MEDIA BACKGROUNDER

The Hart report:
The Economics of aEuropean Hydrogen Infrastructure for Automotive

Introduction

In 2004, Linde commissioned David Hart, of e4Tech, Switzerland to assess the costs of a hydrogen production, distribution and refueling infrastructure to support commercialisation of hydrogen passenger cars in the European Union, forecast by the automotive industry. The Report is published on 24 February 2005.

Previous Studies

There have been some studies of hydrogen infrastructure in the past, but none are publicly available on the costs of such an infrastructure in Europe. The perception is that this would be extremely expensive. The influential National Academies of Science concluded in a 2004 Report on the $1.7bn United States Hydrogen Program that:

"The most significant challenge [for the Hydrogen Program] will be the high cost and logistical complexity of hydrogen distribution to fueling stations."

The importance of this Report is in supporting energy *systems analysis* by government economists and scientists, as well as automotive, energy and industrial gas corporations, in ascertaining the large-scale viability of hydrogen car commercialisation, which would have significant environmental benefits in reducing air pollution and greenhouse gas emissions, and diversifying energy supply in the automotive sector, presently 99% dependent on oil.

Implementation strategies

The objective of hydrogen infrastructure development is not to supplant the existing gasoline infrastructure, but to complement it, in the way diesel was introduced in Europe in the 1970's. Like mobile telecommunications networks, costs are typically managed by a gradual roll-out.

Two strategic frameworks are considered by the Report – development focused on Europe's largest urban clusters (Scenario 1), and a more targeted development targeted at Europe's automotive industry centres (Scenario 2).

The supply of hydrogen under Scenario 1 focuses hydrogen infrastructure development in Europe's fifty most highly urbanised areas, with populations of over one million, to achieve greatest delivery potential to market. The infrastructure is built up in four phases of five years, in which urban areas are added in groups and then linked by main roads (See Figure 1).

For details of Scenario 2, please refer to the Report in full.

Pathways

The Report considers three pathways, or concepts, for infrastructure development, in order to assess the investment costs of each.

1. Centralised considers 100% centrally-produced hydrogen using large-scale steam methane reformers (SMR) and liquefication, delivered to filling stations by tanker
2. Distributed Steam-methane reforming (SMR) considers 50% of total hydrogen requirements, produced and delivered as in Concept 1, and the remainder produced on-site at filling stations by small steam reformers

3. Distributed Electrolysis considers 50% of total hydrogen requirements, produced and delivered as in Concept 1, and the remainder produced on-site using electrolysers

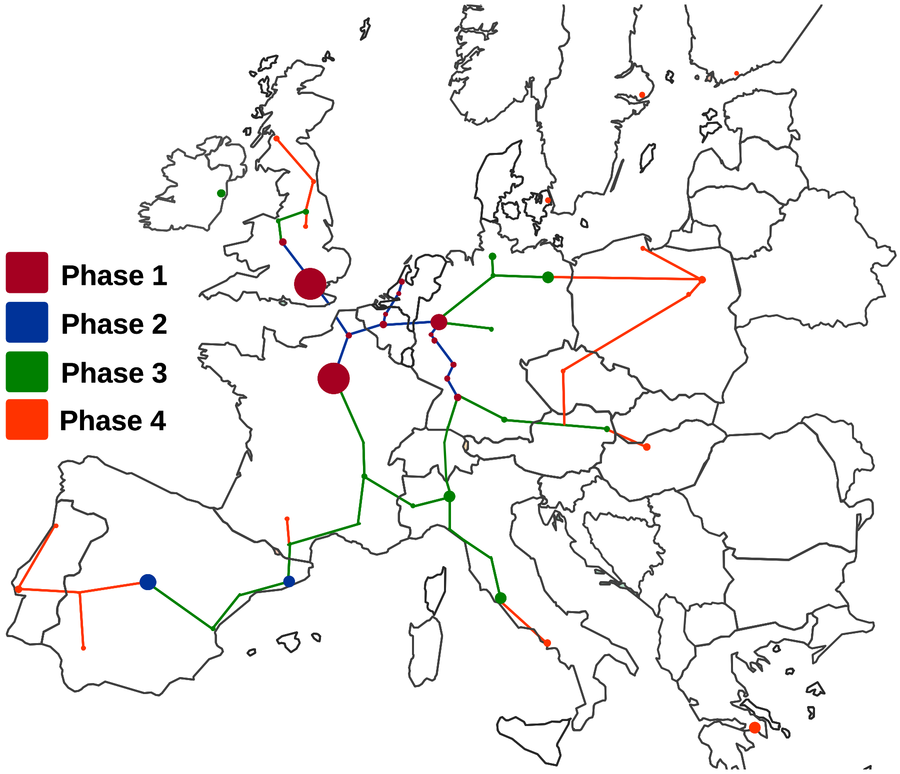

Figure 1: Staged build-up of hydrogen infrastructure in Europe (Scenario 1)

Hydrogen Demand and Hydrogen Car Commercialisation

Based on forecasts from the automotive industry, two market scenarios (low- and high- uptake) were modelled to establish hydrogen demand from a growing hydrogen car population. (See Figure 2, high uptake).

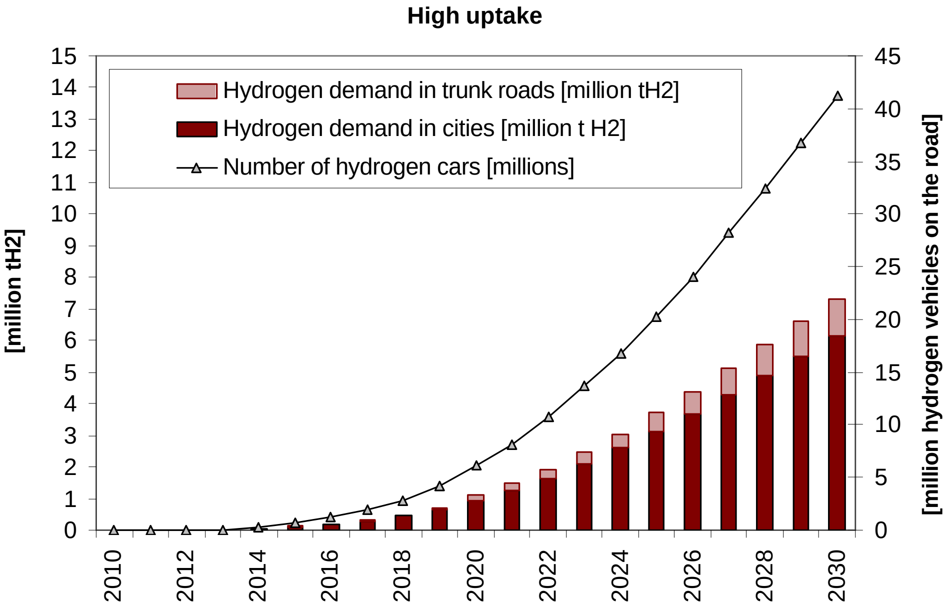

Figure 2: Hydrogen vehicle uptake and corresponding hydrogen demand to 2030, high uptake

Price of Hydrogen

For the purposes of the study, the price of hydrogen was taken as untaxed, and sold at average 2003 prices of taxed gasoline at petrol stations. The level of taxation on hydrogen will affect results in the future; however, this should be balanced by the growing price of gasoline.

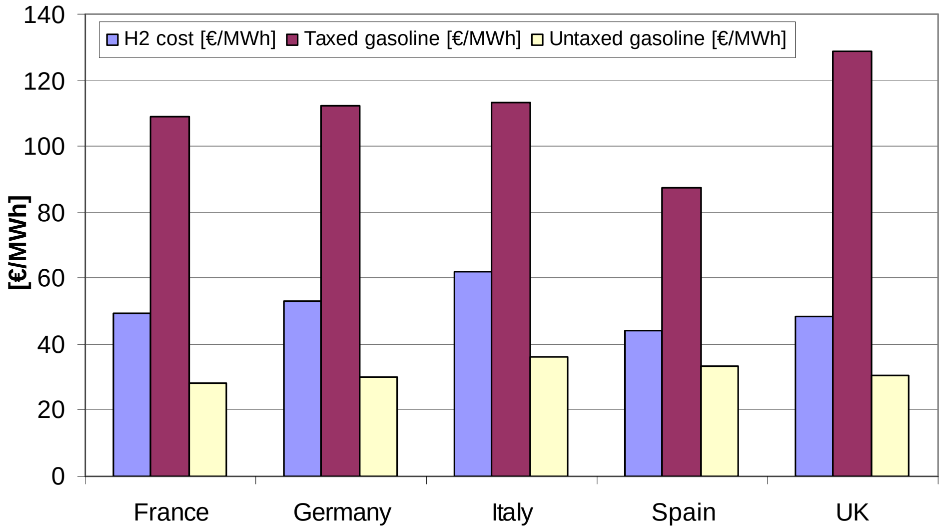

Figure 3: Price of hydrogen in Europe's five main markets vs. gasoline (2003)

Summary of findings

1. Hydrogen infrastructure relatively inexpensive

2020 outlook: Medium-term costs are manageable

The total cost of the hydrogen infrastructure in a high-uptake scenario is less than €5bn by 2020, and approximately half in a low-uptake scenario, under all pathways. The cheapest pathway is centralised production, at €3.5bn.

Total investment annualised for the whole of Europe is at €580m pa with centralised production, and €750-850m for a distributed configuration to 2020.

Initial investment in a hydrogen infrastructure benefits from 'waste hydrogen' from chemical factories, providing enough hydrogen to power thousands of cars, and holding off new production plant build until 2015-18, depending on market uptake.

2030 outlook: Centralised infrastructure significantly less expensive

By 2030, total investment costs rise vary considerably depending on the production and distribution system, and market uptake (€8-€33bn).

The most economic pathway is Concept 1 – using large-scale steam reformers and tanker distribution. The total cost of infrastructure development in this scenario is €8bn with low market uptake, and €18bn with high market uptake. (see Figure 5)

While there is greater investment in centralised production plant in Concept 1, and greater investment in transportation, economies of scale mean that as the hydrogen car population expands significantly, demand is met without the levels of investment required in on-site hydrogen production (Concepts 2 and 3).

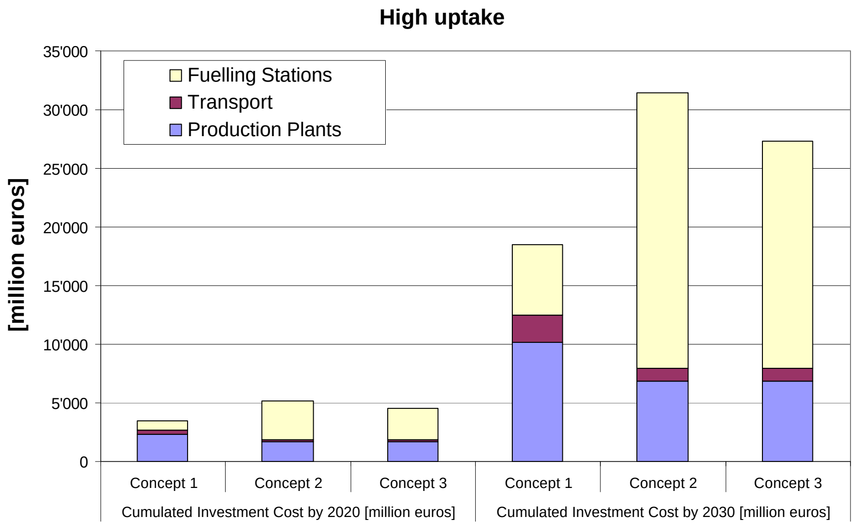

Figure 4: Cumulative investment, Europe, scenario 1, by segment

2. Reaching the market: Filling stations

The scenarios considered allow the car manufacturers to roll out vehicles in consecutive regions rather than over a very wide area. Filling stations must be built to ensure capacity is available ahead of demand.

In areas with large numbers of urban areas, the number of fuelling stations in Germany reaches 5,000 by 2030, with 3,400 in the UK, 2,700 in France and just over 2,000 in Italy with high market uptake. (See Figure 4)

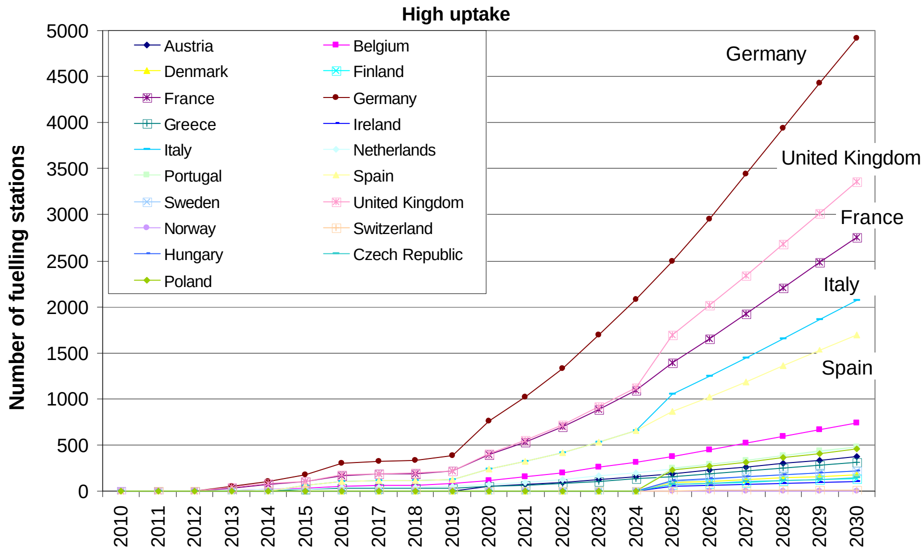

Figure 5: Fuelling stations by country, high uptake case, scenario 1

3. Investment costs vary by country (see Appendix A)
The investment costs of each country depend on the strategic plan for hydrogen infrastructure build-up in that country.

Under the population-targeted scenario, total investment costs are disproportionately greater for Belgium, Denmark, Germany, Greece, Portugal and the UK [note 1], due to a high level of urbanisation relative to the total population of these countries. The availability of hydrogen to car users in these populations will be proportionately greater, and these countries would see greater benefits in terms of greater use of hydrogen cars by population.

With high uptake, the total cost by 2020 for Germany and the UK is €870m for 1.9 m hydrogen cars, and €573m for 1.2 m hydrogen cars, respectively. For the same reason, the largest metropolitan areas in Europe, Greater London and Ile-de-France, which cover over ten million people each, would require substantial investment of €100m by 2020, rising to €500m by 2030, in a high uptake scenario supporting 5.5m cars each by 2030, the equivalent of Spain and over double the required investment for other major cities such as Berlin.

In countries with lower population densities but with multiple areas of high population, the costs of distribution and of a greater number of filling stations on trunk roads mean the cost of infrastructure is proportionately greater to support the same hydrogen car population than in countries with greater population densities. Countries affected by this are France, Italy and Poland. The cost per hydrogen car is €664 in Poland, compared with €466 in the Netherlands by 2030.

Note 1
Though the Netherlands, for example, has a high population density, it has few urban areas over the 1m threshold and therefore hydrogen vehicles do not penetrate to as high a proportion of the population as in some regions.

APPENDIX

Table A – Scenario 1, Concept 1, High Uptake – Population reached, H2 vehicles served, Investment costs and cost per H2 car – by country

Country	Population reached [million]		H2 vehicles served [millions]		Investment cost [million euros]		Cost per hydrogen car [€ /hydrogen car]	
	2020	2030	2020	2030	2020	2030	2020	2030
Austria	0.08	1.4	0.04	0.7	132	362	3'329	516
Belgium	0.6	3.1	0.3	1.4	232	874	853	619
Denmark	0.0	0.8	0.0	0.3	0	159	0	577
Finland	0.0	0.5	0.0	0.2	0	145	0	665
France	2.2	12.6	1.1	6.1	570	2’797	538	456
Germany	3.5	21.6	1.9	11.6	870	4923	467	423
Greece	0.5	2.9	0.2	0.9	151	361	890	387
Ireland	0.0	0.4	0.0	0.2	0	130	0	827
Italy	1.1	8.3	0.6	4.7	355	1’953	549	412
Netherlands	0.5	2.8	0.2	1.2	174	539	782	466
Portugal	0.0	1.8	0.0	0.7	0	365	0	545
Spain	1.5	9.3	0.7	4.2	356	1’723	538	411
Sweden	0.0	0.7	0.0	0.3	0	174	0	517
UK	2.5	16.4	1.2	7.6	573	3’212	498	422
Switzerland	n/a	n/a	n/a	n/a	110	113	n/a	n/a
Hungary	0.0	1.1	0.0	0.3	0	179	0	645
Czech Republic	0.0	0.6	0.0	0.2	0	147	0	753
Poland	0.0	2.0	0.0	0.5	0	356	0	664