



Market perspectives of H₂ vehicles

Analysis of current status and requirements

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Acknowledgement

The funding received for this report was provided by the European Commission through the EFONET project under the 7th RTD Framework Program. The author would like to thank Martine Uytendinck and Christoph Stiller (LBST) for their valuable contributions to this report. This project is registered by ECN under the number 600049.

Abstract

This report serves as discussion document for the workshop '*Technologies for fuel cells and hydrogen in road transport*' in March 2009 in Paris. The workshop is part of the Efonet (Energy Foresight Network, www.efonet.org) program initiated by the European Commission.

As a starting point, the status quo of fuel cell technology is analyzed from an innovation perspective, compared with the current vehicle deployment in demonstration projects worldwide. Then, cost reductions of fuel cell and drive train components that can be achieved as function over time are modelled in a learning curve approach. This provides a forecast on the expected vehicle cost by cumulative production, enabling discussion on the connection between necessary vehicle deployment and current demonstration projects, also in respect to project finance.

Within the EU HyWays project, four scenarios have been developed to model the penetration rates for hydrogen vehicles in transport. All scenarios are determined by two influencing factors, policy support and level of technological learning. Depending on the scenario, it is assumed that mass production of vehicles starts either by 2013 (2016) with a group of 5 (4) first movers that achieve up to 90% plant utilization in different time frames. Given the bandwidth of scenario results, it is possible to redefine cost targets and provide recommendations for the necessary policy support.

The report also provides an assessment of current hydrogen vehicle RD&D activities by different OEMs and gives an indication on the expected market entry strategies and time frame. To conclude, cost of conventional and hydrogen vehicles are compared on a €/km level, testing several policy measures for their suitability to lower the expected high vehicle cost for the end-consumer.

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1. Introduction

Our current road transport system still largely remains dependent on oil and is responsible for a quarter of world CO₂ emissions¹. Over the next decades, the situation is expected to worsen when more cars will be added to the existing fleet mainly through demand growth from emerging economies. Governments worldwide have responded with the discussion and introduction of stricter CO₂ emission targets (EU: 130g/km CO₂, 95g/km for 2020 aspired) that are likely to be further sharpened in the future. Triggered by these developments and the current economic downturn the demand side reacts and enquires more fuel efficient and environmentally benign cars.

OECD estimates that 30% fuel economy improvement is feasible through advances of the existing technologies and in addition hybridization is expected to further contribute to reduce CO₂ emissions. However, long term emission targets in the area of 50% reduction and above, have been considered only possible through electric vehicles and hydrogen fuel cells². Hydrogen offers enhanced sustainability benefits in terms of cost-competitiveness, low well-to-tank carbon content, high energy efficiency and flexible reliance on diverse primary energy sources for the production of the hydrogen.

The market introduction of vehicles that run on hydrogen fuel has long been promised by car manufactures (OEMs), showing prototypes on display at automotive consumer fairs and thus creating high expectations. Nevertheless, no model has yet found its way to the showroom and it has been questioned if hydrogen vehicles will ever be able to leave the R&D stage. Customer expectations might have been triggered too early too far and little communication has been provided to the public at what stage of technological development the technology effectively is.

OEMs have also postponed the shift to start up small series production of hydrogen production due to high uncertainties with regard to the evolution of the necessary infrastructure. Hydrogen represents a radical shift in transportation technology. As such, the introduction of hydrogen vehicles into road transport has to be seen as system innovation which has to emerge simultaneously with the necessary infrastructure. It has been a problem that the debate has been routed not from a system perspective but for a long time vehicles and infrastructure have been discussed apart. OEMs, oil&gas industry, infrastructure suppliers and governments were not willing to agree on risk sharing and necessary funding for the infrastructure and vehicle incentives.

It is unlikely that industry stakeholders alone will be able cover additional necessary cost during market introduction and transition to hydrogen vehicles, this will largely depend on the willingness of governments to provide policy instruments that can help to overcome initial market barriers. In California, due to the ZEV mandate as regulatory measure and incentives for refuelling stations, the state has today attracted a number of OEM trials (Honda, GM) and has the highest number of refuelling stations worldwide (although still with limited access). To support the further market introduction of vehicles the necessary shift that needs to be made involves the start of retail like stations for the end-consumer.

Targeted deployment policies for hydrogen vehicles and infrastructure need to emerge simultaneously to bring down the cost of FCVs (with growing production numbers) and lower the infrastructure investment risk. According to the U.S. Department of Energy (DOE), this would lead to a situation where FCVs have reached a competitive situation³.

¹ IEA 2008.

² International Transport Forum 2008, OECD.

³ Analysis of the transition for hydrogen fuel cell vehicles and the potential hydrogen energy infrastructure requirements, ORNL 2008.

However, realities are also changing and become adapted to the developments. In the 2008 review, the Californian Air Resource board has changed the requirements to introduce hydrogen fuel cell vehicles demanded by the ZEV mandate between 2012 and 2014 to a lower number. It is now allowed to comply with more electric vehicles instead of hydrogen ones⁴.

This report is summarizing the current development status of hydrogen vehicles and market introduction strategies of OEMs, taking into account the expected cost per vehicle and market penetration rates as a function of time. Cost reduction via learning curve effects and the vehicle penetration scenarios are the result of extensive research within the EU HyWays project, incorporating the views of a broad base of industry stakeholder and research institutes⁵.

In chapter two, the current status of hydrogen fuel cell technology is examined and put into perspective from an innovation point of view in order to create a better understanding for the challenges that lie ahead. As vehicle cost is one of the major concerns and current barriers for broader introduction, in the third chapter it is explained how learning rates (verified by automotive industry experts) on the component level contribute to anticipated cost reductions per vehicle and give an idea about the necessary production volumes. In the following, four scenarios that model market introduction of fuel cell vehicles by means of achievable penetration rates over time are presented. Market strategies of different OEMs that are active in fuel cell vehicle RD&D are provided in the fifth chapter, together with an overview of manufacturers and models that have been announced to be closer to commercialization. In the sixth of this report, a new approach to compare cost by €/km of conventional and hydrogen vehicles is introduced, together with a policy portfolio to lower the expected high cost of FCV for the end-consumer. The report concludes with final conclusions on the market perspectives for FCVs.

⁴ The Zero Emission Vehicle program (ZEV) requires all volume vehicle manufacturers to produce 25,000 ZEVs in 2012-2014 and 50,000 ZEVs from 2015-2017. Regularly updated, the ZEV mandate has been last changed in April 2008. The number of required FCV vehicles has been reduced to 7,500 (previously 25,000). Majority of the vehicles are expected to be PHEV. California Air Resource Board, 2008.

⁵ HyWays - The European Hydrogen Energy Roadmap.

2. Situation of hydrogen vehicles from an innovation perspective

Availability of vehicles is one of the key issues for broader market introduction of hydrogen fuelled vehicles. Demonstration projects have raised overall awareness in public. From the consumer perspective, hydrogen vehicles are ever delayed and OEMs have not managed to offer vehicles in the showroom. Concrete announcements about mass production and retail prices remain rare because of high uncertainties on expected cost reductions. Nevertheless, even for the assumed first users such as commercial fleet operators (who normally only use a limited number of refuelling stations) no investment decisions can be made without knowing what cost will be associated with the vehicle.⁶ Consecutively it is assessed where hydrogen vehicles are from an innovation perspective to provide a better understanding on the measures that have to be taken.

Over the last years, the output in units of produced hydrogen vehicles has grown but on a low level, with only a few hundreds of vehicles produced worldwide. In 2007, production was in the area of 300 vehicles; in 2008 it was expected to be close to 500 units of production (H₂ fuel cell and H₂ ICE). This recent increase is due to the started larger field trials of Honda (FCX Clarity) and GM (Equinox, Project Driveway)⁷. Daimler announced to ramp-up production in the hundreds of vehicles for its new F-cell vehicle, which is based on the B-class in 2009. Among other OEMs that have produced larger numbers hydrogen cars are Ford (Focus), Nissan (X-Trail) and VW (Passat Lingyu). Both BMW (Hydrogen 7) and Mazda (RX-7) have produced dual-fuel vehicles that run on petrol and hydrogen (H₂-ICE).

Honda has started to lease the FCX Clarity model to selected customers in the US (southern California) and governmental institutions in Japan. The field trial has started in 2008 and about 200 units are planned to be handed out during this period⁸. GM deploys more than 100 units of its Equinox model in the US, Japan, Korea, China and Germany (there labelled GM HydroGen 4). Yet, vehicles are only provided to selected individuals and institutions.

Currently, also a limited number of hydrogen vehicles are deployed in a number of demonstration projects at different locations worldwide. Some of the most important projects are the Clean Energy Partnership in Berlin (CEP II), the California Fuel Cell Partnership (CaFCP) and the Japan Hydrogen and Fuel Cell Demonstration project (JHFC). They all have in common that their purpose is to test and validate the technology in a real-life environment. Thereby valuable information about technical and economic performance is retained that can help to refine and improve the technology to enhance potential for commercialisation. However, vehicle use is restricted to the participants of the respective demonstration project or selected institutions with local impact (awareness raising factor). Sometimes the users of the vehicles provide financial support the project itself (for e.g. Vattenfall in Berlin uses H₂ vehicles for their employees).

From an innovation perspective, hydrogen applications in passenger vehicles remain on a small scale, i.e. the total number of vehicles deployed worldwide remains low. On the technological development trajectory, large-scale demonstration projects represent the next important step before early markets are entered (see Figure 2.1).

⁶ Minimal user requirements for hydrogen vehicles - Gaps analysis, HyLights, 2008.

⁷ 2008 Light duty vehicle survey, Fuel Cell Today.

⁸ 36month lease agreements, 600US\$ lease p.m.

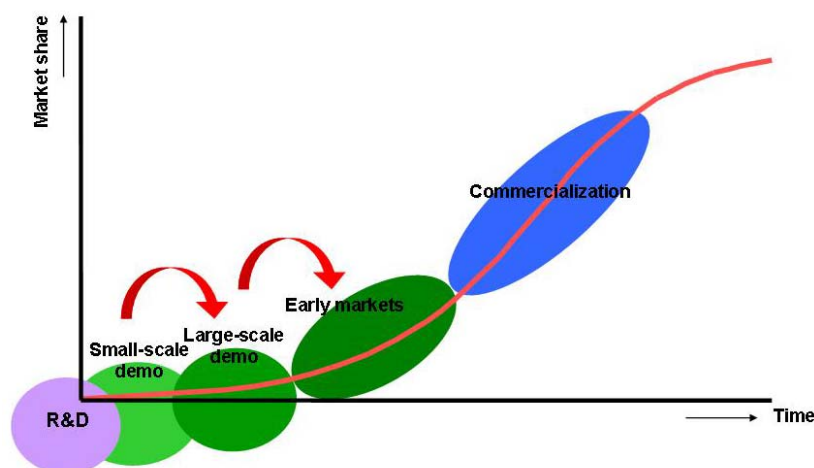


Figure 2.1 *Technology development trajectory*

However, this shift towards large production volumes is not easily achieved through demonstration projects alone and is only the start of a longer trajectory towards mass production. The next critical step is to bring the technology from a controlled environment to the early markets where the hydrogen technologies have to compete with existing technologies.

Large-scale demonstrations can be characterised by the fact that they have a much more integrated approach towards technology testing, but also on market formation and the decrease of uncertainties, accompanied by a gradual ramp-up of vehicle production. The more mature the technology becomes, the larger the demonstration projects need to be (in terms of the number of vehicles deployed) in order to obtain sufficient learning effects. With the advent of large-scale demonstration projects, hydrogen technology is being exposed to public space and accessible by a larger group of people. The focus here is the development of all key technologies of a hydrogen economy to market maturity. It might be sufficient to have a small number of vehicles operating to test their general technical performance, but to learn more about the daily operational characteristics a sizeable fleet and a cluster of filling stations is necessary.

Large-scale demonstrations are currently being triggered by several financial programmes, e.g. on EU level with the establishment of the Joint Technology Initiative (JTI) in 2007 that has allocated ca. €1bn in public-private funding for RD&D until 2013. According to the ‘H₂ and fuel cell demonstration roadmap for road vehicles’ by the JTI, the first phase until 2010 foresees up to 100 vehicles on the road by 2010, followed by up to 500 vehicles in the second phase until 2013.⁹ From 2014, the roadmap should anticipate further progress towards the Snapshot 2020 targets that anticipates a range of 0.4 and 1.8m sold vehicles per year.¹⁰

On national level, the German government allocated €1,4bn for hydrogen fuel cell RD&D (2007-2016) to the National Innovation Strategy Hydrogen and Fuel Cells. Other EU countries have started to collaborate in larger projects. The respective hydrogen industry groups and associations in Norway (HyNor), Sweden (Hydrogen Sweden) and Denmark (HydrogenLink) have founded the Scandinavian Hydrogen Highway Partnership, planning to seed fuelling stations along a highway that links the three countries and deploying 500 passenger cars and 100 buses by 2015. Already since 2002, the Japanese government supports the extensive JHFC hydrogen demonstration project involving OEMs Toyota, Honda, Nissan, Suzuki, Mazda, Daimler and GM/Opel. The JHFC is currently in the second project phase and discussions about the extension beyond are ongoing. An overview of planned vehicle deployment in demonstration projects is provided in Table 2.1.

⁹ Fuel Cell and Hydrogen Technology in Transportation Applications, FCH JTI, Brussels 2008.

¹⁰ Snapshot 2020 targets defined by HFP Implementation Plan.

Table 2.1 *Foreseen vehicle deployment in demonstration projects*

Project Name	Scope	Deployment Plan	Timeline
Californian Fuel Cell Partnership (CaFCP)	California	Thousands of vehicles	2010-2013
Joint Technology Initiative (JTI)	EU	Tens of thousands 100 vehicles, 100 buses 500 vehicles, 500 buses	2013-2016 2010 2013
Clean Energy Partnership Phase II	Germany (Berlin, Hamburg)	40 passenger cars	2008-2010
Clean Energy Partnership Phase III		Not specified	2011-2016
JHFC Phase II	Japan	60 vehicles	2006-2010
JHFC Phase III		Under discussion	Under discussion
Scandinavian Hydrogen Highway	Norway, Sweden, Denmark	500 passenger cars 500 speciality vehicles 100 buses	2015

Since demonstration projects also create a refuelling infrastructure with a low number of stations in the respective area, it is expected that those areas could later on serve as a starting point for early market applications, eventually growing larger and spreading out beyond the original area. The number of currently operating hydrogen fuelling stations is by far the highest in the US, concentrated in the area around Los Angeles. Reason is that California has introduced regulatory measures (ZEV mandate) early that can give indications about the expected vehicle deployment. Generally, the US has infrastructure incentives available on both national and state-level (e.g. California) However, most fuelling stations have limited access (e.g. for certain OEMs only), but progress to retail-like stations is expected.

In Europe, hydrogen fuelling stations are predominately found in Western Europe, in particular Germany and Scandinavia (Denmark, Norway). A few stations exist in France (Rhône-Alpe), Spain (Zaragoza) and Italy (Piemonte-Lombardia).

3. Expected cost of hydrogen vehicles

None of the car manufacturers has yet reached a production volume that causes cost to go down extensively because of mass-manufacturing (automatisation) only. An initial production (first series) of vehicles is necessary to propel the first large demonstration projects. Those vehicles will still cost more than double (see Fig. 3.1) compared to conventional vehicles. The initial population is only the first step to bring down cost through cumulative production and paving the way to a mass-market rollout.

The concept of learning curves has been applied to study the cost of vehicle production with hydrogen fuel cells and hydrogen internal combustion engines in the European Commission project HyWays. It was decided to apply the baseline for component cost data from the CONCAWE/JRC/EUCAR (2006) study. These data are based on initial commercialisation of 100,000 units and the learning curve approach is used to provide an outlook on the estimated vehicle cost. The cost reduction of a technology as a function of cumulative experience of produced units is described as a learning curve. The essential parameter is the progress ratio, with a ratio of 0.90 the costs of a unit decrease by 10% with every duplication of the cumulative production. To minimise the uncertainties in prices for different hydrogen technologies, different progress ratios are applied for fuel cell and hydrogen ICE powered cars. The progress ratios used are the result of research experiences from the automotive partners in the HyWays project (Daimler, BMW, and GM/Opel). Also two different scenarios are assessed, one with fast learning (high learning even after market entrance) and one with modest learning (assuming lower learning effects after 10 years), see Table 3.1.

Table 3.1 *Progress ratios of hydrogen and fuel cell components*

Component	Fast learning (low PR)		Modest learning (high PR)	
	Initial phase	10 years after market entrance	Initial phase	10 years after market entrance
Hydrogen Tank*		0.85	0.85	0.98
Electric Motor & Controller		0.90		
Li-Ion Battery		0.90		
FC System	0.80	0.90	0.82	0.92
H ₂ -ICE**		1.00		1.00

* In the first ten years after market introduction the PR is the same for both scenarios, after 10 years the learning effects are lower in the case of the modest learning scenario.

** The CONCAWE/JRC/EUCAR WTW-Study assumes the same production cost for gasoline and hydrogen engines.

The calculation of the vehicle price is based on these assumptions and the projected price development for compact-class hydrogen powered vehicles over the cumulated total production volume is shown in Figure 3.1.

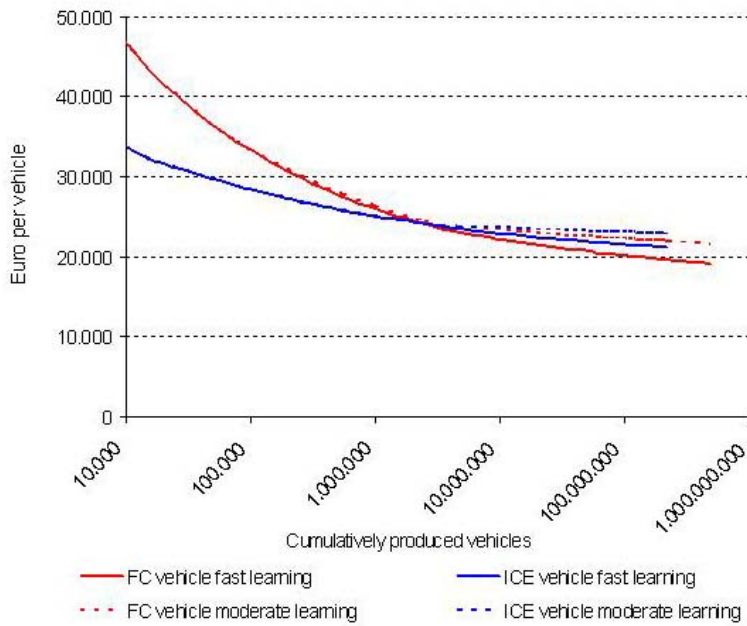


Figure 3.1 *Cost reductions of hydrogen cars for the two progress ratios*

For modelling reasons, 10,000 vehicles have been assumed as initial population, when mass market rollout will take place. Those initial vehicles are expected to be deployed within a number of demonstration projects, such as the FCH JTI and others. The earlier implementation plan (IP) of the JTI had set a target of some thousand vehicles operating once the large-scale demonstration is completed in 2015. However, the current roadmap of the JTI foresees only few hundred vehicles to be deployed within the JTI financed demonstration projects, indicating that other actors have to step in to finance additional deployment.

It is a common misconception that due to learning effects, total annual cost for vehicle deployment will go down immediately after finalisation of the first series of demonstration projects. Even though costs go down rapidly, the fast increase in deployment leads to a substantial increase in total annual budgets needed to bridge the cost gap between the reference and the hydrogen vehicle. Only after a number of years, the total annual budget reaches its peak to slowly decrease afterwards. This leads to the awkward situation that due to the success of the deployment scheme, a continuation of the support scheme is endangered since a yearly multiplication of the support budget is not foreseen upfront.

In the early demonstration phase, the automotive industry (OEM) basically covers the cost of the production of the prototypes. Vehicles are not sold to the end-user, but the end-user sometimes has to pay a (modest) compensation for the use of the vehicles. When deployment goes up and production of small series starts, the OEMs cannot afford selling the vehicles with a loss. This effect, together with the increasing size of the demonstration projects, leads to required support levels that are several orders of magnitude higher than during the early demonstration phase. Deployment support in this phase cannot be provided by EC programs, since we are dealing with a series of identical vehicles and the focus of EC support is rather on the R&D and demonstration phase. It is therefore unclear who is bearing the cost for the remaining large-scale demonstrations, though the options are very limited. The challenge therefore lies in the optimal deployment of the first vehicles to achieve maximum learning effects. At the same time high commitment at member state level is indispensable for the preparation of future markets and stable financing. In chapter six, it is further elaborated on possible options for support on member state level.

4. Scenarios for hydrogen vehicle deployment

As discussed in the second chapter, positioning hydrogen vehicles on a technology development trajectory reveals that they are still in the early development stage and a precise forecast of the market development cannot be made yet. The EU HyWays project has instead developed four scenarios to model market penetration. The scenarios have been defined by the two factors of policy support and technological learning as the main means of control. Both factors have been characterised by varying input levels and can therefore be used as boundaries for the scenarios. The rationale behind policy support is to describe the potential impact of governmental support (EU and national level), but also to show the impact of different intensities. For an overview on the four scenarios and its input parameters, see Table 4.1.

The development of fuel cell components and storage technologies is of crucial importance to enable a transition from today's production volumes towards an early market phase with some thousand vehicles. It is assumed that the large-scale demonstrations validate the technology and a four-year term for series development. In the most optimistic case, market introduction could start around 2013.

Table 4.1 *Scenarios used to determine penetration rate of hydrogen vehicles*

Scenario	Policy support	Technology learning
Very high policy support, fast learning	Deployment support available and implemented before barriers appear	Mass production starts in 2013, 5 first movers (OEMs), each increasing capacity by a new production of 100,000 units p.a., plant utilization up to 90% in three years
High policy support, fast learning	Deployment implemented when barriers have appeared	Mass production starts in 2016, 4 first movers (OEMs), plant utilization up to 90% in five years, max. capacity by the four plants 100,000 units p.a.
High policy support, modest learning	Action only undertaken once problems become visible	
Modest policy support, modest learning	Action only undertaken once problems become clearly visible, policy not hydrogen specific (sustainability)	

As each scenario had a distinct definition of how the first movers would behave and ramp up their production, it provided the basis to model the expected production volumes. Starting from the hypothetical quantitative scenarios an S-curve was calibrated for each of the scenarios to generic production volumes and used to further extrapolate penetration shares as a function of time until 2050. The outcome of the modelling exercise can be found in Figure 4.1.

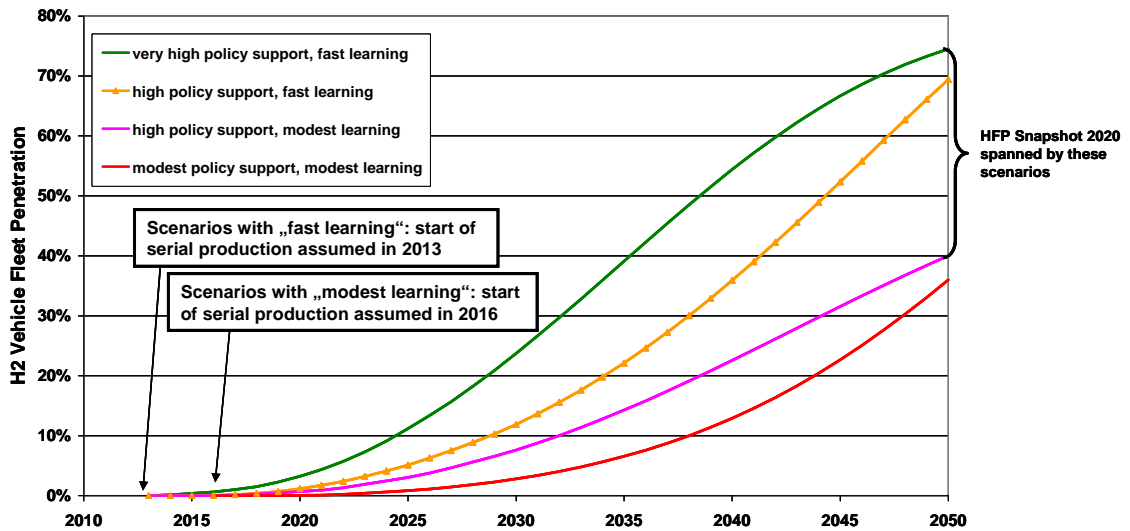


Figure 4.1 Development of the penetration rate of hydrogen vehicles

The exercise allowed to draw conclusions for the achievable and appropriate penetration target by 2020, the ‘Snapshot 2020’¹¹. The target for the FCH JTI has been redefined to a maximum penetration rate of 1-3% of the total passenger fleet, translating to a range of 0.4-1.8 million vehicles per year¹². Linked to learning cost curves on the component level, the scenario of ‘high policy support, fast learning’ was chosen as an ambitious but realistic option to reach cost targets for 2020 (100€/kW for the power train, 10€/kWh for the H₂ storage system).

¹¹ Snapshot 2020: By this point in time the S-curve should take off. This means production volumes increase substantially to 100,000 per year due to almost cost competitiveness of the technology.

¹² For comparison, the yearly amount of sold passenger cars in the EU is 15 million.

5. Vehicle availability

For the private end-consumer, driving a hydrogen vehicle today is only made possible at public Drive & Ride events, which are for example organized by the current vehicle demonstration projects. Usually, curiosity to experience and try the new technology is very high among consumer, as can be seen from the open day at the Californian Fuel Cell Partnership (see Figure 5.1). Frequently the question is asked at what point in time vehicles will be available in the showroom and at what cost. Currently, only individuals living in Southern California can apply to be awarded leasing an FCV Clarity, but the amount of vehicles to be handed out is very limited. Otherwise, extensive testing is reserved to the employees of companies participating in the demonstration projects. After all, the vehicles are still in the R&D phase and might not yet deliver the necessary level of comfort expected by the end-consumer. In cases, such as the Honda FCX Clarity and the new Daimler F-cell, vehicles are very close to deliver the same performance as a conventional vehicle.



Figure 5.1 *Open day at Californian Fuel Cell Partnership, Sacramento 2008*

The following chapter provides an overview about several OEMs that are known to be active in the development of fuel cell vehicles and strategies regarding market introduction. It should be treated as a non-exhaustive overview limited to companies that have progressed beyond the showcase stage.

BMW has extensively promoted its Hydrogen 7 over the last two years. The vehicle is based on a regular 7-series model with a hydrogen internal combustion engine that can run both on petrol and hydrogen. BMW has handed out around 100 of the Hydrogen 7 to high profile individuals chosen as hydrogen ambassadors (e.g. the President of the EU parliament and Al Gore). Nevertheless, no follow-up plan of the Hydrogen 7 has been revealed and BMW has only made commitments to follow fuel cell auxiliary power units (APU) for the moment.

Daimler has repeatedly confirmed to take the introduction of hydrogen fuel cell vehicles very seriously. Daimler has advanced the originally foreseen production start of the new F-cell vehicle from 2010 to 2009. The company now plans to start producing hundreds of F-cell units, based on the B-class (the old F-cell was based on the A-class). The vehicle is driven by a fuel cell with a power output of 100kw and 320nm max. torque. First vehicles are assumed to be offered in a lease-package to end-customers. Based on the expected further learning effects with

the F-cell and achievement of cost reductions early commercialization is forecasted for 2014/2015 (100,000 vehicles per year).

Honda continues to hand out the purpose built FCX Clarity model to selected customers in the US and Japan. Honda has selected a dealer network near to hydrogen fuelling stations that will service the vehicles. The FCX has a range of up to 400km and a top speed of 160 km/h. Vehicles are handed out in a 36 month lease agreement for a lease pay of 600US\$ per month. With start of production in June 2008 in Japan, Honda anticipates to build 200 units over the next three years. No information has been revealed whether Honda considers introduction of the FCX in Europe.

At *GM/Opel*, project Drive Way stimulates deployment of the Equinox fuel cell SUV (100 units built) in the US (California, NY city and Washington D.C.). By the end of 2008, further roll-out has started in Germany, China, Korea and Japan. Labelled as GM HydroGen 4, the Equinox is also deployed in Europe at the Clean Energy Partnership in Berlin. No recent updates concerning the anticipated market introduction of fuel cell vehicles have been published by GM. Most attention is apparently given to the Chevy Volt, an electric vehicle with a combustion engine range extender.

In 2005, *Ford* launched a fleet of 30 hydrogen vehicles based on the Focus model, currently deployed at different demonstration projects in Europe and the US. Ford has also introduced the SUV concept Ford Edge that is tested in Sacramento. The company announced to follow its current activities with the Focus until the end of 2009 and is in parallel also working on a completely new fuel cell vehicle.

Nissan's latest FCV, the X-trail SUV has been launched in 2005 and is currently tested in California and Japan. The X-trail possesses an electric motor with 90kw, bringing the vehicle to 140km/h top speed and a 500km range. In February 2009, the company announced that it has begun testing its new fuel cell vehicle with a power output of now 130kw (as opposed to 90kw). Nissan reported that it believes the model introduced to the market should be either a sports or a luxury car because it should additional appeal to the consumers beyond being environmentally friendly. Besides Japan, the company targets California and EU depending on emergence of a refuelling network. Decisions about a FCV market introduction are said to be made in 2009 to ensure a launch date in 2014. In 2008, the advances in FC technology made by Nissan have also helped *Renault* to present a Scenic FCV prototype. However, Renault follows a number of environmental friendly propulsion technologies but currently focuses on electric vehicles (Supplier for Project Better Place).

Mazda has undertaken advanced research and deployment of hydrogen vehicles since the last 15 years. Currently, its RX-8 sports coupe model is operating in demonstration projects in Japan. As the only manufacturer worldwide, Mazda uses a rotary engine (RE) that runs on both petrol and hydrogen. The fuel can be selected by flipping a switch in the cockpit. Mazda has also signed a contract with HyNor, the Norwegian project to facilitate hydrogen transportation in Norway, and to deliver 30 RX-8 starting in 2008. Besides the RX 8 model, Mazda will also ship some units of its new Mazda 5/Premacy RE van to Norway.

Korean OEM *Kia-Hyundai* Automotive Group has bundled fuel cell research in a joint R&D centre built in 2005 just outside Seoul. Currently, the fourth-generation Kia Borrego fuel cell SUV is road tested in California and Korea. Kia announced to start small production volumes of the Borrego by 2010 to expand road testing. The Borrego is powered by a 115kw fuel cell and has a claimed range of 510km. Hyundai has currently 32 units of its Tucson and Sportage fuel cell SUVs operating in demonstration projects in the US (California, Michigan) and Korea. At the 2007 Frankfurt automotive industry fair a study called 'i-blue' was revealed based on the i30 compact car. The study was described as having a top speed of 165km/h and a range of 600km.

Hyundai is targeting to start up series production of a blue drive fuel cell vehicle (i-blue) by 2012.

Toyota has introduced its improved FCHV-adv (based on the Highlander SUV) model which is currently leased out to the Japanese government and tested in California. The vehicle is reported to have a range of more than 500km. Toyota presented its long-term strategy towards market introduction of fuel cell vehicles in Brussels in 2008, revealing that the company wants to start early series production in 2015, provided it can achieve its anticipated cost reductions.

At both its research facilities in Germany and China, *Volkswagen* is pursuing the development of fuel cell vehicles. In its R&D centre close to Wolfsburg, the Touran HyMotion has been developed that has an 80kw engine and is capable of a 140km/h top speed. Currently, the Touran is road tested further in the Clean Energy Partnership Berlin (CEP). Building on the development of the Touran HyMotion, VW has shown the Tiguan HyMotion SUV with a 107kw fuel cell in 2007. Together with scientists at its automotive research centre at Tongji University in Shanghai, the Chinese joint venture of Volkswagen (Shanghai Volkswagen Automotive Company) has built 16 new hydrogen vehicles based on the Passat model. The car can go up to 140km/h top speed and has a range of 234km with a single tank of hydrogen. Previously, Volkswagen had the vehicles operating during the Beijing Olympic Games 2008. Those 16 vehicles are now deployed at the Californian Fuel Cell Partnership in Sacramento.

Table 5.1 gives an overview of the expected models that are available or made available by vehicle size, together with the planned market introduction.

Table 5.1 *Current vehicle testing and planned market introduction*

Segment	Currently testing			Planned market introduction
	Europe	US	Japan	
A-Micro				
B-Sub compact				
C-Compact	Daimler F-cell			2009, small series 2014/15, 100,000 units
D-Mid-size		Honda FCX Clarity	Honda FCX Clarity	Not known
	Ford Focus	Ford Focus	Nissan	2014
			Hyundai i-blue	Not known 2012
E-Full size				
F-Luxury				
MPV	Mazda Premacy RE		Mazda Premacy RE	Not known
SUV	GM HydroGen 4	GM Equinox	Toyota FCVH	Not known 2015

Commitments to introduce hydrogen fuel cell vehicles on a large-scale vary between OEMs. Some (Daimler, Toyota) have published concrete roadmaps concerning how they are planning to go along the technology trajectory to arrive at a point to offer vehicles to the end-consumer. Virtually all manufacturers have taken on the challenge to develop more environmentally friendly vehicles. In a survey of automotive executives, hybrid-vehicles in its different versions (micro, mild, full-hybrid) is seen as the most important (short term) solution, while electric vehicles and hydrogen fuel cells follow in the medium to long-term.¹³ However, the current worldwide economic downturn has also hit automotive industry. Now, OEMs taking customer

¹³ Momentum: KPMGs Global Auto Executive Survey 2009.

demand for more economic and environmentally benign vehicles more seriously and accelerate the introduction of short term technologies.

Market entry strategies show some similarities among OEMs. For cost reasons, mostly existing vehicles (platforms) have been retrofitted with fuel cells, hydrogen storage and the electric drive train. After technological improvements some OEMs have made experiences with deploying the new technology onto in different vehicle platforms of their portfolio. In the next step, purpose built hydrogen vehicles are appearing (e.g. FCX Clarity). Daimler has revealed plans to share a common platform for its next generation of environmentally benign vehicle 'Blue Zero'. A battery-electric vehicle for short distances (E-Cell, 200km range), a fuel cell vehicle (F-cell, 400km range) and an electric vehicle with range extender (E-Cell plus, 600km range) all planned to be built upon the next generation B-class platform.

6. Policy framework

Hydrogen vehicles driven in demonstration projects and field trials have very high production cost because of their innovative technology combined with low production figures. Therefore, vehicles are usually leased out, but true cost are absorbed by the OEM (the FCX Clarity is estimated to have production cost of 1m US\$).

Once production starts with pre-series and production volumes grow (beyond 10,000 units), the cost will not be borne anymore by OEMs alone. Hence, a situation arises when the vehicle will still be expensive, but should be adopted by the end-consumer. In the early stages, cost will be so high that only institutional customers will be able to deploy vehicles. Costs are expected to come down once 100,000 vehicles are produced. At this point in time, the remaining cost gap could be covered by means of policy support to bring the vehicle cost further down to a level that is in the range of what customers are used to pay for a conventional vehicle. Additional cost per hydrogen vehicle for the end-user will still be substantial. No funding from EU level will be available anymore to cover the extra cost. That means that in this phase, only the member states and regional governments can provide the required incentives to facilitate a quick ramp-up of the deployment of hydrogen applications. A support framework should address both the high additional cost for hydrogen vehicles and hydrogen as a fuel.

Within the EU HyLights project, a straightforward tool has been developed that calculates the cost gap between conventional and hydrogen vehicles.¹⁴ By applying the tool, several policy instruments as well as the sensitivity to factors such as vehicle price, hydrogen fuel price and policy measures can be tested. Based on the HyWays cost data, a gap of approximately 10 €/km¹⁵ - taking into account both vehicle and fuel cost - between a gasoline and hydrogen (FC hybrid) vehicle has to be bridged assuming around 100,000 vehicles are built.

The €/km cost is firstly dominated by the vehicle cost (and taxes), followed by the fuel cost. Taxation applies to both vehicle and fuel costs. The current taxation schemes throughout Europe differ substantially. This not only influences the gap (€/km) between gasoline and hydrogen, but also the potential to implement support schemes for hydrogen in transport. In all countries VAT, fuel excise duty and road taxes affect the cost of the vehicle and fuel, but differences in these taxes are minor and influence the cost per kilometre only little (around 0,2 - 0,5€/km). The biggest difference in the current taxation schemes is the registration tax on vehicles, see Figure 6.1 below.

¹⁴ HyLights Policy Support Tool.

¹⁵ With a vehicle cost level according to HyWays at 100.000 vehicles produced and a H2 fuel price of 6 €/kg.

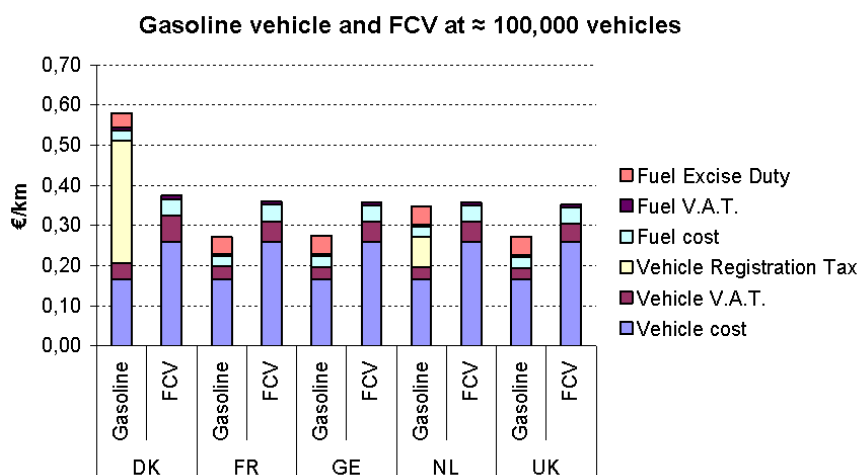


Figure 6.1 *Vehicle cost difference in selected EU countries*
 Note: Based on 2008 support schemes.

Countries like Denmark and the Netherlands (Energy labels) have high registration tax, on the other hand those countries with automotive industry do not have registration tax.¹⁶ In Denmark and the Netherlands hydrogen vehicles are exempted from registration tax. This provides (already today) an incentive which covers the gap (almost) completely (30 €/km in Denmark and 5 €/km in the Netherlands), see Figure 6.1. On the other hand, countries without registration tax (like Germany) have to implement new specific policy support schemes and cannot build upon current taxation (by giving exemptions on current taxes) to support hydrogen in transport. However, one has to take into account that current (advantageous for hydrogen) tax regimes could change in the future. In the Netherlands, it has been already decided that registration tax will be phased out and replaced by road tax.

Various other policy instruments are suitable to reduce the gap (€/km) between gasoline and hydrogen vehicles. Both registration tax and congestion charge have the highest impact on €/km and can potentially completely cover a cost gap of 10 €/km gap. Higher price levels for conventional fuel and lower prices for hydrogen have a much smaller impact (around 1-2 €/km). The inclusion of externalities and road transport in CO₂ pricing schemes has only marginal impact (1.4 €/km assuming a CO₂ price of 100€/ton) and has moreover the side effect that it only reduces the gap between hydrogen vehicles and conventional technologies but not or less between hydrogen vehicles and other environmentally friendly transport options.

The actual financial gap in the phase until 100,000 vehicles are produced is difficult to assess since none of the manufacturers has yet publicly announced production volumes together with an indication for sales prices. Research within HyLights has shown that fleet operators could be a starting point for vehicle deployment, but only on a case-by-case decisions basis. Yet, due to the lack of information on price levels, fleet operators are actually not in the position to make informed investment decisions and thus have not started to implement corporate policies supporting hydrogen vehicles. In addition, it is unclear if and how a series of early markets could evolve into the mass market and what the requirements are for those vehicles (performance, tolerance to additional costs). In case the introduced fuel cell vehicles are significantly more expensive to buy, but cheaper to use this could represent a case for very cheap hydrogen fuel. This advantage could also be further accelerated by new business models which spread the high initial cost over the full lifetime of the vehicle (e.g. leasing agreements).

¹⁶ One exception in this respect is France. Registration tax is applicable, but for historical reasons it has never been recognized as registration tax on EU level. The tax height is determined on the regional level.

7. Conclusions

Automotive industry is aware of the increasing political pressure of tightening CO₂ emission regulations and the changing demand from consumers to offer more economic, environmentally benign cars. On the short term technologies such as hybridization will contribute their share to emission reduction, however it is also clear that hydrogen and electric cars remain as only options to lower CO₂ emissions substantially and comply with the anticipated stricter emission regulations in the future. Roadmaps from automotive industry foresee electric vehicles and hydrogen fuel cells as complementary technologies. Electric vehicles (plug-in hybrid and battery electric vehicles) will be the choice for short range trips, while fuel cell vehicles will cover the medium to long range.

Several OEMs are facilitating their R&D efforts for FCVs, with some of them already having presented roadmaps how and when to make the step towards mass production. However, the analysis from the innovation perspective has shown that hydrogen fuel cells remain in the early development phase, facing massive challenges moving along the development trajectory. Regarding the vehicle supply, further cost reductions depend to a large extent on the achievement to deploy a larger number of vehicles beyond the demonstration (10,000 vehicles) phase. Forecasts made in the HyWays project predict that vehicle cost will only come down (assuming retail prices of 23 k€ for compact cars) once 100,000 vehicles are produced. Not reaching the necessary vehicle production numbers could further postpone mass introduction due to insufficient technology learning effects and remaining high cost. In addition, currently only one OEM has made concrete announcements to start up production in the area of hundreds of thousands, while a greater number of first movers is necessary. The availability of adequate refuelling infrastructure is directly linked to a successful introduction of hydrogen vehicles. Some OEMs have intensified collaborations with infrastructure suppliers. Daimler, together with Linde estimated the cost for a hydrogen refuelling infrastructure of 1,000 stations to be €1.7 bn for Germany (€1.4 bn are currently spent on RD&D).

The near term challenge is the deployment of an increasing number of vehicles to bridge the gap between demonstration and early commercialization. Although several thousands of vehicles may be produced, costs will still be high in comparison to the conventional vehicle. Starting point should be the extension of demonstration projects with a strong regional basis, (local stakeholders) targeting the establishment of retail-like hydrogen refuelling stations and deployment of an increasing number of vehicles. Vehicle deployment will take place at a limited number of (hydrogen committed) locations worldwide that possess favourable conditions and therefore accumulate the majority of the vehicles. In the phase once 100,000 vehicles have been built, the price difference becomes within reach of various policy existing instruments (10 €/t/km). Countries that already feature high taxation on conventional vehicles are in a better position to introduce or extend tax exemptions for hydrogen vehicles. However, vehicle and fuel incentives cannot not be treated separately and need to be approached in a package-like manner.

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