HyWays

SECOND PHASE OF THE PROJECT

REPORT ON THE HYWAYS SCENARIO ASSUMPTIONS

(DELIVERABLE D3.13)

VERSION FINAL

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Disclaimer

The results in this report are a reflection of a non-final stage of the HyWays project, with substantial stakeholder consultation still under way. Significant modifications are still due, and consequently none of the results given in this report should in any way be considered as final HyWays results.

1 Introduction

To evaluate the possible future role of hydrogen in society, one has to make assumptions about how this society will develop over time. By and large, this means that the energy system has to be parameterised, indicating against which socio-economic background the introduction of hydrogen will take place. HyWays aims at providing a roadmap for the development of hydrogen in the European Union and does not intend to develop new energy scenarios. Therefore, it was decided to use an existing and well-accepted European outlook as a reference. The HyWays consortium selected "European Energy and Transport: Trends to 2030" (Energy Trends 2030[1]) to serve as the basis for the development of the baseline scenario. In this chapter, the general assumptions, the extension from 2030 to 2050 as well as some modifications to the development of energy demand are discussed. It should be noted that although the timeframe was extended up to 2050, the most reliable indicators from HyWays concern 2030. Beyond that, the outcomes should be viewed as purely indicative because of the increasing uncertainties of such long-term projections.

Compared to the assumptions in HyWays phase I[2], the following major changes were made in HyWays phase II:

- New primary energy prices were taken from the well-known EU study WETO-H2[3] to reflect the newest developments and research results here.
- New vehicle market penetration scenarios were developed which also include more conservative penetration rates.
- New learning curves for hydrogen vehicles (which take into account the new Concawe/Eucar figures[4]); these lead to a higher starting cost for hydrogen ve-

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[1] Mantzos L, Capros P, Kouvaritakis N, Zeka-Paschou M, Chesshire J, Buil-mot J.F.: European Energy and Transport – Trends to 2030; 2003

[2] For more background information see HyWays (2006): HyWays A European Roadmap: Assumptions, visions and robust conclusions from project Phase I; L-B-Systemtechnik GmbH, Ottobrun, Germany., http://www.hyways.de/

[3] See EC – European Commission: World energy, technology and climate policy outlook 2030 – WETO. EU publication Nr EUR 20366, Brussels, 2003 and Purwanto A.: The outlook for hydrogen: WETO-H2 scenarios (WETO-H2 project), IPTS EU Commission, presentation at Cluster-workshop Sustainability of a hydrogen economy, February 21st 2006, Frankfurt. Download: http://www.isi.fraunhofer.de/trias/workshop-feb-2006.htm

[4] For HyWays phase I the study JRC/CONCAWE/EUCAR: Well to wheels analysis of future

hicles when the mass market takes off.

- Development of detailed infrastructure build-up assumptions which will be reported separately in HyWays deliverable D3.20 (see http://www.hyways.de/).

2 Implications and usability of Energy Trends 2030 scenario

The Energy Trends 2030 scenario is based on assumptions about the key driving parameters for energy use in the European Union. These include estimates of the drivers that determine demand, most notably the Gross Domestic Product (GDP), and demographic characteristics such as population size and household composition. Using these parameters, the demand for the end-use of energy is determined, specifying for example the impact that GDP growth has on the energy demand of industry.

2.1 Development of energy prices

While GDP is the main driver for the demand side of the energy system, the prices of fuels, more specifically the price differences between fuels, are an important driver for the supply side.

The projected energy prices in the Energy Trends 2030 scenario provoked intensive discussions. A number of HyWays partners as well as other stakeholders were of the opinion that these oil price projections are unrealistically low and do not reflect recent market developments.

Therefore the consortium decided to update the energy prices in the second Phase of HyWays and used the energy assumptions of the WETO-H2 study[5] which involve changes for the long-term coal price. It is now assumed that the coal price does not develop independently from the oil price in the future, because of the possibility of using coal for liquid processes in the long run. In addition, we integrated our own price

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automotive fuels and powertrains in the European context, 2003, is used and for HyWays phase II an update in 2006 is used.

[5] See EC – European Commission: World energy, technology and climate policy outlook 2030 – WETO. EU publication Nr EUR 20366, Brussels, 2003 and Purwanto A. The outlook for hydrogen: WETO-H2 scenarios (WETO-H2 project), IPTS EU Commission, presentation at Cluster-workshop Sustain-ability of a hydrogen economy, February 21st 2006, Frankfurt. Download: http://www.isi.fraunhofer.de/trias/workshop-feb-2006.htm

estimations for biomass which include the competition for biomass use, and lignite prices which take into account that there is only limited competition for lignite use because WETO-H2 does not include these. The energy prices used are shown in Figure 2.1 .

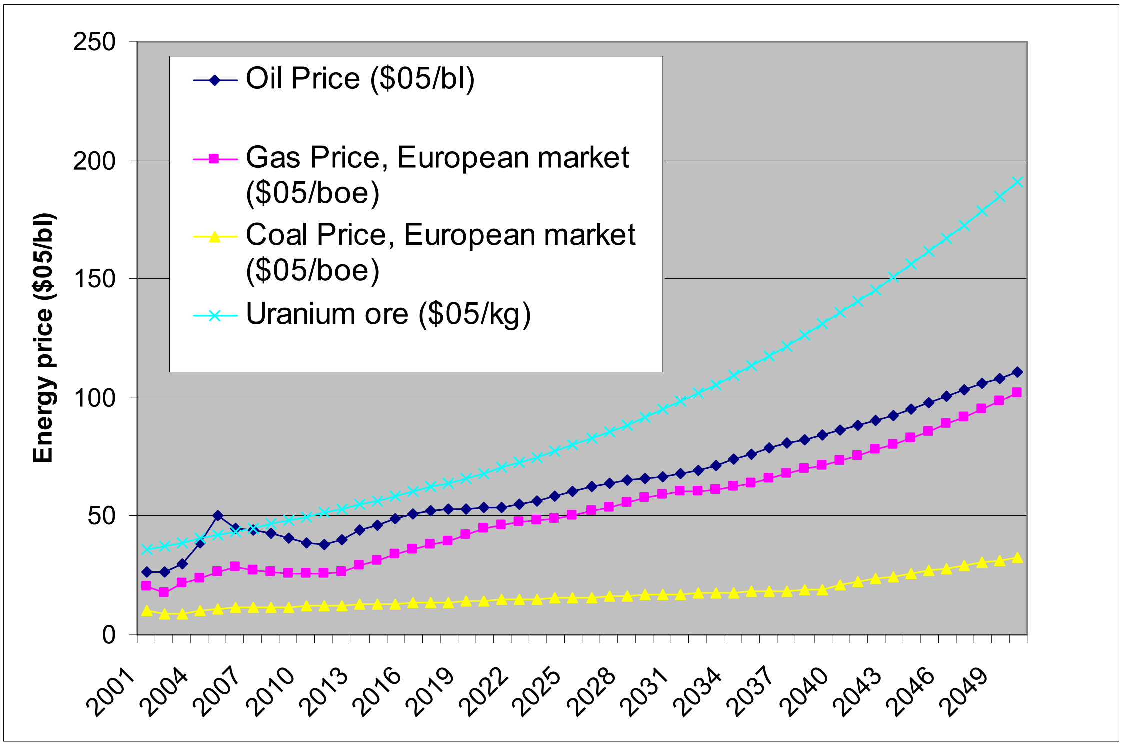

Figure 2.1 *Fuel price projections in € per barrel of oil equivalent (boe) (based on WETO-H2)*

2.2 HyWays assumption about the demand for passenger car transport

Developments in the passenger car market play an essential role for the hydrogen car potential and are thus crucial for the HyWays roadmap. It is foreseen that this market will have the highest volume effects on hydrogen applications in the next fifty years. Therefore, it was vital to come up with a realistic estimate of growth in the transport sector that is accepted by the various stakeholders. The consortium decided to deviate from the numbers based on Energy Trends 2030, particularly for passenger cars, as the growth here is considered to be too high. Instead it is assumed that average car ownership and usage in all Member States is comparable to levels in present-day Germany. The resulting specific HyWays assumptions are compared to the extrapolations from the original Energy Trends 2030 in Figure 2.2.

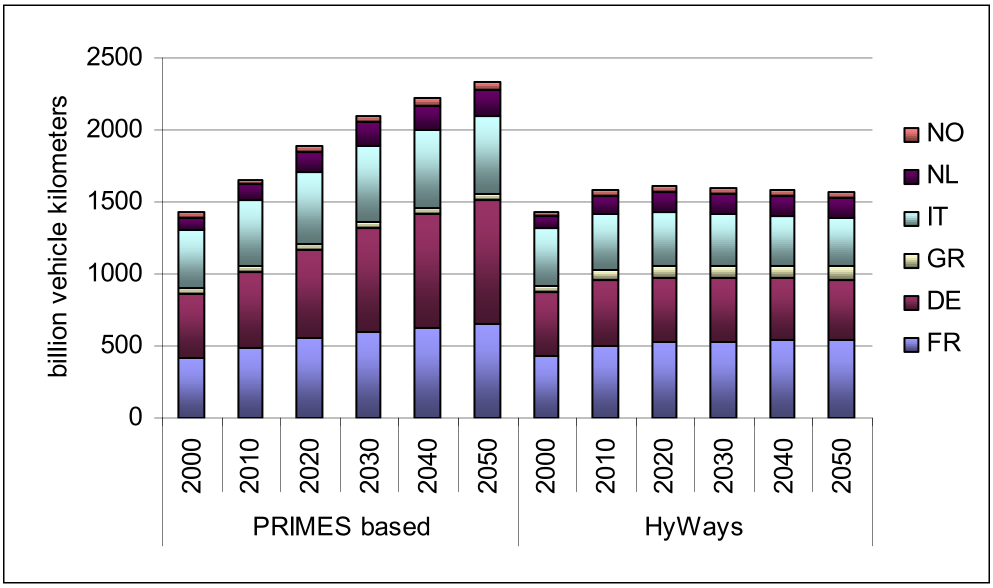

Figure 2.2 Projections of the passenger car stock in the six current HyWays countries: HyWays assumptions (right) and Energy Trends 2030 scenario assumptions (left)

3 Policies and policy instruments

The economic and political background against which the role of hydrogen is assessed will play a key role in evaluating the effects of hydrogen. The Energy Trends 2030 scenario is a “business-as-usual” scenario intended to serve as a benchmark for policy-oriented scenarios such as a climate change or energy efficiency scenario. It was not meant to be interpreted as portraying the most likely development of future energy consumption, but rather as showing the consequences of developments should no new policy measures be implemented. Thus, the standard Energy Trends 2030 scenario has relatively few policies. It only takes into account those policies that were in place or in the process of being implemented at the end of 2001. This implies that important drivers for hydrogen are lacking, such as a climate change policy.

The first addition to the policy framework of the Energy Trends 2030 scenario was to extend it to include policies agreed on at the end of 2004. Furthermore, while the Energy Trends 2030 scenario was restricted to national policy instruments actually in place, the HyWays baseline scenario assumes these policies also include targets set by the EU, most particularly concerning renewable resources and climate change policies. This leaves the choice of instruments open with which these targets are to be achieved. For renewables, the targets are based on official publications by the EU. The targets are 22% of all electricity produced from renewable energy sources in the EU-15 region in 2010 and 27.6% from 2020 onwards. For the period 2030 to 2050 it is assumed that the minimum share of renewable energy remains constant.

HyWays does not aim to do a full assessment of the policies that are favourable to the introduction of hydrogen into the energy system. If hydrogen scenarios which are relatively rich in environmental policies were compared with a baseline like Energy Trends 2030, which does not feature many such policies, the combined value added of hydrogen plus environmental policies would be assessed rather than the value added of hydrogen alone. Therefore, contrary to the Energy Trends 2030 approach, the HyWays baseline needs to include the major drivers for a hydrogen economy, such as limitations on greenhouse gas emissions, policies to promote renewable energy sources or increased fuel prices.

As a baseline assumption, therefore, the HyWays baseline scenario assumes that the EU will adopt a policy on the emission of greenhouse gases after 2012. There is still a lot of uncertainty about the actual policy to be implemented in the post-Kyoto era, but the clear target is a maximum 2ºC rise in global average temperature by the end of the century. According to recent projections of the IPCC (UNEP, 2001), this may be achievable by adopting a 35% reduction target for CO_2 emissions in the EU-region up to 2050, under the assumption of long-term global equality with respect to CO_2 emission rights. In HyWays, this CO_2 emission target is set for Europe as a whole, as well as across the various sectors. Since the free market assumption implies the reduction of emissions using the most cost-effective option, setting the target at such an overall level implies the effectuation of an emission-trading scheme with trading between sectors and between countries.

Since transport is one of the sectors examined in detail in this project, policies on emissions from the transport sector are crucial when assessing the benefits of hydrogen. In particular, care should be taken to properly account for the currently proposed legislation that aims at improving the emission characteristics for cars. Therefore, in the assessment of emissions, the two new EURO legislations (V and VI) were incorporated for cars. These put limits on pollutant emission levels (EURO V), and on fuel consumption (both). In addition, the limits on the SO_2-content of fuels were also included as required by a specific Directive. The fuel consumption limits are assumed to be a result of Voluntary Agreements between car manufacturers and the EC, as a reaction to the Kyoto protocol and other possible future initiatives to counteract climate changes. It is assumed that the two new legislations will come into force in 2010 and 2015, respectively.

4 Three hydrogen scenarios

In contrast to the “business-as-usual” world view provided by the baseline scenario, additional assumptions are made in order to construct a framework for the hydrogen roadmap. The deployment rates of hydrogen end-use applications as well as the learning rate for fuel cells were considered to be important drivers for the introduction of hydrogen. These drivers form the axes of the hydrogen scenarios in HyWays.

		Deployment rate of hydrogen based end-use applications		
		high	medium	low
learning rate	High	scenario 1	scenario 2	scenario 3
	moderate	scenario 4	scenario 5	scenario 6

The approach chosen is that the onset of the hydrogen economy is driven by the deployment of end-use technologies with a focus on mobile and stationary applications. While portable applications may play a crucial role in kick-starting the hydrogen economy, their impact on hydrogen demand is limited and therefore a qualitative treatment of these applications is considered sufficient in HyWays.

Three sets of penetration rates are assumed for the hydrogen consumption technologies, one reflecting an optimistic view of the potential of these technologies (“high”), one reflecting a less optimistic view (“medium”) and one reflecting a more pessimistic view (“low”). In the baseline, no hydrogen technologies manage to make inroads into the market. Assumptions are also made about the cost decreases that result from deployment (through ‘learning-by-doing’). Again, an optimistic view with high cost decreases and a less optimistic view with lower decreases are chosen. The resulting impact on costs is determined by applying a learning curve approach, see section 5.4.

Combining the two sets of penetration rates and the two sets of cost decrease assumptions results in six scenarios depicting the possible future role of hydrogen technologies. Three scenarios (1, 2 and 6) were identified as HyWays scenarios; scenarios 1 and 2 as optimistic scenarios and scenario 6 as a more pessimistic scenario.

5 Deployment of hydrogen technologies and technology progress

5.1 Deployment of hydrogen technologies

It is not possible to make a reliable market development forecast for mobile and stationary hydrogen and fuel cell applications due to the uncertainties which still exist on the technical level. Crucial sub-systems such as fuel cell stacks or hydrogen storage systems but also key components like catalysts and membrane-electrode-assemblies have already achieved significant progress but still require further breakthroughs to reach mass commercialisation, so that a more evolutionary based forecast is not within the scope of this work. Considering the key findings of the HFP Deployment Strategy and the Strategic Research Agenda[6], HyWays introduces a set of three different penetration rates reflecting a range from very optimistic to more conservative that has been adapted to the specific needs of both mobile and stationary applications.

5.2 Mobile Applications

Hydrogen-powered vehicles with PEM (Polymer Electrolyte Membrane) fuel cell power trains and somewhat less often with internal combustion engines are being demonstrated in ongoing projects worldwide. As outlined in the Deployment Strategy[7] the following four steps concerning the introduction of fuel cell powered vehicles have been assumed:

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[6] European Hydrogen & Fuel Cell Technology Platform: Deployment Strategy Foundation Report and Strategic Research Agenda Foundation Report (August 2005) can be downloaded at https://www.hfpeurope.org/hfp/keydocs

[7] Deployment Strategy Foundation Report, chapter 2.4.1

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

The development of fuel cell components and hydrogen storage technologies is crucial in the above-mentioned steps. Especially the transition from step 2 to 3 requires close collaboration and feedback between basic research on components and fuel cell stacks on the one hand and the technical validation of integrated systems in demonstration programmes on the other to permit organic growth in the dependency of the technical and economic progress. In this context, in order to prove that cost reductions for critical sub-systems such as fuel cell stacks or hydrogen storage tanks are feasible, more and more units need to be demonstrated, for example in large-scale demonstration projects such as Lighthouse Projects in the 2010 to 2015 time frame. For a mass-market rollout around 2015, it is assumed that the following “quality gates” have to be achieved which have been adopted from the Strategic Research Agenda:

Table 5.1 *Comparison of the current status with 2015 SRA targets for fuel cell systems for passenger cars*[8]

		Current Status	2015 Target
Power density	litre/ kW	3.0	1.5
Cycle efficiency (NEDC)	-	37%	> 40%
Specific cost	€/ kW	> 4,000	< 100 (> 150,000 units/ a)

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[8] Strategic Research Agenda Foundation Report chapter 2.4.3.1

In terms of barriers, not only technical issues need to be resolved but industry development cycles in terms of timing also need to be considered. For the high penetration scenario it was assumed that mass production of hydrogen and fuel cell vehicles starts in 2013 led by a group of 5 first movers who each increase their capacities with a new plant of 100,000 units per year with an assumed plant utilization of 5%, 50%, and 90% respectively in the first three years. In the low penetration scenario, the hypothetic start of mass production was shifted to 2016 and the number of first movers reduced to 4 who increase their plant utilization rate from 5% to 90% over a five years time frame (maximum production capacity of each of the four plants 100,000 units per year). After the production capacities of the first movers have reached full utilisation after 3 (high penetration) and 5 years (low penetration), respectively, it was assumed that followers enter the market in a similar way and that the first movers then double their production capacities. Based on these hypothetic quantitative scenarios, an S-Curve[9] was calibrated to the generic production volumes and used to extrapolate penetration shares until 2050. This is shown for both scenarios as well as a medium penetration scenario in the table below.

Table 5.2 *Scenarios for the potential development of hydrogen vehicles, share in vehicle stock*

Total share of fleet	2010	2020	2030	2040	2050
High penetration	-*	3.3%	23.7%	54.4%	74.5%
Medium penetration	-*	1.2%	11.9%	35.9%	69.4%
Low penetration	-*	0.1%	2.8%	12.9%	36.0%

* Demonstration vehicles and fleets only

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[9] A modified Makeham Curve was used, applying a time shift of t_0 (start year of mass production) while the other parameters were calculated according to a “best fit approach” with the hypothetic absolute production volumes for each year and scenario (high, low)

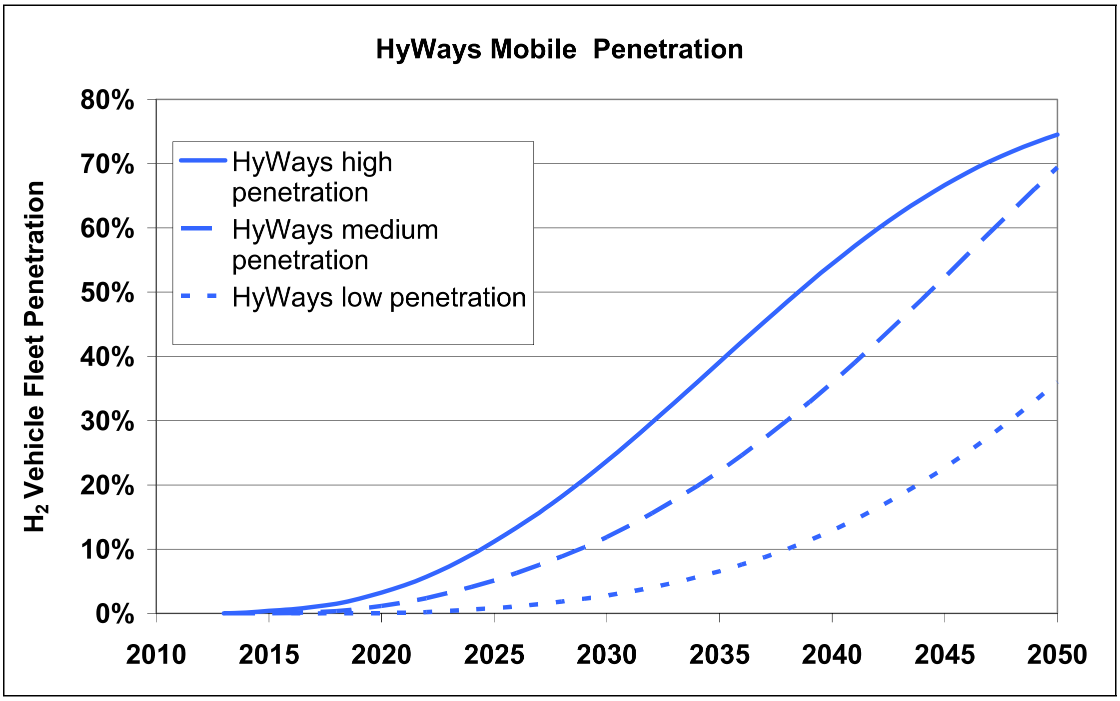

Figure 5.1 Penetration scenarios of hydrogen vehicles (for which model calculations are carried out in phase II)

In addition to passenger cars, these penetration curves were also applied to commercial light duty vehicles and public transport buses. Long haulage heavy duty trucks and coaches were not considered relevant due to their extremely long range requirements and the fact that the internal combustion engines of these vehicles usually operate in a higher efficiency range.

For cost calculation (see also chapter 5.4 with the learning curve approach) it is assumed that outside the EU the same number of hydrogen vehicles will be build.

5.3 Stationary Applications

Small and medium-sized hydrogen-fuelled combined heat and power systems (micro-CHP) are expected to evolve from a possible precursory major mass-market application for natural gas-based fuel cells. Initially the gas-based systems will not only serve as a precursor of hydrogen fuel cell systems, but also as a direct competitor. This is the case since the infrastructure for gas-based systems is well developed in many countries, while hydrogen grids first need to be constructed. The technological characteristics of hydrogen-fuelled systems may represent a second barrier, as they are perhaps less suited to micro-CHP applications than natural gas fuel cell systems. Finally, existing heating systems also have high theoretical efficiencies, such as condensing boilers combined with solar thermal water heaters. Moreover, the energy efficiency of the power sector will also increase in the future and the CO_2 emission coefficient may decrease sharply due to the introduction of CCS or renewables, leading to an erosion of the value added of micro-CHP. These are the major reasons why a more moderate development is assumed for hydrogen fuelled systems in stationary end-uses than in mobile applications. The penetration rates for households and commercial buildings are given in Table 5.1 and Table 5.2, respectively.

Table 5.1 *Scenarios for the potential development of stationary hydrogen applications in the residential sector*

Total share of households	2010	2020	2030	2040	2050
High penetration	-	1%	4%	8%	10%
Medium penetration	-	1%	4%	8%	10%
Low penetration	-	0.1%	0.5%	2%	5%

Table 5.2 *Scenarios for the possible development of stationary hydrogen applications in the commercial and services sector*

Total share of commercial demand	2010	2020	2030	2040	2050
High penetration	-	0.3%	1.3%	2.7%	3.3%
Medium penetration	-	0.3%	1.3%	2.7%	3.3%
Low penetration	-	>0%	0.2%	0.7%	1.7%

In the longer term, fossil reserves become increasingly scarce, creating greater opportunities for hydrogen-fuelled systems. However, even if a relatively cheap production technology for hydrogen from non-fossil fuels becomes available, hydrogen will still have to compete with the direct application of electricity which will prove a hard task especially for residential and commercial applications in urbanised areas with relatively high demand densities. This is the major reason for the expected limited penetration in the longer term, and for the difference between residential and commercial penetration because the latter is even more concentrated in urbanised areas than the former.

For larger-scale fuel cell systems, a co-production facility of hydrogen for transport and electricity may prove an exception to the scenario outlined above. Plans are already being drawn up for building such a facility, in which electricity is generated from hydrogen using a fuel cell because of its higher efficiency. There may be other exceptions, e. g. existing hydrogen pipeline infrastructure close to urban areas, or an admixture of hydrogen in the natural gas grid may result in the early introduction in the stationary sector being followed by substantial take-up of hydrogen technologies in this area. This would be particularly interesting if the hydrogen concerned were surplus hydrogen, for example from chlorine production, and hence relatively cheap.

5.4 Investment costs of hydrogen vehicles

One major influence on the results of the analysis is the assumption concerning the future cost developments of technologies. The learning curve concept is applied to the cost estimate of hydrogen vehicles.

A learning curve describes technological progress as a function of accumulating experience with that specific technology. Quite often, the technological progress analysed within a learning curve is parameterised as a cost reduction due to an increase in the accumulated production. Such an estimate is based on historical statistics in the cumulative output. The essential parameter to be estimated is the so-called "progress ratio" (PR). For example, a technology with a progress ratio of 0.8 means that the unit price will be reduced by 20 percent with each doubling of the cumulative output. The progress ratio is estimated from available historical data or can be derived from the statistics on the learning curves of related technologies.

It is important to note that learning curves do not represent a physical law. They are an empirical phenomenon with significant uncertainties surrounding both the estimation of specific progress ratios and their extrapolation for long-term forecasts of the cost reduction of technologies. In order to minimise the uncertainties in the price scenarios for fuel cell and hydrogen technologies in HyWays, the fuel cell and hydrogen ICE powered cars are split into different components with different progress ratios (see Table below, and (Tsuchiya, 2002)[10]). Two different scenarios for the progress ratios were selected (see Table 5.3) in order to specifically handle the uncertainties associated with fuel cells.

Table 5.3 *Progress ratios of H_2-technology components for a fuel cell car (figures from HyWays automobile industry partners)*

Component	Low PR (fast learning)		High PR (moderate learning)	
	Initial phase	After 10 years	Initial phase	After 10 years
Alternative fuel tank	0.85		0.85	0.93
Electric motor	0.90		0.90	0.98
Li-Ion battery	0.90		0.90	0.98
FC system	0.80	0.90	0.82	0.92
H2-ICE[a]	1.00		1.00	

[a] The EUCAR WTW-Study assumes the same production cost for gasoline and hydrogen engines.

The progress ratios are based on the research activities of the automotive partners in HyWays, derived from different comparable technologies, and taken from the specifications of other research projects.

The calculation of the vehicle price is based on the assumptions in Table 5.3. Figure 5.2 shows the projected price development for hydrogen-powered cars. The starting price for the gasoline car as well as the fuel cell car corresponds to specifications from (EUCAR, 2004) for the year 2010.

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[10] Tsuchiya, H., O. Kobayashi (2002): Fuel Cell Cost Study by Learning Curve. Submitted to Annual Meeting of the International Energy Workshop Jointly organized by EMF/IIASA, 18-20 June 2002 at Stanford University USA, http://www.iiasa.ac.at/Research/ECS/IEW2002/docs/Paper_Tsuchiya.pdf

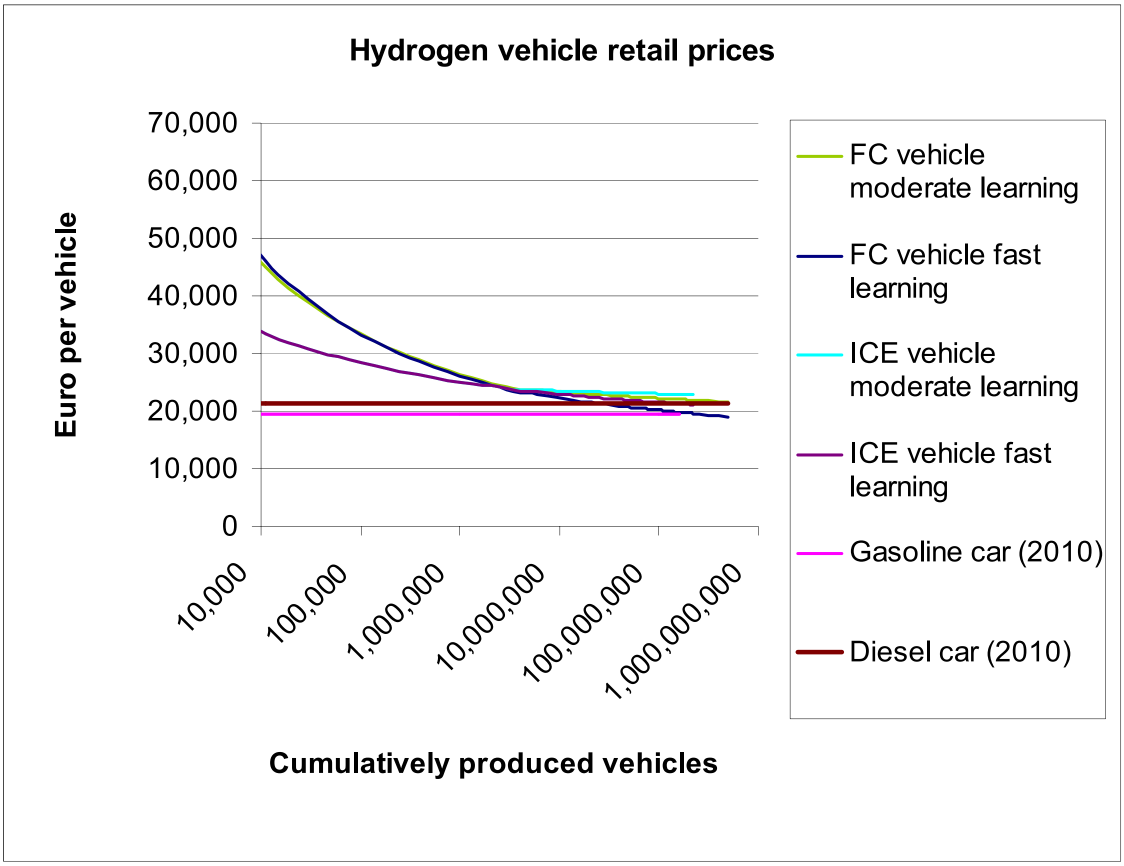

Figure 5.2 Cost reduction of hydrogen cars (only the medium class cars are shown) for the moderate and fast learning scenarios and, as a reference, the gasoline and diesel car figures for 2010