not as a hazardous industrial material.

- There will also need to be major initiatives to promote public acceptance of hydrogen, particularly addressing concerns about the safety of infrastructure.

- Projected investment costs for hydrogen infrastructure are massive and the risk is high with the uncertainty surrounding the new technologies and the date and rate of market introduction. To manage this uncertainty will require significant stakeholder partnerships (governments, technology developers, and hydrogen suppliers).

- Governments in particular will have a role in (a) stimulating innovation through RD&D, (b) supporting early market introduction and (c) minimising risk of investment by industry.

Part TWO – Hydrogen End-Use and Storage

There is much debate as to when different hydrogen energy technologies will enter the commercial market. Hydrogen energy applications can be divided into three key areas: portable, stationary and transportation. For each of these areas to achieve commercialisation, certain technological breakthroughs will be required. These breakthroughs could influence criteria such as economies of scale and thus accelerate the market-readiness of the offerings.

In addition, the effect of regional and policy aspects will be important and may lead to the timing of market introduction varying from one member state to another.

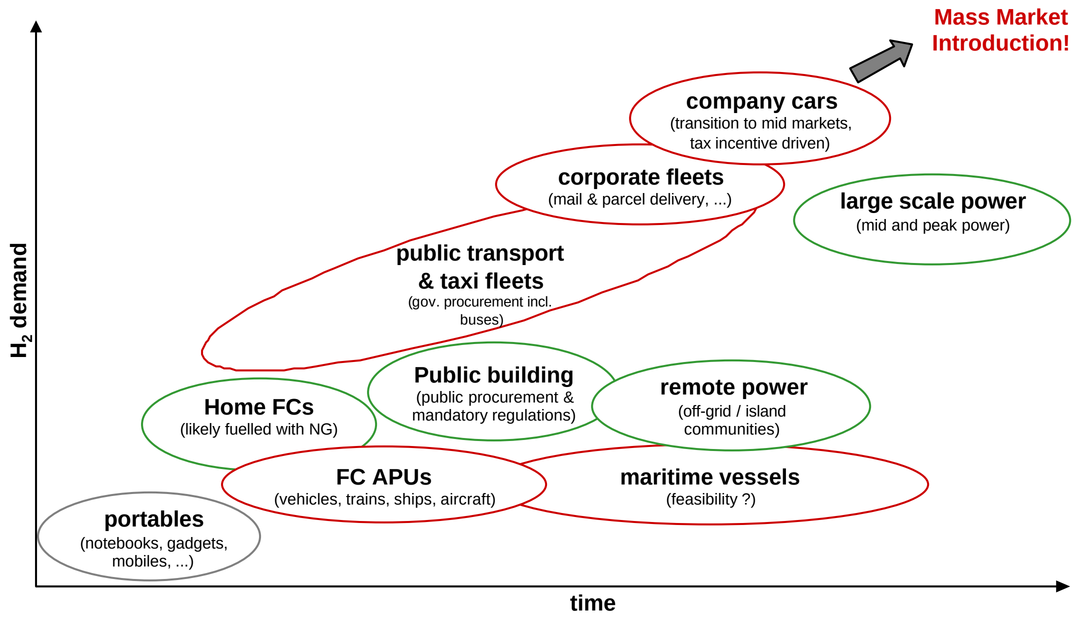


Figure 2-1 Expected introduction of hydrogen energy applications in various end-use sectors (red – transport, green – stationary, grey – portable)

Figure 2-1 shows the expected timing for the introduction of hydrogen into different energy applications and the corresponding hydrogen demand that each application is expected to generate. The timing is based on the general consensus of key stakeholders in the transport and energy areas.

Portable Applications

Japanese announcements [FCDIC – Fuel Cell Development Information Centre of Japan, regular information letter] suggest that portable fuel cells and fuel cell-powered auxiliary power units (APUs) could be market-ready by as early as 2004/2005. However, due to the low power nature of these offerings, they will not have a large impact on local and global energy markets. If the recent production rate increase of portable fuel cells [Fuel Cell Today, 2003] is assumed to continue exponentially, then we can expect that 400,000 portable fuel cells will be manufactured by 2010 and that this level will rise to 430 million by 2020 (see fig. 2-2). In the area of portable applications there is a need for technological breakthroughs involving hydrogen storage. These breakthroughs may also come from defense applications where there is a drive towards battery alternatives.

Technical and economic studies [LBST study for Ballard, 2003] have been carried out that look at the supply of portable mini fuel cells (> 500 W_{el}) into industrial or recreational applications. These suggest that a bottom-up hydrogen infrastructure build-up will be preferred. If hydrogen should become the preferred fuel for portable applications (methanol is also being considered), then the key effect of portable fuel cells on the hydrogen-energy market may be to lead the way in building a wide supply infrastructure of bottled hydrogen for other applications. A second consequence may be that an early acceptance of hydrogen for everyday use will be achieved.

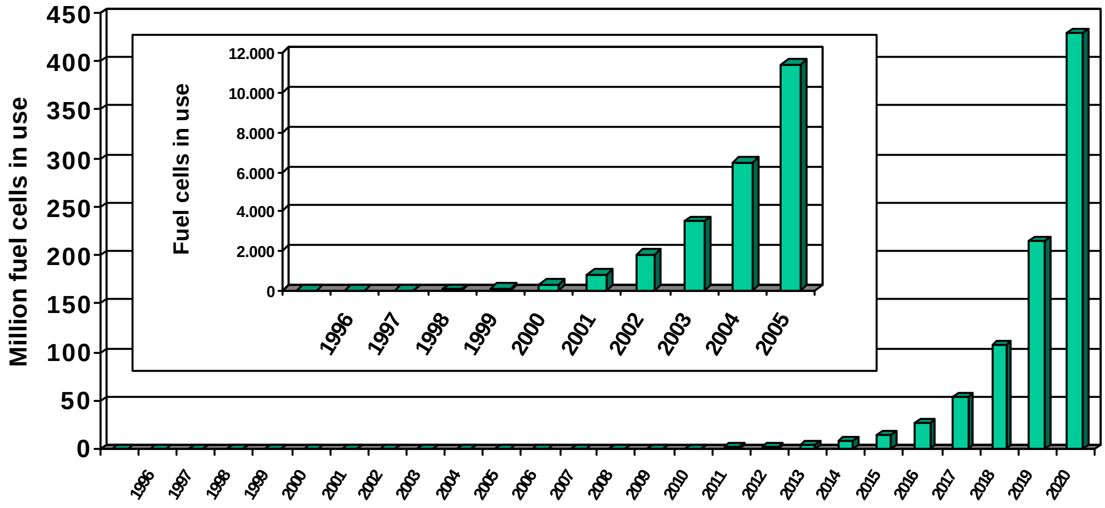


Figure 2-2 Exponential build-up scenario for portable fuel cells [Source until 2003: Fuel Cell Today, thereafter exponential extrapolation]

Stationary Applications

Stationary fuel cells for industrial and residential use are expected to be second to market following portable applications. It is expected that the introduction of fuel cells will have a definitive impact on stationary energy markets, mostly for electricity and natural gas, as these applications will require large amounts of hydrogen fuel. The infrastructure required for these fuel cells can be envisaged as being very decentralised. It is expected that in the transition phase to a long-term renewable supply of hydrogen that the current natural gas transport and distribution grid will be employed, with hydrogen being produced by small on-site reformers at the user location. Often, these reformers will form an integral part of the fuel cell system.

For economic reasons, a wide hydrogen supply infrastructure for industrial or residential applications is not expected to be in place in the foreseeable future. However, a recent German demonstration project [EQHHPP Hamburg PAFC project with liquid hydrogen storage, 2000] has proven that the operation of residential fuel cells using a direct hydrogen supply can be carried out safely. Until a suitable hydrogen supply infrastructure is developed, fuel cells for industrial and residential use will typically be fuelled by natural gas, LPG or methanol. This technology has an expected market entry of between 2006 and 2008. As a reformer-based onsite hydrogen supply requires complex process technology, the specific costs of power from fuel cell CHP systems will be higher than that from conventional equipment such as gas turbines or gas engines. Final costs will again depend on regional costs and local energy policy.

The long-term driving forces behind the use of fuel cells for residential and industrial use are expected to be lower overall cost, higher efficiency, a reduction in noise emissions, reduced maintenance, higher availability than conventional CHP technologies such as gas-engines or gas turbines, improved grid reliability and synergy with other energy end-use sectors. Large numbers of installations are expected to appear across Europe, with millions of kW_{el} installed capacity. Fuel cell technology is aligned with a general European trend towards the installation of small and micro-combined power plants. Key development issues for stationary fuel cells are lifetime (at least > 40.000 hrs), cost (< 500 €/kW_{el}) and reliability (> 98%) and these remain significant challenges for the sector.

It is expected that in the longer term, i.e. after 2020, a hydrogen infrastructure for stationary applications could develop. The success of this will depend on a number of factors including the degree of decentralisation in stationary energy markets, energy demand reduction, the need for load levelling capabilities for renewable energy and the success of competing technologies such as combining a hydrogen admixture to the natural gas in the existing grid. Additionally carbon capture schemes for large-scale centralised power generation could be based in the future on natural gas reforming or fossil fuel gasification technologies, with large scale production of hydrogen and its consumption in efficient combined cycle gas turbine (CCGT) schemes.

These different options will have to be tested, with lighthouse demonstration projects being a viable way of achieving this. A current limiting step in these demonstration projects is the lack of small reformers for fuel cells in the 1 - 10 kW_{el} class. A possible means of bridging this technology gap could be to use local hydrogen distribution grids fed with hydrogen from either commercially available central reformers, electrolysers or from by-product hydrogen. In this way, a hydrogen infrastructure for stationary supply would evolve from local clusters.

It is not expected that the direct use of hydrogen to provide power for industrial or residential use will play an important role in the short-medium term. However, longer term, an increasing amount of hydrogen for use as an energy buffer may be required. The development of the necessary infrastructure will have to be adapted to the changing needs of the evolving decentralised energy markets. It will likely start with local and virtual hydrogen supply islands.

Transport Applications

In terms of potential GHG emission reduction, the transport energy sector is the area where a move to hydrogen fuelling could have the greatest effect. However, introducing hydrogen fuel to the transportation area also poses key technical challenges. For fuel cell drive systems, good transient response low specific costs, lifetime and hybridisation (e.g. for regenerative breaking) are key drivers. Until fuel cell vehicles become market ready, hydrogen cars or buses operated by internal combustion engines could bridge the gap and help to develop the hydrogen fuel supply infrastructure.

Fleet-operated vehicles (possibly in the public sector) are expected to be among the first vehicles to switch to hydrogen fuel. The advantages in using fleet vehicles in the initial stages of the hydrogen economy include central refuelling and maintenance, controlled safety conditions and high public visibility. A key example of this are the European funded demonstration projects CUTE and ECTOS, which in 2003 introduced 30 fuel cell buses into operation in 10 cities across Europe. These new buses bring the total number of fuel cell buses that have been demonstrated world-wide to 75.

In addition to the demonstration of fuel cells in public service buses, the maritime sector has also been active in this area, with fuel cells being used to power auxiliary drive systems for manoeuvring in harbours and non-propulsion energy for ships as they come into dock. Military vehicles including submarines have also utilised fuel cell technology.

Nevertheless, a wide market entry of hydrogen into public fuelling stations is not expected before 2010 – 2015, as most auto-manufacturers will not be ready for mass production of their hydrogen-powered cars before this time.

As hydrogen in transport will have the largest impact on the hydrogen infrastructure build-up, it has been the topic of most of the detailed hydrogen infrastructure scenario discussions. Fig. 2-3 depicts a hydrogen vehicle introduction scenario with a European hydrogen car population of about 5 million by 2020 with lower and upper boundaries of 2 and 9 million cars respectively. These scenarios do not distinguish between internal combustion and fuel cell-operated vehicles. If we take the mid-range scenario of 5 million cars by 2020, the corresponding figures suggest that 50,000 hydrogen cars will be on the road by 2010, and 530,000 by 2015.

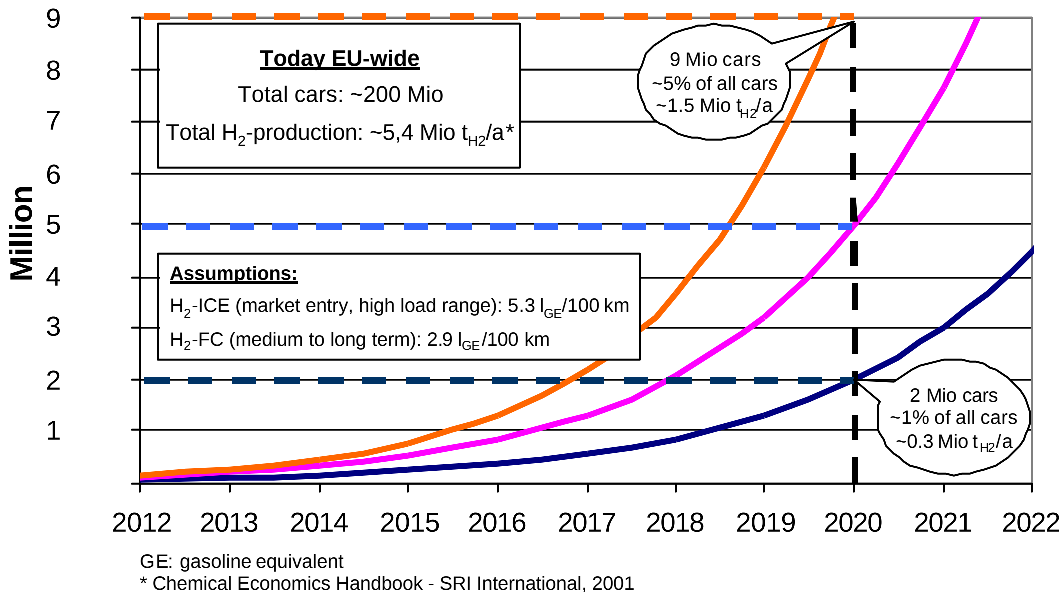


Figure 2-3 Possible Cumulative Hydrogen Vehicle Population Development by 2020

In trying to understand what might be optimum conditions for developing a hydrogen vehicle population, we can look to the experience of CNG vehicle introduction in Argentina[1]. Two key factors ensured the success of these vehicles; the first being the fast and continuous build-up of the fuelling infrastructure (goal: customer acceptance), the second being a build-up curve that followed optimum fuel station utilisation (goal: economic interest of the fuel providers). These factors provide the desired development curves for the automobile industry, i.e. a rapid exponential growth of vehicle demand, and the avoidance of disruptive developments in the fuel infrastructure transition phase. However in this real-life example both the fuel and vehicle technologies were readily available.

When we turn to the future hydrogen economy, there are a number of key issues that need to be resolved before the introduction of fuel cell vehicles into the transport sector can be considered. These include major performance challenges for fuel cell vehicles that still need to be met such as life expectancy, reliability, and performance degradation. The R&D challenges for internal combustion engines are mostly enhanced efficiency and hybridisation.

In addition, there are challenges for the development of the fuelling infrastructure, as previously discussed. Therefore significant R&D and demonstration programmes will be needed to validate new vehicle and hydrogen technologies. While an exponential growth curve for fuel cell vehicles is anticipated and desired by industry, it remains difficult to give an exact prediction of the vehicle market uptake, while the technologies & the supporting component supply infrastructure are so immature. Therefore for mass market entry, this will necessitate significant investment by vehicle manufacturers & their component suppliers in manufacturing capacity. Once this „infrastructure“ has been created along with investment confidence then we can expect a rapid build-up to several million cars within a short period.

[1] In Argentina about 1 Million CNG vehicles are in operation today, served by about 1.300 fuelling stations. Specific attention was paid to maintaining a high ratio of natural gas sales per fueling station (>400 Nm³/hr) during the infrastructure build-up phase. This ensured a successful introduction and take-up of CNG. It was also helped by the high regional concentration of the population.

Exploiting Synergies Between End-use Sectors

As discussed above, hydrogen has the potential to be used as an energy carrier in three main sectors, namely transport, stationary and portable. When developing an infrastructure to support these applications, it would make sense to exploit any synergies between the sectors.

One such example is the concept of an energy station, combining power generation and hydrogen refuelling at the same location. This could provide the means to manage the utilisation rate of refuelling sites, particularly in the early stages of vehicle introduction when demand will be limited. Such an energy station could help to establish local stationary hydrogen energy clusters for small industrial or residential use.

Hydrogen can also play a role in managing the intermittence of renewable power generation from technologies such as wind and PV (both in grid connected and off-grid schemes). This is conceptually similar to energy storage schemes for managing peak and off-peak supply/demand imbalances, using compressed air plants or pumped-hydro-storage. However, these current installations are insufficient for load-managing large amounts of future renewable generation. It has therefore been proposed to use the surplus electricity to generate hydrogen *via* electrolysis and use the hydrogen as daily and/or seasonal storage. In addition, this hydrogen could also be employed as a vehicle fuel.

One can also envisage that hydrogen fuel cell vehicles could be used to supply electricity (and heat) to residential or office buildings, while parked during working hours. Another option could be the establishment of cylinder-filling points at refuelling stations. Such filling points would serve as an infrastructure for portable fuel cell applications in industrial, household and recreational use.

The convergence of the sectors to a common fuel provides the opportunity to improve the economics of hydrogen distribution and supply by developing such innovative approaches to optimise the use of these novel energy conversion devices.

Hydrogen Demand

A major issue for both hydrogen end-use and hydrogen production is how the volume demand of hydrogen will develop and whether the supply/demand balance can be managed efficiently. From the perspective of the hydrogen user, the source of hydrogen is less relevant as long as competitive costs and supply reliability can be guaranteed (although there is a long term expectation that hydrogen will be derived from sustainable and ultimately renewable pathways). From the perspective of the hydrogen producer, the major criteria will be predictable and significant hydrogen demand growth and a profitable market development.

In the short term, the demand for stationary power applications will rely on the natural gas infrastructure and therefore will not immediately impact the demand of hydrogen. Fig 2-4 assumes a scenario that looks towards 2010, where there are fuel cell installations in the range of 2.6 - 10 MW with 6,000 annual full-load hours and 40% electrical efficiency [Allied Business, 2001]. In this scenario, a total hydrogen demand of 35 – 134 GWh or 1 - 4 thousand tons of hydrogen would be needed.

Although the expected number of portable hydrogen applications will be high in total numbers they will have negligible effect on the overall hydrogen demand. Thus, they will not be considered here further.

In the period 2010-2015, commercial introduction of hydrogen-powered vehicles is expected to begin. These vehicles will likely be a mixture of those powered by both fuel cells and those powered with internal combustion engines. Once mass production occurs within Europe, the hydrogen fuel demand for vehicle applications will be the main driver for developing a wide hydrogen supply infrastructure.

For simplicity, in the example below, only passenger cars will be used to calculate the total hydrogen fuel demand. Hydrogen-powered city buses, although having a higher specific fuel consumption and greater annual driving distances, are not considered below as the total number of buses on the road will be insignificant relative to the number of passenger cars.

To give an indication of the volume of hydrogen that will be needed and also underlying the wide range of uncertainty, we can imagine a future scenario where we have a range of between 2 and 9 million cars on the road, each with an average annual total driving distance of 15,000 km and a specific average fuel consumption of 2.9 – 5.3 l_{GE}/100 km[2]. Using these figures, it is estimated that an extra 2.3 - 20.6 billion Nm³ or 0.2 – 1.8 million tons of hydrogen will be required in Europe[3] annually (fig. 2-4).

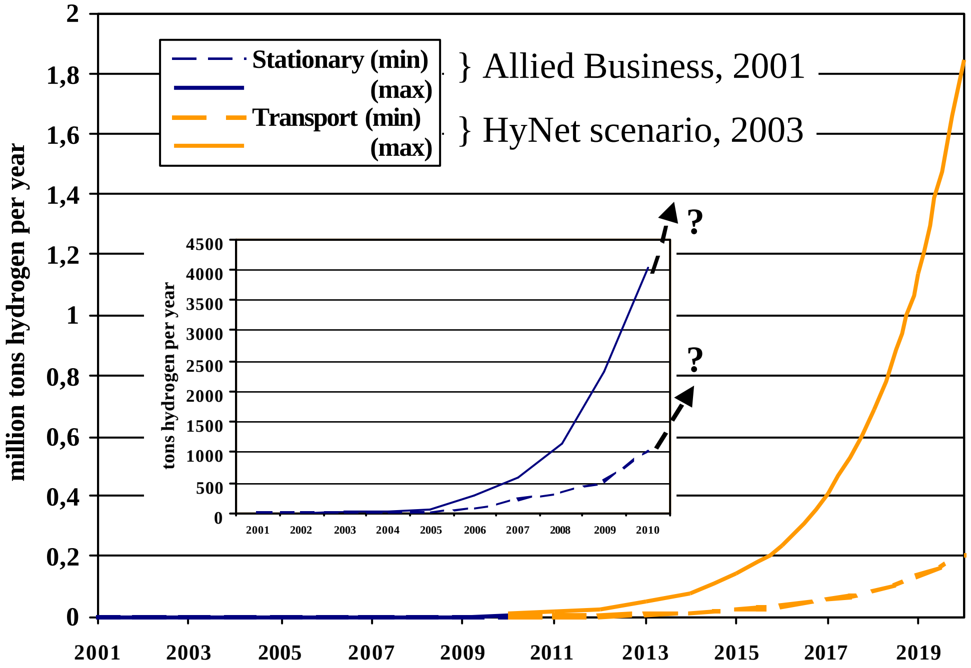


Figure 2-4 Possible hydrogen demand growth for use as a fuel in Europe

Conclusions

- Small portable applications are expected to enter the market in the next 2-3 years and will help introduce the benefits of fuel cells and hydrogen to the general public.
- Stationary fuel cells are expected to be commercialised in the latter half of this decade, but these are expected to consume predominantly fossil fuels such as natural gas.
- Transport applications will be the main driver for hydrogen demand but mass production of passenger vehicles will not take place before the period 2010 to 2015. Experience from the build-up of other alternatively fuelled vehicle populations (e.g CNG-cars in Argentina) should be investigated more closely.
- There is significant uncertainty in future hydrogen demand forecasts, while fuel cell and other enabling technologies such as hydrogen internal combustion engines or their system environments are still not ready for mass market introduction.

[2] Specific fuel consumption: fuel cell car: 2.9 l_{GE}/100 km, ICE-car: 5.3 l_{GE}/100 km

Hydrogen Storage

A major technology challenge continues to be the hydrogen storage required for these new energy applications. Three main storage modes are considered, namely compressed, liquid and ad- or absorption in solids. Although storage is an important component in any end-use sector and also for the hydrogen infrastructure, the highest system complexity and most stringent specifications are required for storage systems for transport applications. This is also the area that requires the most ambitious timing for developing a standard solution to the storage problem. Fig. 2-5 gives an overview of the volumetric and gravimetric system storage densities for gaseous, liquid and solid hydrogen storage solutions. Current state-of-the art technology claims range from

- 2 – 4 MJ/ltr and 3 – 7 wt% for compressed hydrogen storage systems (350 – 700 bar),
- 3 – 5.5 MJ/ltr and 1 – 5 wt% for metal hydrides storage systems (low and high temperature),
- 3 – 9 MJ/ltr and 5 – 6 wt% for active bulk carbon (AX21 at 77K), and
- 4 – 6 MJ/ltr and 5 – 12 wt% for liquid vehicle type hydrogen vessels.

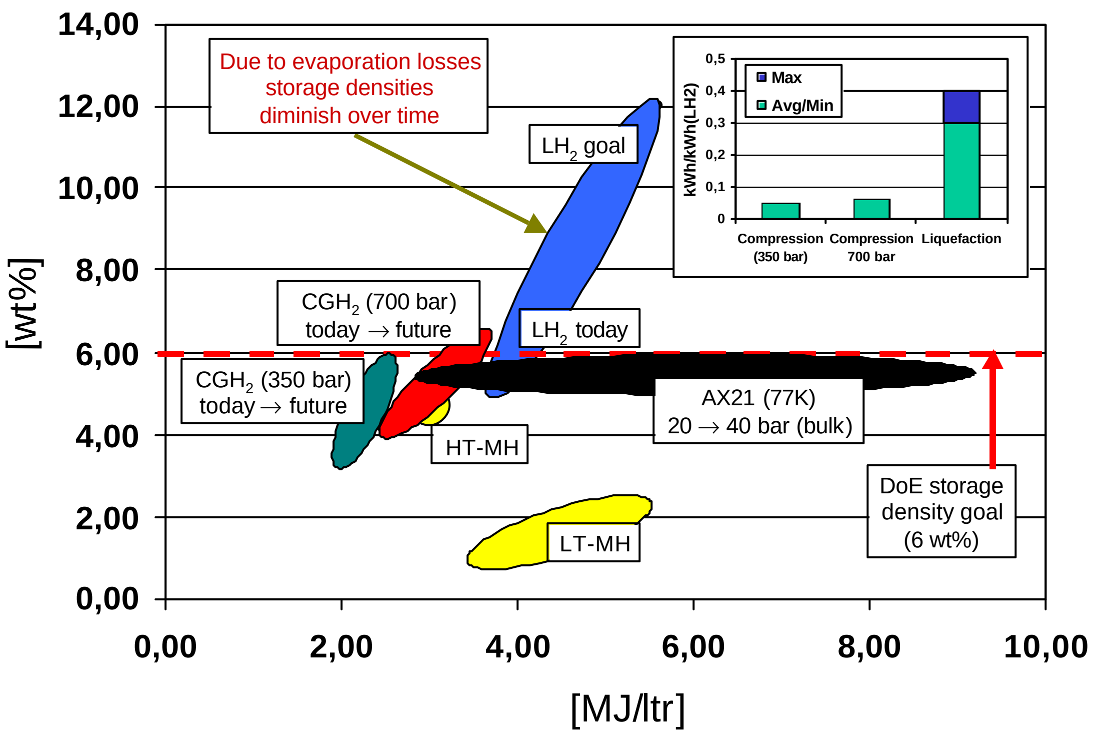


Figure 2-5 Gravimetric and volumetric storage densities of on-board hydrogen storage vessel systems (the insert shows the energy required to provide liquid or compressed hydrogen for vehicle storage at 350 and 700 bar, all from initial pressure of 30 bar)

The drawback of this type of graphical representation is that it displays only a part of the complete set of criteria necessary to compare alternative storage options. Important information that is lacking includes:

- energy demand along the complete energy chains (fig. 2-5 only displays the energy required to provide the fuel without considering the energy chain, e.g. for distribution),
- dependency on gross system size,

[3] For comparison today the total hydrogen production in Europe is about 5.4 million tons per year

- influence of system parameters such as total energy required along the supply chain (e.g. hydrogen liquefaction consumes 20-30% of the hydrogen handled),
- dimensional constraints and flexibility (vessels of arbitrary geometries),
- operational parameters such as hydrogen leakage to the atmosphere and reduced holding time without hydrogen ventilation,
- safety criteria (e.g. behaviour in case of accidents),
- peripheral requirements such as extra equipment for exporting thermal energy when filling (i.e. for any ab- or adsorption in solid materials),
- required recycling schemes, i.e. for chemical hydrides must be accepted back from the vehicles and recycled (e.g. borate to sodium borohydride), and last but not least
- system costs including the fuelling station and hydrogen transport/distribution needs.

The above constraints have to be considered in combination with the operational requirements and load profiles (e.g. vehicle range, available volume and geometry on-board, lifetime, costs and possible emissions). A final decision in favour of an optimum storage choice for individual applications is not yet possible, and there may not be a single solution, as different storage technologies will be more appropriate for different applications.

Extensive research is required to develop new hydrogen storage systems. These solutions must provide materials, systems and refuelling interface solutions that will provide vehicles and other end-use applications that will satisfy the customers' needs.

Once hydrogen vehicles are commercialised, a typical driving range of at least 400-500 km will be expected. In addition, the costs per km driven will have to be competitive with conventional gasoline vehicles, regardless of whether the hydrogen vehicle is fuel cell or internal combustion engine-powered.

There will be a strong relationship between the development of hydrogen storage systems and the development of a hydrogen energy infrastructure. Thus it will be important to consider the infrastructure question when investigating the viability of the different storage options – liquid and compressed or ad-/absorbed. Although adding complexity in the decision process, this work will also have to recognise the need to avoid "stranded" investments. As long as the final options for combinations of hydrogen supply and hydrogen end-use technology remain unresolved, research and limited development on all storage options should be continued.

In addition, research and development will also have to focus on complete vehicle concepts that will fully utilise and integrate the new storage technologies into the vehicle. As prototypes from the U.S., Japan and Europe have shown, these new concepts can result in added customer value either by integrating the technical systems into a separate unit, by developing electric hybrid drive concepts, or by consequently adapting the vehicle technology to the fuel cell characteristics in such as in 'all-by-wire' systems. These additional benefits would help justify the higher prices for the added vehicle quality and thus lower the market entry barrier for hydrogen vehicles.

Conclusions

- Hydrogen storage is a critical enabling technology, particularly for vehicle applications.
- The challenges are significant and will require extensive R&D to develop innovative solutions.

Part THREE – Hydrogen Regulations, Codes & Standards

The relationship between regulations and standards

All fuels possess characteristics that may make them hazardous if mishandled. Industry has an excellent track record of handling hydrogen over several decades, and indeed hydrogen was a significant component in town gas. To minimise the risk of accidents and any hazards that may arise from the chemical and physical properties of hydrogen, both regulations and legislation are required. These should be put in place for production, transportation and storage, and use of hydrogen. Industrial codes and standards already exist, and so this applies particularly for non-industrial applications and for the public use of hydrogen.

On a national basis regulations are usually of a general character and often developed by government organisations. They focus on issues such as protection of workers, third parties and property. Both international (USA, Europe, Asia etc.) and national regulations may be applied. Regulations are commonly developed with reference to suitable standards.

Standards, conversely, are developed by international or national standard organisations, such as ISO, IEC, CEN/CENEL, NFPA, ASME etc. They are considered to indicate "best practice" in which industry and other organisations with suitable knowledge and competence produce guidelines for technology, production methods, analysis techniques, monitoring procedures, inspection, maintenance, control etc. Standards are not legal requirements in Europe, but they are considered very important by industry and are intended to support the free exchange of goods and services through achievement of common goals.

Suitably well-developed and acknowledged standards are, and should be, included in the harmonised standards upon which relevant regulations will be developed.

Harmonisation of regulations and standards

Regulations and standards in the US, EU and Asia are frequently not harmonised, which can cause problems with regard to the free exchange of goods and services. Equally, in the development of ISO standards the different regions may take different views of certain aspects of the standards.

To date, the development of hydrogen related standards within ISO and IEC has only been harmonised with existing European or international regulations to a very limited extent (e.g. harmonisation between ISO TC 197 and the UN ECE CGH_2 and LH_2 regulation draft documents). At worst, this may in the future lead to a mismatch between the text of the standard and any relevant regulations, or to incomplete standards where important requirements are not adequately included.

It is therefore very important to ensure that expertise from the development of relevant regulations is represented in the standard committees (e.g. as practised via the global cooperaion group, initiated by EIHP2. Common rules for interpretation must therefore be established).

Interpretation of mandatory regulations and requirements is not straightforward. The technical and safety-related documentation required is frequently time consuming and may be subject to interpretation. This could in turn lead to large variations in safety systems and the resulting level of safety. This might then slow the progress of development towards a future "hydrogen society", due to either

- the occurrence of serious accidents, considerably slowing the pace of development; or
- unnecessarily expensive and complicated safety solutions that materially reduce the competitiveness of emerging applications.

Commitment and funding

A challenge within ISO TC 197 (hydrogen energy/applications/technology) and other working groups is that some of the participating organisations are less active than others. The consequences of this may be both in reduced quality and acceptance of the standards. This could arise through

- A lack of expert knowledge within all relevant areas;
- All interests may not be suitably represented;
- Unsuitable issues may be included related to competitive pressures.

The development of good standards is dependent on the participation of organisations and persons with expert knowledge of technical issues, hydrogen hazards and relevant rules and regulations. This includes representatives from commercial and R&D organisations and competence within international and national regulatory bodies.

A further challenge in standards development in the case of hydrogen is that there is currently no commercial environment to create a market pull.

Public funding as common in Japan and the U.S. can make it easier to justify significant resources to these areas where either a small or no market exists in the near term.

Achieving a balance between early standards allowing uptake of technology, and technology 'lock-in'

Many hydrogen technology options are at a premature state and significant development is required to bring the technology to commercialisation. The development of standards must be started at early stages to enable its uptake at a suitable time. However, the standards must not set fixed requirements to technology solutions too early, since this may hinder further technology development and result in sub optimal solutions.

Basically standards should deal with the safety, performance and use of end products (e.g. vehicles in the case of transport) and their relevant systems. They should work as guidelines for the technology pathways without hindering development.

Standards provisions may therefore address functional requirements rather than specific designs; methodologies for the characterisation and evaluation of end products and systems on an internationally agreed basis (i.e. ISO, IEC), and the means to enable possible common use of the infrastructures.

Risk analysis and the need for common methodologies and statistical data

Risk analysis is a requirement in relevant EU regulations, and the results are used to document an acceptable safety level. Central elements in risk analysis include accident statistics, failure frequencies and reliability data on process equipment, safety functions and safety equipment. The available data within the field of hydrogen today come from large industrial installations, and may not be relevant for small hydrogen applications in public environments. Clear differences exist, for example, in equipment dimensions, layout, and process conditions such as temperature and pressure of operation.

The collection of relevant data and the harmonisation of risk analysis methodologies are vital to ensure acceptable risk levels within the field of hydrogen safety. A safety and risk specific dialogue should be established to share information by developing standardised protocols and e.g. exchanging sensitive information - if necessary on a confidential level.

Experience sharing and competence building in the approval of hydrogen applications

Experience from the CUTE/ECTOS projects indicates that the lack of experience with the use of hydrogen for non-industrial or public applications can be a significant barrier to obtaining licences or approvals from the relevant authorities. No regulations currently detail the safety requirements for such applications, while at this early stage of the project all parties involved have limited experience with the use of hydrogen in public transport applications. The organisations responsible for carrying out CE marking of equipment or components may also have limited experience and competence regarding hydrogen safety.

Gaining and sharing experience and building competence within organisations will be essential to achieve an effective approval process which takes into account the relevant safety aspects of hydrogen.

Results and experience may be shared between important hydrogen projects

Many valuable data are generated through demonstration projects, such as the CUTE and ECTOS projects. Here experience and data from the operation of 10 refuelling stations and 30 hydrogen buses are being systematically collected. Important experience from the process of achieving authority approval has been collected and will be used to help make future processes smoother. First experience from a fully integrated public refuelling station for hydrogen and liquid hydrocarbons will be collected from the CEP in Berlin. Another relevant EU research project is HySafe, focused on hydrogen safety matters, including the development of standards and regulations. The majority of organisations participating in CUTE are industrial, while HySafe is dominated by research organisations. Other relevant projects include EIHP2, STORHY and NaturalHy, with clear synergies between these projects.

An EoI by European industry and risk&safety institutions, led by Air Liquide and named HyApproval, will compile all requirements for approving hydrogen refuelling stations in Europe.

Effective collaboration is required between R&D institutions and commercial companies to ensure the implementation of hydrogen safety research results into technical solutions, regulations and standards.

Conclusions

- Legal requirements or regulations are ranked above standards. They are legally binding and enforceable documents emanating from governments. Standards in general are voluntary agreements drafted by standardisation committees on a global, regional or national level. Standards are documents, established by consensus and approved by a recognised body.

- Standards, although not legally binding, are important for the development of any industry and harmonisation across Europe and globally will help ensure the successful introduction of hydrogen and fuel cells.

- It is therefore very important to ensure that expertise from the development of relevant regulations is represented in the standard committees.

- Regulations for Europe which can be transferred to member states laws uniformly are desirable in order to allow the local/ regional implementation of H_2 & FC technologies following to the same regulatory requirements in all EU member states.

- Public funding can make it easier to justify significant resources to these areas where either a small or no market exists in the near term

- It will be important to achieve a balance between standards that can facilitate the uptake of new technology and premature standards that can lock-in a sub-optimal outcome.

- The collection of relevant data and the harmonisation of risk analysis methodologies are vital to ensure acceptable risk levels within the field of hydrogen safety. Methods will have to be developed to share risk and safety relevant information in standardised format.

- Gaining and sharing experience and building competence within organisations will be essential to achieve an effective approval process which takes into account the relevant safety aspects of hydrogen.

- Effective collaboration is required between R&D institutions and commercial companies to ensure the implementation of hydrogen safety research results into technical solutions, regulations and standards

Part FOUR – Socio-economic and Policy Issues in Building a Hydrogen Supply Infrastructure

The Political importance of a European Hydrogen Roadmap

Urgent action is required to ensure the future economic competitiveness of Europe in the field of hydrogen technologies. The High Level Group for Hydrogen and Fuel Cells (HLG) pointed out the vital need for Europe to create a political framework that "enables new technologies to gain market entry within the broader context of future transport and energy strategies and policies" and develop a European Roadmap for Hydrogen. HyNet was asked by the European Commission's DG Research to build on the vision of the HLG by developing a first-stage European Hydrogen Roadmap by the end of 2003. This preliminary roadmap would be the base for a fully validated roadmap developed under the HyWays project under the Framework 6 research programme.

The starting point for the roadmap was the HLG report, which gave a vision of Europe's transition process towards hydrogen as displayed in fig. 4-1.

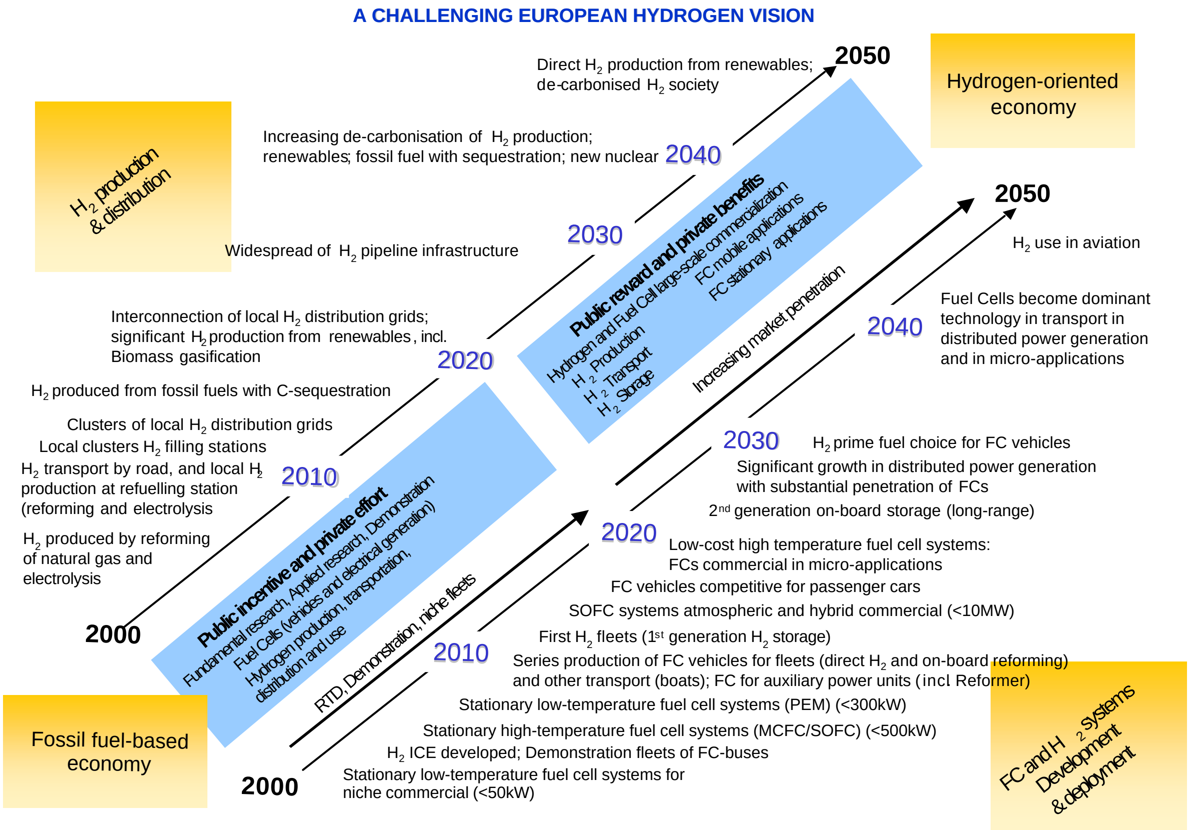


Figure 4-1 A Challenging European Vision, HLG

Existing Hydrogen Roadmaps and Market Development Schemes

In addition to the perspective provided by the HLG, other existing hydrogen roadmaps have been analysed and common structures identified. The following activities in the US, Canada and Japan have been examined:

- National Hydrogen Energy Roadmap, U.S. Dept. of Energy (DoE)
- Canadian Fuel Cell Commercialisation Roadmap
- Roadmap for Polymer Electrolyte Fuel Cell (PEFC) Technologies (FCCJ Japan)

All these roadmaps assume an idealised hydrogen market penetration, expressed by an S-curve shaped model, such as can be applied to many historical developments, including vehicle uptake in US households in the first half of the 20th century. The different sections of this S-curve reflect different stages of market development:

- the demonstration phase; early markets; mid & late markets

The development of hydrogen end-use technologies was described in part two and fig. 2-1 from a technical perspective. In addition to technical progress and the further development of hydrogen-related R&D, key political and socio-economic issues have been identified for the three market development phases mentioned above.

Political and Socio-Economic Issues for a European Hydrogen Roadmap

The transition towards a hydrogen economy will require political and socio-economic policy measures to be taken. This will both remove barriers and ensure a coherent framework within which different organisations can manage the risks of entering an emerging market. The fulfilment of the individual tasks of each phase – e.g. putting appropriate regulations, codes & standards in place for demonstrations – is a major milestone before the next transition step can be undertaken. Work within HyNet has identified the critical actions and milestones displayed in fig. 4-2 and described below by market phase.

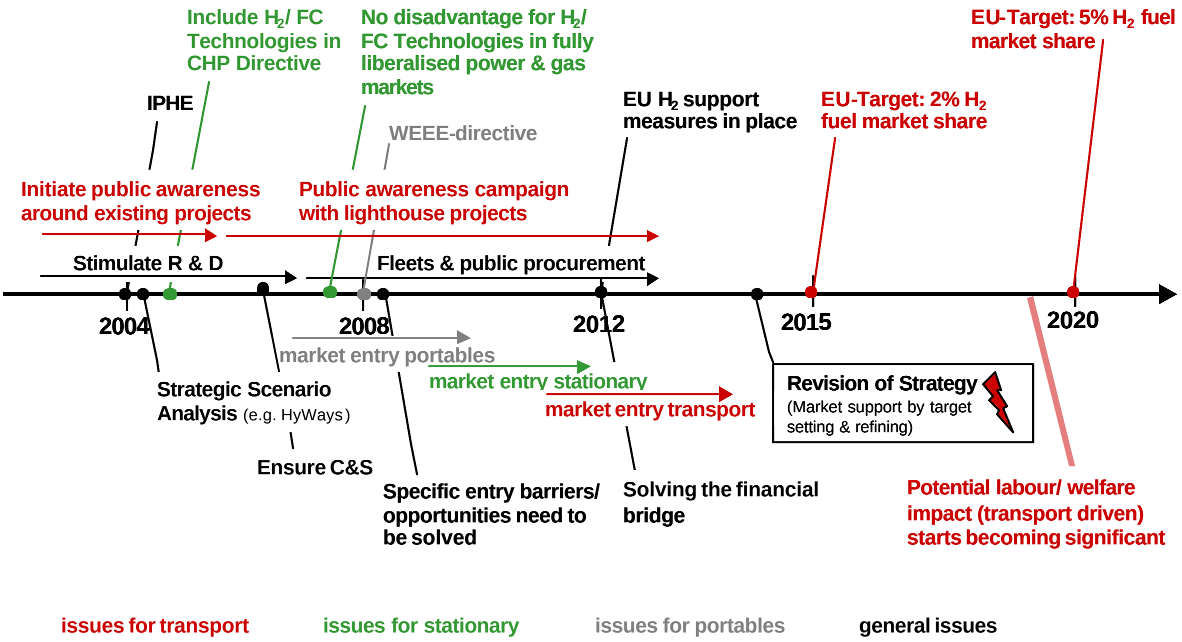


Figure 4-2 Critical policy and socio-economic issues identified by HyNet

Demonstration Phase

Within the next few years a fully working and coherent legislation for the construction and operation of hydrogen applications and the corresponding infrastructure needs to be in place on a European level, to allow national implementation. An integrated European approach is a necessary prerequisite. Given that the time to market is short if competitiveness is to be maintained, the rapid development of this legislation is desirable, which will require high-level support by the EC.

In parallel, a further increase in research and development of hydrogen related technologies is needed to enable Europe to gain leadership. Complementary actions should be undertaken in the field of education where a broad range of activities can support the commercialisation of hydrogen. These may vary from the harmonised education and training standards of technical staff to hydrogen-focused university degrees.

Early Markets

This stage of a transition towards a hydrogen economy is critical, since high growth rates lead to attractive sales volumes and simplify the business case for both hydrogen application producers and infrastructure providers. In this context governmental procurement is expected to be invaluable to stimulate early markets. This, in turn, assists the development of economies of scale for both technology producers and infrastructure providers. The process of identifying early markets by establishing sustainable "Hydrogen Communities" or "Hydrogen Competence Centers", which can be part-funded by the EC (e.g through the "Quick-Start" Program of the GROWTH Initiative), and which will demonstrate and stimulate early hydrogen markets is fundamentally important. Success will have important knock-on effects. Moreover, it is essential that the momentum generated by these “Lighthouse Projects” be capitalised upon in entering the next phase of technology development and application.

Currently, entry barriers for hydrogen applications exist on a technical, economic and socio-economic level. Finding financial solutions to reducing the uncertainty between the RD&D phase and the mature markets (i.e. bridging this early market phase) will be a major issue for constructing a hydrogen infrastructure and production facilities for hydrogen applications. Besides fiscal incentives on a European and national level, the allocation of venture and other private capital is a prerequisite for the development of a successful hydrogen technology space and for building up a supporting infrastructure. Moreover, it must be clear that current investments in infrastructure, which are generally long-term, can result in future profits (i.e. investments must not lead to stranded assets). Mechanisms to raise private money should be capitalised upon, to enable the requisite growth in production capacities for hydrogen technologies in this stage of commercialisation. Investment risk can be reduced if clear goals & policy signals for the uptake of hydrogen technologies and infrastructures are set.

Mid & Late Markets

During these latter market phases, private customers become a prime target group for hydrogen applications, and hydrogen can be considered to have left its niche markets. This will require proof that hydrogen can be competitive in the long term. Transition strategies need to be in place to lead from subsidised or regulated early markets to free markets where hydrogen technologies and applications are fully competitive.

By this stage hydrogen will have overcome some major hurdles and its impact on labour and environmental will start to be seen. However, there is still a danger that unforeseen barriers reduce the speed of penetration. Ongoing verification between the original strategy (roadmap) and the goals achieved can clarify these issues, and may highlight a need for strategy revision. It is therefore important to continue the strategic scenario work begun in the demonstration phase and to establish a monitoring process that updates the European Hydrogen Roadmap. In this way technological, political and public development towards a hydrogen economy can be aligned as appropriate.

Table 4-1 summarises important policy and socio-economic issues for the first three market phases of the transition towards hydrogen

Market phase	Policy Issues	Socio-Economic Issues
Demonstration	Ensure suitable regulations, codes & standards • Integrated EU approach for mobile, stationary and portable applications • include & build on EIHP and HarmonHy • maintain communication with other regions (US, Japan) • Goal: Harmonised GTR & ISO standards	Strategic Scenario Analysis • analysis of energy supply and distribution pathways • analysis of competitive technologies • labour market analysis including effect on supply chain structures
	Stimulate R&D • Use Framework 6 • Maintain global technology competitiveness • Enhance competitiveness of H_2 technologies	Advocacy of decision makers in public policy and industrial strategy
	Stimulate Demonstration • Develop Public Awareness Campaigns • Lighthouse Projects	Use portable consumer goods for familiarising the public with H_2 applications
	Drive the Education of Engineers & Staff • Professorial H_2 system chairs funded by EC and industry would help skills base • Develop EU standards for skills and training of technical staff (e.g. handbooks) Education at school level • provide basic H_2 knowledge (e.g. teaching material)	Industrial R&D will require significant numbers of engineers & staff compared with today • today only some engineering degrees focus on H2 technologies at a component level • There are very few activities on integrated "system level" (H_2 economy)
	International Hydrogen Partnership • ensure appropriate EU participation • ensure synergies with U.S. and Japan actions	
Early Markets	As above plus	As above plus
	Ensure EU H_2 support measures in place • fiscal incentives and depreciation regimes • taxation incentives • clear fixed duration & exit strategy	Managing financial uncertainty - help bridge the investment gap • attract venture capital and public/ private funding mechanisms • financing/ funding of infrastructure build up • define acceptable commercial targets and envelope
	Ensure appropriate public/ private procurement • (governmental, e.g. explore opportunities for "dual use technologies") fleets/ lighthouse projects, industry commitment on co-funding, supported by fiscal and legislative incentives • stationary applications (supported by planning & building regulations, energy efficiency standards)	Revision of Strategy: specific entry barriers / opportunities have to be addressed • insurance (barrier) • special mortgage packages (opportunity)
	Ensure favourable conditions for stationary applications in fully liberalised markets • legislation shall not disadvantage hydrogen • develop CHP directive and enable distributed generation	On basis of a technology- neutral CHP directive H_2 and FC technology must prove their competitiveness in the CHP and power markets
Mid & Late Markets	As above plus	As above plus
	Ensure competitiveness of H_2 applications • Shift from government-driven to free markets • start phase out of support measures as mainstream markets are fully penetrated	Revision of Strategy • Market support by target setting • "Validation" of roadmap legal obligations • 3 possible scenarios: "GO" (fast transient to mass markets), "Slow down" (H_2 in niche markets, transient to mass markets after further R&D), "NO GO"
		Materialisation of positive socio-economic effects • potential labour/ welfare impacts • environmental effects

Table 4-1 Summary of critical policy and socio-economic issues identified by HyNet

Conclusions

- The challenges faced by hydrogen are not simply technical but also socio-economic.
- To ensure success, governments will have to take an active role in stimulating research, development and large-scale demonstration.
- To stimulate commercialisation in its early market introduction, long-term policy support will be essential and fiscal instruments will be needed.
- This support should be of finite duration but long enough to ensure that it bridges the early immature market and the point that the hydrogen economy is robust, self-financing and competitive in a free market.

Part FIVE – Dissemination and Public Outreach

Public education and outreach programmes are an important, essential and integral part of the strategy towards the realisation of a European hydrogen-based society. The overall objective of public education and outreach is to inform and educate key audiences of the prospects of hydrogen, fuel cell systems and related infrastructure in the near future, and the long-term benefits of adopting these technologies.

The task is wide ranging and embraces many aspects. The programme will therefore require a broad approach to cover an increased level of activity, which will require substantially larger budgets for public education and outreach campaigns than the present levels of funding.

Knowledge of the potential benefits of hydrogen and fuel cells in the short-, mid- and long-term and the probable challenges ahead will facilitate the campaign to support a hydrogen economy.

The goal of public education and outreach

The specific goal of public education and outreach is to achieve, amongst key audiences, a level of understanding of hydrogen and fuel cells in order to facilitate the market acceptance and commercialisation of these technologies. Another goal is to manage the expectations of the public and to make certain that they are realistic and attainable within the present context. A successful outcome of the campaign will ensure that the target audiences will recognise the imminence of the hydrogen economy and appreciate the environmental and commercial benefits of hydrogen as an energy carrier. A successful campaign will enable the public to understand these benefits and, where appropriate, to play a role in the transition to a sustainable energy economy based on hydrogen. There should be a particular emphasis on managing perceptions of hydrogen as a fuel.

Current public awareness

At present the general public's understanding of the complexity of the issues surrounding the hydrogen economy is limited, despite coverage of this topic in the media having increased significantly in recent years.

There is a growing awareness of hydrogen and fuel cells within national governments, and strong support from the European Commission. However on regional and local levels the awareness is generally less developed and inhomogeneous, although there are some regional and municipal governments who have demonstrated leadership.

The authorities in most countries do not have any experience in terms of regulations for hydrogen. In cases where some experience does exist, it is generally positive and supportive but there is a risk of overly cautious or sometimes negative stances.

The topic of hydrogen and fuel cells is covered in the curricula of schools and universities in a number of countries. Demonstration kits of fuel cell units are available in a significant number of schools only in Germany and Luxembourg. Teaching material such as books and videos is available only to a limited extent in some countries. Some of the material is from the automotive industry or from the manufacturers of fuel cell demonstration units.

Target audiences

A number of specific target groups have been identified in addition to the general public. These are grouped into four major categories plus a "general public" category that embraces all four groups. The main audiences in each category are listed in the table below.

Legislature and regulatory bodies / society	Commercial Sector	Basic Education	Technical Training
Government officials incl. defense personnel Politicians Authorities responsible for regulations, codes & standards NGOs Media	Industry Utilities Key end users Associations	Teachers/ Professors Students Authorities responsible for national or federal state curricula	Mechanics and technicians
General Public			

Within the individual target audiences of each category some groups are classified in terms of having a high or a medium priority as listed below:

High Priority

- Authorities responsible for regulations and the implementation of codes and standards
- National, regional and local governments
- Students, educators, authorities responsible for national curricula
- Media
- Mechanics and technicians

Medium Priority

- Key end users (e.g. public sector)
- Industry
- Commerce, banking, finance, insurance companies

Actions for public education and outreach

Six activities have been identified to achieve the goals of public education and outreach. These are :

- gathering of information
- dissemination of information
- promotion and management of demonstrations for educational purposes
- fostering of partnerships to promote education and outreach
- management of public expectation
- reporting on results and lessons learned in EC research projects

All six categories are essential in a public education and outreach strategy on hydrogen, fuel cells and related infrastructure. Concrete actions have to be defined and carried out for each of these six categories. In each case the priorities of the activities should be established on a more detailed level to select those actions within the group marked as "high priority". A further need is to consider the potential activities in terms of the achievements expected in the short to mid-term and mid to long-term periods.

Role of the European Commission

A clear vision for hydrogen, fuel cells and related infrastructure at the level of the European Union is considered to be an important prerequisite for the formulation of a strategy for the development and deployment of hydrogen technologies. There should be a clear mission statement for the desired public education and outreach activities. Public education and outreach requires a long-term strategy to accompany research, development and demonstration from the earliest stages. There is therefore an urgent need for the European Commission to address the current disproportionate funding between RD&D and public education and outreach activities and to allocate a significant budget to redress the situation.

Funding priorities

There is a need for the European Commission to set funding priorities for activities of public education and outreach on hydrogen, fuel cells and related infrastructure. The emphasis should be to:

- change the scope and extent of funding making significant amounts available for public education and outreach.
- provide funding levels of up to 100% for certain activities such as public education, which is a governmental duty for the benefit of society.

A recommended means of achieving these changes is through the creation of a European Hydrogen Institute set up and funded by the European Commission to implement the programme and to carry out public education and outreach activities but not research.

Recommended actions

It is recommended that the European Commission undertake the following activities:

- Publish the results and "lessons learned" for each of the EC funded projects (the CORDIS Database only presents objectives, but not results).
- Effective dissemination activities for each of the EC funded projects.

Conclusions

- Public education is urgently needed to achieve a level of understanding of hydrogen and fuel cells to facilitate market acceptance and commercialisation. We recommend that the European Commission prioritise support for such outreach activities.

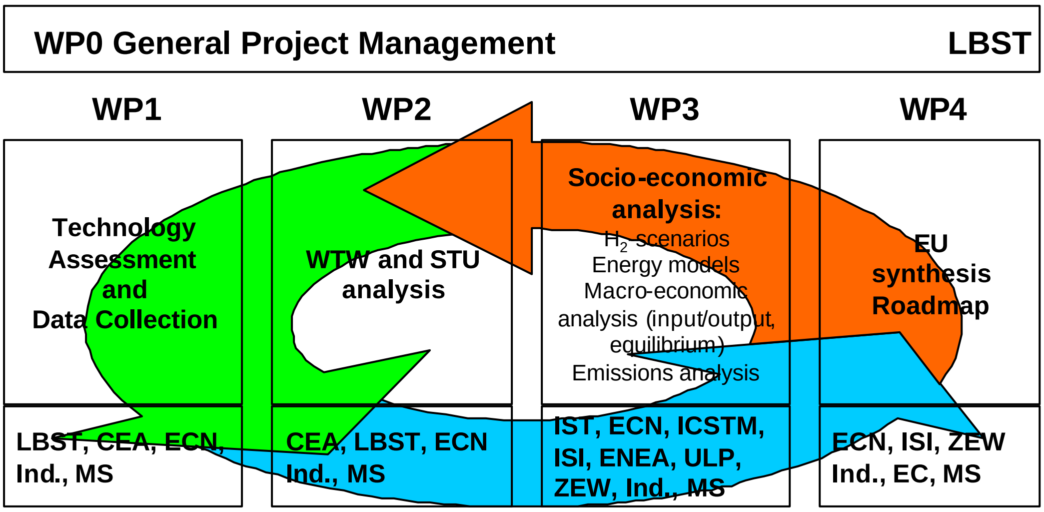
- Academic programmes need to be developed in all member states to help develop the skills needed to sustain this industry and ensure international industrial competitiveness.

- Within Europe, national, regional and local governments need to develop consistent strategies and policies for sustainable energy and transport systems that include the possibility of hydrogen. Such strategies would include the role that public bodies can play in stimulating early markets.

Outlook – Next Steps Towards a Fully Validated European Hydrogen Roadmap

In parallel to the process of developing a HyNet roadmap, a proposal “HyWays” for the preparation of a fully validated European Hydrogen Energy Roadmap has been submitted and a contract negotiated with the European Commission.

The partners of HyWays have agreed to use the input from the High Level Group on Hydrogen and Fuel Cells (HLG) and the HyNet Roadmap as a “starting vector”. HyWays started in April 2004. The objective is to develop member state roadmaps by using inputs from the participating member states and regional experts who will evaluate the technical, economic, social and ecological constraints and consequences. A summary of the work packages and main activities is illustrated below.



Ind. - Industry (20 auto, energy/oil and process companies)
MS - regional or member state experts

Global HyWays work package structure

These individual roadmaps will be validated iteratively by experts from the member states and later synthesised into a common European roadmap. This complex “bottom-up” analytical process will require the application of well-designed tools and models, which will be developed in the first phase of the project. The initial results will be synthesised in a preliminary analysis in co-operation with the five member states France, Germany, Greece, Italy, the Netherlands and Norway as representatives of the main regions of Europe.

In a second phase further member states, including the new acceding countries of Eastern Europe, will join the project partnership and will be incorporated in the synthesised roadmap.

HyWays acknowledges that hydrogen is one choice among other alternative fuels and is willing to contribute to the balanced debate on a future energy policy for Europe.

ANNEX

HYNET Workshop – straw poll of issues and concerns faced by Europe

During HyNet's MATRIX Workshop in Amsterdam on 21/22 July 2003 a group of about 40 experts were asked to identify major drivers and barriers for the introduction of hydrogen energy in Europe. This polling of the participants provided some interesting insights into the current perspectives of European hydrogen experts on the likelihood for success for the future introduction of hydrogen energy. The result of this process was compiled during the workshop and is summarised below:

- Europe's commitment to cleaner energies was a strong driver and key to long success
- European political support for hydrogen over a long period is essential
- There is a belief that industry will introduce innovation but the financial risks are potentially too high without government support
- Technology challenges are significant and must be supported by the development of codes and standards that are supportive of innovation.

Participants of HyNet's MATRIX Workshop 21/22 July 2003 in Amsterdam

1	Angelo Amorelli	BP
2	Joaquin Ancin	EHN
3	James Barron	Shell
4	Stefan Berger	GM/Opel
5	Volker Blandow	L-B-Systemtechnik
6	Achim Boening	Hoechst infraserv
7	Daniel Bourdin	EdF
8	Ulrich Bünger	L-B-Systemtechnik
9	Hendrik de Wit	Linde (HoekLoos)
10	Bettina Drehmann	Ballard Europe
11	Tim Evison	Messer Griesheim
12	Rei Fernandes	IST
13	Emma Guthrie	Air Products
14	Per Sigurd Heggem	Raufoss
15	Harm Jeeninga	ECN
16	Mike Jones	BP
17	Michel Junker	ALPHEA
18	Roger Koch	TÜV Nord
19	Pierre Laforgue	EdF
20	Paul Lucchese	CEA
21	Patrick Maio	Ernst&Young
22	Teresa Martinez	CSIC
23	Friedel Michel	Messer Griesheim
24	Cyrille Millet	Air Liquide
25	Thomas Neubauer	Ballard Europe
26	Andreas Otto	HERA
27	Marieke Reijalt	Fuel Cell Europe Italy
28	Jan Rogut	Central Mining Institute Poland
29	Carsten Rohr	Imperial College
30	Christoph Schmid	DMT
31	Philippe Schulz	Total
32	Jacques Smolenaars	Hexion
33	Hugo Vandenborre	Vandenborre Hydrogen Technologies
34	Oliver Weinmann	Vattenfall Europe
35	Jörg Wind	DaimlerChrysler
36	Guillermo Wolf	Repsol
37	Stefan Zisler	Vattenfall Europe