HyWays

The European Hydrogen Roadmap

Action Plan

Policy Measures for the Introduction of Hydrogen Energy in Europe

Summary

The HyWays Roadmap has outlined that as a result of the introduction of hydrogen into the energy system, substantial emission reduction can be achieved in a cost effective way, see (HyWays, 2007). At the same time, security of supply is improved and new economic opportunities are created. Despite the advantages, initial barriers prevent hydrogen from entering the energy system at a sufficient rate if no further policy incentives are provided. This Action Plan, developed based on the HyWays Roadmap, gives concrete policy actions that need to be taken to enable hydrogen to overcome smoothly these initial barriers.

Immediate action is needed to decrease the vulnerability of the economy to shocks in and/or structurally high oil prices as well as to ensure that the full potential offered by hydrogen as an emission reduction option is utilised. Yet, hydrogen is insufficiently high on the agenda of policy makers. As a result, the required deployment support is still lacking. The interests of ministries, which sooner or later will have to deal directly or indirectly with the consequences of the introduction of hydrogen, need to be aligned upfront. This will prevent delay as the technology progresses through the various transition phases before reaching full commercialisation.

Large-scale demonstration projects can play a key role in convincing policy makers that the performance of hydrogen technologies is progressing fast and has the potential to emerge quickly from the R&D-stage into the pre-commercial phase. A hydrogen support framework should therefore be implemented with highest priority. However, this might take several years. At present, large-scale demonstration projects are already being prepared. A public-private partnership, such as a Joint Technology Initiative (JTI), can bridge the period until the required support scheme is operational. Within such a public-private partnership, R&D and deployment support go hand in hand.

The main challenge lies in bringing down the cost for hydrogen end-use applications and in the build-up of a hydrogen infrastructure. Cost reductions can be obtained through both R&D (technological progress) and deployment (economies of scale). A monitoring framework is needed to ensure that support levels are appropriate and both R&D and deployment support are in balance in order to reach the point where hydrogen is competitive at minimum (cumulative) costs and as early as possible.

A European hydrogen specific support framework is needed
In the first phase, incentives need to be provided through a hydrogen specific support scheme. As competitiveness improves, the hydrogen specific support scheme can gradually be replaced by general schemes that support sustainability.

- At a European level, the R&D budgets for hydrogen production and its end-use applications need to increase to 80 M€ per year.
- At Member State level, a hydrogen specific deployment support framework needs to be implemented. Total costs of a deployment support scheme are in the range of 180 M€ per year. Starting point is equalising total costs (€ct/km) for road transport through financial measures such as tax incentives.
- Substantial investments are needed for infrastructure build-up. Tax-exemptions for hydrogen as a fuel play a crucial role in this initial phase where underutilisation of infrastructure will have a strong negative effect on profitability.
- Early markets need to be created utilising the advantages offered by hydrogen applications. Examples are city centre access regulations or procurement of zero emission vehicles within governmental and public services.

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1. Introduction

HyWays has the aim to develop a validated and well accepted roadmap for the introduction of hydrogen in the energy system. The HyWays Roadmap report has shown that as a result of the introduction of hydrogen, CO_2 emissions from road transport can be reduced by over 50% by 2050 in a cost effective way. The introduction of hydrogen in road transport contributes to improving air quality in the short to medium term, specifically in the most polluted areas such as city centres where the sense of urgency is greatest. In addition, security of supply is improved since hydrogen decouples energy demand from production. The HyWays Roadmap provides a detailed sketch of the build-up of a hydrogen energy system. The Action Plan – this report – outlines the policy actions needed to initiate and facilitate the desired transition. This chapter briefly describes the aim and context of the HyWays project. A more comprehensive description can be found in the HyWays Roadmap report (HyWays, 2007).

1.1 The need for a European Hydrogen Roadmap and Action Plan

HyWays explores and plans for the potential that the integration of hydrogen technologies into the energy system have to contribute to the challenges of ensuring that Europe's peoples and economies have a secure, environmentally sustainable and economically competitive supply of energy services for generations to come. In short, hydrogen technologies offer enhanced sustainability benefits in terms of cost-competitiveness, low well-to-tank carbon content, high energy efficiency and flexible reliance on diverse primary energy resources. Providing the ability to take a frontrunner position in the worldwide market for hydrogen technologies, it provides new economic opportunities and strengthens European competitiveness.

Despite these promising prospects, the introduction of hydrogen into the energy system does not happen autonomously. The introduction of hydrogen is a very innovative energy technology option that is not compatible with all existing fuelling and propulsion systems. Fuelling infrastructure and vehicle fleets will have to be build up in parallel from zero, requiring very diligent planning and governmental support. Substantial barriers have to be overcome, ranging from economic and technological to institutional barriers. The HyWays Roadmap and Action Plan for hydrogen in Europe provide a strategy to overcome these barriers.

1.2 The HyWays approach

HyWays deviates from a number of other road mapping exercises in that it integrates extensive modelling and stakeholder preferences in an iterative way, covering both technological and socio-economic aspects. Stakeholder validation and taking into account of country specific conditions are key elements of the road mapping process, see Figure 1.1. In the HyWays project the roadmap is based primarily on country-specific analyses of 10 member states (MS). The countries selected (FI, FR, DE, EL, IT, NL, NO, PL, ES and UK) ensure a large coverage, both in land and population, and represent the diversity and geographical spread of Europe, increasing the confidence in the validity of the synthesis at European level.

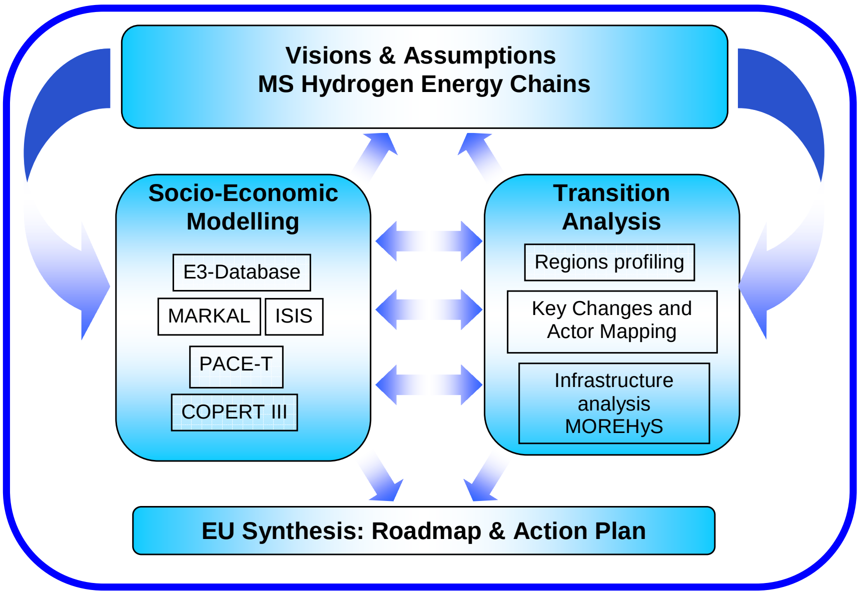

Figure 1.1 *Schematic representation of the HyWays process*

Within the context of the HyWays project, a number of reports are published:

- A Flyer on main results and key actions and recommendations;
- An Executive Summary of the Roadmap and Action Plan;
- The HyWays Roadmap;
- An Action Plan (this report);
- A Member States' Vision Report on the Introduction of Hydrogen in the European Energy System;
- Various background reports.

These documents are available for download at the HyWays web site: www.HyWays.de. This report comprises the Action Plan. The Action Plan is closely linked to the HyWays Hydrogen Roadmap and the Member States' Vision Report. Therefore, first a short summary of the HyWays Roadmap is given (chapter 2). Next, the need for a hydrogen support scheme is outlined and the general scope of the support scheme is described. In chapter 4, the basic characteristics of a hydrogen support scheme are presented, followed by a description of potential measures to be implemented at various policy levels (chapter 5). The report concludes with a list of main actions that need to be taken in order to overcome the initial barriers that prevent hydrogen from entering the energy system at a sufficient rate.

2. Summary of the HyWays Roadmap

The HyWays Action Plan is closely linked to the HyWays Roadmap. The Roadmap describes how hydrogen can be introduced into the energy system. It deals with technological, economic and environmental aspects of the various hydrogen pathways and includes cost targets and research priorities. The Action Plan, outlined in this report, provides concrete policy actions that need to be taken with priority in order to overcome the initial barriers that hamper hydrogen from entering the energy system. This chapter is a summary of the HyWays Roadmap, see (HyWays, 2007). The full Roadmap can be downloaded from www.HyWays.de.

MS-visions

The vision on how hydrogen should be introduced in the energy system played a major role in the HyWays project. Over 50 member state (MS) workshops were conducted with key stakeholders, during which inputs for the models were collected and outcomes of the analysis discussed, leading to further refinement of the MS-visions. Each country outlined its own preferences. As a result, it was concluded that Europe will need a portfolio of hydrogen energy chains. According to the stakeholders, hydrogen production in the early phase (up to 2020) will rely mainly on existing by-product, steam methane reforming and electrolysis (both onsite) to satisfy early demand. As the energy system evolves until 2050, stakeholders expect the production portfolio to broaden, with centralized electrolysis and thermo-chemistry from renewable feed-stocks (solar, wind, biomass) and sustainable sources (coal and natural gas with CCS and nuclear).

Main challenges

The introduction of hydrogen into the energy system faces two major barriers:

- *Cost reduction.* The cost of hydrogen end-use applications, especially for road transport, need to be reduced considerably to become competitive. A substantial increase in R&D investments is needed together with well balanced distribution of deployment to ensure that the economic break-even point is reached as soon as possible at minimum cumulative costs.
- *Policy support.* Hydrogen is generally not on the agenda of the ministries responsible for the reduction of greenhouse gasses and other pollutants, nor in ministries dealing with security of supply. As a result, the required deployment support schemes for hydrogen end-use technologies and infrastructure build-up are lacking.

Main conclusions from the HyWays project

- *Emission reduction.* If hydrogen is introduced into the energy system, the cost to reduce one unit of CO_2 decreases by 4% in 2030 and 15% in 2050, implying that hydrogen is a cost-effective option for the reduction of CO_2. A cash flow analysis shows however that a substantial period of time is required to pay back the initial investments (start-up costs). Total well-to-wheel reduction of CO_2 emissions will amount to 190 – 410 Mton per year in 2050.[1] About 85% of the reduction in emissions is related to road transport, reducing CO_2 emission from road transport by about 50% in 2050. Furthermore, the introduction of hydrogen in road transport contributes to a noticeable improvement of air quality in the short to medium term. This holds specifically for the most polluted areas such a city centres where the sense of urgency is greatest.
- *Security of supply.* Like electricity, hydrogen decouples energy demand from resources. The resulting diversification of the energy system leads to a substantial improvement in security of supply. The total oil consumption of road transport could be decreased by around 40% by the year 2050 as compared to today if 80% of the conventional vehicles were replaced by hydrogen vehicles. Based on the long-term visions as developed by the member states that participated in the HyWays project, about 100 Mtoe of oil is substituted due to the

[1] For the 10 countries analysed in HyWays.

introduction of hydrogen in transport. For the direct production of hydrogen, so excluding hydrogen produced by means of electrolysis, about 33 Mtoe of coal and natural gas and 13 Mtoe of biomass will be needed in 2050. According to these visions, about 45% of the hydrogen is produced by means of electrolysis from renewable, sustainable and nuclear energy. Equally important is the fact that several pathways exist that can produce hydrogen at comparable price levels and in sufficient amounts. This range of production options ensures a relatively stable hydrogen production price. At oil prices over $50 – $60 per barrel equivalent, hydrogen does become cost competitive as a fuel.

- *Sustainable use of fossil fuels.* Use of hydrogen for electricity production from fossil fuels in large centralized plants will contribute to achieving a significant reduction of CO_2 emissions if combined with CO_2 capture and sequestration processes.
- *Contribution to targets for renewable energy and energy savings.* The introduction of hydrogen into the energy system offers the opportunity to increase the share of renewable energy. Hydrogen can also act as a temporary energy storage option, so hydrogen facilitates the large-scale introduction of intermittent resources such as wind energy. Hydrogen produced from biomass allows for substantial efficiency gains compared to biofuels (and conventional fuels) when used in fuel cell and hybrid vehicles, thus contributing to energy conservation goals. The efficiency gain over biofuels is particularly important since the potential for biomass is limited and strong competition exists (e.g. power sector, feedstocks, food).
- *Impact on economic growth and employment.* The transition to hydrogen offers an economic opportunity if Europe is able to strengthen its position as a car manufacturer and energy equipment manufacturer. Substantial shifts in employment are observed between sectors, highlighting the need for education and training programmes. The shift to the production of dedicated propulsion systems will contribute to maintaining highly skilled labour in Europe rather than outsourcing these to countries where labour costs are low. Assuming that the import/export shares of vehicles in Europe remain the same, the overall impact on economic growth will be slightly positive (around +0.01% per year). This situation changes considerably if Europe is not able to maintain its position as major car manufacturer in which case there will be a substantial negative impact on welfare in Europe. The major benefit for economic growth is a strong decrease in vulnerability of the economy to shocks and structural high oil prices. Studies from the IEA and European Central Bank, for example, indicate that the (temporary) impact on GDP growth of prices shocks or structural high oil prices amounts to -0.2% to -0.4% of GDP growth.
- *End-use applications.* The main markets for hydrogen end-use applications are passenger transport, light duty vehicles and city busses. About half of the transport sector is expected to make a fuel shift towards hydrogen. Heavy duty transport (trucks) and long distance coaches are expected to switch to alternative fuels (e.g. biofuels). The penetration of hydrogen in the residential and tertiary sector is expected to be limited to remote areas and specific niches where a hydrogen infrastructure is already present.
- *Cost of end-use applications and infrastructure build-up.* The costs per kilometre driven for mass-produced cars are comparable to conventional vehicles, provided that the necessary cost reductions are obtained. A substantial period of time is needed before the initial investments are paid back. Total cumulative investments for infrastructure build-up amount to € 60 billion for the period up to 2030. This is about 1% of the societal costs for meeting the 450 ppm CO_2 target in Europe.

Table 2.1. *Summary of the deployment phases targets and main actions outlined in the Roadmap and Action Plan*

	2010	2015	2020	2030	2050
Phases	**Technology development with focus on cost reduction**	**Pre-commercial technology refinement & market preparation** **Start of commercialisation**	HFP Snapshot 2020 **materialisation of first impacts** • New hydrogen supply capacities partially based on low carbon sources • improvement in local air quality • More than 5% of new car sales H_2 &FC	HyWays Snapshot 2030 **Hydrogen & FC are competitive** • Creation of new 200,000 – 300,000 jobs/ safeguarding existing jobs • Shift towards carbon-free hydrogen supply • **More than 20% of new car sales H_2 & FC**	**H_2 & FC dominant technologies high impact** • 80% of light duty vehicles & city buses fuelled with CO_2 free hydrogen • reaching more than 80% CO_2 reduction in passenger car transport • In stationary end-use applications, hydrogen is used in remote locations and island grids
Targets	**LHPs facilitate initial fleet of a few 1,000 vehicles by 2015** • PPP "Lighthouse Projects" • Increase R&D budgets to 80 M€/year • Financial support for large scale demonstration projects		<u>Vehicles:</u> **2.5 million of fleet** <u>Cost</u> **H_2: 4 €/kg (50 €/barrel)** **FC: 100 €/ kW** **Tank: 10 €/kWh**	<u>Vehicles:</u> **25 million of fleet** <u>Cost</u> **H_2: 3 €/kg (50 €/barrel)** **FC: 50 €/ kW** **Tank: 5 €/kWh**	
Required Policy Support Actions	**Develop H_2 specific support framework** • Create / support early markets • Implement performance monitoring framework • Long term security for investing stakeholders • Education and training programmes • Harmonisation of regulations codes and standards	**H_2 specific support framework** • In place before 2015 at MS level • Deployment supports, e.g. tax incentives of 180 M€/year • Public procurement • Planning and execution of strategic development of hydrogen infrastructure		**Gradual switch from hydrogen specific support to generic support of sustainability (2020 →)**	**Incentives provided through general support schemes for sustainability**
	2010	2015	2020	2030	2050

3. The need for a hydrogen support scheme

This chapter outlines the need to provide incentives through a policy support scheme for hydrogen to overcome the initial barriers to the introduction of hydrogen. First, the main challenges to be tackled by the policy support scheme are presented. Next, the scope of the policy support scheme is described. Finally, the general characteristics of a policy support scheme for hydrogen are presented. This chapter provides the basis for chapter 4, where the hydrogen specific support scheme is worked out in more detail.

3.1 Main challenges

The HyWays Roadmap report has shown that CO_2 emission from road transport can be reduced by over 50% by 2050 in a cost effective way by the introduction of hydrogen. Furthermore, the introduction of hydrogen in road transport contributes to a noticeable improvement of air quality in the short to medium term. This holds specifically for the most polluted areas such as city centres where the sense of urgency is greatest. Hydrogen has the potential to contribute strongly to security of supply, since it decouples demand from production. Despite these promising prospects, hydrogen does not enter the energy system autonomously. Initial barriers have to be overcome before hydrogen can compete with the reference technology and alternative options. Policy support is needed to overcome these initial hurdles.

Two major achievements that are required in the first phase of the introduction of hydrogen in the energy system are:

- A quick ramp-up of the deployment of hydrogen end-use technologies, bridging the gap between the R&D stage and the commercialisation phase. If the deployment is too slow, upfront investments in infrastructure build-up and technology development have an unacceptably long pay back time. There is at present no policy support framework for the deployment of hydrogen technologies;
- Substantial cost reductions and further performance improvement, requiring an increase in R&D budgets (technological progress) together with deployment support (economy of scale). R&D expenditures need to be aligned with deployment to ensure that the break-even point is reached at minimum costs.

Until now, demonstration projects were funded mainly by industry and through R&D programmes. Hydrogen technologies are now entering the next phase of innovation, leaving behind the pure R&D phase. Large-scale demonstration projects are under preparation, see e.g. www.HyLights.eu. The step towards early commercialisation should be made through a series of large-scale demonstration projects of increasing size. Deployment and R&D activities go hand in hand between the phase of the development of prototypes and commercialisation. However R&D programmes, such as the EC Framework Programmes (FP7), are not applicable in the case of (small) series of – more or less – identical vehicles being built. The required deployment support can therefore not be provided by European research programmes. In addition, industry is willing to make significant investments in the prototype phase. However, as soon as series production starts, industry can not afford to sell the product at a loss. Both aspects indicate the need for a deployment support framework.

From incremental innovation to system change

Hydrogen technologies are so-called disruptive technologies. Their introduction requires changes in all parts of the energy system. Incremental innovations, which are (minor) modifications of existing (still applied) technologies, do fit quite well in the current, though unsustainable, energy system. Ambitious long-term policy goals on the reduction of greenhouse gasses can only be met by changing the current energy system into a sustainable one. Since incremental innovations provide little to no incentives for the energy system to change, the contribution in meeting long-term policy goals is limited. In fact, as a result of the lock-in effects created by these incremental innovations, the required transformation of the energy system might be severely delayed. Hydrogen needs to be phased-in gradually giving the energy system time to change. In the mean time, other incremental technologies have to be applied along with hydrogen in order to meet short- and medium-term policy goals. However, these technologies should preferably pave the way for hydrogen, while lock-out effects need to be avoided. The second generation of biomass-to-liquids (BTL), for example, offers substantial synergies with hydrogen in the production process.

From an innovation perspective, the period up to 2020 is short term, even if this is medium- to long-term in the political arena. Substantial time is needed to replace existing applications, build-up of production capacity and adapt the existing infrastructure. Given the long term challenges with respect to the reduction of greenhouse gas emissions and security of supply, system changes are inevitable. Incremental innovations, which can offer some relief in the short term, can be introduced at a higher pace, e.g. by blending a limited percentage of biofuels in the current fuel mix. However, if more ambitious goals need to be met, more changes are needed in the energy system to be able to deploy these technologies. This implies that these options in turn will also be confronted with time delays caused by the turnover rate of the existing stock. It is not possible to meet long-term climate change goals by means of incremental innovations, whilst ensuring security of supply at the same time. Hydrogen does offer the potential to reduce emissions on the long-term way beyond what is likely to be achieved with competing technologies. At the same time security of supply is ensured due to the high potential for diversification of the production mix.

3.2 General scope of the policy support framework

In order to overcome the challenges in the first phase of deployment of hydrogen end-use applications, the policy framework should:

1. Facilitate technological progress through R&D;
2. Facilitate the deployment of hydrogen end-use applications and infrastructure build-up;
3. Monitor the balance between R&D and deployment;
4. Ensure a level playing field.

The first two aspects support the introduction of hydrogen in a direct way. The third and fourth aspects are necessary boundary conditions.

Deployment support

At present hydrogen is, in general, not part of the portfolio of emission reduction options to mitigate climate change. Hydrogen can however contribute substantially to improving local air quality by 2020, specifically in areas with high levels of pollutants. Hydrogen will not contribute to achieving the emission reduction goals for Kyoto (2008 – 2012). Furthermore, hydrogen may have a small effect on total emissions on a macro level in 2020. Although hydrogen could be at the brink of commercialisation by 2020, due to the upfront investments needed for the deployment of end-use application and for the build-up of hydrogen infrastructure, hydrogen is not the most cost effective emission reduction option for the period up to 2020. After 2020, this picture changes and the costs to reduce additional CO_2 emissions are lower for a system that includes hydrogen, see the HyWays Roadmap report (HyWays, 2007). For this reason interests at ministries responsible for achieving climate change goals to develop a deployment support framework for hydrogen have been rather low. A related barrier is that within these ministries the knowledge of the potential added value of hydrogen is rather low.

A R&D and deployment framework to support hydrogen does (partially) exist in some countries. However, the origin of these programmes is not within the ministries dealing with climate change or security of supply, but rather in ministries dealing with innovation or economic competitiveness. For example in Germany, a country with a very strong automotive sector, a programme on the support of hydrogen has been established by the Ministry for

Transport, Building and Urban Affairs. A total of 500 M€ of public funding is being made available for R&D and deployment for the period 2007 to 2016.

Large-scale demonstration projects are likely to be the most effective way to convince the policy makers that hydrogen is not only a promise for the future, but an option that needs support now in order to meet their future ambitions. Here, a 'chicken and egg' problem seems to occur. Without the appropriate deployment support, large-scale demonstration projects cannot be financed and will not take place or will be severely delayed. Subsequently, without the large-scale demonstration projects, hydrogen will be insufficiently high on the political agenda and deployment support schemes to enable large-scale demonstration projects will not exist. One of the potential ways to force a breakthrough is by establishing a public-private partnership between the EU government and industry, for example in the form of a so-called Joint Technology Initiative (JTI).

Actions and recommendations:

- Raise interest in hydrogen at the political level; otherwise the required policy incentives needed to overcome the initial barriers will be insufficient and the implementation will be severely delayed.
- Implement large-scale demonstration projects to play a crucial role in putting hydrogen as a priority issue on the political agenda.

Cost reductions

The decrease in the cost of a certain technology is determined by two factors (Martinus, 2005). Firstly cost reductions are obtained by economies of scale as a result of an increase in production capacity (the so-called "learning by doing"). Secondly, cost reductions are obtained through R&D on matters such as performance, production process, materials and component optimisation. Hydrogen end-use applications in particular contain a number of components which have not been subject to mass fabrication, thus offering a large potential for cost reduction. However, these cost reductions can only be achieved through an appropriate combination of R&D and deployment.

In addition to the magnitude of the R&D budgets being in line with the deployment pace, (see also section 3.1), the R&D priorities should also be well aligned, ensuring that the most pronounced barriers are reduced. The added value notion that hydrogen can be produced from basically all energy sources has a down side in the sense that various barriers may have to be overcome in a wide number of hydrogen energy chains. In road transport, cost reduction of the drive train, specifically the costs of the fuel cell and onboard storage, are areas where R&D is expected to be able to bring down costs substantially. At the same time, performance (total driving distance, fuel consumption) may go up through efficiency improvements.

Monitoring of R&D and deployment efforts

The end-use applications have to be deployed at the right pace: not too slow and not too fast either. The deployment support scheme needs to ensure that the market penetration of hydrogen end-use applications increases at a sufficient pace. Only then will industry be able to achieve the required return on investments for the infrastructure build-up as well as for the build-up of production capacity for the end-use applications. Should the hydrogen end-use applications be deployed too fast, the learning effects will not able to penetrate the production process at equal speed. As a result, the break-even point where hydrogen becomes cost competitive is reached at higher cumulative costs due to the hampered learning. A monitoring framework has to be set up that ensures that both deployment and R&D efforts are in good balance. If deployment and R&D efforts are well balanced, the break-even point is reached as early as possible and at minimum cumulative costs.

Ensuring a level playing field
The policy support framework should ensure that the market within Europe is harmonised. Regulations for hydrogen technologies, e.g. in the area of safety, should be harmonised within Europe to create one European market rather than several markets dependent upon the characteristics of individual member states. As an example, in some countries it is not yet permissible to drive on a public road with a hydrogen vehicle registered in that specific country. This has a negative impact on the potential for large-scale demonstration projects and the expansion of these areas to other regions. In addition it also inhibits the national automotive industry from further development and demonstration of their prototypes. A continuation of this situation may lead to the case where only part of the European automotive industry is able to advance with hydrogen vehicles. This has a negative impact on Europe's competitiveness with non-EU countries.

Apart from creating a level playing field within Europe through the harmonisation of internal markets, there is also a need to maintain a level playing field with non-EU countries. If R&D and deployment conditions in countries such as the US and Japan are more favourable than those in Europe, due for example to more favourable deployment incentives, Europe may lag behind.

Actions and recommendations:
- Initiate steps towards large-scale demonstration projects, followed by a further ramp-up of the deployment through a series of early markets of increasing size in order to reach the commercialisation phase.
- Implement deployment support frameworks for hydrogen at member state level to enable these consecutive steps to be taken.
- Provide the deployment support, specifically in the early stage of market introduction, hand in hand with R&D support to ensure that the break-even point where hydrogen does become cost competitive is reached as early as possible at a minimum of total cumulative costs

3.3 Main characteristics of the support framework

The hydrogen support framework can be characterised by a number of elements:
- ***Level***; EU, MS, Local/regional
- ***Type***; financial, regulatory or other
- ***Focus;*** General vs. technology specific support
- ***Flexibility;*** Effectiveness to support a specific stage in the innovation trajectory

In this section, the link between the general characteristics of support schemes and the contribution to act upon the barriers preventing hydrogen to enter the energy system are described.

3.3.1 Policy support on EU, MS and local/regional level

Support frameworks can be introduced at the EU-level, national level and the local/regional level. At each of these levels, the drivers to support technology development and implementation differ. Drivers which do play a major role on all levels are the protection of employment and ensuring economic stability, preferably by creating additional economic growth. At the EU-level, innovation is a primary driver whereas at the national level, the need to meet the Kyoto target at minimum costs is an important driver as well as the need to improve security of supply. At regional and local level, improvement of local air pollution, specifically in heavily polluted city centres where urgency is highest, is a key driver.

The main focus of hydrogen programmes at the EU-level is on R&D aspects, for example through the Framework Programmes. These programmes are not suitable for the demonstration phase of a technology.[2] One of the key criteria of R&D programmes is that no support is given for production of a series of identical products; the innovative aspects are foremost. Therefore cost reductions obtained through economy of scale have to be obtained through deployment support programmes.

Financial support for deployment is not available through European programmes. As soon as a technology enters the deployment phase, it has to rely, if necessary, on financial support schemes for technology deployment at the national and regional/local level. R&D funding is also available at the national level where the research strategy should preferably have synergies with the European research agenda. When the technology has become mature, obligations can be set again at the European level. Options to regulate deployment of a specific technology are limited at the national level due to constraints with respect to market protection.

In the case of hydrogen, R&D programmes are available at both European and national level. However, national programmes to stimulate large-scale deployment of hydrogen end-use applications are lacking, due to the fact that hydrogen is not high enough on the political agenda of the ministries responsible for these programmes, see also section 3.1. The current support of ongoing demonstration projects is being financed from R&D-related budgets. However, these budgets are no longer applicable for the development of identical vehicles even if the fleets are small. This does not mean that further R&D is not needed anymore. Deployment schemes should go hand in hand with R&D support in the early phase of market introduction.

On a local and regional level, limited financial resources are available to subsidise the deployment of hydrogen end-use applications. However, a number of other measures are available which can potentially provide strong incentives to deploy hydrogen vehicles. For example zero emission vehicles could have preferential access to city centres or parts thereof, bus lanes, preferred parking etc. A number of cities and regions have already shown high interest in deploying hydrogen vehicles, due to their ability to improve major environmental problems such as local air quality and noise. Throughout Europe, a number of cities have already started implementing measures to discourage or even prevent very polluting vehicles from entering the city centre. A further sharpening of the regulations for city centre access is yet not feasible due to the lack of the commercial availability of vehicles that can meet, for example, zero-emission standards. It is likely that more ambitious restrictions will be put into force as soon as zero-emission vehicles become commercially available.

3.3.2 Type of policy support

The introduction of hydrogen into the energy system can be supported through financial incentives, such as taxes (including exemptions) or subsidies. Another type of instrument is regulations, such as minimum performance standards or limited city centre access. Finally, other instruments such as information (e.g. labelling systems) and education can be applied.

For hydrogen, the main barriers are in the area of deployment support as well as cost reduction of the end-use application, particularly the drive train of the hydrogen vehicle. Another major issue is the cash flow during the first phase of infrastructure build-up where upfront investments have to be made in order to meet future demand.

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[2] Applying for R&D support requires submission of comprehensive projects proposals, which usually requires several months of preparation. In addition there is no guarantee upfront that the proposal will be approved, and the evaluation process usually takes several months. After the proposal has been approved and the contract signed, it is quite complicated to deviate substantially from the contents as written down in the proposal. Given the substantial amount of time between the idea underlying the proposal and the start of the project, conditions may have changed considerably. The ability to adapt to this is desirable, specifically in a rapidly growing market with high technological progress.

Given the fact that hydrogen is yet to enter the phase of large-scale demonstration projects, regulations such as minimum shares of zero emission vehicles in total sales should be applied with utmost care (HyLights, 2006). Technological progress in this phase is hard to predict. A minimum progress level is likely but cannot be guaranteed. Obligations can provide a strong incentive with respect to market pull, but if the demand cannot be met, undesired market disruptions may occur, leading to a strong erosion of the willingness to support hydrogen.

Regulations with respect to city centre access can also provide strong incentives for the deployment of hydrogen vehicles. As a result of these types of regulations, early markets that tolerate initial additional costs can be created. However, a good balance needs to be sought between commercial availability of the technology and the timing of the implementation of these types of minimum performance regulations. A dialogue between the automotive industry and regions and cities needs to be established to harmonise expectations and to develop a common introduction strategy for zero emission vehicles by creating a series of early markets of increasing size. EC-funded projects such as HyLights (www.HyLights.eu) aim to facilitate this process.

Regulatory measures are considered to be inappropriate instruments in the early phase of market introduction. It is the financial support schemes that play a crucial role in providing the necessary incentives to overcome the initial barriers for the introduction of hydrogen. These support schemes should comprise deployment as well as R&D schemes, since both factors go hand in hand (and have to be well balanced) in bringing down the costs and improving the performance of hydrogen technology. As outlined in section 3.3.1, R&D schemes can be applied at both European and national levels. Deployment support schemes are, in general, implemented at national level although some funding may also be available on a local or regional level. Deployment support schemes should deal with both hydrogen end-use applications as well as infrastructure build-up. An outline of the design of such a hydrogen specific support scheme is given in chapter 4. Examples of possible financial measures are tax exemptions for hydrogen as a fuel and preferential road tax rates and vehicle purchase prices.

The proposed strategy to support the implementation of hydrogen technologies through R&D and deployment support schemes in the early phase is in line with the general innovation strategy for the support of innovative technologies in Europe. When the commercialisation phase is reached, specific R&D and deployment support for hydrogen technologies can gradually be replaced by general instruments that support sustainability, see section 3.3.3.

Education and training as well as the harmonisation of regulations, codes and standards can definitely contribute to creating the right boundary conditions for the introduction of hydrogen. However, they cannot provide the main incentives that will enable the initial cost hurdles for hydrogen to be overcome.

3.3.3 Generic vs. technology specific support

The introduction of hydrogen into the energy system can be facilitated by both generic and technology specific policy support schemes. Hydrogen end-use applications have to compete with both the conventional technology as well as other incremental innovations. Often, they are improvements of the reference technology, sharing a substantial part of the components. As a result, the additional costs of incremental innovations are usually low. At the same time, the potential for further cost reductions is limited. Deployment of hydrogen end-use technologies requires changes in all parts of the energy system: production, infrastructure and end-use applications. Initial costs of disruptive technologies such as hydrogen are, in general, substantially higher since fewer components are shared with the reference technology. In contrast to incremental innovations, the potential for cost reductions are high.

Generic schemes supporting sustainability, such as an emission trading scheme or CO_2 taxation, increase the costs of the conventional, polluting technology. Therefore, they provide an incentive to both disruptive technologies such as hydrogen as well as incremental innovations. However, they do not provide specific incentives to overcome the initial gap between hydrogen and alternative options. The philosophy behind generic instruments is that the market itself, under optimal conditions, will redirect itself. The main characteristic of this kind of generic market- based instruments is that the options that provide the highest return on investments in the short term are favoured over options that provide the highest economic and environmental potential in the long run. It leads to the lowest costs over the short term, but due to lock-in effects, may not lead to the lowest costs over a longer period of time.

By means of technology specific support schemes, the initial cost gap between hydrogen and competing options can be brought down. A second advantage of technology specific support schemes is that they can more effectively minimise barriers by targeting their origins. However, the technology specific support schemes hamper the competition between options, thus creating market imperfections that may prevent the energy system from moving towards its optimal state.

Both generic and technology specific support schemes offer advantages. Being a disruptive technology, hydrogen has to be introduced into the market gradually. Within the market introduction phase, costs have to be brought down towards a level where hydrogen can compete with alternative options. These objectives can be met by applying a hydrogen specific technology support scheme. As soon as mass market introduction has started, the technology specific support should be cut back and generic market-based instruments supporting sustainability should take over.

Actions and recommendations:

- Provide a hydrogen specific policy support scheme in the early phase to make hydrogen compete with alternative, non-disruptive options to ensure a gradual phase-in.
- Replace, with increasing competitiveness, the hydrogen specific support schemes by generic support schemes promoting sustainability.

3.3.4 Flexibility and implementation

The fact that hydrogen is a disruptive technology containing several components that have not yet been produced by means of mass manufacturing implies that firstly a large potential for cost reduction exists and secondly that specifically in the first phase of market introduction costs may go down very fast. Costs are assumed to go down by a certain percentage every time the cumulative capacity doubles (Neij, 1997). The period of time needed to double cumulative capacity is relatively short in the early phase. For a mature technology which has been mass produced for years, further cost reductions take a considerable amount of time.

Given the fact that costs for hydrogen technology, specifically for the end-use applications, are expected to go down rapidly in time, a rather flexible support scheme is needed to be able to follow the rapid improvement in the competitiveness of the hydrogen technology. If the costs go down substantially and the support scheme is not able to adapt to that, the result will be severe over-stimulation of the market. This again may lead to an over-heated market and exploding support budgets. History has shown that in these cases, future support levels were decreased substantially (or even put to a halt) towards levels that were insufficient to provide the required incentives. This creates a very undesirable ‘stop and go’ cycle. Not only will the effectiveness of the policy instruments be too low, but also the willingness to support the technology may be seriously affected since substantial public money will be lost. Also from an industry perspective, an overheated market situation followed by a severe slow down or even complete stop of demand development is a very undesirable situation. Therefore, it is of utmost importance to stimulate the deployment of hydrogen technologies by means of flexible support instruments. The monitoring of the technical and economic performance is a key issue in this respect.

Besides flexibility, a timely design and implementation of policy schemes is also a key issue. The support scheme has to be in place at the moment when it is first needed. If the policy scheme is only being developed when the sense of urgency arrives, its implementation will be, at a minimum, several years later than is actually needed. As a result, the introduction process is severely hampered (slowed down) and/or might even become redundant. Taking into account the fact that large-scale demonstration projects are under preparation and a small series (hundreds of vehicles) of hydrogen vehicles are being built, a deployment support scheme needs to be designed and implemented as soon as possible in order to avoid delays in the required ramp-up of the deployment rate. Within the HyLights project, www.HyLights.eu, the first steps to develop the basic design of such a framework for hydrogen in transport is being undertaken.

A potential barrier that can slow down the pace with which the required policy incentives are implemented is the fact that at the member state level the support schemes can have an impact for several ministries. Ministries likely to be involved sooner or later are ministries responsible for environmental pollution and climate change, economic competitiveness and innovation, security of supply and economic stability, governmental budgets (finance), mining (fossil fuels) and agriculture (biomass), science and education etc. These ministries may be involved in different phases of the design and implementation of the support scheme as well as in different phases of the innovation process. Some of them initiate the process, e.g. ministries involved in energy innovation, whilst others are just confronted with the consequences at a stage where the introduction of hydrogen does become visible at a macro level, e.g. since the demand for biomass goes up substantially, thus interfering with other agricultural needs. Each of these ministries has their own interests. These interests may even be partly conflicting. In the US, all relevant ministries are involved in the early phase of the decision making process. By doing that, harmonisation of interest is obtained at the start of the process and interests are aligned. This avoids that ministries not involved in the initial phase of the introduction of hydrogen, will experience unexpected side effects at a later stage that are not in line with their own interests.

Actions and recommendations:

- Stimulate the deployment of hydrogen technologies by means of flexible support instruments in order to ensure a gradual and controlled phase-in of hydrogen technologies whilst maximising cost-effectiveness.
- Devise deployment support schemes that are able to adapt to the expected rapid improvement of the economic and technical performance of hydrogen technologies.
- Establish, as a prerequisite, a monitoring framework with respect to the development of technical and economic performance in order to be able to adapt to changing conditions.
- Design and implement, with the highest priority, a deployment support scheme for hydrogen to avoid undesirable and substantial delay in the ramp-up of the deployment of hydrogen vehicles.
- Align, at an early stage, the interests of all ministries involved in the early and later phases of the introduction of hydrogen into the energy system. Ensure mutual cooperation and take care upfront of resistance due to the occurrence of unexpected side effects that are not in line with the interests of a specific ministry.

4. A hydrogen specific support framework

In the previous chapter, the general characteristics of a support framework are described in relation to the incentives needed to introduce hydrogen into the energy system. In this chapter the framework and conditions for a hydrogen specific support scheme are further elaborated building on the general characterisation outlined in chapter 3.

4.1 The need for a tailor-made approach

In the past, several renewable energy technologies have gone through the innovation stage that is now being entered by hydrogen. A rather obvious approach might be to adapt the support framework developed for renewable options, such as wind and photovoltaics, and extend this to hydrogen. However, there are some important differences between renewable energy technologies and hydrogen. Renewable electricity production options can make use of the existing energy distribution grid (high voltage power lines). More important, end-use applications can (obviously) switch without a problem from conventional to renewable electricity. In the case of high market shares of intermittent renewable electricity production, reinforcements of the electricity infrastructure may be needed alongside changes in the power sector.

Support schemes for renewable electricity either stimulate demand (e.g. by tax exemptions for green electricity), or production (e.g. by subsidising investments in production capacity). A more detailed analysis of the potential to use existing support schemes of renewable energy to support hydrogen can be found in (Jeeninga et.al., 2006). For hydrogen, not only barriers in production have to be overcome, but initially also major hurdles exist with respect to end-use applications and infrastructure. Therefore, copying or adapting schemes designed for renewable options such as renewable electricity is not possible in the case of hydrogen. Given that barriers have to be overcome in all parts of the energy chain and that various production pathways are feasible, hydrogen needs a tailor-made support scheme.

A general starting point for support schemes for technology deployment is to remove the additional costs between the new technology and the reference option (Jeeninga et.al., 2006). The additional costs may depend on the specific situation. For example, in early markets, additional costs may be substantially lower due to the ability to utilise specific advantages of the new technology. In the case of hydrogen, calculation of the additional costs is very complex, since the additional costs are not only determined by the additional costs of the end-use application but also by the cost of hydrogen as a fuel as well as the fuel efficiency. Additional costs have therefore to be assessed based upon a comparison of the total costs of the use of the application.

With road transport for example, total costs for the end-user can be expressed in terms of €ct/km driven. These total costs are determined by various factors such as the retail price, maintenance costs and depreciation of the vehicle as well as the fuel efficiency (GJ/km) and the costs of the fuel (€/GJ). Costs of the fuel are determined by the cost to produce hydrogen as well as the costs for the hydrogen infrastructure (costs to transport hydrogen from the production location to the fuelling station (including costs of storage)). The total costs for the end-user can be influenced in various ways. Providing financial incentives to production, infrastructure or end-use applications will all lower the costs for the end-user of the hydrogen application. Each approach has different side effects. By de-taxing hydrogen as a fuel for example, production is indirectly stimulated since demand will go up as a result of the lower price. In this case, it is up to the market to decide what pathways to use to provide the hydrogen. If production capacity is subsidised, specific production pathways, such as renewable energy based pathways, can be stimulated over others.

Taking into account the rapidly changing conditions with respect to the improvement of the competitiveness of hydrogen technologies in time[3], a single support scheme addressing all barriers effectively at their origin while at the same time offering the required flexibility to adapt to these changing circumstances, seems hardly possible. A potential solution, that also addresses the fact that different actors (and markets) are involved in specific parts of the energy chain, is to break down the deployment support scheme into two – mutually dependent – support schemes. The first support scheme can address cost of the fuel, the second support scheme then addresses the costs of the end-use application, such as the vehicle. Target levels have to be set for fuel costs (€ct/GJ) and vehicle costs (€/vehicle) in a way that the total costs (€ct/km) are equal to the total costs of the conventional vehicle. It is likely that support levels vary between different vehicle classes. Further research with respect to this topic is undertaken within the HyLights project (www.HyLights.de).

Actions and recommendations:

- Hydrogen needs a tailor-made support scheme in order to be able to address the various barriers in production, infrastructure and end-use.
- The starting point for such a support scheme could be equal costs for the use of the hydrogen technology in comparison to the reference option.
- For road transport, design and implement support schemes for hydrogen as a fuel as well as hydrogen vehicles. Both schemes should be adjusted to each other to ensure that the total costs (€ct/km), being a function of fuel costs and vehicle costs, match the total costs of the reference option.
- Preferably, the basic design of the deployment support scheme should be harmonised throughout Europe. Given the differences in tax regimes that exist between countries in Europe, a tailor-made adjustment needs to be made on a member state level.

4.2 Link to support schemes for renewable energy and sustainable transport

Although existing policy support schemes cannot be copied to support hydrogen, hydrogen can become an explicit part of the support schemes for renewable energy and sustainable transport. Even though these incentives alone are not sufficient for hydrogen to overcome the initial barriers, they will help to decrease the gap between hydrogen applications and the reference technology. However, some major drawbacks might exist, depending on the nature of the support scheme that hydrogen could become a part of.

In the case that obligations are set for a minimum share of hydrogen as a fuel (or hydrogen based end-use applications) through support schemes for renewable energy or sustainable transport, the same drawbacks hold as for setting obligations through a hydrogen specific support scheme, see section 3.3.2. In the case of hydrogen, the availability (or the sustainability) of the fuel is not the only barrier, the main barriers to be overcome are for the end-use applications. This is unlike green electricity that can be used without any problem for existing end-use applications. Other incremental innovations, such as biofuels, can up to a certain percentage be blended with conventional fuels without having to make adjustments to the conventional vehicles. For higher shares of biofuels, e.g. E85, additional costs for the end-use application are very small and fuel costs are the main barrier. Therefore, in these cases, support schemes for the energy carrier are effective instruments. For hydrogen, supporting hydrogen as a fuel is only part of the solution. This is outlined in more detail in section 4.1. In the case of hydrogen, demand (deployment) and production (capacity) are not automatically in balance when providing incentives to either demand or production. Stimulating one without the other

[3] E.g. costs go down fast and performance goes up.

may cause major misfits, which can lead to an unnecessary decrease in support for and belief in hydrogen as a transition option.

Embedding hydrogen in financial support schemes for renewable energy and sustainable transport will increase the share of renewable sources in the hydrogen production mix. However, competing incremental innovations are also likely to profit from these types of support schemes. Even though the gap with the conventional technology may become smaller, the initial gap with competing incremental innovations remains unaltered, see also chapter 3.

Finally, another potential draw back of incorporating hydrogen into the existing framework is the fact that the idea might arise that this type of support should be sufficient to enable hydrogen into the energy system. If this type of support scheme is sufficient for competing, though incremental options, it should do for hydrogen too? As outlined in chapter 3, for the early introduction phase a hydrogen specific support scheme is necessary to bridge the initial gap with competing options. As a result, policy makers might be disappointed due to the fact that hydrogen does not enter the energy system at the pace they had expected. Even though embedding hydrogen in the existing and upcoming support frameworks for sustainable transport and renewable energy can provide part of the required incentives for the introduction of hydrogen, policy makers need to be aware that in the initial phase an additional support scheme for hydrogen is required.

Recommendation:

- Inform policy makers in order to ensure that they understand the need for an additional hydrogen specific policy support scheme on top of support schemes for renewable energy and sustainable transport in the initial phase of the introduction of hydrogen into the energy system.

4.3 A public-private partnership

In the previous sections it is concluded that a flexible deployment support mechanism is needed which has to go hand in hand with R&D support. Large-scale demonstration projects for hydrogen in road transport are being prepared and small series of hydrogen vehicles are being built. Yet, suitable deployment support schemes are lacking and it may take a substantial amount of time before they are finally implemented. A public-private partnership (PPP) between the European Commission and industry, for example in the form of a so-called Joint Technology Initiative (JTI), can play a crucial role to prevent that the introduction of hydrogen technologies is substantially hampered due to a lack of policy incentives. Such a public-private partnership offers the required flexibility between deployment and R&D support and can be established reasonably soon.

Actions and recommendations:

- A public-private partnership between the European Commission (EC) and industry can play a crucial role in safeguarding the progress of the introduction of hydrogen technology by bridging the time until the required policy incentives for hydrogen are in place.
- Involve Member States within this public-private partnership, given their crucial role in the implementation of a hydrogen specific support scheme.

4.4 The role of early markets and niche markets

Early markets and niche markets may play an important role in bridging the gap between the prototype phase and the commercialisation phase. ***Early markets*** are parts of the full (commercial) market with slightly deviating characteristics. As a result, a higher tolerance exists with respect to the additional costs by utilising (some of) the advantages offered by hydrogen technology. Examples of early markets are remote areas (e.g. islands) for stationary hydrogen end-use applications or public buses in city centres for hydrogen in transport applications. ***Niche markets*** are specialised markets where applications that share some components with 'regular' hydrogen applications are used.[4] Examples of niche markets are aerospace (fuel cell for power production), fork lifts, specialised vehicles to transport disabled people at airports and the use of small fuel cells in portable consumer electronics.

Niche markets may play an important role, for example by making the general public more familiar with the (positive) contribution of hydrogen technology. Nevertheless, usually either their size is limited in comparison to main markets (e.g. the market for fork lifts and specialised vehicles at airports is much smaller than the market for passenger cars) or deviate significantly in technological properties (e.g. the fuel cell in consumer electronics has to produce Watts rather than kWatts). Therefore, niche markets are considered to be supportive rather than a main driving force.

An early market may exist since its properties deviate from mass market. Early markets can be created due to the following characteristics:

- Financial aspects;
- Technological requirements;
- Other aspects, such as local air pollution and noise.

Financial aspects

In a full competitive market, maintaining the level playing field between the different market players is a key issue. The level playing field will be disturbed if only part of the players competing in an open market is confronted with higher costs e.g. due to environmental regulations. Market share will be lost to players who are not confronted with this increase in costs. In a monopolistic situation, higher costs can be transferred to the customer. Sometimes even 'the customer' is difficult to identify directly. Governmental organisations are examples of such a monopolistic situation. Other potential early markets are competitive markets which can only be entered in case specific requirements are met. This holds for example for areas which only can be entered by zero-emission vehicles. In this case, all market players have to meet the same conditions.

Some markets have a temporary monopolistic nature. In the Netherlands, public transport in cities and regions is being put out to tender. This implies that in principle every market player can enter the market. However, the market player that wins the tendering procedure gets the right (or obligation) to operate the public transport services for a number of years. Within the conditions of the tender, specific boundary conditions with respect to environmental performance, such as the obligation to operate a minimum of *x*% zero emission vehicles, can be included. A complicating factor is that in some cases the price of the services, e.g. a bus trip, is fixed all over the country or region.

Technological requirements

In some markets, the requirements with respect to the technological performance, such as daily driving distance, top speed and pay load, differ from the mass markets. In the early phase, hydrogen vehicles may not be able to meet yet for all aspects the performance levels of the conventional vehicle. In many cases, the conventional vehicle has a severe over-performance. Specifically in rural areas, the ability to cover 200 – 300 km a day without refuelling is more

[44] Within the context of the HyWays project, the potential to contribute to changes in the energy system on a macro level is the leading perspective for defining niche markets.

than sufficient. Another aspect that specifically is important in the early phase of infrastructure build-up is the ability to refuel the vehicle. For fleets that return every day to their ‘home base’, i.e. a garage for city busses, a single fuelling station in the neighbourhood of their home base would be sufficient to serve the whole fleet. This specifically holds for those markets where daily driving distance is below the distance the vehicle can cover without refuelling.

Other aspects

Even in the early phase, on specific aspects the hydrogen vehicle will already perform better than the reference vehicle. Rather than searching for markets that can match the performance of hydrogen applications, markets that are able to exploit the value added of the hydrogen vehicle could be exploited. Potential characteristics that can be utilised are improvement of air quality and noise reduction. Other aspects that may be of relevance are the public and governmental support for hydrogen. Specifically in areas where the manufacturer of the technology is located, support is usually higher, resulting from the fact that the industrial branch is responsible for part of the employment (and associated welfare) in the region. In addition, in this case the local knowledge network can be exploited quite well due to the short (geographical) distance to the manufacturer.

Early market development

Some of the early markets as described above may exist by itself. Other early markets may be created deliberately, e.g. by setting implementing agreements on greening of governmental car fleets or by limiting city centre access to zero emission vehicles. In order to reach the commercialisation phase, a series of early markets with increasing size has to be exploited. This evolution of early markets should be able to gradually bring the hydrogen technology to the level where it can fully meet the technological and economic requirements. Most convenient early markets to start with are those early markets with favourable conditions with respect to economics, technological performance as well as other aspects. Such an ‘early’ early market could for example be a governmental department (monopolistic situation) that operates in a major city (local air pollution, noise reduction), providing a local service (single fuelling point, limited daily distance) in an area that strongly benefits from the industrial activity of the technology providers (public acceptance, local support).

5. Concrete incentives to enable the introduction of hydrogen technology

In this chapter, possible incentives to be implemented at EU, national and local/regional level are discussed. The incentives mentioned in this chapter can all play a more or less important role in the support of hydrogen. The majority of the incentives involve facilitation, but are by themselves insufficient to act as a single driver for the introduction of hydrogen. The core of the incentives that can act as main drivers is outlined in chapter 4 of this report. They are also briefly mentioned in this chapter again.

5.1 Incentives at the EU-level

As indicated in section 3.1, direct support for hydrogen can be provided through the Framework Programmes (e.g. FP7). A key issue is to maintain the right balance between R&D efforts and deployment support at the national and local/regional level. If necessary, R&D budgets need to be raised in case of discrepancies between R&D and deployment expenditures, see section 4.1. A prerequisite to be able to maintain a good balance is the establishment of a European-wide monitoring framework for costs and technical performance of hydrogen technology. A point requiring attention is the harmonisation of the R&D programmes at EU-level with the R&D programmes at Member State level.

In addition to providing direct R&D support for hydrogen specific technologies, indirect support can also be given by supporting the development of sustainable and renewable non-hydrogen technology that may play a crucial role in the hydrogen pathways. This indirect support will help to pave the way for the introduction of hydrogen in the energy system. Examples are sustainable options such as CCS and renewable options such as wind energy, biomass, solar thermal power production, photovoltaic energy and hybrid vehicles. At the EU-level, various labelling schemes are or will be implemented in the near future. Examples are an energy labelling scheme for domestic appliances (washing machines, fridges, freezers, ovens, clothes dryers etc.), extending to existing dwellings as well as passenger cars. The environmental benefits such as zero emission technology should be clearly visible within the energy system labelling schemes. This is specifically important since a number of Member States do base their subsidy schemes on the environmental performance as outlined by the energy label. This also holds true for some governmental departments as well as companies who base their policies with respect to the type of vehicle that is acceptable as a company car also on the labelling system.

Given the current mandate of the European Commission, large-scale deployment support schemes cannot be implemented at the European level. However, the EU can play a crucial role in harmonising regulations at the Member State levels. This includes harmonisation of codes and standards, but also the main characteristics of a deployment support scheme. The EU can also play an important role in putting hydrogen technology higher on the political agenda of ministries at the Member State level. In addition, the EC can play a role in promoting incentives to transform the current energy system into a more sustainable one. The implementation of external costs at the Member State level is an example of such an incentive.

A basic characteristic of the European Emission Trading Scheme (ETS) is that it promotes sustainability through regulation, aiming to minimise costs in the short term by relying on market forces, see section 3.3.3 for the potential draw backs for hydrogen. The transport sector is not yet included in the ETS system. Expanding ETS to the transport sector will, in the short term, be counter productive for the introduction of hydrogen into road transport, since incremental innovations will be forced in, creating undesirable lock-in effects. For the power sector, the Emission Trading System will provide incentives for sustainable and renewable energy production, although also in this case a far reaching transformation of the power sector towards hydrogen is slowed down due to the focus on short-term cost optimisation.

Last but not least a public-private partnership between the EC and industry, e.g. in the form of a Joint Technology Initiative can play a crucial role, see also section 4.3. In the early commercialisation phase, technology specific deployment support and R&D must go hand-in-hand. Moreover, small series of hydrogen vehicles are being built, outlining the urgency for a deployment support scheme. Such a scheme, which is expected to be of a rather complex nature (see section 4.1) is yet lacking and it may take several years before it is actually implemented, potentially slowing down the ramp-up of hydrogen technology. A public-private partnership is the most suitable framework to be able to provide the required R&D and deployment support.

5.2 Incentives at the MS-level

Member States play a crucial role with respect to implementing deployment support schemes, see section 3.1. Besides being the key actor to provide deployment support, the ability to provide R&D support tailored to the country specific conditions is another key asset. In the past, transformation and build-up of infrastructure have been initiated and/or controlled by governmental bodies. As a result of liberalisation, the governmental involvement in infrastructure related activities has decreased. Despite these changing market conditions, the government can still provide valuable contributions to infrastructure development by initiating and coordinating a coherent planning of infrastructure build-up. The first steps taken in infrastructure build-up should go into a direction that also fits future large-scale demand in both an economically and environmentally sustainable way.

At the governmental level, a variety of potential policy instruments are available for financial support of hydrogen pathways. First of all, hydrogen vehicles should be stimulated through road pricing instruments. In addition, hydrogen as a fuel needs, at least in the early phase, to be de-taxed. Some countries have excise taxes on the purchase of new vehicles in addition to V.A.T., (e.g. Denmark, the Netherlands), providing a substantial potential for tax exemptions. Legislation in force in the Netherlands in 2007 provides for a tax exemption of € 6.000 for a hybrid vehicle[5] (VROM, 2007). The Danish government has issued a National Energy Plan onwards 2025 where hydrogen cars are free of all taxes (Hydrogen Link, 2006). Given the very high excise taxes on the purchase of new vehicles in Denmark, this offers a major tax advantage. In countries where there are no excise taxes on new vehicles, tax incentives could be provided through lowering V.A.T. An adverse effect that definitely needs to be avoided is the fact that governmental taxation does increase due to that fact that the additional costs of the hydrogen vehicle are also taxed.[6] As a minimum requirement, the additional costs of environmentally friendly technology such as hydrogen applications should not be taxed. Other possibilities are tax exemptions for zero emission company cars.

Embedding hydrogen in existing support schemes for renewable energy will provide incentives for the hydrogen production mix and will increase the share of renewable based hydrogen. In the early phase of the introduction of hydrogen these support schemes are insufficient by themselves to overcome the initial barriers. On a Member State level, early markets for hydrogen applications can be created and facilitated. Governmental services can set targets for minimum shares of zero emission vehicles. Codes and standards, to be harmonised on a European level, should be implemented timely. Also the development and implementation of education and training programmes needs to be facilitated. Finally, internalisation of external costs will improve the conditions for a cost effective deployment of hydrogen technology.

[5] Some boundary conditions have to be met: e.g. minimum requirements were set for the power of the electric motor.

[6] In other words, if a hydrogen vehicle has additional costs of € 2,000 in a country with 20% V.A.T. and 40% of excise taxes, the consumer has to pay an additional € 3,360 for the vehicle and tax revenues go up by € 1,360. As a minimum requirement, the additional costs of environmentally friendly technology such as hydrogen applications should not be taxed.

5.3 Incentives at local and regional level

Local and regional governments can play a key role in creating strong early markets, see also section 4.4. In addition, several facilitation incentives can be provided. Examples of instruments to create early markets are limited city centre access, allowing only zero emission vehicles to enter specific parts of the city. Furthermore local governmental services can play a key role by providing early markets. Local governmental vehicle fleets normally return to one single location at the end of the day, facilitating hydrogen refuelling at a single fuelling point. Targets should be set for a minimum share of zero emission vehicles.

Demonstration projects in the past, such as the one with battery electric vehicles in La Rochelle, France, have shown that optimisation of logistics can provide significant advantages over the reference situation, at the same time creating favourable market conditions for the deployment of zero emission vehicles. By building a logistics centre just at a strategic location, all goods to be transported to the city centre are collected. Not only the distribution of goods is optimised – one vehicle delivers five packages at one customer rather than five vehicles one – also a market situation that enables the preferred deployment of zero emission vehicles is created.[7] Another example is the privilege for zero emission taxis to be first in line to pick up customers.

Facilitating measures are the ability to make use of e.g. bus lanes, preferred parking, no parking fee, reduced fee or privileged access to parking permits. Also, in some cases subsidy schemes do exist on local and regional level which can be utilised to support zero emission technology.

[7] Only a limited number of vehicles is needed to serve the whole city centre, one single fuelling station is sufficient to supply all vehicles

6. Actions needed to facilitate the introduction of hydrogen

Hydrogen is not likely to enter the energy system autonomously at a sufficient rate. It can contribute to main policy goals (HyWays, 2007) since hydrogen:
- has the potential to contribute in a cost effective way to a substantial reduction of greenhouse gas emissions as well as other emissions for services where limited alternatives exist;
- contributes to security of supply by decoupling demand and production, specifically for services which currently heavily rely on oil-based fuels;
- contributes to welfare by decreasing the vulnerability of the economy to high oil prices and by providing opportunities to strengthen Europe's position in car and energy equipment manufacturing.

Immediate action is required to overcome the initial barriers that hamper the introduction of hydrogen into the energy system. Substantial cost reductions have to be achieved through both R&D and deployment (economy of scale). Policy support is a key factor in achieving these cost reductions. Still, hydrogen is not sufficiently high at the political agenda. As a result, deployment support schemes for hydrogen are lacking and R&D budgets are too low.

Main Actions
To enable a gradual introduction of hydrogen into the energy system, the following main actions are required:

- *Design and implement a technology specific support framework for hydrogen*. Generic enabling frameworks to support sustainability will give hydrogen and alternative options an advantage over conventional technologies. In order to bridge the cost gap with alternative options, a technology specific framework for hydrogen is needed. This should comprise the following elements:
  - *Innovation*; Increase the R&D budgets for hydrogen and its end-use applications to (a minimum of) 80 M€ / year (HFP, 2007).
  - *Deployment support*; A hydrogen specific deployment support framework needs to be developed. Deployment is an important factor in bringing down the costs of hydrogen applications to a level where they can compete, and eventually can become more profitable, than the reference technology. The starting point for such a deployment support framework is to equalise the total costs (€ct/km) for the use of a hydrogen vehicle in comparison to a conventional vehicle. In the initial phase, substantial deployment support is however needed with budgets of around 180 M€ per year (HFP, 2007).
  - *No tax on hydrogen as a fuel;* De-tax hydrogen as a fuel in the first phase of the introduction of hydrogen into the energy system. Substantial investments are needed in infrastructure build-up. Tax-exemptions can play a crucial role in this initial phase where underutilisation will have a strong negative effect on profitability.
  - *Tax exemptions for hydrogen vehicles;* The additional costs of the hydrogen vehicle have to be (partly) compensated for by tax exemptions (or subsidies).
  - *Creation of early markets;* National and local governments should create early markets which tolerate higher additional costs for the vehicle. Examples are limited city centre access or procurement of zero emission vehicles within governmental services. An EU-wide procurement scheme for hydrogen vehicles should be established, involving EU governments at all levels as well as private fleets.
- *Planning and financing of infrastructure build-up;* In the early phase of the hydrogen transition, underutilisation of the infrastructure is likely to occur. Careful planning is needed to ensure that the infrastructure build-up in the early phase will also fit the long-term and corresponding high demand.

- *Level playing field;* Remove barriers within Europe (harmonisation of regulations, codes and standards) and set European incentives for deployment and R&D (at a minimum) at a comparable level in order to be able to compete with areas outside Europe (US, Japan).
- *Early alignment of interests of all ministries involved;* Align at an early stage interests of all ministries which have to deal directly or indirectly in an early or later phase with the effects of the introduction of hydrogen. Handle potential resistance due to the occurrence of unexpected side effects that are not in line with the interests of a specific ministry upfront. This prevents delay as hydrogen reaches the next transition phase.
- *Monitoring framework;* Implement a monitoring framework, assuring appropriate support levels and a good balance between R&D and deployment, in order to minimise total cumulative costs to reach the break-even point.
- *Look for synergies with other options;* While preparing for the system change towards hydrogen, investments will also be made in near-term options to optimise the current (internal combustion engine) system for sustainability. Focus investments on options that provide synergies with hydrogen production and end-use applications, such as 2nd generation biomass-to-liquids (BTL from biomass gasification) and hybrid vehicles (i.e. regenerative braking, power management).
- *Education and training;* Set up and implement education and training programmes on hydrogen and fuel cells so as to facilitate the large employment shifts. In addition, policy makers need to be informed in order to ensure that they do understand the need for an additional hydrogen specific policy support scheme on top of support schemes for renewable energy and sustainable transport in the initial phase of the introduction of hydrogen into the energy system.
- *A European public-private partnership* for hydrogen and its end-use applications, e.g. in the form of a Joint Technology Initiative (JTI), is key in achieving these objectives and should be established by 2008.

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Hydrogen Energy in Europe

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