Economic aspects related to introduction of Hydrogen as transportation fuel

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Norway's first hydrogen refuelling station opened in Stavanger August 23rd 2006.

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Executive Summary

The challenge of reducing the GHG emissions to an acceptable level calls for a complete decarbonisation of the transportation sector within 2050. Over the last 2 decades we have witnessed subsequent hypes pointing at “the solution” to reach the targets, one after the other being “busted” either due to alleged opposition from strong industry lobbyists in the 1990s or to the lack technological break-throughs. The questions around the sustainability of the bio-fuel alternatives have also hampered the introduction of low carbon solutions. Lately, however, a consensus has arisen between industrial and public stakeholders as well as academia, that a “silver bullet” solution solving the emission problems within transportation does not exist, and that a portfolio of power trains and alternative fuels are needed to meet these challenges.

In a well functioning market, the price of a commodity or a service is given by the balance between the supply and the demand. Neither hydrogen technologies nor hydrogen fuel may yet be considered commercial in this context. For new technologies and fuels there are more aspects involved such as the customer’s acceptance of the commodity, the availability (density of refuelling stations), the vehicle’s driving range, second hand price for the hydrogen vehicles etc. Societal and economic issues, thus, play a significant role in the process of introducing hydrogen as a transportation fuel, including safety, taxes or subsidies and especially predictable framework conditions. The latter is crucial to ensure the customer’s engagement in an alternative concept of transportation, such as hydrogen.

Early markets for hydrogen technologies are currently in emergence, in areas such as remote telecommunication towers, fuel cells for forklifts and critical load facilities. These markets may eventually feed in to further technology development and facilitate cost reduction needed to enter other and larger market segments.

Due to tax exemption for zero emission vehicles in some European countries in which taxation of conventional Internal Combustion Engine powered vehicles is high, hydrogen powered fuel cell vehicles are already close to commercially competitive in these countries (especially in Denmark and Norway). Along with support programs in many countries, and early adopters being willing to pay more for a zero emission alternative, there is a pre-commercial market expected to emerge within few years.

This report is especially focusing on the aspects triggering the customer’s willingness to pay for a hydrogen vehicle and fuel, and the main conclusion is that there is a significant share of the population that is willing to pay somewhat more due to environmental benefits of hydrogen. However, it is crucial to underline that the

majority of customers are not willing to pay more for hydrogen based transportation, and therefore it is concluded that hydrogen based transportation needs to reach the cost level of conventional vehicles and fuels to have a true commercial break through.

Various methods to reveal the willingness to pay is discussed in this report, and in general it is concluded the adequacy of the methods is questionable and the reliability of the results from interviews is limited. This is related to another finding that the public's knowledge about hydrogen based transportation is generally low, limiting the value of the replies to questionnaires provided to the inexperienced consumer. Outreach and information dissemination are thus still highly needed activities to prepare the mass marked for hydrogen based transportation.

Hydrogen as fuel is new to the vast majority of people. To convince a customer to engage in this new option, the total cost of ownership (TCO) should be in the range or lower than that of conventional fuels. At least this appears to be important to the majority of the public. So, like for the battery electric vehicles (BEVs) the TCO should be presented in a way that the man in the street understands. The unit of measurement for the zero emission vehicles differs from that of fossil fuelled vehicles (litre of gasoline or diesel) in that fuel (electricity) for the BEV measured in kilowatt hours (kWh) and for the hydrogen vehicle typically in kilograms (kg). This project's partners suggest that hydrogen fuel price should be presented to the public in a unit of measurement reflecting a "on a kilometre travelled" basis similar to that of conventional fuels. Hydrogen fuel should therefore preferably be priced per 100 grams, providing an approximate 10 km travel distance. The unit of normal cubic meter (Nm^3, equal to 89 grams of hydrogen) may also constitute an adequate unit for marketing hydrogen.

Uncertainties for a customer to engage in hydrogen based transportation also include their limited knowledge of what they pay for current transportation services, making it even more difficult for them to compare the new options such as battery electric or hydrogen electric vehicles.

For those engaging in demonstrating hydrogen based transportation, the economic aspects are playing a crucial role in the success of their projects. Being engaged in new technologies, there are in general a significant share of unexpected cost (typically in the range of 25%) accrued during the execution of such projects. One way of counteracting this is to "over"-budget the project, leaving room for covering these unforeseen costs, so that one may avoid stakeholders taking on high losses during the execution of the project, rendering this stakeholder negative to engage in a new similar project.

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List of Abbreviations:

BEV	Battery Electric Vehicle
CAPEX	Capital expenditure
CCS	Carbon Capture and Storage
FCEV	Fuel Cell Electric Vehicle
GGE (gge)	gallon gasoline equivalent
GHG	Greenhouse Gas
HEV	Hybrid Electric Vehicle
HRS	Hydrogen Refuelling Station
IEA	International Energy Agency
ICE	Internal Combustion Engine
ICEV	Internal Combustion Engine Vehicle
IPCC	Intergovernmental Panel on Climate Change
kWh	Kilowatt-hour (unit of measure: energy)
LHV	Lower Heating Value
OPEX	Operational expenditure
PEM	Proton Exchange Membrane (fuel cell)
PHEV	Plug-in Hybrid Electric Vehicle
TtW	Tank to Wheel
WTP	Willingness to Pay
WtW	Well to Wheel
ZEV	Zero Emissions Vehicle

1 Introduction

1.1 The Challenge

The transportation sector contributes by 26% to the overall global Greenhouse Gas (GHG) emissions [Chapman 2007], the second largest share, next to stationary power generation. Among the various forms of transportation; automotive, aviation, maritime and rail, road transport takes by far the largest share of around 75% [WWF 2008].

The two main drivers in the strive for reducing GHG emissions from transportation are:

i) the highly debated global warming issues,

ii) the dwindling crude oil resources fuelling the growing transportation sector.

As oil prices increase, more energy demanding and less environmentally benign sources like oil sand, extra heavy crude, or oil shale are being exploited, exacerbating the problem. Clearly there is a delicate balance between economical interests and ecologically acceptable solutions.

With close to 1 billion vehicles on the road, predominantly power by fossil based gasoline and diesel, de-carbonization of the transportation sector is the only viable solution to reach the internationally recognized targets for GHG emission reductions.

1.2 Subsequent hypes since 1990

Focus on the de-carbonization issue was originally brought about by the California Air Resources Board[1] passing the Zero Emissions Vehicle (ZEV) mandate in 1990 to combat local urban air pollution. This initially lead to the development of a series of battery electric vehicles (BEVs) by GM, Toyota, Honda, Ford, Nissan, and Chrysler and others. Similarly, some hydrogen powered Fuel Cell Electric Vehicles (FCEVs) were also demonstrated towards the end of the 20th century. It has been heavily

[1] More information may be found at: http://www.arb.ca.gov

debated that the oil industry together with the car manufacturers worked against the mandate, and that the marked failure of the electric car was caused by this opposition. Moreover, towards the end of the 1990s media pointed at hydrogen FCEVs as *"The Solution"*, with several car manufacturers announcing mass production in 2003. With slower technologic progress than foreseen this year was passed in silence, as both cost and durability of the fuel cells for vehicle propulsion were still unsatisfactory. In the shadow of the FCEV-hype, biomass based fuels took over the limelight, eventually suffering from the crucial arguments of lacking sustainability and competing with food production, still rendering this solution highly questionable.

Thus, over the two last decades we have seen one hype taking over for another, finally flowing into a common understanding that there is *No silver bullet* covering all market segments of transportation. The range of the BEVs limits these as city cars, and the limited biomass resources renders this option as an add-on to be blended into fossil fuels at various levels. The need for a portfolio of power trains and alternative fuels was finally manifested through the Coalition report[2] published December 2010, supported by data input from 30 industry companies and suppliers.

Figure 1. The Coalition report published in the fall of 2010.

1.3 *The traditional technical approach*

The technical approach to reducing GHG emissions from road transportation includes the following three basic elements:

1) Increase efficiency in existing technologies

2) Introduce new technologies as well as reduce weight/size of vehicles

3) Utilize more environmentally sound fuels

[2] www.zeroemissionvehicles.eu/uploads/Power_trains_for_Europe.pdf

Continued incremental energy efficiency increase of conventional propulsion technologies has not been sufficient to compensate for the increasing transportation demand over the years. So, expecting that efficiency increase alone will solve the problem is far too optimistic.

Introduction of new technologies is potentially a much more powerful measure, but require changes to production lines and challenges large investments. The internal combustion engine (ICE) has been subject to more than 100 years of development, and is provided to the market at low cost due to mass production. The transition to new propulsion technologies is therefore highly challenging in view of the immature state of these technologies. Reducing weight and size of vehicles will in any case be beneficial. Utilization of more environmentally sound fuels, however, will be an indisputable element as fossil based carbon on board the vehicles must be replaced.

It has been concluded that it is unlikely that technological innovation constitutes the sole answer to the climate change problems. Behavioural changes brought about by policy will also be required [Chapman 2007].

1.4 Several approaches needed

Solving the technological challenges is a prerequisite for succeeding in introducing hydrogen as a transportation fuel, but it is not sufficient alone to ensure this introduction. Economic and societal factors play decisive roles and must likewise be addressed and the corresponding challenges overcome. Numerous studies have shown that although a high level of consciousness of environmental challenges has been reached, the average man in the street is not willing to pay extra for more environmentally sound solutions. Societal issues linked to people's inherent scepticism to new technologies and their traditional and conventional ways of thinking within a narrow and well known framework also plays a significant role in preserving established solutions on daily life. Moreover, this confines and slows down the process of adapting new technologies although the economic competitiveness may be reached.

On this arena, political engagement and intervention is needed, and strong political incentives and regulations may lead the development in the right direction. This is exactly what we have experienced over the last few years, in Japan, the US and Europe, especially in Germany.

In September 2009 the world's 9 leading auto manufacturers[3] signed a Memorandum of understanding that they would jointly launched FCEVs in the market by 2015. Simultaneously, the intention of building 1000 hydrogen refuelling stations (HRS) in Germany was confirmed by leading European energy companies.

German government is directly involved in this initiative, through the substantial National Innovation Program (NOW[4]), with a budget of €1,4 billion.

Figure 2. Representatives for leading European energy companies and car producer Daimler signing up for the launch of 1000 hydrogen refuelling stations in Germany.

Such public private partnerships provide a crucial element of risk sharing related to large investments in refuelling infrastructure. It is, moreover, accepted that societal and socio-economic issues constitute an integral part of a successful introduction of alternative fuels.

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[3] Daimler, Ford, General Motors/Opel, Honda, Hyundai, Kia, Renault, Nissan and Toyota

[4] Nationale Organization Wasserstoff, http://www.now-gmbh.de/

1.5 Societal and socio-economic issues

A series of aspects are relevant in this context.

- Behavioural change
  - *Studies of how behavioural change may be promoted by policy measures which enhance the attractiveness of alternatives to private car use.*
  - *Identification of economical thresholds for customers to alter travel habits*
- Development of adequate regulatory measures and taxation for promoting sales of more environmentally sound vehicles.
- Assessment of how a combination of taxes and regulations may facilitate introduction of improved technology altogether may alter travel habits
- Establishment of methodology for quantification of the effect of various measures.

We will touch upon several of these in this report.

1.6 Outline of this report

This report will deliberately NOT focus on technological issues as these are dealt with in numerous other studies.

Moreover, the pure societal issues have been covered in the previous deliverable (Praktiknjo, et al. 2011). This report, thus, focuses on the economic issues, and is hence devoting most of its content to cost and prices of hydrogen vehicles and hydrogen as transportation fuel in a customer and end user perspective.

In the following Section, a basic introduction to the Economic Aspects of demand and supply is provided. These mechanisms will eventually be leading the market penetration, although we are perfectly aware that the market for hydrogen as a transportation fuel is non-existing and probably will need several years to be established.

In Section 3 the customers' Willingness to Pay (WTP) for hydrogen vehicles and fuel is treated through a review and assessment of available literature over the last decade.

In Section 4 the current cost targets of hydrogen as fuel is compared to the actual production cost as well as that of conventional fuel prices. Moreover, aspects related the unit of measurement of hydrogen (e.g., kilogram or Normal cubic metre) compared to the conventional unit of litre are discussed.

Section 5 deals with unexpected cost accrued in the demonstration projects assessed in this project and pinpoints some key factors from where these cost arise.

Based on these various parts of this report, conclusions are drawn and recommendations for future Light house projects are provided in Section 6.

Finally, an Economic Matrix summarizing relevant studies in literature may be found in Annex 1.

2 A basic introduction to the Economic Aspects

2.1 The balance between demand and supply in the market

Economics is the social science that studies the allocation of scarce resources. Scarcity is communicated with price signals. The scarcer a resource is the higher price is necessary to make someone willing to sell (or make others unwilling to buy.) Hence, prices and quantities can be determined by balancing market interactions.

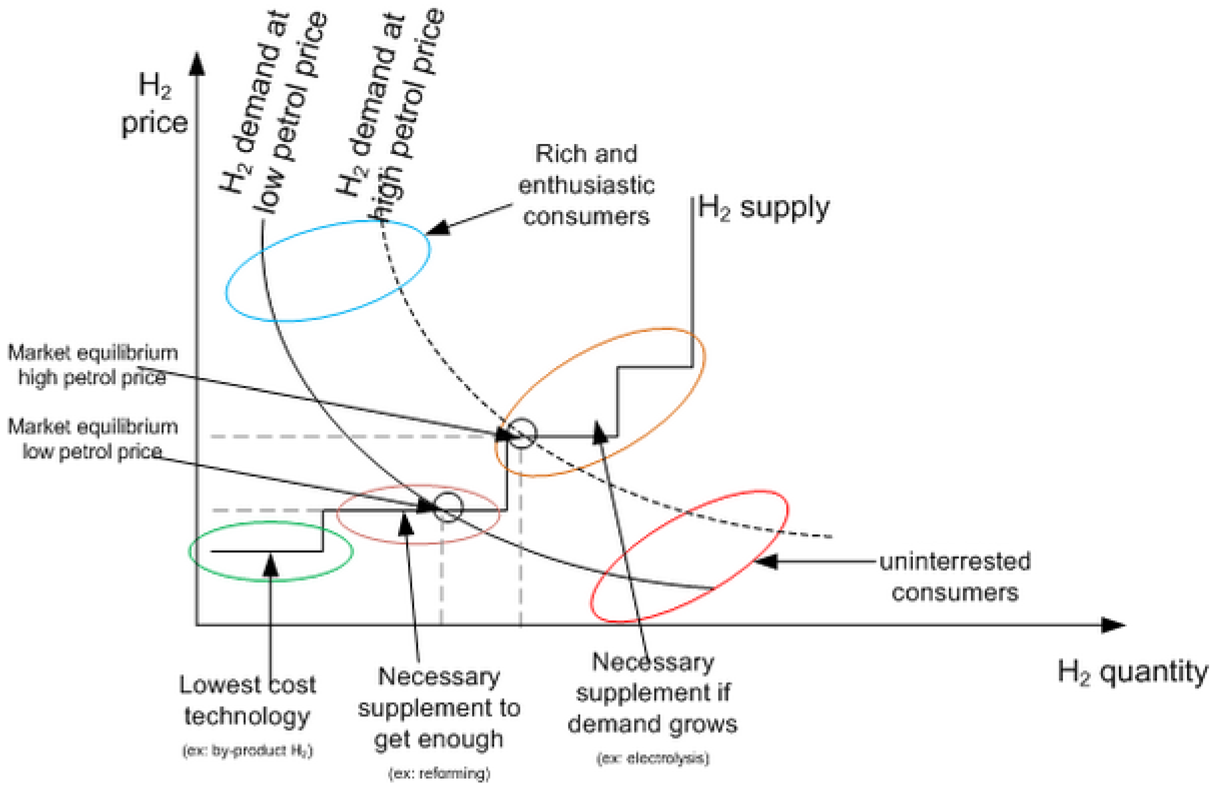

Figure 3 The balance between cost and quantity of hydrogen deployed inthe market, indicating the influence of cost for conventional fuel (here petrol).

The market *demand curve* is basically individual customers' demand curves aggregated. The individual demand curves will typically have the same characteristic as the market demand curve. If the price is high the individual wants to buy less than if the price is low. Hence for the "first" unit the consumer is typically willing to pay more than for the second unit etc.

A shift in an external factor that increase *all* consumers' willingness (or ability) to pay, such as improved efficiency of hydrogen vehicles, higher price of other fuels, or wage growth, will shift the entire curve upwards. Apart from measurable factors such as prices of other fuel and wages, the individual customers' hydrogen demand mostly depends on their attitudes and preferences. S*upply* is more tangible and mainly depends on cost structures of the alternative production technologies. Hydrogen can for example be supplied as a by-product, produced with electrolysis or steam reforming (oxygen deficit combustion followed by water shift) of hydrocarbons or biological material. A *supply curve* can be formed by ranking the supply technologies by ascending *marginal cost* (MC). MC is defined as the cost increment when producing one more unit. A technological improvement or fall in feedstock price would lead to a lower MC of that particular technology, which is illustrated by a downwards shift of its section of the supply curve, and could lead to a change in the rank of supply alternatives. While the height of the curve section corresponds to the cost, the length of the section corresponds to the available production capacity at that cost.

In some regions, some of the hydrogen demand can be satisfied by cheap by-product from for example ammonia production. If the demanded volume is higher than what is technically possible to supply from the source with the lowest MC, then the hydrogen supply must be supplemented. Among all hydrogen supply technologies in operation, the *highest* MC will equal the price, which is the same for all producers. For the more efficient producers, price will exceed costs. The costs of various hydrogen supply technologies is well surveyed, see for example Wårheim Johansen & Hermansen (2006), Stiller et al. (2007), or Lemus & Duart (2010).

Two distinct types of market failure are relevant for the hydrogen market: 1. External costs, and 2. Network effects. External costs refer to the fact that hydrogen is a more desirable fuel than petrol and diesel because the environmental damage (an external cost) is smaller. Network effects refer to an obstacle to the change of fuel infrastructure, the so-called *"hen and egg"* problem. Each hydrogen user contribute to a larger hydrogen market - a benefit to other hydrogen users because a larger number of filling stations is viable and the technology more mature, and this is not automatically taken into account. These two market failures will be explored in the following section.

2.2 *Market failures*

2.2.1 External costs avoided with hydrogen as a car fuel

Energy use, particularly in transportation, is littered with costs that are *external* in the sense that they are not charged the decision maker but shared thinly among everyone. The total cost to society of burning oil is not only the cost of getting it out of the ground; it also includes the damage due to pollution, congestion, traffic accidents etc. Because external costs (benefits) are not taken into account, the consumed quantity will be higher (lower) than the overall optimum. Such market failures can be corrected by taxes or subsidies that make the external costs or benefit internal to the decision maker.

The main usefulness of hydrogen is that it has less environmental impact than fossil fuels. When fossil fuels are taxed properly, then hydrogen can compete on price (Hansen, 2009). However, fuel taxes not only reduce the demand for consumption that damage the environment, but also help balance the governments' budgets with less distortion to the incentives to work than payroll or income tax. Therefore we can probably not expect hydrogen to be subsidized or even untaxed permanently.

There are two basic advantages to the buyer of hydrogen over other *"future-proof"* fuels Transport Energy Strategy (TES, 2007). When fuel cells become commercially available, hydrogen can be combined with an electric drive train, which is more efficient than conventional ICE. The potential feedstock supply is higher than for example bio fuels (TES, 2007). Electric drive trains can also be combined with batteries. However, presently available batteries are relatively large, heavy and expensive so the driving range is rather short.

2.2.2 Network effects related to the introduction of hydrogen

The main economic phenomena that hinder the introduction of hydrogen relates to network effects and the "hen and egg" feedback from market size to costs and convenience. Essentially a hydrogen vehicle is more useful the more filling stations are around, and the viable number of filling stations will be higher the more people drive hydrogen cars.

Presently the demand side of most demonstration projects seems to consist mainly of enthusiasts and fleet vehicle operators such as bus companies. In the longer run, when fuel cell vehicles get more accessible, then the demand side can be expected to include people in general. Rather than as a result of interactions between buyers and sellers in a market, the price per kg of hydrogen in demonstration projects such as HyNor is set at a level that corresponds to the same cost per km as diesel (Wårheim Johansen and Hermansen, 2006).

Williams et al. (2005) raise uncertainties about whether enough customers will adopt a new technology and they formulate their concern with the concepts "economies of scale" and "network externalities". Conrad (2005) has made a quantitative model of the network effect. Greaker and Heggedal (2007) analyze a similar market externality and show that there could be several market equilibria, and discuss what it could take to reach the best one.

Keles et al. (2008) address the feedback problem with a system dynamics model. They consider several scenarios of government support, and conclude that the lowest total cost is achieved with high initial support which leads to a rapid introduction. The high volume reduces the unit cost and therefore fewer subsidies are necessary in the later periods.

Wietschel et al. (2009) analyze the macro economic impact of hydrogen. They apply three modelling approaches; "input-output", "computable general equilibrium" and "system dynamics". Their presented work shows that hydrogen as an energy carrier has impact on employment, gross domestic product and international competitiveness.

Kårsten (2010) has interviewed some of the HyNor actors and describe their economic issues. His explanation of the stagnation in the years 2008-9 is that no "state of the art" fuel cell vehicles were available in Norway, and this created some doubt whether one actually stood on the threshold of the "hydrogen future". The paper is not yet published, but Chapter 6 of his (Norwegian) PhD thesis (Kårsten, 2008) is similar.

2.3 *Impact of taxes and subsidies on prices and volumes*

The supply curve has the marginal cost on the vertical axis and the quantity that this marginal unit comes on top of on the horizontal axis. A tax (subsidy) per unit of hydrogen would essentially increase (reduce) the marginal cost of supply by the same amount and shift the supply curve upwards (downwards). The subsidy (or tax) per unit and the change in unit price are not necessarily equal. A tax (subsidy) leads to a combination of reduced (increased) price to the producer and increased (decreased) the price to the consumer. The extents of these changes depend on the combination of *slopes* of the supply and demand curves.

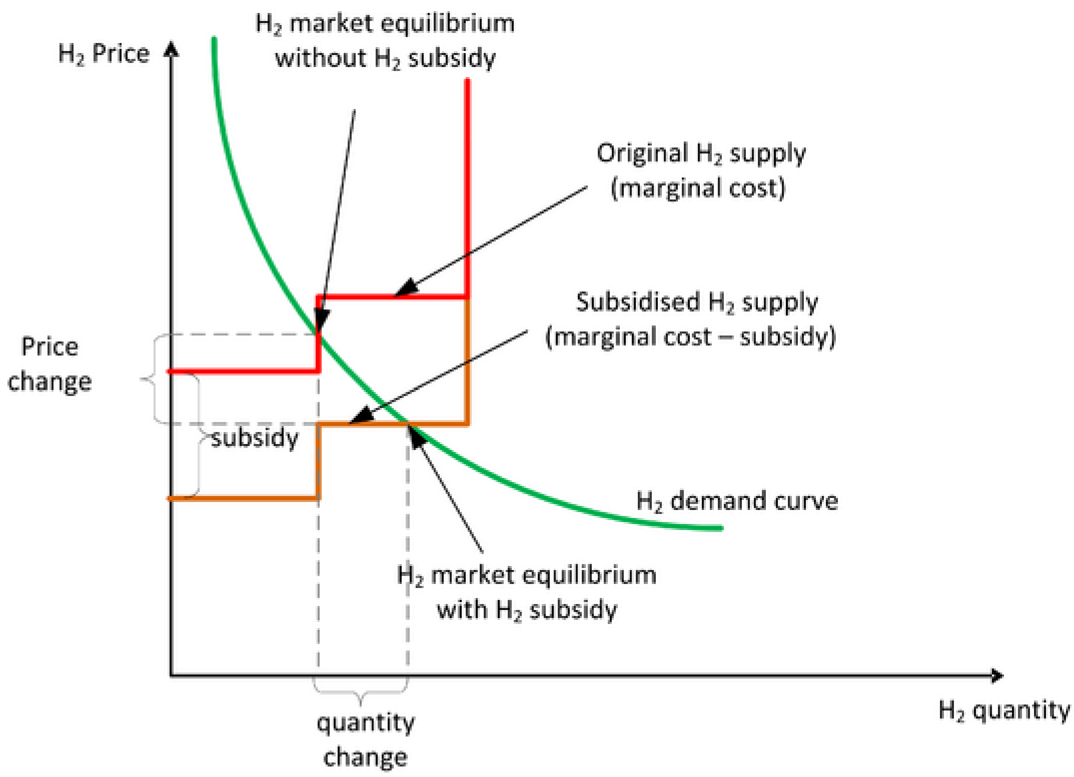

Figure 4 The influence of subsidies on the market volume of hydrogen as a fuel.

2.4 Engineers and economists views on how, where and when to produce H_2

In order to limit the computational complexity to a manageable level, simplifications are necessary. Papers written by engineers often focus on what the cost would be if a decision to produce is already made, and focus on *one* production technology at the time. Papers written by economist often focus on decision maker interactions, and therefore no resources are left to model the production processes realistically. For example, the alternative production technologies can be represented as sections of a supply curve. For each such section all input prices are assumed to be fixed and the cost components are summed from the bottom and up, called "bottom up" models. Then the role of the economists' "top down" approach is to check whether the assumed prices are consistent with the input and output quantities that result from uncoordinated bottom-up models.

Economic models that are used to identify good decisions are based on *relevant* costs. A cost is relevant if it is affected by the considered decision. In the short run, some costs must be paid regardless of production, in this instance only cost of input that you are able to change is relevant. However, in the long run, you will only commit to the irreversible or "fixed" costs unless there is sufficient margin between price and variable cost to cover them. Typical fixed cost is the cost of capital, i.e. depreciation of machinery and interest rate that must be paid regardless of production. Typical variable costs are the feedstock.

In the short run most of the electrolysis cost is electricity. Electricity prices are *very* volatile because of the difficulty of storing from periods of abundance to periods of scarcity (and even worse to borrow the other way). Electrolysers need not be operated continuously, they can be turned off when the electricity price is high and on when it is low. Therefore only the price at the points in time when you actually produce is relevant. An electrolyser is practically an option on the difference between the spot price of electricity and the hydrogen price (adjusted for the efficiency). The value of an option increases with the price difference volatility. A similar principle is well known and used to optimize the operation of natural gas power plants. These plants options on the difference between the prices of electricity and natural gas (adjusted for the efficiency), called "spark-spread". If the average or "mix" price is assumed rather than prices during the moments when it is favourable to produce, then the cost of hydrogen will be overestimated.

When the production gets sufficiently large, then it is good for efficient allocation of electricity to allow hour-dependent prices. This lets short-term scarcity or abundance to be taken into account, and the demand from electrolysers will be motivated by low prices to take place during the hours when scarcity is low. If the electrolysis production gets large enough to dominate the electricity market then the price level will be bid up. The inflated feedstock price and the improved efficiencies of equipment, both due to higher production volumes, are likely to pull costs in the opposite directions. "Economies of scale" makes the average cost decline, and large plants are usually more efficient than small.

The price of fossil fuel and other exhaustible resources consist of the extraction cost and the value of the lost opportunity to sell it later. This scarcity premium should theoretically increase gradually over time as the resource is produced and gradually depleted (Hotelling, 1931). Therefore hydrogen produced with renewable energy will gradually get cheaper relative to fossil fuels so it can compete without subsidies.

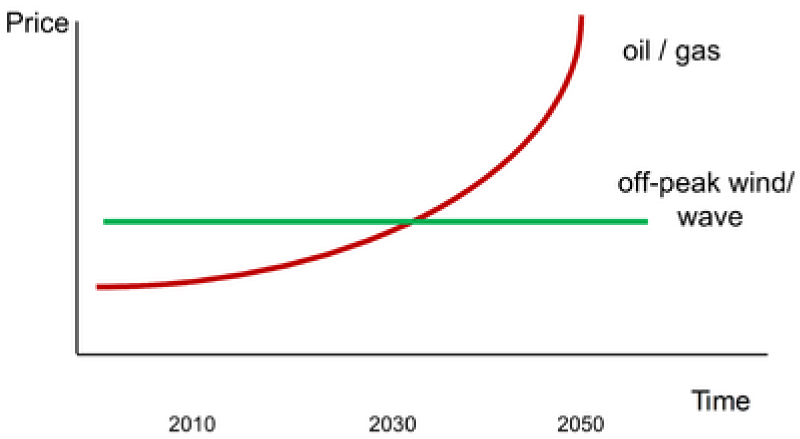

Figure 5 The competitiveness of alternative energy resources as fossil energy cost is expected to rise.

3 **Willingness to Pay for hydrogen based transportation** *- a literature survey*

3.1 Preface

Hydrogen based transportation is still in its infancy, despite the significant number of demonstration projects that have been carried out, proving technological feasibility. Cost and durability of the energy converter – the fuel cell – is, however, still a challenge. A passenger bus with hydrogen fuel cells is about 4 times more expensive than a conventional diesel bus[5].

Small series of hydrogen fuel cell passenger cars have already been launched and larger series will be introduced to the market by 9 leading international auto manufacturers in 2015[6].

The success of hydrogen as a fuel for transportation depends on public acceptance. In a market economy acceptance is related to successful sale; users actually purchasing personal mobility in terms of buying both vehicles and fuel. If either the hydrogen fuel or hydrogen powered vehicles are not accepted by potential customers, hydrogen based transportation will not be realized.

In this chapter we deal with issues related to the acceptance of hydrogen based transportation. More accurately we focus on customers' Willingness to Pay (WTP) for hydrogen based transportation services, for hydrogen passenger cars and for the fuel itself. Assume that for whatever reason, customers are willing to pay a premium for the hydrogen vehicles and the fuel (hydrogen) compared to conventional fossil fuel and fuelled vehicles. Then roll out of hydrogen infrastructure and market introduction of hydrogen vehicles will be much easier and faster than if customers are reluctant and due to assumed risks and inconveniences require hydrogen vehicles and fuel to be priced well below conventional alternatives. The premium approach is discussed in Section 3.3.

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5 J Woodward : Hydrogen bus fleet to roll into Whistler, Vancouver Sun, Saturday, August 04, 2007 http://www2.canada.com/components/print.aspx?id=6319262c-1c96-4674-b53a-4583582eeb1e&k=3619

6 Letter of Understanding, signed Stuttgart, Germany, September 9, 2009:

http://www.daimler.com/dccom/0-5-658451-1-1235421-1-0-0-0-0-0-13-7165-0-0-0-0-0-0-0.html

The discussion in this chapter is mainly based on a review of journal articles published over the last two decades addressing acceptance and WTP. The main focus is on hydrogen. However, as most studies in this field make comparisons to conventional fuelled vehicles and transportation services, conventional fuel options are more or less inherently included. We also draw on literature on hybrid electric vehicles (HEVs) and battery electric vehicles (BEVs) as these alternatives share some of the same benefits (non-fossil fuel and low emission) and some of the same challenges like high costs, and limited infrastructure for charging/refuelling. Consequently, the literature on different alternative fuels (as discussed in Section 3.5.3) yields some insight in WTP and the important factors for future market success of hydrogen based transport. As an introduction to the studies on acceptance and WTP, we (in Section 3.2) refer to basic economic modelling, textbooks on cost-benefit and standard references when it comes to methodologies for eliciting WTP.

3.2 Methods to reveal Willingness to Pay

Willingness to Pay (WTP) is defined as *the maximum price or amount that a person is willing to pay or exchange in order to acquire a good or service*. To make the exposition easy, we start out with an example assuming this good to be a specific hydrogen vehicle (and also that a person buy at most one vehicle). Then it is safe to state that the individual WTP depends on personal preferences, income and prices of alternative vehicles as well as prices of other related goods and services including, but of course not limited to, for example fuel and commuter passes, road tax etc. Instead of buying a car, moving to live at another location may be an option so housing costs may also be relevant.

Based on existing literature it is possible to make some statements on the total value i.e. WTP for a hydrogen vehicle and identify some of the most important determinants of the WTP.

Before taking a closer look at the hydrogen vehicle example and other hydrogen specific issues, we provide a simplified and short introduction to some relevant methods used to measure the WTP, and moreover address validity and reliability issues of results from such studies.

3.2.1 Stated preferences methods

WTP can be elicited in several ways. The easiest way is simply to ask the respondent to make a direct statement on the value. The response is definitely depending on the information held by the respondent. Hence, informing the respondent in an adequate way is most important to get a valid answer. This direct asking method is called *contingent valuation* as the respondent is asked to state his/her WTP, contingent on a specific hypothetical scenario. In the hydrogen passenger vehicle case, the scenario contains a description of the relevant vehicle and its characteristics (emission, vehicle range, density of refuelling stations etc).

The contingent valuation method is typically applied for estimating the economic values for environmental services, conservation of land and species etc. The best known case is probably the Exxon Valdes oil spill which became most important for environmental valuation as we know it today, (Arrow et al., 1993; Portney, 1994; Carson and Hanemann, 2005 and Carson, 2008). This triggered research and profound discussions on all kind of problems and pitfalls that exists within contingent valuation (Hausman, 1993).

Instead of posing a direct question, it is possible to design a choice experiment. The respondent is presented a number of hypothetical scenarios - constructed sets of alternatives. For each set the respondent is asked to make a choice – picking the best alternative or ranking the alternatives. Like *contingent valuation*, this is a hypothetical method and is called *contingent choice* method. The method differs from contingent valuation because the respondent is not directly asked to come up with her/his statement. Instead, values are inferred from the choices or tradeoffs that the respondent makes during the experiment.

Both *contingent valuation* and *contingent choice* are stated preference methods. The base is the respondents' statements about figures and decisions - not actual behaviour. Bateman et al (2002) offer a useful manual on *Economic Evaluation with Stated Preference Techniques*. This manual also list examples of applications.

Revealed preference methods are based on observed actual behaviour for example in the market for transport services and automobiles. This is hardly possible for eliciting values of WTP for hydrogen based transport. Despite a significant number of demonstration projects[7], hydrogen transportation and hydrogen vehicles are by and large hypothetical options for the majority of the public.

Contingent valuation and contingent choice methods are not the only ways of estimating WTP for a good or a service. Examples of other methods for estimating WTP include the market price method, the hedonic price method, the travel cost method, the replacement cost method cost and the benefit transfer method, see for example the textbook on Cost-Benefit Analysis by Boardman et al (2006). However, the *contingent valuation* and contingent *choice methods* are the two we find relevant in relation to the existing studies on WTP for hydrogen based transportation goods and services. This should not be a surprise as markets for such goods and services are still hypothetical.

3.2.2 Validity and reliability of results

One of the crucial questions about stated preference methods applied to eliciting WTP is whether the results are valid[8] and reliable[9]. In case of the hydrogen vehicle, is the stated WTP actually a valid and reliable indicator on market behaviour or is it just signalling something about the respondent's ideals? Indeed, a statement made in a survey carries no obligation towards future behaviour in the market. We also note that almost all papers on WTP for hydrogen based transport and hydrogen vehicles include a paragraph or some remarks on this issue and references are made to the theory of reasoned action (Fishbein and Ajzen, 1975) and the theory of planned behaviour (Ajzen, 1985, 1987). Ajzen and Driver (1992) treat WTP for public goods as a behavioural intention which is important but not determining actual behaviour (Ajzen, 1991).

[7] In 2010 twenty two new Hydrogen Refuelling Stations (HRSs) were built, http://www.h2stations.org/

[8] Refers to the degree to which a stated preference study measures the intended quantity (Bateman et al. 2006)

[9] Refers to replicability of a willingness to pay measurement over time and across different stated preference applications (Bateman et al., 2006).

On their web-site on ecosystem valuation[10] King and Mazzota claim that *contingent valuation* is constantly debated and that many economists, psychologists and sociologists, for different reasons, do not believe the dollar estimates that result from *contingent valuation* are valid. Besides, many jurists and policy-makers will not accept the results of *contingent valuation*.

Regarding *contingent choice* methods, the criticism is not that harsh. Bateman et al. (2002) offer lots of references to this complex set of issues. To bring some balance we will remark that several surveys support that respondents make apparent valid statements on WTP even for "public goods" as remote and untouched nature. In a survey by Veisten and Navrud (2006) a significant share of the respondents actually paid an amount equivalent to their individual stated WTP for the conservation of virgin forests in Norway that almost no one visits.

We will not go into this matter in more depth here, but merely make some final comments that appear relevant for the hydrogen based transportation studies. WTP is an indication of an individual's total economic value of for example a specific project (large scale hydrogen bus introduction) or a policy. In general, the economic value can be characterized differently dependent on the type of values arising. It is usual to divide the total economic value into use and non-use (passive use) value[11]. The non-use value is a major element when it comes to for example conservation of species or restoration of an environment. Non-use refers to the fact that the respondents is willing to pay to maintain an existing good or environmental service although the respondent have no intention or even no possibility of making any use of the specific good or service, as for example the virgin Norwegian forests already referred to. Existence value, altruistic and bequest values are usually referred to explaining the non-use values. Not surprisingly, non-use value is a major issue regarding the validity of WTP figures. For the different relevant hydrogen cases we are looking into – the respondent is assumed to benefit from the services himself/herself (for example city environmental improvements and signalling effects

[10] http://www.ecosystemvaluation.org/

[11] Much information is offered by for example the US National Oceanic and Atmospheric Administration: http://www.csc.noaa.gov/coastal/economics/envvaluation.htm

of buying a hydrogen car). Although we can not exclude altruistic values etc, the non-use values should not be totally dominant. This should add to the validity of the WTP figures on hydrogen based transport.

3.3 The premium payment approach

Hydrogen based transport yield environmental benefits. Hydrogen vehicles utilizing fuel cell technology have zero tailpipe emissions and compared to petrol or diesel engines the fuel cell vehicle has and a much lower noise level due to the electric drive train. Hence, large scale introduction of hydrogen cars and buses has an environmental potential. Accordingly, within some of the contingent valuation studies referred to in this report, respondents were asked about their WTP a tax for funding such an introduction[12]. The other approach used, has been to ask respondents about the WTP a premium over and above the price of a relevant alternative service or good. In our hydrogen case these alternatives are typically:

- *a ride with a conventional bus*
- *a conventional passenger vehicle similar to the relevant hydrogen vehicle*

In the following we will focus on the hydrogen passenger vehicle and the premium payment approach. To improve understanding of the hydrogen vehicle case, we present a simple illustration based on a hypothetical survey amongst 50 respondents. It is assumed that each respondent has stated his or hers willingness of a „premium payment" of a hydrogen vehicle over and above the price of an conventional vehicle. For the illustration it is further assumed that the premium is in the range € 0 - € 7000. We start out by sorting the individual stated price premiums. Such ordering yields a "demand" curve as in Figure 6. In this case it is assumed that each respondent at most will buy one vehicle at the stated premium. The individual WTP values are discrete so the curve is stepwise and each step should be 1 unit (one vehicle) wide or several units wide if several respondents have the same WTP. Individuals with high WTP are found to the left in the figure and individuals are sorted by decreasing WTP. Thus, to the right we find persons with low WTP. If the market price premium (over

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[12] Indeed, tax is a standard payment method, or "payment vehicle" within contingent valuation surveys

and above the similar conventional vehicle) is fixed to *P,* individuals with WTP greater (or equal to) *P* are implicitly assumed to actually buy the hydrogen vehicle. By purchasing the car the individual makes a gain (or at least not a loss) as she/he gets the vehicle for the price of the conventional car plus the premium *P* while she/he is willing to give up an amount that exceeds this amount. Hence the vehicle is god value for money. In total, if the price premium is *P*, the number of vehicles sold will be *Q.*

In a real survey there might be problems with outliers and protesters and answers tend to be clustered around even sums (1k€, 2k€ etc.)[13].

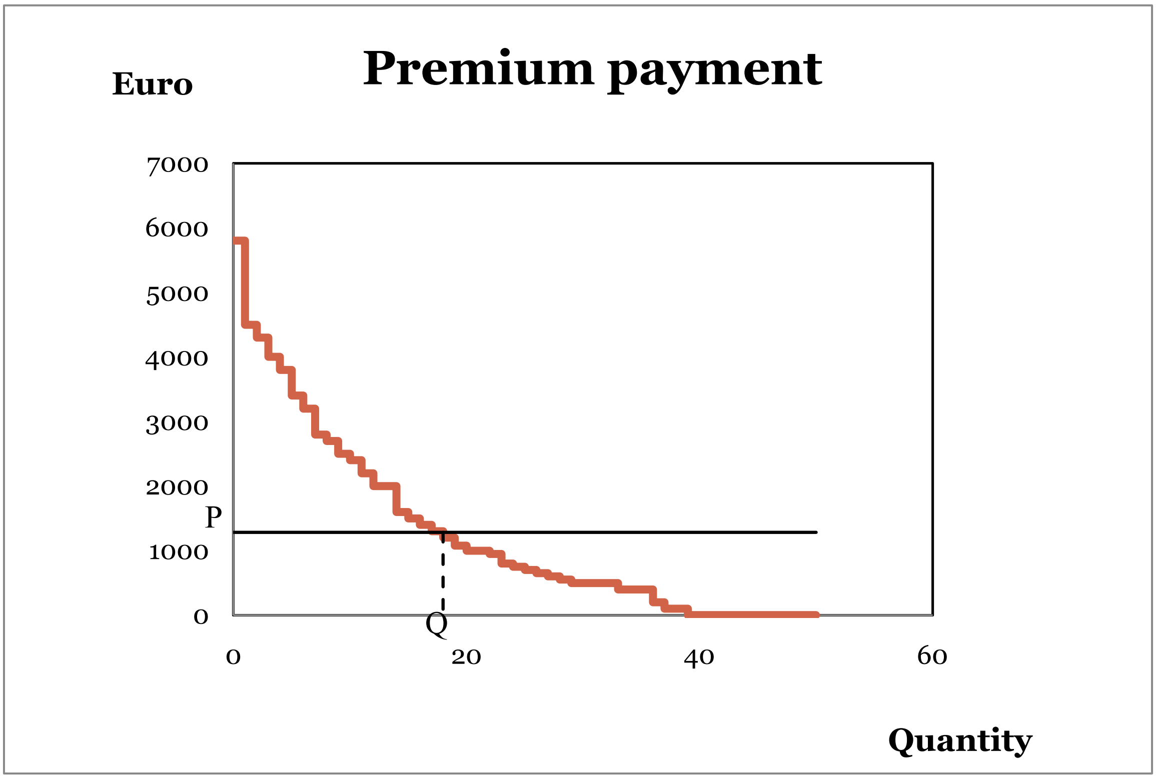

Figure 6 Illustrative example of Willingness to pay a premium for a new hydrogen car over and above the price of a specific conventional vehicle

If the price of alternative zero or low emission vehicles - for example battery electric or hybrid cars - drop, we will expect that the WTP a premium for the hydrogen vehicle

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[13] Besides, such a small sample as in the example (50 individuals) will be far from satisfactory for estimating the underlying WTP distribution in the population.

is reduced amongst individuals and the curve in Figure 6 shifts downwards. In contrast, we should see an upward shift of the curve if price of hydrogen fuel goes down or the (anticipated) second hand value of the hydrogen vehicles increases due to for example great improvements in fuel cell technology.

Mapping the distribution of the WTP a premium is of much greater value than just obtaining the average premium number. The point is that the quantity purchased (or at least intended purchase) for a given premium will depend on the curve - not the average premium. If the “demand” curve is linear (the distribution is uniform), which is a typical textbook case, a market price premium equal to average stated premium will exclude one half of the customers. In fact this will be the case for all distributions of WTP that are symmetrical. By experimenting with different curves it is easily seen that the shape, or distribution of stated premiums, is essential (Figure 7).

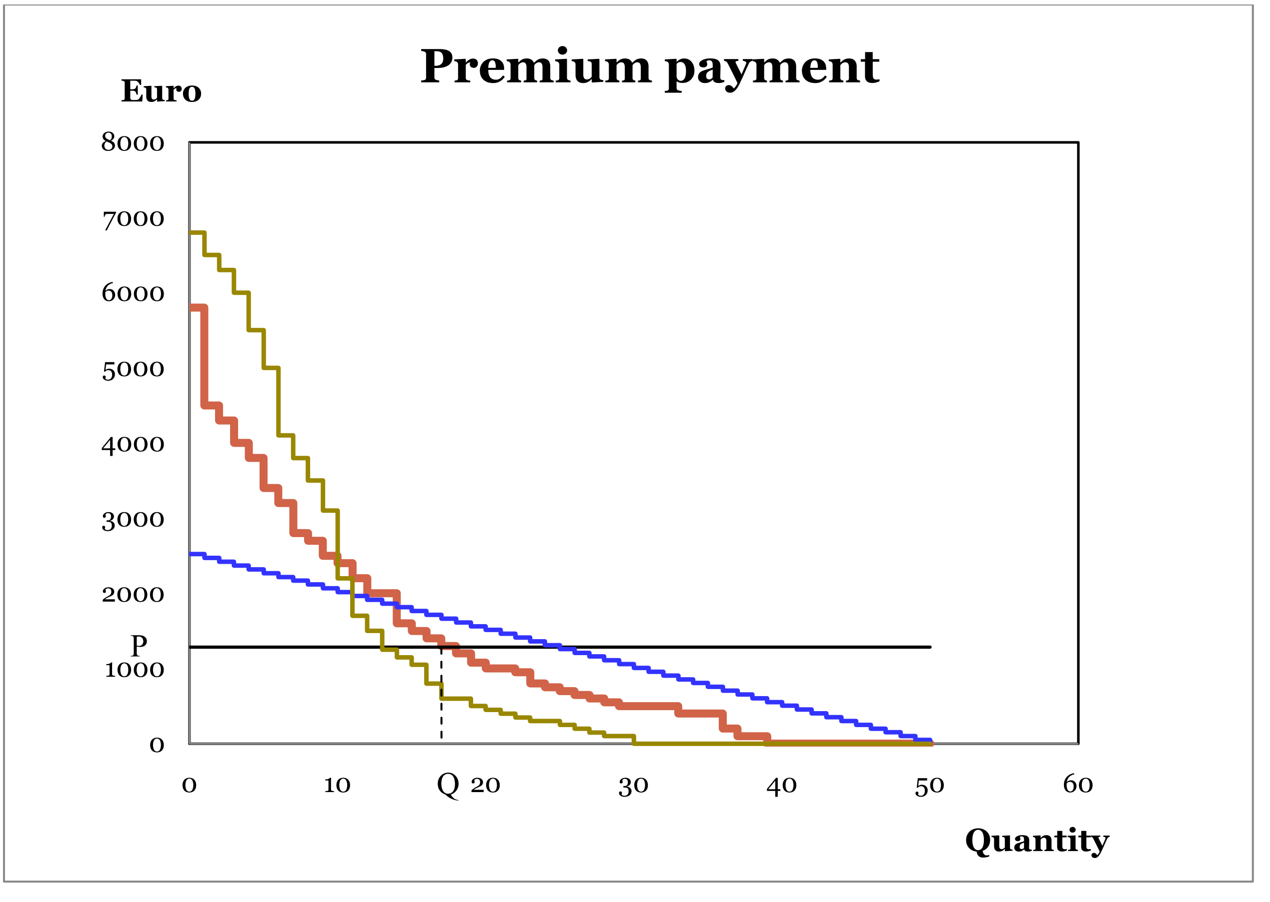

Figure 7 Distributions of willingness to pay a premium- an illustration in which the average willingness to pay is the same for all three “demand” curves depicted.

This is important regarding new technologies like those found in hydrogen vehicles. A valid “demand” curve would tell something about the premium that suppliers can charge over and above the price of conventional technology and still be able to sell a satisfactory quantity. As indicated by the linear “textbook” curve in Figure 7, the demand will be cut off at quite low premiums compared to the other two cases illustrated.

The publications on WTP for hydrogen transportation services typically present the average and median and some frequencies like the number of respondents with zero WTP. None of the references assessed in this work present a full distribution for the vehicle case for a representative sample. Martin et al. (2009) offers an empirical probability distribution for premium payments (see 3.5.2.1) amongst self selected respondents and O’Garra and Mourato (2007) presents a similar distribution (i.e. frequencies) for the for the bus fare hydrogen premium.

However, stated choice surveys are used to establish market models for estimation of market shares. Such models were found for battery electric vehicles and alternative fuelled vehicles, but none for hydrogen vehicles were identified.

Typically, the WTP is assumed to be positive and for our illustration (Figure 6 and Figure 7) we assume that the premium payment is non-negative. Indeed, if WTP is negative, the respondent requires compensation to engage in the alternative mode of transportation. If the respondent is very concerned about safety, a compensation for entering a hydrogen bus may seem reasonable. About negative WTP see Bohara et al. (2001).

In most of the surveys respondents that are not supportive of large scale introduction of hydrogen busses are not asked about their WTP. This makes the outcome of such studies less representative for the actual market opinion. However, in the vehicle case, the value of being offered a hydrogen car will hardly be negative as the reluctant respondent or customer will opt for a conventional vehicle (the customer is not forced to buy the hydrogen vehicle).

3.4 Perception, knowledge, awareness and attitude

Successful market introduction of hydrogen vehicles depends on acceptance and customers actually buying and using these vehicles. As fuel cell technology is still not fully mature, costs are high and acquiring hydrogen vehicles may be perceived as risky for the buyer. Vehicle reliability, length of service life, development of refuelling infrastructure, maintenance cost and second hand value are all uncertain – or even unknown factors. Hence, general acceptance is necessary, but hardly satisfactory for market success. A substantial number of customers should be willing to carry the risks and to pay prices that make it interesting for actors to market vehicles, build infrastructure, supply fuel and provide services**.**

As these hydrogen technologies are „new", they by and large are unknown to the public. Evidently it is an almost mission impossible to estimate how customers will behave in a potential emerging future "hydrogen market". However, there are a number of publications on perception, knowledge, awareness and attitudes[14] of hydrogen based transport. The social matrix in a recent report from the PrepareH2 – project (Praktiknjo et al., 2011) lists 27 studies. Some quantitative studies focus on statistical testing hypotheses and identifying determinants of attitude towards hydrogen based transport. Such determinants are socio-economic variables like age, gender, educational level, income, knowledge and environmental attitudes. The goal of most of the publications is of course not to estimate likelihood of future market success. Surveying perception, knowledge, awareness and attitudes is important for several reasons including policy-making and for improving research and demonstration programs. Never the less, these publications yield information that appears most relevant for making statements on potentials for hydrogen based transport in a market place. A number of the studies also explicitly address WTP. Indeed there is a continuum of studies, some with most weight on perception, knowledge, awareness and attitudes and other are more focused on WTP aspects/issues. Studies on WTP are typically based on attitudinal studies when it comes to formulating hypothesis regarding factors affecting WTP.

[14] Sudarmadi et al. (2001) offer definitions of these concepts. Remark that these do not appear to be strictly defined as the meaning of the concepts seems to differ.

Recently, Roche et al. (2010) reviewed the literature on “public attitudes and demand for hydrogen and fuel cell vehicles”. According to Roche et al., four different research approaches, or conceptual frameworks, can be distinguished: (1) General attitudinal surveys, (2) Risk perception studies, (3) Non-market economic valuation studies based on stated preference techniques for economic valuation and (4) Others. In Praktiknjo, 2011 all studies on this matter are denoted “social studies” with the main emphasis on (1) and less on (3).

In this report emphasis is mainly on WTP-figures which fall into category 3. The link between this category and category 1 - attitudinal studies are quite strong. Hence, as an introduction to the WTP literature, we provide a section on public perceptions, knowledge, awareness and attitude (Section 3.4). The other categories 2 and 4 are not covered here[15]. Also remark that relevant publications addressing WTP in relation to hydrogen is presented in a tabular form in Annex 1.

Although the issues are interlinked, the relation between attitudes and actual behaviour in the market regarding hydrogen technology is in general not clear. Altmann et al (2003) make a remark on the positive attitudes towards hydrogen technology found in the literature on one side and the very modest purchasing intentions and willingness to pay for environmental transport on the other side. Altmann et al. (2003) make a reference to the theory of reasoned action (Fishbein et al. ,1975), and remarks that “*intended behavior (i.e. as measured by willingness to pay) is a better indicator of (actual) behavior than attitudes*” as attitudes only guide intentions on how to behave. The point is that making a statement on willingness to pay brings economic reasoning, budget constraints and prioritizing into the respondent’s mind, at least if the respondent is properly informed and instructed .

[15] In total Roche et al. (2010) make reference to 8 articles within categories (2) and (4), of which two are published later than the year 2000.

3.4.1 Findings from studies on perceptions, knowledge, awareness and attitude

Recent reviews on public perceptions, knowledge, awareness[16] and acceptance of hydrogen based transport are offered by Ricci et al. (2008), Truett et al. (2008) and Roche et al. (2010). Altmann et al. (2003) review papers related to electrical vehicles as well as hydrogen based transport. All these reviews also include aspects on WTP. A significant part of the reviewed hydrogen studies are carried out prior to, or in parallel to hydrogen demonstration projects.

Ricci et al. (2008) found that in general, public awareness of hydrogen appears to be low – with some exceptions. Also a widespread lack of knowledge about hydrogen and fuel cells was found as few people were able to answer technical questions correctly. *"Demand for information appears to be quite high."* However, levels of support for hydrogen busses were particularly high in those studies were questionnaires were administered on board the hydrogen busses. Although the low level of knowledge of this, to the public, new technology it seems that the technology is widely accepted. This is in line with findings of Altmann et al. (2003) on electric vehicles and other environmental transportation technologies; attitudes are in general positive or very positive.

Truett et al (2008) sum up the eight most relevant findings from 15 surveys conducted in Europe (E) and North America (NA). Findings[17] are in line with those of Ricci et al – as surveys reviewed are more or less the same:

1. *Respondents who are more educated are more accepting of hydrogen technologies (NA).*
2. *Respondents who are more knowledgeable about hydrogen and/or fuel cells are more accepting of hydrogen technologies (E, NA).*
3. *When asked about issues of trust, respondents generally expressed distrust of the government or political parties but trusted scientists and environmental protection organizations (E).*
4. *Technical knowledge about hydrogen and fuel cell technologies is low (E, NA).*
5. *Respondents may express opinions about a technology even when they are lacking in knowledge of that technology (E).*
6. *Women and men have different priorities when deciding on an automobile purchase (E).*
7. *Public acceptance to hydrogen is vulnerable to perceptions of decreased safety (E, NA).*
8. *Public acceptance to hydrogen is vulnerable to perceptions of increased cost (E, NA).*

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[16] Ricci et al. (2008) use the term perception, apparently covering awareness and knowledge.

[17] We acknowledge Oak Ridge National Laboratory for these 8 points.

3.5 Results from previous studies on Willingness to Pay

In this section we turn to the results of WTP studies on hydrogen based transportation reported in the literature. The studies reviewed address two different areas. One strand of the literature deals with hydrogen bus transportation services, mainly WTP for large scale introduction of such busses in order to achieve environmental improvements – less noise and fewer emissions - in cities. Another stream of literature deals with different aspects of hydrogen passenger vehicles.

Apparently, paying a fare and riding a hydrogen bus represents something else than buying and driving a hydrogen passenger vehicle. The services offered by the bus and the hydrogen passenger vehicle are consequently perceived as quite different.

Apart from being less noisy, the hydrogen bus ride is quite similar to a ride with a conventional bus; you enter the bus, pay the fare and get transported like all other passengers.

A passenger vehicle is a private good. The utility of the vehicle stems from the use of the vehicle on the road and the transportation services offered. Like a hydrogen bus, a hydrogen vehicle is a mean for improvement of especially urban environments. This will typically be of some value also for the buyer of the hydrogen vehicle. However in addition, a passenger hydrogen vehicle has the potential of demonstrating environmental concern, adding to the owner's reputation as a decent and caring individual. So, a hydrogen vehicle offers a range of quite different (transportation, environmental and reputation) services and the WTP-figure reflects the sum of all these services and others as well. Respondents' WTP figures for private vehicles should also be influenced by inconvenience (distance to refuelling stations) and risk elements due to immature technology (frequent breakdowns - and uncertainty about second hand value etc.). Such inconveniences will not be reflected in the bus cases.

In case of a large scale introduction of hydrogen busses, there should be an environmental effect for certain. In contrast, an individual purchase of a hydrogen passenger vehicle does not ensure any such effect. To obtain a significant effect, it is necessary that a considerable number of customers accept and buy hydrogen vehicles. In sum this seems to support a hypothesis that surveys on hydrogen bus services tell something about WTP for improved urban environments, while WTP for hydrogen passenger cars is more on individual ideals and signalling effects.

Most of the literature on WTP for hydrogen based transportation deals with WTP for large scale introduction of hydrogen busses as a measure to improve noise and emission levels in large cities and respondents are asked about how much they will pay per fare to support such an introduction

Before going into the details we will refer to Altmann et al (2003) who reviewed 24 papers on public preferences for new environmental transport technologies[18]. The papers deal with hydrogen based transport (5), battery electrical vehicles (13) and others (6). Twenty of the articles are published prior to year 2000; According to Altmann et al. *"environmental concerns are not found to have a significant influence on acceptance of, or willingness to pay for cleaner transport"*. He further notes that not even environmentalists are necessarily willing to pay for the environmental benefits alone.

Regarding passenger vehicles, Altmann et al. remark that some studies indicate positive WTP for cleaner transport and there are also a significant market for electric vehicles identified among particular multi-vehicle households and households with lasting needs of making short travels, etc. The final conclusion is that environmental concern will not be the determinant of customer's choice. *"The key concern will be price and performance. If alternative fuel vehicle are able to compete with internal combustion fuel vehicles in terms of price and performance, then environmental concern may indeed act as a predictor of consumer choice".*

These findings – the apparent mismatch between positive attitudes towards alternative fuel vehicles, electric vehicle especially, and the purchasing intentions - are also emphasized by Roche et al (2010).

[18] In addition 3 surveys not reported in the literature are summarized.

3.5.1 Bus transportation services

During the last decade several studies have been carried out on attitudes towards for hydrogen based transport (i.e. fuel cell bus transportation) and WTP for environmental benefits achieved by hypothetical large scale introduction of such buses in cities. The studies include Maack et al. (2004), Haraldson et al. (2006), Saxe et al. (2007), Altmann et al. (2004) and O'Garra et al. (2005, 2007) and O'Garra and Mourato (2007). All these studies accompanied hydrogen fuel cell bus demonstration projects. Indeed, consumer interactions with hydrogen buses have been the source of most hydrogen response studies to date (Martin et al., 2009).

Maack et al (2004) report findings from the Ecological City Transport System (ECTOS) project that was carried out in Reykjavik, Iceland during 2001-2005. Three hydrogen busses were in operation from 2003. One year later a survey amongst bus passengers, neighbours and people on the street was carried out. Two hundred respondents were asked ten questions about awareness, pollution from traffic, acceptance of hydrogen as a future fuel and the bus project itself. The questionnaire comprised one question about WTP for hydrogen. The question was stated in this way: *"Presumably the price for hydrogen will be more expensive as fuel than oil. Which price would you accept?"*

Respondents were offered 5 alternative answers ranging from 20% below to 20% above the oil price. The results are summarized in Table 1.

Alternative price range for Hydrogen compared to oil		**Percentage responses**
A	Acceptable if 20% cheaper	8,1
B	Acceptable if 10% cheaper	20,3
C	Same price	34,5
D	Acceptable if 10% more	27,4
E	Acceptable if 20% more	9,6
	Sum	100,0

Table 1 Acceptable price for hydrogen compared to oil price. Source: Maack et al. (2004).

Approximately 70% of the respondents had noticed the hydrogen buses once in a while or more often. In this survey 86% claimed to be positive to hydrogen as a future fuel replacing crude oil-based fuels (diesel and gasoline) for buses, cars and vessels. Hence questions were not only about hydrogen busses. Of the respondents 63%

would accept hydrogen if the hydrogen induces costs were at the same level as oil or lower (i.e. WTP less or equal to zero). Of these 63%, more than half would accept "Same price" and 37% of the respondents would accept to pay a premium for hydrogen. Protesters were not identified and removed. A few statistical tests were performed and a slight positive correlation between attitude towards hydrogen and WTP was confirmed.

The answers indicate that the acceptable price is more or less symmetrically distributed around the oil price and most bus passengers would accept "Same price" (alternative C) while neighbours and people on the streets seem to have a somewhat higher WTP for hydrogen. The exact meaning of "price for hydrogen" compared to the price of oil or gasoline was not clarified to the respondents. The authors assume that respondents are considering the cost of the service delivered by the fuel. Regarding bus transportation services, the obvious interpretation of cost will be fare price[19].

The result regarding WTP in the Reykjavik 2004 study is in line with the result from a somewhat similar survey made amongst bus passengers in Stockholm (Haraldsson et al, 2006). The question was asked to 518 passengers on hydrogen fuel cell busses and 64% of the respondents claimed that they would not accept higher fares for having more fuel cell buses running in the city. Saxe et al (2007) report findings in a follow-up study. Concerning the WTP, no statistically significant differences were found compared to the first survey.

There are, however, some differences between the Stockholm and Reykjavik surveys. For example in Stockholm the respondents were asked if they would accept to pay a higher fare or not and possible answers were "Yes" or "No", while in Reykjavik respondents were asked about acceptable price for hydrogen compared to oil (utilising the *contingent valuation* method (ref Section 2.2.2)). The apparent consistency between the replies from the studies supports that bus passengers in

[19] In fact, respondents onboard hydrogen buses reveal that they are at least willing to pay "Same price". Several possible explanations seem possible why they are paying for a service they find too expensive. One alternative is that respondents are expressing what the cost level should be. Respondents with a negative premium are in fact claiming a compensation

Reykjavik interpreted the question as considering the bus fare price, although this was not explicitly mentioned.

Altmann et al (2004) present some preliminary results on WTP for introduction of hydrogen buses at a large scale in London and Luxembourg as a measure to obtain environmental benefits such as improved air quality and reduced noise. To a certain degree this AcceptH2 [20] publication may be seen as a forerunner of later publications on hydrogen bus services. Interviewees were asked whether they would support the introduction of hydrogen busses. Two thirds of the London respondents and 40% of Luxembourg respondents were positive to the introduction of hydrogen busses even if fares would increase. The results presented by Altmann et al (2004) indicate that people in London especially, were somewhat more positive towards paying extra fares in order to obtain environmental benefits compared to people in Reykjavik and Stockholm (Haraldson et al., 2006 and Maack et al., 2004). More recent reporting from the AcceptH2 project such as O'Garra et al. (2007) also indicates such a difference. However, there is no statistical evidence of such a hypothesis. This would require further surveys in both Reykjavik and Stockholm in line with the surveys in London etc. carried out by O'Garra et al. It may be speculated that the higher concern and WTP in London is related to the more severe air pollution here compared to Reykjavik and Stockholm.

O'Garra et al. (2007) is probably the best known and most cited study combining a study of attitude and study of WTP for hydrogen based transport. O'Garra et al used *contingent valuation* and compared WTP for air pollution reductions associated with a hypothetical large-scale introduction of hydrogen FC buses in four cities: Berlin, London, Luxembourg and Perth. Respondents were presented the following scenario:

> *"Suppose that there was a proposal to substitute the buses in the [city] transport system for hydrogen [fuel cell] buses. As I mentioned earlier, these hydrogen buses would emit zero air pollution, be less noisy and more efficient than conventional buses. However they would also be more costly to run".*

[20] AcceptH2 is an EU-project, more information may be found at: http://www.accepth2.com/

Respondents were then asked whether they would support the introduction of hydrogen busses, and if so, how much they would be willing to pay extra per single bus fare compared to the actual price. It was made clear that the hydrogen busses could only be introduced if respondents were willing to pay a higher fare. Besides, residents of London and Perth were asked about paying extra taxes for such a large scale measure. Both bus users and non bus users were interviewed in 2003 and 2004. The total sample size is 1358 of which 81% were bus users. The authors remark that the results should be interpreted with some caution as the samples are relatively small and the statistical models performed very modestly.

Bus users in all cities appear to be willing to pay an average premium ranging from € 0,27 to € 0,35 per single bus fare – adjusted for living costs. The lowest WTP is found in Berlin were the standard bus fare is relatively expensive (2 Euros in Berlin, close to 1 Euro in London and 1,20 in the other cities). Berlin has also the highest number of protests as 23 % of the respondents refusing to state their WTP. This is also assumed to be related to the relatively high fares in Berlin.

A regression analysis could not identify any variable that significantly influences the WTP for single bus fares in every city. In fact, the determinants of WTP proved to be quite different from city to city. Income was significant only for London and Berlin – with WTP increasing with income. Infrequent bus rides had a higher WTP than more frequent riders - in Berlin and London.

In the three European cities younger respondents reported higher WTP than older while age was not significant in Perth. Female was willing to pay more than male in Berlin. Educational level was significant only for Perth as people with university education was willing to pay more than people without.

Results also indicate that environmental attitude[21] and environmental behaviour[22] positively influences WTP. With reference to three studies in the 1990-ties[23] O'Garra

21 measured by degree of agreement with the following statement: ''Solving environmental problems should be one of the top 3 priorities'

22 indicated by how often the respondent donates to an environmental cause

23 Ewing and Sarigöllü (1998), Segal (1995) and Chiu and Tzeng (1999)

et al summarizes that this is in contrast with prior findings reported in the literature "*which tend to indicate that on the whole, environmental concerns are not key determinants in the choice of transport technologies.*"

In London and Perth also non bus users were interviewed in order to reveal their willingness to pay a tax to fund the replacement of conventional buses. In these two cities all tax paying respondents - both bus users and non bus users were asked – in total 674 of which 35% protested and was removed from the sample. Approximately 5% stated a WTP equal to zero. At the average, residents of London were willing to pay € 24 and residents of Perth € 16 annually (adjusted for living costs). Based on the population in London and the WTP figures for the bus replacement project a total of £ 170 million per annum should be "available". With 6 500 busses, this amounts to approximately £ 260 000 per bus assuming the service life of a bus is 10 years. According to the authors, this figure is very close to the price of a conventional bus. The *contingent valuation* -study hence indicates that if the price for the hydrogen bus is twice the price for a conventional bus, it is acceptable, as long as operation costs are the same.

O'Garra and Mourato (2007) compares the different statistical regression approaches for identifying determinants of WTP for pollution and noise reduction associated with large scale introduction of hydrogen busses in London. The case and the design of the survey is almost the same as in O'Garra et al 2007 in which London is one of four cities. Respondents supporting the introduction were asked about how much they would pay extra for bus fare per month. The total sample of paying bus users was 531. Almost 2/3 used the bus at least once a week and approximately ¼ less than once a month. About half of the respondents tended to buy single fares while the rest had some season pass (weekly, monthly or annual). In this survey 85% of the respondents were willing to pay some extra – in average close to 7 £/month. On an annual basis this yields approx 84£ which is well above the tax estimate of € 24 found in the four-city study carried out almost in parallel. It should be noted that the samples are different and that the main focus of this London study is the statistical approaches itself. The study confirms that the determinants of WTP vary across the sample (i.e., quantiles) – hence determinants in the low end tend to be different from determinants at the high end. For example bus use frequency is a significant driver for lower values of WTP, but has no impact on higher WTP values. Environmental attitude and prior knowledge about hydrogen were important drivers in the high end of WTP.

More details on O'Garra et al (2007) and O'Garra and Mourato (2007) studies are presented in O'Garra et al (2005) which is a final analysis report within the AcceptH2 project. The latter survey is focusing on changes in WTP due to the bus demonstration projects in London, Berlin, Luxembourg and Perth. Hence, WTP found prior to the bus demonstration projects and reported by for example O'Garra (2007) are compared to WTP after approximately 6 months of demonstration. The number of hydrogen buses used was quite limited as just 3 buses were running in each city. However, respondents in the ex post (after approx 6 months of trials) were more aware about hydrogen vehicles than ex ante (before trials). Unconditional support for large scale introduction of H2 buses also increased significantly during this short period of time. However, the missing connection between environmental attitude and WTP - reported by Altmann et al. (2003) was confirmed at least partly. Despite increased support for large scale H2 bus introduction, estimated WTP extra bus fare did not change significantly from what was found in surveys prior to the bus trials. WTP taxes also remained at same level except in Luxembourg were WTP taxes increased significantly[24].

O'Garra et al. also remark that the direct experience of H2 buses seems to have no effect on the attitudes or preferences for hydrogen buses. Hence in total, half a year of trials has not produced any major changes to public awareness or WTP. We will add that the trial period is quite short and with 3 buses in each city the demonstration programme had limited visibility. For a passenger the hydrogen bus is quite similar to a conventional bus and the absence of CO_2 emission can not be experienced. On this background it is not a surprise that there are almost no differences between the ex post WTP and ex ante WTP based on balanced information, including that given by an interviewer. Never the less, if changed – the WTP figures are increased – not decreased which after all is good news for people advocating hydrogen based transport. We wish to underline that in the WTP surveys of large scale bus introduction, the respondents were not offered any alternative environmental friendly

[24] Also for Perth the survey indicate such an increase but significant only at the 10% level.

mode of transport or any alternative measure for emission and noise reduction. Apparently, large scale hydrogen bus introduction is the only option presented. One objection to our remark is that respondents are given the option of not supporting the introduction of hydrogen busses. In any case alternative measures and alternative transportation services are not an essential part of the studies. Hence based on the literature it is hardly possible to claim that there is a specific hydrogen premium. It appears most likely that the WTP figures would have been the same for an alternative technology that yield the same benefits – for example battery electric buses.

3.5.2 Hydrogen passenger vehicles

Successful market introduction of hydrogen vehicles depends on acceptance and customers actually buying and using these vehicles. In this section we review literature on WTP for hydrogen passenger vehicles and make comparisons to findings for other alternative low emission fuel- especially battery electric vehicles (BEVs).

It appears that the WTP for a hydrogen vehicle depends on the vehicle characteristics, service and refuelling infrastructure, fuel prices, anticipated second hand value etc. As this is a new transportation technology, there are also a range of public incentives offered which may be important to customers[25]. This is illustrated in Figure 8 which comprises factor important to the total user cost of the hydrogen vehicle.

When asking about the WTP for a hydrogen vehicle, the respondent has to take into account a lot of factors, as illustrated in Figure 8. When buying a hydrogen vehicle, the customer enters into a new concept of transportation of which he or she has limited knowledge and which implies risks regarding technology development, stability of political incentives etc. Hence, the WTP figures depend on the scenario

[25] In Norway incentives include free parking in public parking lots and access to public transportation lanes. Besides there are no VAT nor import duties on zero emission vehicles

presented to the respondents. If the scenario includes low fuel prices we would expect this to increase the WTP for the vehicle (ref. Figure 6).

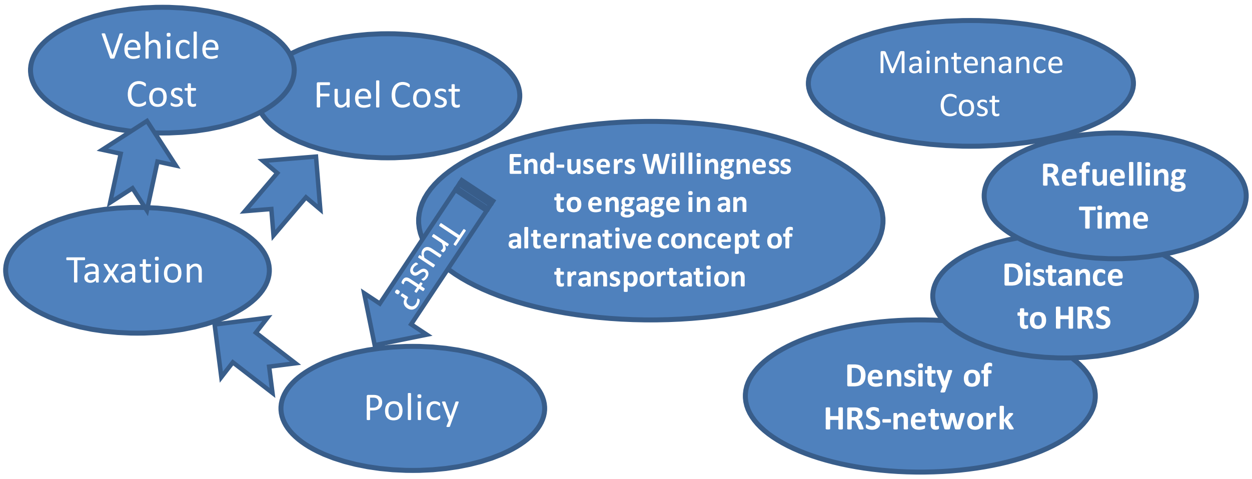

Figure 8 The End-users' Willingness to Pay (WTP) is about much more than the cost of hydrogen as fuel.

Political incentives (in terms of subsidies or tax-exemption) are highly decisive for introduction of zero emission vehicles (ZEVs), especially in countries where taxation on vehicles is high, like in Denmark and Norway. Other economic as well as non-economic incentives also play important roles (see text box on Norwegian incentives below).

Incentives for Zero Emission Vehicles* in Norway:

- Admission to bus-lanes
- Free parking on all public P-lots
- Free Toll Roads and Ferries
- Exempt of Purchase Tax and VAT
- Reduces Road tax
- Half tax when used as company cars
- Higher mileage for car allowance

**Defined as Battery Electric and Fuel Cell Electric Vehicles*

The end-user interested in purchasing a vehicle utilizing a new fuel (like hydrogen) will naturally feel that it is risky to engage in this alternative if the current incentives are subject to frequent revisions and may disappear over the life span of the vehicle.

Based on the literature and the focus of demonstration projects and interest of the participants of the PreparH_2 we focus on three elements or issues of the hydrogen concept:

- *The passenger hydrogen vehicle itself*
- *Refuelling infrastructure and vehicle range*
- *Fuel (hydrogen) prices*

First we address surveys that focus on the hydrogen vehicle itself. It appears that there are a number of potential customers willing to pay a premium for a hydrogen fuel cell passenger vehicle. Next we look into the importance of vehicle range and refuelling infrastructure. These seem to be the two most important factors for the respondents valuing the hydrogen concept.

Finally, the hydrogen fuel price is addressed. Not surprisingly no surveys focusing on WTP for the fuel were identified. Surveys on hydrogen vehicles make specific assumptions on fuel price. Typically, the hydrogen fuel cost is assumed comparable to gasoline or diesel on a kilometre travelled basis[26] and any premium that respondents are willing to pay for the hydrogen concept is assigned to the vehicle.

In the end of this chapter (3.5.3) we review literature on other alternative fuelled vehicles – mainly battery electric and hybrid vehicles as these alternatives share several characteristics with the hydrogen car. For battery technologies (typically Li-based) for transportation are still not fully mature, range and charging infrastructure represent challenges, second hand market value risky due to technology development etc. Although there are certain differences as well it is evident that lessons can be learned from these alternative transportation concepts.

With this in mind, we turn to the quantification of the hydrogen vehicle concept and WTP. Remember that for the market introduction it is not necessary that everybody is eager to adopt the hydrogen technology and, hence, willing to pay a sufficient premium. It is sufficient that a share of the potential customers will actively support the development of the technology by actually buying the products in the early

[26] Given the superior efficiency of the fuel cell system compared to the Internal Combustion Engine, the hydrogen cost is typically set at 9€ per kilogram, providing approximately 100 km driving.

phases. According to Rogers (2003) innovators are the first 2.5 percent of a group to adopt a new idea. The next 13.5 percent to adopt an innovation are labelled early adopters. (100 percent is total sale over the life cycle). When it comes to the mass market the situation will be quite different (More, 1999), but the mass market is still a future vision, and More tells us that the mass market will not emerge before technology has reached some maturity and proved its benefits. In the meantime, the mass market is foreseen to emerge from 2020 on[6].

A number of studies on WTP for hydrogen based transportation have been carried out in parallel to the hydrogen bus demonstration programs mainly in Europe. But we find only a few studies on hydrogen passenger vehicles. Moreover, Roche et al (2010) remark that although there are an increasing number of studies on hydrogen and fuel cell vehicles, comparative analysis between existing studies is hindered as methodology is varying widely and many of the samples used are small and unrepresentative.

Most studies make use of conventional vehicles as the reference case to which the hydrogen option is compared to. Studies comparing hydrogen vehicles with battery electrical vehicles or other alternative fuelled vehicles are scarce. This is a problem in the short run as we aim at comparing hydrogen to other alternative fuels and new propulsion technologies in this study and a challenge in the long run for future studies.

3.5.2.1 Passenger hydrogen vehicles

Altmann et al. (2003) found that most empirical studies on alternative fuel passenger vehicles focus on electric vehicles and hybrids. Recent overviews (i.e. Potoglou and Kanaroglou, 2007 and Erdem et al., 2010) confirm that this situation is unchanged. So there are only few studies on WTP and hydrogen powered passenger cars reported in the literature. Furthermore, in spite of the fact that both battery electrical and hydrogen fuel cell vehicles are so-called zero-emission vehicles and they both face range and infrastructure challenges, no WTP-studies that compares hydrogen and electric or hybrid vehicles have been found in literature.

Mourato et al. (2004) study driver preferences and WTP for fuel cell taxis in London. Martin et al. (2009) elicits WTP for hydrogen passenger cars and indentifies what respondents find to be important characteristics of hydrogen cars. In both studies conventional vehicles are assumed to be the relevant alternative.

Mourato et al (2004) used the *contingent valuation* method to measure preferences (WTP) of London taxi drivers towards FC vehicles. The taxi drivers owning or leasing conventional cabs were offered an 18 months lease of a hydrogen fuel cell vehicle and the project would cover maintenance, servicing, insurance and a breakdown recovery service. Environmental benefits were advertised to be reduced noise and no emissions. Refuelling costs was stated to be equivalent to diesel. The range of the vehicles was 140 miles (225 km) – lower than for the existing cabs and there would be only two available refuelling stations in reasonable vicinity. Moreover, the fuel cell vehicle had some reduced capacity for carrying luggage. In other respects the vehicle was assumed to be equivalent to a conventional cab.

Drivers interested were told that 6 vehicles would be available and if demand turned out to be high, drivers had to pay for participating. Accordingly, the respondents were asked about maximum WTP on an annual basis for participating. Feasible annual payment was in the range £ 0-5000 with steps equal to £ 500.

In addition to the lease option, the drivers were presented a second case or scenario in which hypothetical fuel cell taxis were sold as production vehicles. In this second scenario the range was improved to 200 miles (320 km), and the hydrogen cost reduced to half of that of diesel on a per mile basis. Besides, hydrogen would be available from 10 refuelling stations in the city. Respondents were asked to state a premium they would be willing to pay for such a vehicle over and above the cost of a conventional diesel model. The interviews took place in 2001 and 99 useable responses were received. Of these 89 were usable for the second scenario.

As found in other perception and attitude studies (ref Section 3.4), the drivers were very positive towards introduction of cleaner fuels and technologies in the taxi industry. All respondents expressed some level of support for environmentally friendly alternatives. A majority of 89% of the drivers were supportive or very supportive.

Apparently, the 18 month lease option seemed to be a good deal, as 65% of drivers were interested in taking part in the project. The residual 35% gave valid reasons for not participating – for approximately one half of them the limited range and refuelling options were crucial hindrances.

Drivers leasing their conventional taxi were willing to pay £ 3500 on average and drivers who owned their taxi were willing to pay somewhat more than £ 2900 per annum for substituting a hydrogen vehicle for their conventional taxi. Mouroto et al remark that drivers leasing their taxi have more to gain by terminate existing lease contracts compared to owners who in any case would experience some insurance payments and depreciation on their own taxi during the 18 month test period.

Although WTP is positive, the average numbers are less than the estimated savings for not operating their old conventional vehicles in terms of avoided payments for lease (or depreciation), servicing, maintenance and insurance. Hence, the authors of this study conclude that the drivers are "*implicitly requiring a compensation for driving the FC vehicles*" and further that *" drivers wish to be compensated, perhaps for the FC vehicles' reduced range and refuelling possibilities, or for driving a car with 'unproven technology'"*. It was found that perceived savings in running costs was the most important determinant for WTP.

Regarding the second scenario (of purchasing the hydrogen fuel cell taxi), the production vehicles with improved range and denser refuelling station network, the average premium above a diesel cab (£ 30 000) was about £ 1600 when a few protesters were removed from the sample. This seems to be quite low as weekly savings due to cheap hydrogen fuel cost was estimated at £ 50. The authors offer the following explanation:

> *"A likely explanation for this apparent anomaly, indicated by several people in the course of the interviews, is that drivers with a positive WTP were also behaving strategically, cautiously stating low values in the belief that their answers would influence the future price of fuel cell taxis. Hence, the results of this part of the survey should be treated as exploratory and not as definitive estimates of the WTP for future hydrogen fuel cell vehicles".*

Martin et al. (2009) report results from a *"ride and drive"*-clinic held in August and September 2007 in Northern California. The vehicle used was a Mercedes-Benz A-

Class hydrogen FCEV. The sample is hardly representative for the average population as all 182 respondents were self selected state and university employees in California. Furthermore, almost everyone agreed or strongly agreed to the statement: *I have a general interest in alternative fuel vehicles*. According to the authors these facts "*do not prevent the use of the dataset to obtain insights into consumer response to hydrogen vehicles and fuelling, especially among likely early adopters "*

After the ride and having witnessed the refuelling, 95% of the respondents reported either a "positive" or "very positive" impression of the Fuel Cell Electric Vehicle (FCEV). Almost as many (80-90%) "felt safe" with both the FCEV and the refuelling and did not consider it to be complicated. The drive clinic visit indeed shifted the respondents' opinion related to safety towards the positive side. Hence, even a short term exposure to FCEV and refuelling technology offered by the drive clinic, seemed to improve participants impression of hydrogen transport technology.

The respondents were asked about WTP for a FCEV fuelled by hydrogen from renewable sources. Apparently, respondents were willing to pay a premium. One half indicated that they were willing to pay at least 4 000 US$ in premium over a similar gasoline car. Respondents seemed less willing to pay a premium for driving the car. Approximately one quarter would not accept increased annual operating costs, the "second" quarter could accept 1 - 500US$ and the "third" quarter could accept 501 – 1 000 US $ extra. Distribution of WTP response is illustrated in **Error! Reference source not found.**

The authors make the remark that the WTP figures should be interpreted with caution as stated WTP is distinct from empirically revealed WTP observed through actual behaviour in the market. "*Rather the stated WTP offers a proxy as to the range of additional expenses that would be tolerable to the consumer*." The authors also to underline that the sample is neither random nor demographically reflective which obviously limits the conclusions that can be drawn from this study.

The London taxi driver study and the Californian drive clinic study yield somewhat opposite results. The London taxi study indicates that drivers are reluctant to pay any premium for a FCEV. In fact the drivers require to be compensated, most probably for low range, inferior refuelling infrastructure and inconveniences due to anticipated unreliable technology. This we can not know for sure, as the authors indicate that the drivers act strategically at least in the second case. The *"ride and drive-clinic"* study indicate that there are a "population" of "techies" who are willing to pay a premium for the hydrogen car apparently in spite of low range and risks connected to refuelling infrastructure, technology, second hand value etc. With reference to Figure 1 (Section 2.3), this is not as contradictory as it seems. According to More (1999) "techis" or market innovators are typically not scared of new technology, while the taxi-drivers are within the so-called majority segments as they are rating reliability and range to be the most important vehicle characteristics.

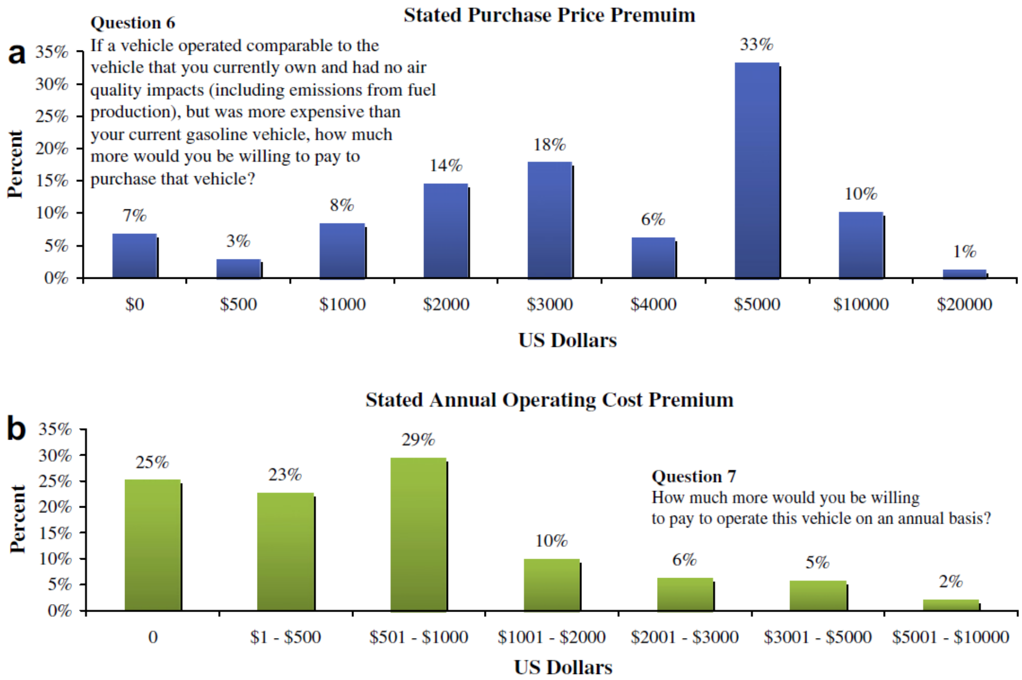

Figure 9. Willingness to pay a premium for Mercedes F-cell

Source: Martin (2009), copyright Elsevier

3.5.2.2 Refuelling infrastructure and vehicle range

Based on literature we can state that vehicle range and refuelling infrastructure are the most important factors influencing the WTP for hydrogen vehicles as well as for other alternative fuelled vehicles (see Section 3.5.4).

Some relevant results were presented by Martin et al. (2009). This "ride and drive clinic"- survey included relevant questions both on refuelling infrastructure and range. After the ride and drive, respondents were asked about tolerance of extra travel time to refuelling station. More accurately they were asked to state how far out of their way they would be willing to drive to find a hydrogen station. In addition respondents were asked to write-in a *vehicle range that they would consider acceptable*. Response distributions to both questions are illustrated in Figure 10, reprinted from the article.

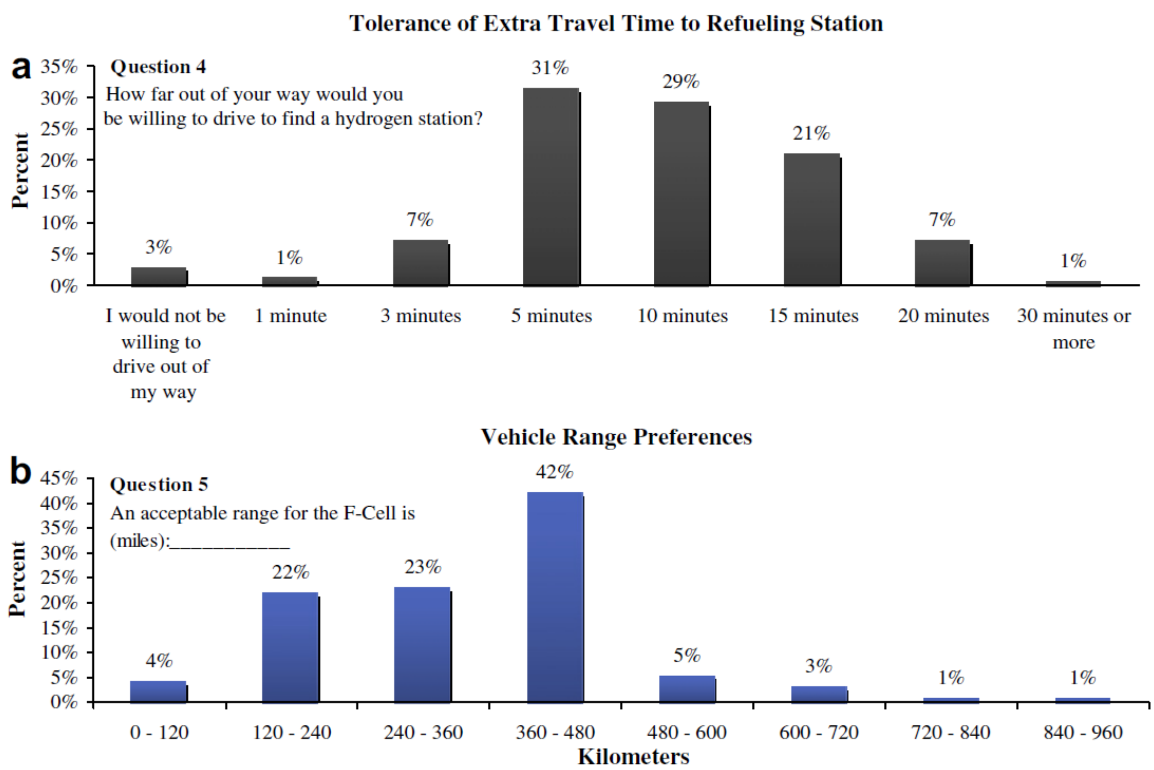

Figure 10. Extra travel time to refuelling station and range of vehicle.

Source: Martin (2009), copyright Elsevier.

Answers indicate that the range should be no less than 360-480 km. The range of the vehicle used in the ride and drive clinic was 160 km.

The majority of respondents say that they are willing to accept to spend 5-10 minutes to find a refuelling station. Within cities, average speed is about 25 km/h (i.e. De Vlieger et al., 2000) so 10 minutes of driving correspond approximately to 4 km.

To sum up, findings from the literature indicate that market success for hydrogen vehicles depends on range not being far below the range of a conventional fossil fuelled vehicle. Besides, easy access to refuelling stations should not be underrated.

3.5.2.3 Fuel prices

Fuel cost is one of the main components of the total cost for owning and using a vehicle. Other main factors are the vehicle purchasing cost, service and maintenance cost and anticipated second hand value (Ramjerdi and Rand, 1999; Steiner 2003). So in general and everything else equal, high fuel cost should be set off by a lower purchasing cost. If both fuel cost and purchasing price are higher than offered by alternative vehicles, rational customers should certainly opt for the cheaper options.

As indicated by several studies (refereed in 3.5.2.1 3.5.3) it appears to be a number of potential customers who are willing to pay a premium for the low and zero emission vehicles. The design of these studies assign the WTP for the hydrogen option to the vehicle itself assuming that fuel cost are in line with fuel cost for conventional vehicles. However, if respondents are willing to pay extra for the environmental benefits etc, this is probably not linked to the price of the vehicle only. To the contrary, it seems more likely that individuals are attracted to the hydrogen concept which in total yields the desired benefits. If so, a survey on WTP for the hydrogen itself would probably indicate some positive WTP for the fuel- if the purchase price of the vehicle etc. were stated to be similar to a conventional vehicle. Summing up WTP for the vehicle and for the hydrogen fuel will then be double counting and erroneous.

For most car owners their attention to the fuel cost depends on their driving pattern and especially their annual mileage. This is self evident and reflected in the market. Diesel vehicles are typically more expensive than petrol vehicles. However, fuel costs are lower for diesel vehicles both because diesel is cheaper (at least it used to be cheaper) than petrol per litre and because the fuel efficiency is somewhat better for a diesel engine than for a petrol engine[27]. As a result customers with long mileage

[27] Besides, the energy content per litre is roughly about 10% higher for diesel than for regular petrol.

traditionally have bought diesel vehicles and diesel engines are used for long mileage vehicles such as taxies, busses, vans and lorries.

If the hydrogen vehicle is marketed, sold and used as a short mileage vehicle, the fuel cost per kilometre is not that important in the sense that the annual fuel bill in any case will be limited. However, for the time being, the battery electrical car is profiled as the best (and often the only) alternative for people valuing zero emission and with needs of making short trips. Hence, for the "short trip" user, the battery electrical vehicle is representing some pre-requisite constraints regarding total user cost for the hydrogen fuel cell alternative.

The advantage of a hydrogen vehicle - at least compared to its zero emission competitor - the battery electrical vehicle, is the range and short refuelling time – making the hydrogen vehicle a more versatile and probably preferred option for longer trips and hence also preferred for longer mileage. That makes it easier for the customer to compare the hydrogen vehicle with conventional petrol and diesel vehicles. So, very general and very rough – the cost of the hydrogen fuel needs to be in range with the fuel cost of a conventional car if the purchase prices are similar. The WTP extra (a premium) for the zero emission vehicle, should allow for a somewhat higher fuel cost or purchase price for the hydrogen vehicle, but based on the literature the feasible margins seems limited at least when it comes to the mass market.. Another competitor for the hydrogen fuel cell vehicle is the hybrid electric vehicle offering lower operating costs, especially for city driving. As the success of Toyota Prius indicates, it is possible to sell an expensive vehicle if the operating costs are low.

Separate studies on WTP for the hydrogen fuel alone were not found in literature. In any case, however, potential fuel savings or extra fuel costs should for a rational customer be possible to quantify. The (average) figure should reflect savings per mile, (average) annual mileage and length of vehicle service life. By discounting the annual savings, they can readily be compared with the vehicle purchase price.

Assuming that annual fuel savings are equal to €1000, then, if the service life of the vehicle is 10 years and the discount rate is 5%, the net present value is about € 7 700. If service life is 20 years the savings is close to € 10 000. Of course, there are a lot of uncertainties regarding future fuel prices. Also the relevant discount rate can be discussed, but this simple example yield after all an illustration.

In an article on car buyers and fuel economy, Turrentine and Kurani (2007) report that *"no household analyzed their fuel cost in a systematic way in their automobile or gasoline purchases."* It was also found that almost none tracked fuel costs over time or included such costs explicitly in the household budget. According to Turrentine and Kurani fuel economy appear to be complicated and it was found that consumers make large errors when estimating gasoline costs and savings over time. Hence, our example above with the normative touch of discounted savings is far from what is going on in the consumers' mind. Turrentine and Kurani also asked the respondents about how much they were willing to pay for a 1,5 times higher fuel economy (50% increase in *miles per gallon*). Some respondents were reluctant to answer, some were guessing what it would cost (higher car quality, hence more expensive), while some gave numbers after first having tried to find a kind of payback period and a few offered large round numbers without explanation. The respondents were also explicitly asked about what payback period they would accept. Two-thirds would not or could not offer a payback time and only very few were able to give reasonable answers. Indeed, reading the article is most entertaining and quite shocking as strict economic reasoning are in fact reported to be totally absent even among financial professional respondents. From a European point of view it seems relevant that the petrol prices in the US have traditionally been very low compared to prices in the EU. Hence, it has been economically rational for the US consumer not to be very concerned about fuel savings, as fuel in any case has represented a minor part of the household expenditures.

Steiner (2003) reports that on average consumers would want an investment (=increased vehicle purchase price) to be paid back within 2,9 years. The question posted by Steiner was as follows:

> *„Suppose that the next vehicle you've decided to buy offers an option of better fuel economy, but at a higher price. The savings in fuel costs would pay back the higher price over time. How soon, in years, would the fuel savings have to pay back the additional cost to persuade you to buy the higher fuel-economy option?*

Of the respondents 27% answered “Don’t Know” while 42% would accept payback time not longer than 2 years. Only 3% would accept more than 5 years even though respondents on average intended to keep the vehicle for more than 5 years. These results seem more or less to be in line with results reported by Turrentine and Kurani who concluded that the numbers obtained were almost worthless. One objection to such an interpretation is that the question posed by Steiner appears to be quite easy to understand. The relatively high share that opt for short payback times may indicate that customers choose vehicle in such a way that they put themselves in a position of being cash constrained (low liquidity) and unable to wait long for the payoff of the extra amount spent up-front in order to acquire a more fuel efficient vehicle.

According to results reported by Steiner (2003) the WTP would be 2,9 times the annual savings. Hence, the value of $1000 in fuel savings will have an average value of $2900[28].

The stated choice experiments by Potoglou and Kanaroglou (2007) indicate that households would pay between $2200 and $5300 in order to save $1000 in annual fuel cost, depending on household income. In the same survey households would pay between $500 and $1200 to save $100 in annual maintenance cost. Apparently, small savings is more valued than big savings as small savings are worth 5-12 times annual savings and big savings 2-5 times only[29].

Such inconsistencies and odd results are known from earlier studies. Green (1983) examined implicit consumer discounting of fuel savings. Eight studies were assessed and discount rates estimated. Green reports that most rates are implausible. On the other side, based on empirical data and comparison of petrol and diesel vehicles Verboven (1999) found that consumers were valuing fuel savings in an economic

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[28] Payback calculation typically ignores interest. This is a well known drawback, especially when payback is long term and interest rates are high.

[29] This seemingly confusing results may be a result of inconsistent respondents for example due to some misinterpretation or that the savings are not reflected in an higher accepted vehicle purchasing price as respondents face short run budget constraints not identified in the survey.

rational way and that the intertemporal trade-offs were more or less in agreement with market interest rates.

To sum up: consumer's tradeoffs between purchasing cost of a vehicle and fuel cost or fuel savings is at best intuitive and not in accordance with rational economic reasoning. According to Turrentime et al. (2007) sound economic reasoning is totally absent.

3.5.3 Lessons from studies on alternative fuelled vehicles

In this sub section we assess results from surveys on alternative fuelled vehicle with low or zero level emission. Surveys typically include battery electric vehicles and electrical hybrids. Some surveys also comprise natural gas fuelled vehicles utilizing internal combustion engines. As with the hydrogen technology, conventional fuelled vehicle are regularly used for comparison. We start out with studies on the vehicles and then in the last part focus on range and refuelling infrastructure issues. The review presented here is far from complete. The aim is to make some comparison between hydrogen fuel cell technology vehicles and other low and zero emission vehicle technology and draw some lessons regarding WTP.

By and large the somewhat mixed findings of WTP for hydrogen vehicles are in line with findings related to other alternative fuelled passenger vehicles as indicated by Altmann et al.(2003) or as summed up by Gould and Golob (1998). Hence, some studies indicate a positive WTP a premium for battery electric vehicles (BEVs), hybrids and alternative fuel vehicles. Other studies support that cost (purchasing price and fuel cost) and range are the most important aspects and that neither the technology itself nor the zero or low emission boost WTP.

Bunch et al. (1993) and Dagsvik et al (2002) studies seems clarifying. Both are analyzing the potential demand for alternative fuelled vehicles (liquid propane gas and battery electric vehicles in addition to dual-fuel vehicles) and both surveys are based on stated preferences. Results indicate that demand is crucially dependent on the vehicle attributes and fuelling and service infrastructure. The empirical results show that alternative fuel vehicles appear to be fully competitive alternatives amongst the respondents compared to conventional gasoline vehicles, provided the attribute values are the same and suitable infrastructures for maintenance and refuelling are established. In addition to purchase price, driving range seems to be of major importance. Dagsvik et al (2002) concludes that unless the limited driving range for battery electric vehicles is increased substantially these vehicles will not be fully competitive in the market.

A recent study by Potoglou and Kanaroglou (2007) based on a stated choice survey in the metropolitan area of Hamilton, Canada, yields similar results. However, it is also indicated that WTP for reduced emission (i.e. pollution level at 10% of present day average car) is in the range of Can$ 2000-5000 dependent on household income. Hence, zero emission itself seems to be of some value in the market. However, also Potoglou and Kanaroglou (2007) warn that results should be interpreted with caution as "*respondents are known to express environmental sensitivity in stated choice surveys…*".

Another recent study is the survey by Erdem et al (2010). This web-based survey was carried out in order to find factors important for WTP for hybrid automobiles in Turkey. The analysis is based on answers from 1974 respondents. The *contingent valuation* method was used to elicit the WTP a premium for a hybrid compared to a midsize conventional fuelled car costing approx 20 000 US$. The respondents could choose among 7 possible given premium classes ranging from 0 to approximately 8000 US$. The average premium found was 8,5%. The author remarks that hybrids are rare in Turkey as only 45 hybrid vehicles are sold in the country. Consumers having high income, higher educational level and that are concerned about global warming appears to be more likely to pay a premium for hybrids. Besides, males were more prone to pay a premium. The respondents also characterized themselves with respect to innovativeness (innovators, early adopters, early majors, late majors and laggards). Respondents characterized as innovators and early adopters were in fact found to be less likely to pay a premium than the laggards. However, participants that were categorized as "risk lovers" were more likely to pay a premium. The authors indicate that risk is connected to uncertainty about the second hand price and maintenance cost. It should be noted that a significant number of the participants have no car at all as only 43% of the population in Turkey own an automobile (in the household). Hence, buying a hybrid appears indeed to be a hypothetical situation for the vast majority of the respondents. This seems to be somewhat in contrast to for example Potoglou and Kanaroglou (2007) who designed the survey so that the low emission vehicle was quite close to the respondents' present vehicle. In addition, only the respondents that were planning to buy a car within 5 years were included.

In total, studies indicate that some customers are willing to pay a premium for a vehicle with reduced emission and lower fuel consumption. This is hardly surprising as hybrids have been available in the market since 1997 and sold at a premium in a cumulative volume exceeding 3 million[30]. Dunn (2010) also offers some insight and references to the hybrid vehicle market (i.e. Toyota Prius).

Hydrogen fuel cell vehicles, battery electrical vehicles, hybrids and other low emission vehicles differ in several respects. The hydrogen vehicle is comparable with hybrids regarding range and takes the emission level further down. However, the existing hybrids profit by using existing refuelling infrastructure of conventional fuels.

Studies yield no evidence that customers are willing to pay extra high premiums for any of these low emission alternatives. Hence, it is expected that hydrogen vehicle will hardly be able to boost the premium paid. From a general point of view, it seems more likely that as more alternatives are marketed, the more competitive the market for low emission vehicles will be and WTP premiums will be difficult to maintain. Nevertheless, a final remark is that studies comparing WTP for electrical vehicles and hydrogen vehicles are indeed missing.

3.5.4 Alternative fuels - range and refuelling infrastructure

Especially battery electric vehicles suffer from short range as battery size and weight are inevitably closely linked. A number of studies and market surveys indicate that the limited range is a major obstacle for market success. Relevant studies prior to year 2000 are reviewed by Altmann et al. (2003). Other studies on this issue, which we have already referred to, are Bunch et al. (1993) and Dagsvik et al (2002). A conclusion drawn from these studies is that range has to be improved to make battery electric vehicles competitive in the market.

Ewing and Sarigöllü (1998) explicitly address the range issue for alternative fuelled vehicles (Battery, natural gas, propane, ethanol and methanol). Based on a stated

[30] The annual production of the Toyota Prius hybrid was around 600 000 vehicles in 2010. Source: Personal Communication with Katsuhiko Hirose, Oslo, May 2011.

choice experiment they find that a changing the range from 300 to 100 miles more than halves the vehicles odds of being chosen by the respondents.

Even more specific results are offered by Bunch et al (1993). Based on a stated preference survey they find that reducing the range from 300 to 225 miles is offset by a decrease in purchase price of $ 2000. A decrease from 300 miles down to 100 miles requires $ 13 000.

It should be noted that, according to Altmann et al. (2004) some studies identified a market for battery electric vehicles among particular multivehicle households and household with continual needs of making short trips. For this market segment the possibility of home charging is an advantage for the battery electric technology compared to the hydrogen fuel cell technology as hydrogen refuelling infrastructure is completely missing. It should be noted that home refuellers for hydrogen fuel cell vehicles have been prospected, especially by Honda related to their leasing of the Clarity model in California[31]. Recently, as more attention on large scale hydrogen refuelling infrastructure has been achieved, especially in Germany (H2mobility), Norway (HyNor) etc., the home refueller option has lost some on its relevance.

The home charging as well as the governmental supported establishment of around 1800 public charging stations in the larger cities seems to be relevant for the apparent success[32] in Norway of new battery electric cars (i.e. Mitsubishi i-MiEV) introduced late 2010. As of May 2011, after ½ year of availability, approximately 500 of the i-MieV are on the road and another 200 are in back-order. This is probably closely linked to the quite generous incentives that are offered for zero emission vehicles in Norway. Import duties and VAT that typically makes conventional (diesel and gasoline powered) cars twice as expensive in Norway than in for example Germany are exempt for battery electrical and hydrogen fuel cell cars. Incentives for zero emission vehicles also include free parking on public parking lots, free passage on toll roads, and access to public transport lanes (ref Text box page 44). In a number of the major cities of Norway these incentives yields significant time and

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[31] More information on Hondas home refueller may be found at: http://www.greenoptimistic.com/2008/06/18/home-made-refueling-station-for-honda-fcx-clarity/

[32] http://presse.mitsubishi-motors.no/artikkel.asp?id=2602.

monetary savings. In sum, buyers are not only motivated by environmental benefits, rather it seems that cost and time gains are important. At least the sales number in Norway far exceeds the number in Sweden where such incentives are not offered.

The, to date, long recharging time for battery electric vehicles has been an issue in the literature. This however, is a drawback not shared with the hydrogen fuel cell vehicle and hence of minor interest, except that the refuelling time is relevant when comparing battery vehicles with hydrogen fuelled vehicles.

There are some studies on alternative fuelled vehicles addressing the refuelling infrastructure issue. Also on this issue Buch et al. (1993) offer some results. The availability of gasoline stations is used as the norm. As long as the fraction of refuelling stations are at least 0,8 compared to the norm, the effect can be ignored. If the fraction goes down to 0,5 - it is compensated by a $2000 vehicle purchase price reduction. If the fraction is just 0,1 the vehicle purchasing price have be reduced by $8000 in order to compensate the respondents so that the vehicle's odds of being chosen in this survey experiment model remain unchanged.

By the end of the year 2010 the number of petrol filling stations were approximately 1800 in Norway and 15 000 in Germany. Hence, a fraction of 0,1 corresponds to about 1500 filling stations in Germany which is in the range of what is planned for the H2mobility[33]-initiative announcing the establishment of 1000 refuelling stations in Germany within 2020.

[33] More information at:
http://www.daimler.com/dccom/0-5-658451-1-1236356-1-0-0-0-0-0-13-7165-0-0-0-0-0-0-0.html

3.6 Conclusions from assessment of Willingness to Pay

Based on international studies we can state that the public are supportive or very positive to hydrogen based transport. This appears to be a general conclusion across countries. Hence the "hydrogen transportation option" has a goodwill that the "hydrogen campaign" can profit by.

At the same time, there is a widespread lack of knowledge about hydrogen and fuel cells and demand for information appears to be quite high.

Surveys on WTP for hydrogen based transportation also indicate that urban citizens are willing to pay for large scale introduction of hydrogen busses in order to achieve environmental benefits – less noise and fewer emissions in cities. Both bus riders and non-bus riders are willing to pay for such improvements. Bus-riders are willing to pay higher bus fares and in general tax-payers are willing to pay a tax to support funding of large scale introduction of hydrogen busses.

In average respondents were willing to pay approximately € 0,30 extra per single fare and the extra tax is in the range € 15-€ 25 per annum per tax-payer. These figures dates back to the first part of the decade 2000-2010 and respondents are citizens of London, Berlin, Luxembourg and Perth. Surveys carried out in Stockholm and Reykjavik also indicate that a share of citizens is supportive although it can not be strictly concluded that the average WTP extra for hydrogen buses is positive. In these two cities the design of the surveys did not aim at eliciting quantitative figures.

Apparently, there are also a number of customers who are willing to pay a premium for hydrogen passenger vehicles compared to conventional gasoline or diesel vehicles. Accordingly, it seems feasible to introduce hydrogen vehicles in the market even if the purchase price is higher than a comparable conventional fuelled vehicle. However, for the mass market it seems prohibitive to maintain any price premium. Besides performance – especially range – should be in line with that of conventional vehicles. Respondents state that they are willing to accept that the refuelling infrastructure is somewhat leaner than for the existing petrol station networks.

The search for determinants for WTP for "hydrogen based transportation" has not established a single set of explanatory variables. In fact: "*Environmental concerns are not found to have a significant influence on acceptance of, or willingness to pay* *for cleaner transport*" (Altmann et al. , 2003). To the contrary, variables seem to vary across countries and also across groups with high and low WTP. So – as environmental concern in general is not a determinant of WTP for hydrogen based transport, environmental attitude and prior knowledge about hydrogen were important drivers in the high end of the WTP range (O'Garra and Mourato, 2007).

Although there are an increasing number of studies on hydrogen and fuel cell vehicles, comparative analysis between existing studies is hindered as methodology is varying widely and many of the samples used are small and unrepresentative (i.e. Roche et al. 2010).

We will underline that in the WTP surveys of large scale bus introduction, the respondents are neither offered any alternative environmental friendly mode of transport nor any alternative measure for emission and noise reduction. Indeed, large scale hydrogen bus introduction is the only option presented. This is also the case for the few hydrogen vehicle surveys. Alternative measures and alternative zero or low emission transportation technologies are not taken into account.

Based on the hydrogen surveys then, it is cannot be claimed that there is a specific premium that the public in general is willing to pay for hydrogen. It appears most likely that the WTP figures would have been the same for hydrogen as for any other alternative technology that yield the same benefits. Unfortunately, there are no discussions in literature of validity of findings with respect to whether premiums found are hydrogen specific.

Comparing results for hydrogen vehicles with results on battery electrical and hybrid vehicles – we by and large see the same kind of results although we have not carried out any statistical tests to confirm the significance of such a hypothesis. Some respondents are willing to pay a premium for passenger vehicles with low or zero emissions despite short range and uncertainties about the lifetime of batteries and fuel cells and second hand value of the vehicles. Premiums seem to be in the same range for hydrogen vehicles as for other alternative fuelled vehicles.

The environmental benefits of battery electric vehicles and hydrogen vehicles are zero tailpipe emission and low noise. With focus on these benefits – which is typically the case for the surveys reviewed in this report - while drawbacks are more or less assumed to be overcome, we would of course expect that WTP for the two technologies should be similar.

To day, the battery electric vehicles represent a somewhat more mature technology than the hydrogen fuel cell vehicles. However, this situation is not reflected in the surveys reviewed. A few years ago also battery electric vehicles were scarcely seen in the streets and people were not familiar with any of the technologies. Recently, these vehicles are starting to sell in small volumes, but strong incentives are needed to pave the road to market penetration. We observe that surveys on hydrogen and battery electrical vehicles present the same kind of benefits and our hypothesis is that it would have been difficult for respondents to separate pros and cons of the technologies and made valid and reliable WTP-statements on the differences.

The next chapter goes further by investigating the cost and pricing of hydrogen, and then assess the price level that needs to be reached in order to make hydrogen an acceptable alternative for customers.

4 Acceptable hydrogen price

4.1 Preface

Over the past years there has been an increasing attention and growing debate on acceptability of fuel costs for potential future sustainable fuels. The success of market introduction of alternative fuels relies, among other things, on the customer's acceptability to pay for the fuel. Therefore, in the PreparH2 project the main emphasis has been on the acceptability of hydrogen cost seen from the end-user perspective.

During the last decade both the European Union (EU) and the US Department of Energy (DoE) have stated price targets for hydrogen in strategic planning documents. These targets have been set at very low and challenging levels between $2 and $4/kg (DoE, 2010), compared to current actual production cost of more than €20/kg in small volumes if all expenses for the hydrogen provision (OPEX) and hardware investments (CAPEX) where to be covered. In larger volumes cost is reported to be in the range of $8-$13/gge[34] depending on volume and energy source.

During the last few years the cost of fossil fuels has risen dramatically compared to previous years. The key for the consumer to engage in an alternative fuel for transportation is the Total Cost of Ownership (TCO). At least for Europe where conventional fuels are more costly than in the US primarily due to taxation, hydrogen as a fuel could become more cost competitive at an earlier stage than in the US. Other fuels may also already cost competitive with taxed fossil fuel however there are other environmental issues which need to be addressed for some of these alternative fuels, such as ethanol, biodiesel etc. For those fuels detailed Life Cycle Assessment (LCA) studies have to be made to confirm that they are an environmental benefit to

[34] DoE's 2010 Technology Validation results show a cost range of $8-$10/gge for a 1,500 kg/day distributed natural gas and $10-13/gge for a 1,500 kg/day distributed electrolysis hydrogen station", (DoE 2010), gge = gallon gasoline equivalent which is close to 1 kg H_2.

the society. Likewise, the sustainability of various routes for hydrogen production and the total GHG-emission footprint needs to be conveyed to a wider audience. All these factors have to be taken into consideration when using fuel in the future and as part of that, public education and outreach has to be increased so that the general public understands the difference. This is the same indication found in the studies regarding social acceptance performed by the PreparH2 project (Praktiknjo et al 2011), that the public does not fully understand the terminology for different fuels and technology. Such education therefore could be a combined effort when it both comes to economics and social acceptance.

The approach in this analysis has been that future pricing of hydrogen seen from the end-user perspective will have to reflect the fuel cost of driving a kilometre on gasoline. For decades to come gasoline will be the most dominant fuel despite a market introduction of hydrogen fuel. The public perception of the cost for a driven kilometre will therefore most likely be a reflection of the price of driving on gasoline. An optimal price of hydrogen should therefore be one that at least matches the fuel cost per driven kilometre which is the basis for the considerations within this chapter.

4.2 Cost of hydrogen

At current stage in the development the cost of hydrogen is much higher than that of conventional fuels. This is mainly due to the fact that most filling stations are built for small demonstration fleets. This actually means that it is impossible to get any of the CAPEX back as commonly there are very few users. Therefore most pricing on hydrogen in demonstration projects is based on a pre-fixed price, decided by each operator/project.

A number of studies have been made in some locations evaluating the future cost of hydrogen. Some of them are aiming towards fulfilling the set targets of the EU/DOE others have focused on the actual cost of hydrogen. Different models have been set up to evaluate the cost, a few aiming at small scale at the early adoption phase, others looking into the future of commercialization.

All such studies have to make a number of assumptions as the knowledge on a fully commercial operation with a large hydrogen uptake is not known as no such stations are currently in operation. However the experience of operating refuelling stations is increasing by the day. For example the oldest station with a commercial operation certificate was opened in Iceland, April 24th 2003 and is now 8 years old and still in operation.

Currently refuelling stations are selling hydrogen at a price dispensed at pump of between € 9-15 per/kg, this is the case for example in Norway, Iceland and Denmark. This means at least for the older generation of vehicles that hydrogen is more expensive than gasoline as such cars are consuming 1,2 – 1,7 kgH2/100 km. Similar gasoline vehicles are burning around 6,5 – 8 litre of gasoline/100km and with the current cost of gasoline around € 1,6 per litre it costs roughly €10-13 to drive 100 km compared to roughly € 12-25 on hydrogen. During demonstration periods this is not an important issue as customers using new technologies are willing to pay a higher price for the vehicles and also for the fuel.

This will however not be the case when market introduction commences and when ordinary end-users are to choose between hydrogen or gasoline. This has been established in previous studies (ref. chapter 3). In Iceland during demonstration of buses and in the early phase of vehicle

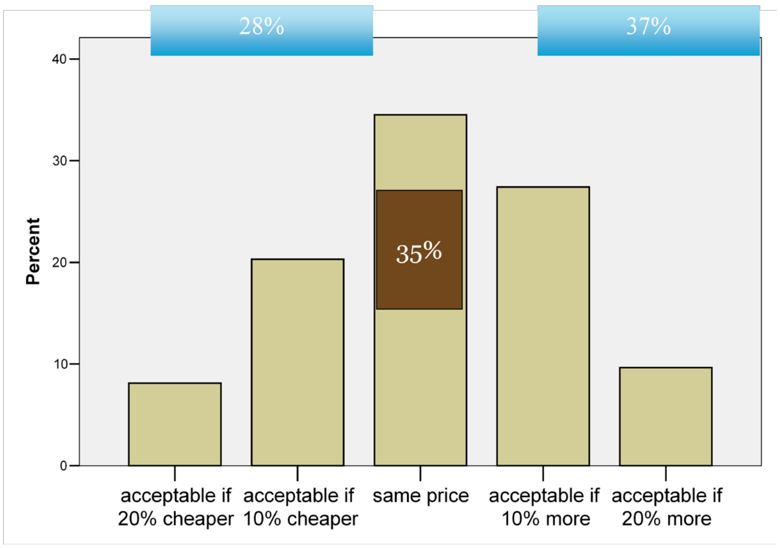

Figure 11 Bus passengers' replies to questions whether they are willing to pay a premium for H_2 based public transportation.

demonstration it is evident that customers are willing to pay the same or slightly higher price for hydrogen.

The Figure shows the responses from the public what they are willing to pay for hydrogen, compared to current fossil fuels (Maack et al. 2004). At that time most people were willing to pay the same as for fossil fuels or slightly higher price. With ever increasing cost of fossil fuels this might have changed as most current users/customers indicate that today they are paying a higher price for hydrogen but if the TCO for Fuel Cell Electric Vehicles (FCEVs) will not reach the same cost as similar fossil fuel vehicles introduction will be very difficult.

4.3 Accepted fuel cost

Asking the public about the acceptability of hydrogen cost is difficult though. The reason is that the public is very confused (Praktiknjo, et al. 2011) and it is very difficult for the public to reply to the question. The key feedback that the PrepareH2 project has received is that the TCO for hydrogen has to be similarly communicated and understood as gasoline if commercialization is to be successful.

Given that FCEV will be cost competitive in the near future with other types of vehicles the operation cost has to be the same. Lifetime, durability, maintenance cost are all elements which have to be taken into account. This has become evident with the increased use of battery electric vehicles (BEVs) as the discussion on lifetime of batteries has become one of the key factors regarding the TCO for BEVs and not the energy (fuel) cost which is much lower than for all other types of fuels.

Evaluating the acceptability of hydrogen is then best done by evaluating the TCO for the future FCEVs. Assuming the same or similar cost, lifetime and maintenance of FCEVs as for gasoline vehicles the cost of the fuel needs to be calculated.

The table below shows a calculation for Iceland where the cost of hydrogen is to match the fuel cost of gasoline per driven km (gasoline equivalent (GE) price), when taking the fuel efficiency into account. As can be seen from the table the current difference between a 1st generation hydrogen powered fuel cell electric vehicle (Ford Focus FCEV 2005) and a relatively low fuel consuming gasoline vehicle (6,5 litres/100 km) is only € 1,4 per 100 km. However, to reach break-even operation of refuelling stations, covering both the CAPEX and the OPEX, calculations indicate that the price of hydrogen needs to be closer to € 10, rather than the € 8,71, which is the current sales price in Iceland. With more efficient FCEVs it is forecasted that the fuel consumption of a vehicle will be closer to 0,9 kg/H2 per 100km then the hydrogen cost to operate a vehicle 100 km is similar to that of the current gasoline vehicle utilising the Internal Combustion Engine (ICE) burning 6,5 l/100km.

	price/liter/kg	100 km	
Gasoline 6,5 litres/100km	1,39	9,02	Current prices
Hydrogen 1,2kg/100 km	8,71	10,45	Current prices
Forcasted/needed price kg	10	10	
Forcasted 0,9kg/100km	10	9	

Table 2. Comparison of cost of fuels for hydrogen and gasoline, given an expected improvement in fuel efficiency from 1,2 to 0,9 kg H_2/100 km.

The table below shows similar calculation for the case in Denmark based on the fuel consumption for future medium sized gasoline Hybrid Electric Vehicles (HEV) and Fuel Cell Electric Vehicles (FCEV) beyond 2015+ and the present gasoline price in Denmark.

	Fuel sales price *Incl. tax & profit*		Consumption *km/L or kg/100 km*		Price/km *€/km*
GASOLINE	€1,61/liter*	→	20 km/liter	→	€0,081/km
					↓
HYDROGEN	€9,69/kg	←	0,831 kg/100 km 30 km/Gasoline Equivalent (GE)	←	€0,081/km

** 95 octane gasoline sales price @ dispenser in Denmark. Calculated as an average of the actual day price in April 2011 and the average day price of the past 12 months, reflecting the upwards price trend*
Source: The Danish Petroleum Association www.eof.dk

Table 3. Back-calculating the acceptable hydrogen prise by comparing with Hybrid Electric Vehicles (HEVs).

The table shows the reflecting hydrogen price in order to match the present cost per driven kilometre in a gasoline HEV vehicle in Denmark based on the present gasoline price dispensed at pump including all applicable taxes. Despite that the fuel economy of both HEV and FCEV will improve over the years the conservative assumption is that the difference will stay the same – 20km/litre for the HEV and 30km/GE Litre for the FCEV; thus the fuel efficiency improvement can be removed from the equation. This despite the fact that FCEV fuel economy is most likely to improve more than HEV throughout the years, as FCEV is a newer technology with more improvement potential, and because that the hybridization potential applied to gasoline vehicle can also be applied to fuel cell vehicles. When gasoline prices most likely increase over the years this will have a positive impact on the willingness to pay for hydrogen as the any increase in fuel cost will be most beneficial to the fuel that is most cost effective on a cost per driven kilometre basis. As indicated by the Danish example, €10/kg appear to be a reasonable dispenser price for hydrogen when compared to the prevailing gasoline price.

4.3.1 Presenting alternative fuels to the public

As has been indicated earlier (both here and in former Prepar-H2 publications) the public understanding for alternative fuels seems limited. Describing new fuels to the public is already challenging enough – but when the unit of measurement of the fuel is also different, i.e. not litres but kilograms (kg) or Normal cubic meters (Nm3) it becomes even more confusing. Another aspect which adds to the complexity is the difference in efficiency of electric drive trains powered by fuel cell or batteries versus the combustion engine. As BEVs, Plug-in Hybrid Electric Vehicles (PHEV) and FCEVs are introduced, well known terms such as fuel consumption measured in X liters/100 km are not generally valid, as electric charge is measured in kWh and hydrogen typically in kg. Again this comes back to education. The public needs help to understand the difference between all the different fuels and what they actually cost in figures they can correlate to, e.g., how much it costs to drive 100 km on the fuel (on average).

Another issue is how the fuel price is presented. This study was never intended to come up with solution for this problem. However, it is important for all infrastructure companies and car manufacturers to think carefully about how to present the price of alternative fuels. Figure 12 illustrates the difference in how the price of hydrogen can be presented at a filling station.

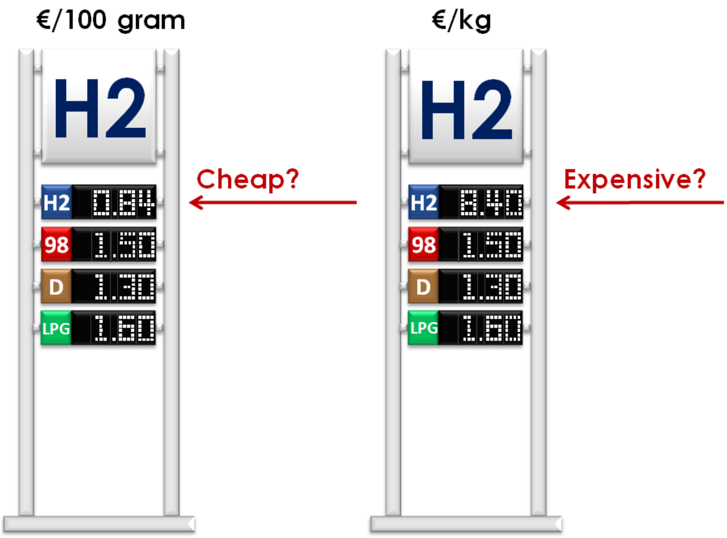

Figure 12. Illustration of how alternatives of hydrogen pricing may influence customers' perception of how costly H_2 is. (Source: Hydrogen Link).

It is established that the gasoline and diesel price is measured in litres but the public does not know how other alternatives will be priced. In demonstration projects this has become evident. Iceland is a good example where only two alternative fuels are sold at filling stations, methane and hydrogen. Those who have used both types of vehicles cannot correlate between the fuel consumption of the vehicles as they fill Nm3 of methane but kg of hydrogen. They therefore cannot understand the price difference, they don't even know if there is a price difference between the two fuels. This can be even more complicated with battery electric vehicles, although users know they are cheap to fill, they actually cannot state the direct costs as over 90% of the fuelling is from home where they are charged for the power consumption for entire household.

How the society presents fuel costs in the future can have a major impact on their acceptability. At the same time it is important to educate the public about the difference of the fuels on price, emission, resources, etc.

4.4 Conclusion

As has been indicated above then the possible accepted price of hydrogen as a transportation fuel in Europe could be close to €10/kg which is considerable higher than indicated e.g. from the DoE and previous EU declarations. With this sales price of hydrogen dispensed at the pump, the establishment of hydrogen refuelling infrastructure could be easier to finance than anticipated to date. However, the payback time for the initial investment will be long as vehicles will only come in low volume to begin with, and therefore there will be a low utilization of the station CAPEX invested in the early years.

In various countries in-depth calculations for a larger scale infrastructure, commercially servicing ´000 of cars have been carried out (e.g., selected European countries (HyWays), GermanHy (Germany), Norway (NorWays[35]) and Iceland). The calculations from the Icelandic study indicate that with a fuel price of around € 9-10 both the CAPEX and the OPEX can be covered during the operation. However until such large scale infrastructure deployment and utilization is realized, efficient public support mechanisms and incentives will be needed to either support the CAPEX or OPEX so that an early infrastructure roll-out can be made possible.

With public-private partnerships, like is currently being evaluated in H2-Mobility in Germany and Scandinavian Hydrogen Highway Partnership (SHHP) it should be possible to cover the initial investment through early public deployment support mechanisms (European and/or national level) and in that sense start the infrastructure build up for the future commercialization of vehicles.

It is crucial at present that car manufacturers, energy companies and European and national governmental entities jointly support and facilitates the rollout of a hydrogen refuelling infrastructure so that it is ready when the vehicles are launched in the market in less than 4 years time (2015). This public commitment in other countries than Germany needs to be verified by the end of 2011 as the Original Equipment Manufacturers (OEMs) already have committed[36] and need to take investment decisions on building series production lines for FCEV to be able to deliver the vehicles commercially in 2015.

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[35] The NorWays-study was a comprehensive national infrastructure study concluded in 2009, coordinated by SINTEF. More information available at: www.ntnu.no\norways

[36] Letter of Understanding, signed Stuttgart, Germany, September 9, 2009: http://www.daimler.com/dccom/0-5-658451-1-1235421-1-0-0-0-0-0-13-7165-0-0-0-0-0-0-0.html

5 Unexpected and hidden cost
– issues raised by H_2 demonstration project participants

5.1 Preface

Introduction of hydrogen as an energy carrier is inherently involving technology development as of the shelf products do not exist or need adaptations for hydrogen applications. Due to the immaturity of several of the components typically used in H2 demonstration projects unexpected cost related to breakdowns and delays are commonly experienced during project execution. One of the goals of this PreparH2 project was to gain insight into which factors had unexpected influence on the economics of projects. When problems occur there are often several different views between the involved project stakeholders when it comes to the cause and effect. Moreover, some persons are very hesitant to reply to questions related to these issues, depending on their responsibilities, their companies' reputation as well as personal pride. Findings reported in this Section stems from the demonstration projects assessed in the Prepar H2-project.

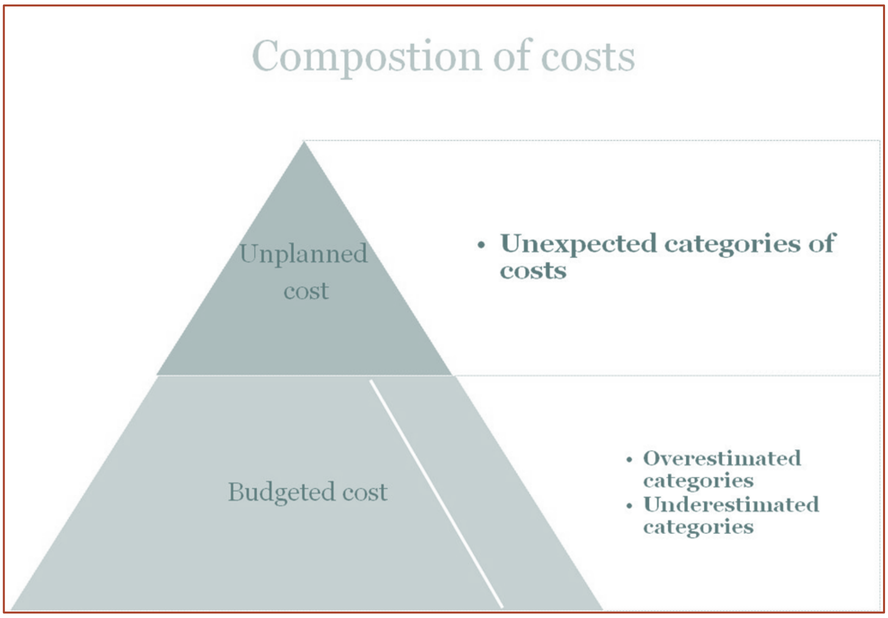

Figure 13. The unplanned cost is separated into two categories, hidden cost (cost never reported and unknown to many partners) and unexpected cost (which is unforeseen cost but reported).

The unexpected cost typically hits Small and Medium Sized Enterprises (SMEs) harder than larger corporations. Also due to size SMEs are immediately and most adversely affected and neither can or want to hide such costs. In general, getting information on this subject proved to be very difficult when interviewing the stakeholders executing the demonstration projects. They have claimed that they should be asked more frequently about social and economic issues but when issues are raised they are very reluctant to answer. It is not clear whether they don't know the answer or don't reply for example in order to avoid higher management in the company to blame them for leaking information

5.2 Unexpected cost

All national demonstration projects investigated in PrepareH2 experienced unexpected cost. However, it was difficult to quantify these costs as interviewees were more willing to communicate social experiences and reluctant to comment on economic issues. Certain technology related topics were mentioned in most locations:

The hydrogen technology is not mature and therefore very few components are of the shelf components. Therefore significant cost was accrued due to down-time, waiting for spare parts. Down-time was experienced to be far more complicated for SMEs than for larger corporations as man power was often devoted specifically for the demonstration project with no other tasks to attend to during down-time.

Supplying hydrogen based transportation may be seen as a supply chain and the degree of maturity of the technology at each step adds to the vulnerability, leading to a domino effect if something goes wrong –eventually hurting many partners in the project.

Technical performance expectations are generally (too) high. Participants often expect that hydrogen technologies will perform just as conventional technologies. They do not expect and fully understand the waiting time for spare parts and that the lack of human knowledge is causing delays, etc.

All of the above mentioned factors might seem straight forward and everyone should be aware of them. However it is often very difficult to convey these messages to the involved and affected stakeholders. Though they may be well informed at the beginning of the project, they tend to forget and when things fail, causing increased expenditures, the momentum of project is lost very fast. Partners may lose interest and "faith" in perceive as "negative messages" are by no means solely negative, as these are crucial to provide the key points for further improvements. As the technology (project) and then some of them think it would have been better for the development of hydrogen technologies to have skipped the project as the experience from the project is what they would call "negative". However, demonstration projects are carried out to provide experience from field tests. Both achievements and challenges should preferably feed in to next generation of the technologies. Hence, what some stakeholders may experience as technological failures and delayed projects with budget overrun may create a negative reputation for certain technologies, including hydrogen for transportation. Thus, for some companies having invested in these developments, certain information may preferably be kept in house. Therefore a constant communication flow between the project partners and involved end users is needed, constantly reminding them that the project is dealing with new and developing technologies. As already indicated, all of the projects providing information for this study had higher cost than the estimated in the beginning. There were also other issues which added to unexpected cost:

i. **Certification of technology** is usually more time consuming and costly than expected. Dealing with custom offices, registration offices, job permits etc. has often been extremely time consuming. Sometimes it is close to impossible to meet the expectations of "officials".
ii. **Communication**: When many SMEs are involved, the communication often becomes a very time consuming effort. Part of this problem can arise from imprecise communication, weak project coordination (management) causing partners to start blaming each other for economic issues caused by another partner and which are affecting them. It is of utmost interest that each partner is well aware of its own and the other partners' responsibilities and how performance and deliveries of one partner can affect others.

iii. **The users interface:** This is maybe best seen where vehicles demonstration have taken place. Most frequently the vehicles are in the hands of companies aiming at spreading the awareness and knowledge about these novel technologies. Therefore many users are assigned to each vehicle of which few or nobody feels truly responsible for the car. If it does not perform as a conventional vehicle it is quickly referred to as a lemon. This may eventually have a negative impact on the project causing extra costs as the vehicles are handled carelessly. The solution is that a single person is fully responsible for the car (“baby”).

Table 4 summarizes the most important above mentioned issues and comments collected in the interviews.

	Delays and unexpected cost		
Themes	**Statements**	**Comment from interview**	**Comment from interview**
1. Budget devision	"Technological complexity must be reflected in the budget. When small extra elements were needed to adjust the technology, there was no money available and all the work was lost.	Technical errors affected daily programs and have lead to longer repair time and then to lower mileage in the demonstration. Should there be added to the demonstration time because of this dead time?	When dealing with unproved technological modules, be prepared that manufacturing is more costly than service or research. Financial backup for the building and pre-testing phase of equipment must be appropriate. Have risks - solution plans ready before launching the project and preferably have a flexible schedule that follows the readiness of the modules and core systems.
2. Cost of failures	*Technical failures will take time to overcome. This raises cost of the demonstration and shortens the time for real demonstration.*	Consider how to deal with staff and hired workforce during dead time if you plan to go for a second project. The negotiations can take long time and SMEs can suffer particularly for waiting times. Be ready to consider calling off a project and returning financial support rather than running into unsolvable questions with later repercussions.	Sometimes partners do not fulfil promises . This causes domino effect on the project and increased the stress on others that needed to take on more work and adapt to the situation. This is both costly and time consuming and the time laps lead to decreasing faith in the project as a whole.
3.Delay management	*If all major players are well informed reactions can often be made well prior to real crisis.*	Try to keep communication lines open and indicate to relevant parties well before a problem becomes a show stopper. It is helpful if all players have good insight into each other's responsibilities and how it becomes necessary prevent problems and react to them in your own position, not the least on the financial side.	We had been unrealistic about how difficult it is to provide fuel cell cars. The team was at last rational and chose a solution that cost less but tested only partially the technology of interest.
4. Supply chain	*Spare parts are not readily available for new technologybut is made ad hoc. Frequent failures in this components will prolong waiting times.*	Economic weakness of one partner can become the link that breaks the project chain.	Putting the technology on an ordinary petrol station and having ordinary station employees to operate, created practical problems. There should have been a better planned solution with respect to card terminal. When we realized that, it was very late.
5. Human relations	*How and when participants communicate can easily affect the progress of the project*	"When there are technical problems, I take the car to the garage. The technicians have to call the company who made the cars. It seems to me that delays in this phase are due to difficult communication between the two parties. "	Try to use IT as much as possible for registration. Prompting users for information before filling vehicles at H2 station has proved to be helpful. Asking various drivers to fill out paper forms has not been successful and takes for ever to collect.

Table 4. Results on unexpected cost from interviews carried out in the PreparH2-project.

It is evident that actual costs for many demonstration projects are higher than the budgeted cost. There are indications from the projects looked at that some cost elements have ~25% higher cost. In one project it was the management part of the project that was underestimated. In another project certification costs were underestimated by 50%. Most of the projects had a calculated 10-15% unexpected cost – this figure was in most cases too low!

Another issue which appear to be a surprise for SMEs is the documentation and reporting efforts required in EU supported projects. EU has the same expectations regarding paperwork etc. for small companies as they have for large companies. For the small companies the requirements seems out of proportion in relation to their small company size and share of project. The SMEs should also take such "unexpected" cost into account when budgeting.
Establishing new projects, it is essential to be aware of former experience and experienced partners can educate newcomers to the field to reduce the economic risk and a potential economic failure.

5.3 Hidden cost

As mentioned earlier it was very difficult to get information on hidden cost. There are however many indications that hidden cost is an issue in most of the projects. Most of that cost seems related to the participation of larger companies as SMEs cannot afford such cost and usually do not have any desire to hide costs. Hidden costs, which are never reported, may typically be related to overtime for dedicated technical personnel working long days to get the technology working.

It may be speculated that cost estimates when drafting a project proposal may sometimes be made "purposely" too low so that chances of funding grant may be increased.

This can be the case both for nationally and EU funded projects. Besides, there are usually constraints on budgets and a stakeholder might think that applying for more than a certain amount will not be accepted, partners might not want to show the correct figures as if funding bodies will see actually how much the technology costs then they would hesitate to provide funding in this case larger companies might be hiding costs or not charging full cost on purpose as for example the learning of the project provides anticipated future benefits. Eventually, the actual reason is difficult to pinpoint. Still this is far more complicated for SMEs which are very vulnerable to any budget changes and they therefore have to be causes when making budgets and it might be worth while seeking help when making budget plans

As interviewees were reluctant to comment on such issues and reply to such questions it is not possible to quantify figures in this sense.

5.4 Conclusion

It is important for stakeholders planning for future H_2 demonstration projects to know that many previous projects have experienced higher costs and that economic constraints are tighter than anticipated[37].

Creating strong alliances and communication pathways is a way to reduce the economic risks and preventing unfavourable outcomes/incidents.

Also by keeping all partners informed of other partners' responsibilities and of consequences for all partners if one partner fails to deliver, unexpected and hidden cost may be avoided or minimized. Still it should be noticed that such efforts are very time consuming for the management team and should be accounted for in the budgeting process.

[37] This project did not evaluate if this is the general case for all new developing projects. However, many of the partners are also participating in other alternative fuelled vehicle demonstrations and the same problem is there that unexpected cost is higher than presumed. Also there the same seems to apply to hidden cost – just as for H_2 projects.

6 Overall recommendations

The literature review indicate that the level of knowledge about hydrogen technologies is generally low, and substantial efforts should therefore be put into informing the public about the recent advances and achievements especially within the fuel cell bus and passenger vehicle development.

Based on the literature on Willingness to Pay (WTP) for hydrogen based transport it appear that a share of the public are willing to pay a premium for hydrogen passenger vehicles compared to conventional gasoline or diesel vehicles. This is however based on surveys where respondents have no or very limited experience with such vehicles. Therefore, there is a need to carry out studies in which one makes use of experiences from early users of hydrogen fuelled vehicles.

Hence, new studies of the acceptance and WTP for hydrogen technologies should preferably be addressing end-users which are exposed to the technologies in terms of information and through test-drives. This way we may avoid erroneous answers resulting from respondents subjected to hypothetical questions and will, hence, ensure a higher reliability of the results.

Ride and drive clinics seems to be a viable and efficient instrument to provide information to the public and directly reach those who are explicitly interested to get acquainted with hydrogen vehicles and indirectly to a wider audience through press coverage.

It is equally crucial to inform the public that the future of road transportation will include Battery Electric Vehicles (BEVs), Hybrid Electric Vehicles (HEVs) as well as Fuel Cell Electric Vehicles (FCEVs) and that introduction of all these alternative drive trains are needed to reach the ambitious goals of GHG emission reductions. The need for this is evident as there is currently widely spread perception in public is that there will be one preferred option one sole solution (the “silver bullet”) to the emission problems in transportation.

Most studies make use of conventional vehicles as the reference case to which the hydrogen option is compared. Studies comparing hydrogen vehicles with battery electrical vehicles or other alternative fuelled vehicles (e.g., natural gas ICEs) are scarce. For future studies in the field it is recommended that hydrogen fuelled vehicles are compared to hybrid vehicles, other alternative fuels and new propulsion technologies. Such studies should yield more information on the pre and cons of different technologies, the willingness to pay a premium for hydrogen vehicles per se, and, moreover, whether the premium found is hydrogen specific and whether these premiums will be remain at this level or will diminish as other alternatives like BEVs and hybrid vehicles are entering the market.

It total: new studies of the acceptance and WTP for hydrogen technologies should preferably be addressing end-users which are exposed to the technologies in terms of information and through test-drives. This way we may avoid erroneous answers resulting from respondents subjected to hypothetical questions and will, hence, ensure a higher reliability of the results.For the mass market, research on WTP indicate that hydrogen based transportation as well as other environmental friendly alternatives, have to be cost competitive to traditional solutions. Hence, it is recommended that the Total Cost of Ownership (TCO) approach should be developed and conveyed to the wide audience to make them able to consider the alternative modes of transportation, and thereby engage more actively in an educated way in their selection of transportation alternatives.

One obstacle to overcome is that the majority of the public is, moreover, not aware of their current expenses for transportation and as new propulsion technologies and alternative fuels are introduced, using new units of measurements (e.g., kWh for BEVs and kg of H2 for FCEVs this adds to their confusion.

It is, thus recommended to carry out comprehensive Comparative Research (reviewing the vast available literature) on the actual cost of hydrogen production versus the public's WTP for the fuel, taking into account learning effects and possible future prices of input factors such as natural gas or electric power. Based on this, the current very stringent cost targets for H_2-production may be adjusted accordingly.

Along with conveying the TCO to potential customers, it is recommended that through Life Cycle Assessment (LCA) studies the total environmental "footprint" of the alternative vehicles and fuels should be made accessible for the wide audience. Otherwise the customer's environmental engagement may lead to purchasing vehicles that are in fact less environmentally sound, based on erroneous perceptions or lack on knowledge. The un-educated customer would become frustrated and it will be de-motivating and may reduce the public's engagement in zero or low emission alternatives.

Regarding economic aspects of hydrogen demonstration projects, the most important lesson for stakeholders planning for future H_2 demonstration projects to know that many previous projects have experienced costs exceeding the budgets. Creating strong alliances and communication pathways is a way to reduce the economic risks and preventing unfavourable outcomes/incidents. Also, by keeping all partners informed of other partners' responsibilities and of consequences for all partners if one partner fails to deliver, unexpected and hidden cost may be avoided or minimized. Still it should be noticed that such efforts are very time consuming for the management team and should be accounted for in the budgeting process.

Last but not least it is crucial at present that car manufacturers, energy companies and European and national governmental entities jointly support and facilitates the rollout of a hydrogen refuelling infrastructure so that it is ready when the vehicles are launched in the market in less than 4 years time (2015). This public commitment in other countries than Germany needs to be verified by the end of 2011 as the Original Equipment Manufacturers (OEMs) already have committed[38] and need to take investment decisions on building series production lines for FCEV to be able to deliver the vehicles commercially in 2015.

[38] Letter of Understanding, signed Stuttgart, Germany, September 9, 2009: http://www.daimler.com/dccom/0-5-658451-1-1235421-1-0-0-0-0-0-13-7165-0-0-0-0-0-0-0.html

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Annex 1 – Economic matrix - WTP

This annex contains an "economic matrix". Entries are reports and papers addressing Willingness to Pay (WTP) for hydrogen based transport. The matrix gives an overview and quick access to relevant publications that are specific on WTP (numbers) for hydrogen based transport.

The format of the matrix is the same as for the "social matrix" presented in the *Prepare-H2* – report: *"Social studies in context with hydrogen deployment: Analysis, quality, gaps and recommendations"* (Praktiknjo et al., 2011).

The number of publications is limited and almost one half is based on surveys where respondents have no prior experience with hydrogen technology and hydrogen based transport. There is only one survey based on respondents that have some experience from operating a hydrogen vehicle (i.e. FCEV).

The colour coding of the matrix is presented in Figure A1.

Besides we have added a table containing four relevant reviews on hydrogen based transportation that also addresses WTP. The focus of these review articles/reports is in general quite broad and related to perceptions, attitudes and acceptance, knowledge gaps and recommendations for future research. Never the less these review articles are a possible gateway into the literature on WTP for hydrogen based transport.

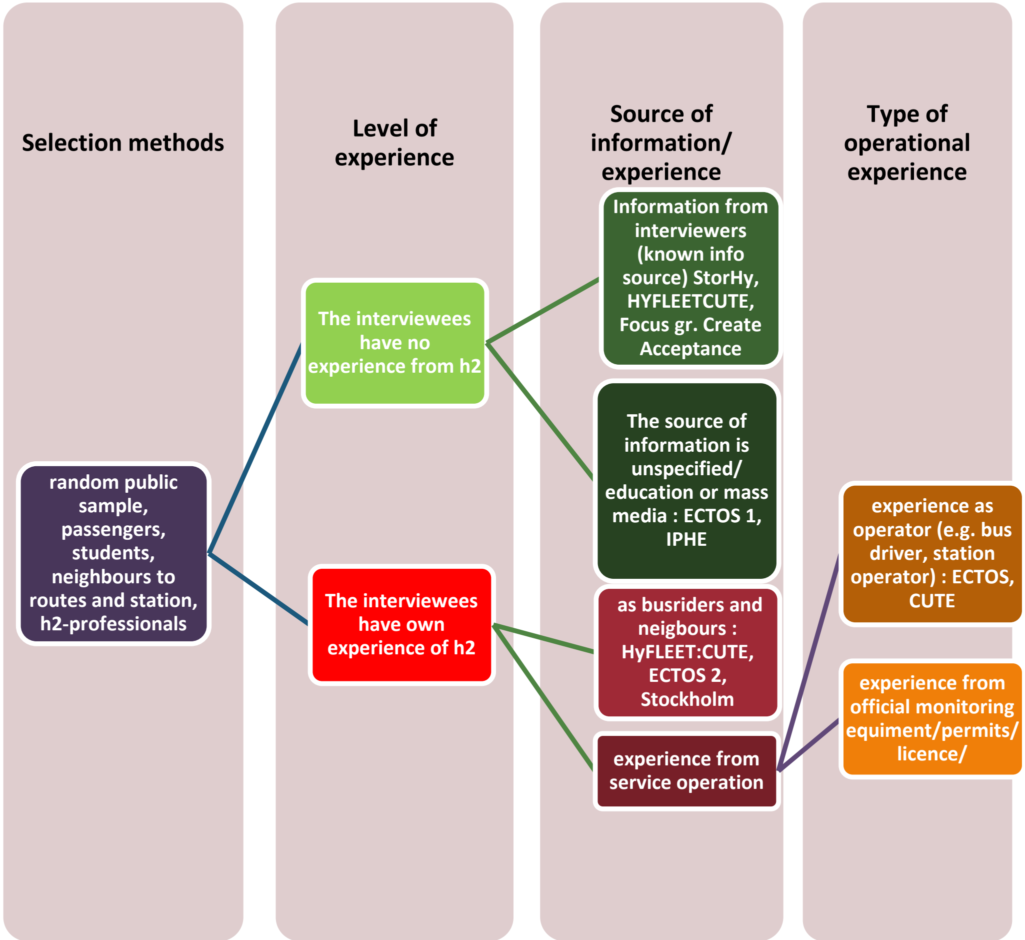

Figure A1: Colour coding of the matrices

The matrices have been organized according to the following criteria and coloured in the matrices as indicated in Figure A1:

Respondents level of experience with hydrogen technology,

a. no personal experience
    i. The information received before interview is known
    ii. The information available to the subjects of the research is unknown
b. own experience
    i. Experience a passive user such as a passenger
    ii. Experience as an operator within the system
        a. Experience from monitoring or permit issuing
        b. Experience from hands on operation of station or vehicles

Table A1 shows studies where interviewees apparently have no experience with H2 and where they have been informed by the interviewers. In fact, before interviewees are asked about WTP they are always given some information that intends to be balanced. Hence, with respect to WTP – all respondents are informed by the interviewer. Remark that other questions on knowledge and awareness may have been posed and answered before the interviewees were informed. Since this matrix focus on WTP – we mark all entries "informed by interviewer". Table A2 shows studies where interviewees have own experience with H2 and where their source of experience is for example from being a passenger on a hydrogen bus or a neighbour to a hydrogen refuelling station (passive). Table A3 shows studies (one entry) where interviewees have own experience with H2 and where their source of experience is from service operation (active) as an operator, in this case as drivers.

The tables A1 – A3 are to be found in the following 5 pages. The references to the studies are given in the reference list. These tables are available also as excel sheets.

Table A4 offers a quick reference to some relevant review articles published since 2003.

Table A1: Economic matrix - WTP: Interviewees have no Experience with H2

(Information from Interviewer before answering on WTP)

Author, Date and (Geography)	Survey carried out	Size and description of sample	Goals	Integrated criteria	Vehicle criteria		HRS criteria	Cost/Willingness to Pay	Method used for eliciting WTP	Conclusions/ Comments
				Environment	Vehicle criteria	Performance	Practicality	Importance/figures		
Mourato et al. (2004) Imperial College, London, UK. (UK, London)	May 2001	London black cab drivers 2 focus-groups used for design of survey. 99 repondents - interviewed Presented features : Scenario 1: A 140 mile range, same price per mile for hydrogen as for diesel and 2 H2 refuelling stations. Scenario 2: A future scenario; increased range to 200 miles, H2 cost half as much as diesel and 10 H2 refuelling stations.	Investigating preferences of London taxi drivers for driving emission free hydrogen fuel cell taxis- eliciting WTP for (scenario 1) leasing a pilot vehicle and (scenario 2) buying a "production" vehicle	Silent taxis considered to be a big advantage over current diesel models	No concern over the safety of the FC taxis, even fuelled by compressed hydrogen	140 miles range disavantage but acceptable for most drivers Loss of booth space for H2 tank accepted, regarding the environmental advantages (silent, zero emissions)	Availabilty of Refueling stations	Scenario 1 - WTP for participation in FC taxi pilot project (i.e. leasing a taxi): £2900 and £3500 in average per year. These figures are less than estimated alternative cost of an conventional taxi, indicating strategic (low) bidding and/or compensation necessary for drivers. Scenario 2: WTP a premium over and above a similar diesel vehicle in average *£ 1600 which is much less than value of fuel savings estimated to £50 per week.*	Contingent Valuation: Scenario 1: Respondents asked to bid for participating in the pilot project. To induce truthtelling repondents were told that no more than 6 bids would be accepted . Bids in steps of £ 500 for participating - i.e. leasing a fuel taxi. Scenario 2: The vehicle assumed to be available in the market.	WTP less than estimasted savings. Strategic (low) bidding and/or claiming compensation for leasing/buying hydrogen taxi.
Neves, T. and S. Mourato (2004). Imperial College ACCEPTH2 -project (De, Berlin UK, London Luxembourg and Australia , Perth)	2003-2004	345 in Berlin 414 in London mainly 300 in Luxembourg 300 in Perth	Investigate public perceptions and attitudes towards hydrogen fuel cell buses, and estimate WTP for environmental benefits (air and noise pollution reductions) of large scale introduction of hydrogen buses in the cities.	Existing diesel buses: Respondents were discontent about noise and fumes.	For existing diesel buses: Respondents satisfied with existing no of bus stops, frequency and security on/of buses.			Average WTP extra per single bus fare to support introduction of hydrogen buses equal to 0.31 € WTP annual extra-taxes is € 23 in average. Contain tax figures for all four cities.- not only for London and Perth as O'Garra et al. 2007. ranging from € 13 in Perth, € 21 in Luxembourg, € 29 in Berlin and € 30 in London.	CV Respondents asked to chose a value from a series of distrete amounts ranging from zero to a maximal amount.	The WTP was significantly influenced by respondents environmental sensibility. Statistical models performs modestly.

Table A1 continued

Author, Date and (Geography)	Survey carried out	Size and description of sample	Goals	Integrated criteria Environment	Vehicle criteria Vehicle criteria	Performance	HRS criteria Practicality	Cost/Willingness to Pay Importance/figures	Method used for eliciting WTP	Conclusions/ Comments
O'Garra et al. (2007) Imperial College ACCEPTH2 -project (De ,Berlin UK, London Luxembourg and Australia, Perth)	2003-2004	Bus users only: 344 in Berlin 300 in Luxembourg Mainly bus users: 414 in London 300 in Perth	Compare WTP for the air pollution reductions associated with a scenario of large-scale introduction of hydrogen FC buses.	Very high rate (90%) of unconditional support of hydrogen bus demonstration. Rate of unconditional support of large scale hydrogen bus introduction 46%.				Average WTP extra per single bus fare to support introduction of hydrogen buses equal to 0.32 € Adjusted for cost of living WTP is lowest in Berlin (€0,27) and highest in Perth (€0,35). WTP annual extra-taxes is € 15 in Perth and €24 in London. Respondents in Berlin and Luxembourg not aseked about tax.	CV Respondents asked to chose a value from a series of distrete amounts ranging from zero to a maximal amount.	Overall there is a positive WTP to support large-scale introduction of H2 busses. Resondents environmental concers and behaviour are found to influence WTP for H2 buses. Regression models performed very modestly
O'Garra, T. and S. Murato (2007) Imperial College, ACCEPTH2 -project (London UK)	2003-2004	531 respondents living in Greater London picked randomly and interviewed by phone in 2003 and 2004 .	To assess the usefulness of Quantile Regression (QR) in identifying the determinants of WTP along the entire distribution. Comparison made with results using an interval regression estimator and an OLS estimator.	Fumes from existing buses are quoted as the least favored attribute of existing London buses				Most repondentss (85%) are willing to pay some extra bus fare (per month) to support the introduction of H2 buses in London. Average extra fare per month equal to £ 7,32	CV Respondents asked to chose a value from a series of seventeen distrete amounts ranging from £ 0 to £ 50.	Generic environmental attitude found to influence WTP positively. Income is mostly significant at higher quantiles (of WTP). Different determinats within different quantiles. It appears to be substantial value in using Quantile Regression (QR) to analyse CV-data

Table A2 : Economic matrix - WTP: Interviewees have own experience with H2

(as passive experience – e.g. bus-passengers, neighbours, etc.)

				Integrated criteria	Vehicle criteria		HRS criteria	Cost/Willingness to Pay		
Author, Date and (Geography)	Survey carried out	Size and description of sample	Goals	Environment	Vehicle criteria	Performance	Practicality	Importance/figures	Method used for eliciting WTP	Conclusions/ Comments
O'Garra, T. (2005b) Imperial College: ACCEPTH2 -project (De, Berlin UK, London Luxembourg and Australia , Perth)	2003-2005	# ex ante + # ex post: 344 + 263 in Berlin 414 + 300 in London 300 + 3001 in Luxembourg 300 + 300 in Perth **Remark: Approx 6 months of H2 bus trials in each city**	Identify which variables influence knowledge, acceptability and WTP for H2 buses and storage and secondly to identify whether there has been statistically significant changes in knowledge, acceptability and WTP (before and after introduction of H2demonstration buses).	Unconditional support for large scale introduction of H2 buses increased in all cities				Identified changes in WTP(extra fare price and extra tax): In Luxembourg an increased WTP extra annual tax, but no change in WTP extra bus fares. In Berlin increased WTP extra annual tax (sign. at 10% level) In Perth increased WTP extra annual tax (sign. at 10% level). Remark: somewhat mixed results between respondents interviewed on board buses and all other respondents.	CV Respondents asked to chose a value from a series of distrete amounts ranging from zero to a maximal amount.	Direct experience of a H2 bus has major effect on WTP values (fares and taxes) in any City
O'Garra, T., (2005) Imperial College. ACCEPTH2 -project (De, Berlin UK, London Luxembourg and Australia , Perth)	2003-2005	# ex ante + # ex post: 344 + 263 in Berlin 414 + 300 in London 300 + 3001 in Luxembourg 300 + 300 in Perth **Remark: Approx 6 months of H2 bus trials in each city**	Investigate public perceptions and attitudes towards hydrogen fuel cell buses, and estimate WTP for environmental benefits (air and noise pollution reductions) of large scale introduction of hydrogen buses in the cities. Further to investigate whether there has been significant changes in knowledge, acceptability and WTP (before and after introduction of H2demonstration buses).	Unconditional support for large scale introduction of H2 buses increased in all cities				The hydrogen bus demonstration program did not significantly increase WTP extra bus fare (average of € 0,35 inn all cities). Willingness to Pay annual extra tax for large scale introduction of hydrogen buses also by and large remained stable. However for Luxembourg ex post WTP increased significantly. There was also an increase for Perth (at 10% level)	CV Respondents asked to chose a value from a series of distrete amounts ranging from zero to a maximal amount.	This report is the basis of journal articles (papers) published on this topic-. More details on methodolody and findings than in the papers.

Table A2 continued

Author, Date and (Geography)	Survey carried out	Size and description of sample	Goals	Environment	Vehicle criteria	Performance	Practicality	Importance/figures	Method used for eliciting WTP	Conclusions/ Comments
Haraldsson,K. et al. (2006) KTH/CUTE (Sweden Stockholm)	2004	518 bus passengers on route 66	To asess passengers' overall experience, attitude and acceptance of fuel cell and hydrogen technology	less noisy than conventional buses	Safety most important factor of public transportation means		Punctuality second most important factor of public transportati	More than half (64%) of bus passengers were not willing to pay higher fares if more fuel cell buses were to be used. 20 % were willilng to pay more and 12% were "neutral".	Responendts asked whether they would pay more.	Respondents felt safe with the technology. Passengers not willing to pay more to enable more fuel cell buses in the city.
Saxe, M. et al. (2007) KTH/CUTE (Sweden Stockholm)	2005	507 bus passengers on route 66	Same as first survey (see above) and to identify changes w.r.t. experience, attitude and acceptance due to one year of hydrogen bus demonstration.	same result as first survey (above)				Same result as first survey- no significant difference compared to first survey (above). In this survey 61% stated that they would not be willing to pay a higher price. 23% were willing to pay more.	Responendts asked whether they would pay more.	Same conlusion as for first survey (see above). Authors' remark: Low WTP could be due to the already high environmental profile of Stocholm Transport with the world's largest ethanol bus fleet.
Maack, M. et al. (2004) ECTOS 2 2004 (Iceland, Reykjavik)	2004	100 passengers, qualitative On board diesel and hydrogen buses	Check on acceptance of bus riders	Connect H2 to water and clean environt, positive for low noise, clean emission, acceleration, trust technology, small majority willing to pay higher prices	Feel safe and comfortable inside the bus	Passengers like riding the bus, its power, speed and punctuality		Overall (all respondents): 35% would accept hydrogen if the price of hydrogen is at the same level as oil . Approx 28% accept hydrogen if cost is loweer (i.e. WTP less than zero) and 37% of the respondents would accept to pay a premium for hydrogen. Pedestrians seems to be more willing to pay a premium for hydrogen.	CV. Respondents were offered five alternatives. Hydrogen is acceptable if * 20% cheaper * 10% cheaper * same price * 10% more * 20% more	High level of acceptance, positive in all aspects, want to see faster development. Need for more info drops from 90% to 45% between 2001 and 2004. WTP : About 1/3 accept to pay more for hydrogen than for oil and 1/3 claim that the price must be lower.
		50 neighbours to bus routes and station qualitative/	Check on acceptance of neighbours	less noise from bus traffic appreciated	Find diesel also safe, no remarks on station	Not mind the noise in diesel buses				
		50 pedestrians, qualitative	Check on public acceptance, collect questions	Find city pollution problematic but mostly want to reduce noise						

Table A3: Economic matrix – WTP: Interviewees have own experience with H2 (as drivers)

Author, Date and (Geography)	Survey carried out	Size and description of sample	Goals	Integrated criteria Environment	Vehicle criteria Vehicle criteria	Performance	HRS criteria Practicality	Cost/Willingness to Pay Importance/figures	Method used for eliciting WTP	Conclusions/ Comments
Martin et al. (2009) Transportation Sustainability Research Center , Institute of Tranportation Studies; both CA, USA, 2007 (USA, CA)	2007	"Ride and drive clinic " with a Mercedes-Benz A-class F-cell hydrogen FCV. 189 self selected repondents. 86% have no former experience with hydrogen.	To get feedback from a range of individuals who were provided an opportunity to drive the FCV and view a fueling demonstration	Roughly 95% of respunendts finished the ride and drive clinic with either a positive or very positive impression of the F-cell	Before clinic: 30% of repondents believed that driving with hydrogen vehicle was less safe than gasoline and 40% considered refueling with hydrogen to be less safe than with gasoline. percentages dropped to 7% and 13% after participation.	Range: Roughly 75% find it acceptable if range is between 240 and 300 miles. Acceleration, braking and handling of the car is acceptable		Purchase price: 50% of repondents indicated that they would be willing to pay at least $4000 in a premium over a similar gasoline car. Regarding annual operating costs: 25% would not accept higher operating cost and 75% would pay no more than $1000 per year.	CV Question on WTP was asked sequentially.	*"..study indicate that short term exposere to FCV and refueling can improve a variety of imressions among participants"*

Table A4: Review articles relevant to WTP for hydrogen based transport (Additional material – colour codes not applicable)

Author, Date and (Geography)	Hydro-gen papers published	Short description	Goals	Integrated criteria	Vehicle criteria		HRS criteria	Cost/Willingness to Pay	Method used for eliciting WTP	Conclusions/ Comments
				Environment	Vehicle criteria	Performance	Practicality	Importance/figures		
Altmann et al. (2003) Imperial College, London UK, ACCEPTH2-project	1998 2003	Literature review - 24 papers on public preferences for new environmental transport technologies. Of these, 5 deals with hydrogen based transport (plus 3 studies not published).	To present, analyse and compare existing studies on hydrogen w.r.t. public perception and to review the litterature on clean vehicles and fuels.	–	–	–	–	Only one reference to WTP for hydrogen based transport (i.e Mourato et al. 2003).		Environmental concerns are not found to have a significant influence on acceptance of, or willingness to pay for cleaner transport (including hydrogen based transportaion).
Truett et al. (2008), Oak Ridge National Laboratory, for the U.S. Departement of Energy	2003-2008	A Compendium on Surveys Evaluating Knowlegde and Opinions of Hydrogen and Fuel Cell Technology with focus on surveys since 2003 i.e. 15 new surveys (plus 6 non-scintific surveys)	To review the literature prior to a planned DoE survey	–	–	–	–			Results from each survey summarised. (Some of the surveys are the source of several papers and/or reports).
Ricci et al. (2008) Institute for Social, Cultural and Policy Research, University of Salford, UK	1998-2007	A litterature review with fous on perceptions and acceptance of hydrogen	To improve current stae of knowledge on lay perception ans acceptance of hydrogen. To identify knowledge gaps by analysisng methods and findings.	–	–	–	–	5 references made to reports/papers on WTP.		Results (findings) from each study summarised and presented in a clear way. Question whether repondents fully understand the pro and cons (for example environmental effects related to hydrogen production) etc. and states that more reseach is needed related to WTP.
Roche et al. (2010)	1998-2008	A literature review of recent attitudinal and preference studies of hydrogen and fuel cell (HFCVs). Overwiew over methodologies.	To summarise studies with focus on conceptual frameworks and methodologies. To identify knowledge gaps and make recommandations for future research.	–	–	–	–	Explicit reference to WTP made only for the ACCEPTH2 project and the London Fuel cell taxi project (Mourato et al. 2003)		Studies carried out so far focus on a single technology and ignore alternative or comlementary technologies.