# D7 Report of Social Impacts of Hydrogen

## Scientific report

### Results of Work Package 2 (Task 2.4) of the HySociety project

### DG Energy and Transport Contract No. NNE5-2001-641


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# 1 Executive Summary

This task aims to analyse possible social impacts of the hydrogen society in Europe. The social impacts include issues such as quality of life, social justice and acceptance of hydrogen. In addition, an evaluation is made of the potential problems associated with the poor safety image of hydrogen and the level of knowledge of the different market actors (policy makers, industry, educational entities and general public).

The development of a hydrogen-based economy not only faces major technical and economic issues; public perception is also one of the potentially major aspects to be taken into account when considering the introduction of innovative technologies such as those based on hydrogen. In general, studies on public acceptance of hydrogen technologies to date are scarce. Existing studies concerning public acceptance of hydrogen technologies are mostly focused on transport, while stationary applications have not been specifically addressed so far (gap of research work).

Within bus demonstration projects the major findings are the following ones. Associations with hydrogen were mainly neutral and knowledge of hydrogen vehicles was relatively weak, but there was overwhelming support for the hydrogen buses trials. Support for large-scale introduction of hydrogen buses and development of local refuelling infrastructures still requires additional information, but they are generally welcomed. These are good news for the hydrogen economy, since public approval of hydrogen infrastructure is critical to its success. In addition it was found that previous knowledge of hydrogen vehicles increased public acceptance of demonstration projects and hydrogen storage twofold. Therefore, fostering informational campaigns about hydrogen applications appears to be the right step towards an improved public perception of the technology and a wider market penetration.

The analysis of a study assessing public preference towards hydrogen buses shows that willingness to pay a premium for their extensive introduction soared in the case of increased bus fare, resulting in about 22% of the average fare, while willingness to pay using extra taxes was relatively lower. The main determinant to influence willingness to pay under both payment vehicles was environmental sensibility.

The works on knowledge level of different market actors are based on an internet search and on the data collected in work package 1 of the Hysociety project (see deliverable D1). The evaluation demonstrates that there is a vast amount of knowledge available on research, development, and technological issues that deal with the pre-market phase of hydrogen related technologies. However, knowledge needed to facilitate a market entry is largely missing. For example, economic knowledge on cost effectiveness, commercial potential and effective partnerships is mostly lacking; the technological knowledge that is still largely missing is knowledge on the integration of hydrogen in and the interaction of hydrogen with energy systems; the socio-cultural knowledge that is missing relates to issues of social acceptance and needs and risk perception; the knowledge gaps on political and institutional aspects deal with responsibility and accountability issues, fiscal incentives, and standards.

It was only mentioned in very few instances which actors should fill the knowledge gaps. In general it can be concluded that the economical knowledge gaps have to be filled through cooperation between industry, R&D and economical scientists; the technological knowledge gaps require similar cooperation if the knowledge required deals with technologies that are dependent on economical aspects, otherwise the actions require only technical researchers. The socio-cultural and political-institutional knowledge gaps need to be filled by a cooperation between industry, R&D, governmental authorities and public representatives or consumers organizations, and gamma researchers. A need that was expressed many times was the need for coordination of knowledge development on an international level to prevent the constant duplication of already existing knowledge, since this aspect was one of the great hurdles in advancing a hydrogen economy.

The analysis on the implications of wide-scale uses of hydrogen as an energy carrier (vector) on "quality of life" (QOL) revealed, that this was a relatively virgin topic, and not much scientific discussion could be found in the social science literature regarding quality of life issues. This clearly underlines the necessity of this kind of analysis, and shows that the topic has perhaps not yet penetrated the line border between the disciplines, social science vs. engineering and economy, where several studies have been made on the various implications of hydrogen use.

The work in the scope of the HySociety project focuses, after screening the methodology suggested and also used in social science to describe "quality of life", on a first attempt on a suitable metrics to make an assessment of the implications that wide-scale use of hydrogen would and should entail. However, it is important to keep in mind that this ranking is highly subjective, and should be re-visited in a larger scientific community that should also include members from social and economical sciences, and not just engineers, like this first effort.

Furthermore, this analysis revealed, that although the overall perception is that hydrogen economy is mostly associated with positive effects regarding quality of life, it could be pointed out certain areas, where also negative impacts could be expected, if not overall, but at least by some parts of the public or other stakeholders. Even if we can clearly see that most of those fears are unsubstantiated, we cannot ignore people's fears, even unwarranted, because those are true to them, and shall affect their behaviour and decisions. Therefore, this is the focal point, where deliberations to educate public of the virtues of hydrogen use should be concentrated. Clear and easy-to-understand messages of the positive sides of the hydrogen economy should be produced and widely communicated in order to alleviate these negative associations.

Social justice is one important point in the discussion of quality of life and is treated in a separate analysis. Social justice in the scope of a hydrogen economy can be characterised by the following five criteria: Access to fair-priced energy services, Freedom of choice, Regional balance, Participation and Protection of privacy. Regarding these criteria, access to fair-priced energy services is the only one that can be appropriately discussed in the context of a hydrogen society. As indicator the share of expenditures for energy services at the average disposable income is used and the indicator index is calculated. Energy services comprise residential electricity and transport. In both categories the current supply is compared with a hydrogen based supply in financial terms. The analysis for Europe in 2020 shows, if a conservative reference scenario with more or less today's oil and gas prices and no ambitious climate policy is assumed as references, the share of expenditures for residential electricity in Europe at the disposable income is estimated to be around 1 % in a conventional system. In comparison to that the index of the cheapest hydrogen option (fuel cell on hydrogen with natural gas reforming) is with 1,75 % slightly higher. The difference becomes much more evident with more expensive hydrogen production options like gasification of biomass (3,2 %) and electrolysis with wind electricity (4,8 %). For conventional transport the share is supposed to be around 2,5 % in 2020. Hydrogen based transport has – dependent on the hydrogen production option – an index of 4,3 % for natural gas reforming, 5,4 % for electrolysis with wind electricity and 6 % for electrolysis with solar thermal electricity from North Africa as the most expensive option. When interpreting these data, one has to keep in mind, that the assumptions of the used data source for electricity and fuel price development are fairly conservative. Other sources estimate the availability of oil and natural gas more pessimistic which leads to higher prices for electricity and fuels in 2020. This would make hydrogen, even from more expensive renewable sources more attractive. Like in other areas of social impacts of a hydrogen economy the knowledge level is pure and further research work has to be carried out.

Like all new technologies which the general public becomes exposed to, hydrogen as an alternative fuel as well as hydrogen-fuelled vehicles have attracted some suspicion as to their safety properties. While current fuels and conventional transport technologies are considered to be "safe" by almost everyone in the chain of production, distribution and end use, hydrogen has to work against the disadvantage of a perception as being potentially unsafe and dangerous. If left unaddressed, public anxieties about explosions or even poisoning might pose considerable barriers to the introduction of hydrogen as an alternative source of energy production and transportation.

‘Expert’ risk assessments perceive hydrogen as a transport fuel which is just as safe as conventional fuels. Especially its behaviour in collisions has been pointed out as being advantageous. Its better performance in explosions and collisions resulting in tank ruptures is added to the fact that hydrogen is non-toxic (as opposed to conventional fuel). Potential hazards in the daily use of hydrogen could occur in situations where hydrogen is stored in enclosed, unventilated spaces, such as private garages. Little evidence exists as to the long-term hazards and risks stemming from problems of the storing of hydrogen by private individuals. Thus, potential dangers involved in the introduction of hydrogen as a transport fuel are not identified in areas such as the production and industrial distribution of hydrogen, where long-term experience has proven hydrogen to be safely manageable. Rather, the storage and commercial use of hydrogen by end-users in a day-to-day/retail environment has been tagged by the scientific community as a key area of necessary accident prevention. As a result, the need for the formulation and implementation of unique hydrogen safety codes and standards of practice governing the private end-use of hydrogen has been recognised.

However, public perception of risks involved in the daily use of mass-marketed hydrogen applications has sedimented around the idea of hydrogen being potentially hazardous not in areas of storage, but in areas which were seen as specifically advantageous for hydrogen, most prominently fears of explosions on generation sites and through tank ruptures or car collisions. Therefore, future risk communication strategies will have to disassociate hydrogen as a transport fuel from icons such as the "Hindenburg" disaster or the Hydrogen Bomb as well as mental images of uncontrollable explosions. Therefore an information as well as an active "experience" campaign (demonstration projects) for future consumers of hydrogen is necessary which brings ‘expert’ and ‘lay’ models of risk in closer congruence. The involvement of formerly detached sections of the public in the emergence of a hydrogen society creates a sense of controllability and familiarity within these sections. This positively reinforces the public acceptance of new and unfamiliar technologies and encourages consumers to make trade-offs in favour of hydrogen applications.

Resulting from the differences in the risk assessments by public and scientific community, a number of risk communication strategies have been proposed. First of all, a unique set of standards, practice and zoning codes needs to be developed and communicated to the target groups in local government, healthcare, emergency services, staff at fuelling stations as well as taxi and bus drivers. These codes and standards of practice need to be backed up by specialised training and education courses targeting the fire, police, public transport and health services. As a long-term education measure, schools and museums have to be used as communication platforms to breed generations of pupils accustomed to the idea of being surrounded by daily-life hydrogen applications. In the short term, awareness-raising strategies known from communication campaigns relating to AIDS, breast cancer etc. should be utilised. Industry- and government-sponsored PR campaigns should promote hydrogen initiatives, long-term events such as a "Hydrogen Year" could be organised, travelling exhibitions could tour the countries supported by local festivals and event weeks. In addition, national fleets of mobile information centres should create awareness and provide information to the general public. More commercial marketing devices, such as event marketing (e.g. performing public safety tests), celebrity endorsement and product placement will have to be incorporated into the communication mix in order to reach unaffected sections of the public.

# 2 Analysis and Discussion of the Public Acceptance of Hydrogen Technologies

*IC Imperial College London*

## 2.1 Introduction

The development of a hydrogen-based economy not only faces major technical and economic issues; public perception is also one of the potentially major aspects to be taken into account when considering the introduction of innovative technologies such as those based on hydrogen.

In order for hydrogen technologies to be introduced on a large scale, public support and acceptance is essential. Possible concern for the general public originates not only from safety issues, involving all phases from production to end-use of hydrogen, but also from the cost of the development and introduction of hydrogen technologies. On the other hand, these technologies have the potential for a positive impact on the environment, which could favour their adoption.

This report focuses on the review of existing studies aimed at assessing public attitude and preference for hydrogen technologies. In particular, these studies essentially address hydrogen technologies for transport; this is probably due to the higher visibility that hydrogen-fuelled vehicles have if compared to stationary or small-scale portable applications and also to their potentially more disruptive nature; this report will accordingly focus on transport; public perception issues related to hydrogen technologies for applications other than transport are therefore not explicitly mentioned.

## 2.2 Review of relevant literature

Despite the importance of public acceptance for the successful introduction of hydrogen technologies, relatively little attention has been devoted so far to the study of this issue, if compared to that dedicated to technical and economic aspects. For instance, public opposition to the introduction of hydrogen could act as a show-stopper and must therefore be properly addressed. The first step in this direction is that of gaining an insight into the level of knowledge and the perception that the general public currently has of hydrogen-fuelled vehicles; this has been done so far by a limited number of survey-based studies conducted in specific locations and targeting specific groups, often in conjunction with small-scale demonstration projects. The EC-funded project "AcceptH2: Public Acceptance of Hydrogen Transport Technologies" (contract ENK5-CT-2002-80653; www.accepth2.com), presently ongoing and on which this report mainly focuses, makes a further step by also assessing the effectiveness of hydrogen bus demonstration projects in different cities; it surveys public perception and willingness to pay for hydrogen buses both before and after the commencement of the demonstration projects; on this base, it will also develop more general recommendations on how to implement successful demonstration projects which can effectively contribute to increase public acceptance of hydrogen.

A review of existing studies on public perception of hydrogen has been carried out in year 2003 (Altmann et al., 2003) in the framework of the project AcceptH2. According to this review, not many studies exist which look at the public acceptance of hydrogen technologies and many of them have been carried out in Germany. These studies generally show a relatively high level of acceptance, albeit coupled with a rather low knowledge of hydrogen technologies; this is an unusual situation, as generally a low level of knowledge results in an accordingly low level of acceptance, being reason for uncertainty and fears.

To mention some of the studies reviewed in the project AcceptH2, the EC-funded study: "The acceptance of hydrogen technologies" by Altmann and Graesel (Altmann, 1998) surveyed both school students in three different schools in Germany and passengers on the first world-wide hydrogen demonstration bus operating in Munich in 1997, and subsequently compared the answers given by school students with those given by people of the same age using the hydrogen bus. The study: "hydrogen vehicles and their ambiance – an analysis of the technical, political and social dimensions" (Dinse, 1999) addresses the general public in Berlin; a questionnaire with generic questions on hydrogen was used in 6 different locations within the city. The study: "Acceptance of hydrogen vehicles – A study on the use of a new and unusual fuel" (Dinse, 2000) instead addresses a completely different target, composed by 1,000 randomly selected BMW employees, who were surveyed on their acceptance of hydrogen as a fuel. The study: "Greening London's black cabs – a study of driver's preferences for fuel cell taxis" (Mourato, 2004) differs from the previously mentioned studies in that not only public perception is surveyed but also willingness to pay, in this case for hydrogen fuel cell taxis; the target is that of taxi drivers in London, whose preferences were investigated for driving this type of taxi, both in the short term as part of a pilot tests and in the long term if these vehicles become commercially available on a large scale.

Despite differences in objectives and targets, the studies reviewed show fairly consistent results overall. Firstly, in most studies environmental concerns are not found to have a significant influence on acceptance of or on preference for hydrogen fuelled vehicles, especially in the short term. Price and performance are by far the most important attributes. Even where a correlation is found between environmental attitude and acceptance of cleaner vehicles, environmental concern is a weaker influence than price and performance. However, some studies suggest that environmental factors may play and increasingly important role in the purchase of hydrogen vehicles in the future, especially if information is adequately disseminated in order to increase awareness within the general public. Secondly, public acceptance of hydrogen vehicles is relatively high among those who have little knowledge of the technology, and it tends to further increase where individuals have directly experienced hydrogen fuelled vehicles as part of test trials. Finally, safety of hydrogen fuelled vehicles, often cited by the experts as one of the main possible barriers to their introduction, did not appear to be a major concern among the general public; this however is the result of a limited number of studies and further investigation is required.

## 2.3 The project AcceptH2

In this context, the project AcceptH2 positions itself as the most comprehensive socio-empirical investigation into the public perception of hydrogen and fuel cell technologies around the world to date. It uses survey-based methods to investigate attitudes towards hydrogen fuel cell buses and to estimate willingness to pay for the environmental benefits associated with the large scale introduction of hydrogen buses in 4 cities (Berlin, London and Luxemburg in Europe; Perth in Australia), both before and after the beginning of major demonstration projects.

The 1st phase of the study, involving surveys to be carried out in all cities before the beginning of the demonstration project, has now been completed and a preliminary, qualitative analysis of the results has been carried out. The 2nd phase of the project, which entails carrying out the same type of surveys after some months from the start of the demonstration projects, in order to assess how these have influenced public perception of hydrogen technologies, has recently started but results are not yet available.

The main outcomes of the comparative analysis performed by Neves (2004) following the completion of the first phase of the project are summarised here and reported in more detail in the following sub-sections.

In general, perceptions about hydrogen was predominantly neutral and knowledge of hydrogen and fuel cell vehicles relatively limited. The lack of knowledge did not appear to affect public interest on the hydrogen bus trials since widespread support was granted to this initiative. However, attitudes towards large scale introduction of hydrogen fuel cell buses and development of a refuelling infrastructure were less enthusiastic and required additional information. Willingness to pay (WTP) for the extensive introduction of hydrogen buses was elicited using the contingent valuation method and two different payment vehicles: the estimated mean WTP per bus fare (£0.21 = €0.31 = A$0.54)[1] was quite high and represented 22% of the mean standard bus fare, while the estimated mean WTP extra taxes annually (£15.37 = €23.18 = A$40.65) was comparatively lower. Models generated using ordinary least square (OLS) regression methods had weak explanatory power ($0.14 < R2 < 0.34$) but were robust and it was found that the main variable that significantly influenced WTP was environmental sensibility.

### 2.3.1 Knowledge and attitudes towards hydrogen vehicles

**Associations with hydrogen**

Respondents were asked "Please tell me the first words that occur to you when I say the word hydrogen?" and associations were classified according to their broad nature (Figure 1). Neutral associations like "fuel" and "energy" represented half of the associa-

1 Exchange rates used throughout this paper (1EUR = 0.66GBP = 1.75AUD) refer to the 14th of June of 2004 and were obtained from the European Central Bank website (www.ecb.int/stats/eurofxref/).

tions made, negative associations like "explosive" and "bomb" represented 20%, positive associations like "alternative fuel" and "clean energy" represented 13%, and 16% of respondents were unable to make any association with the word hydrogen.

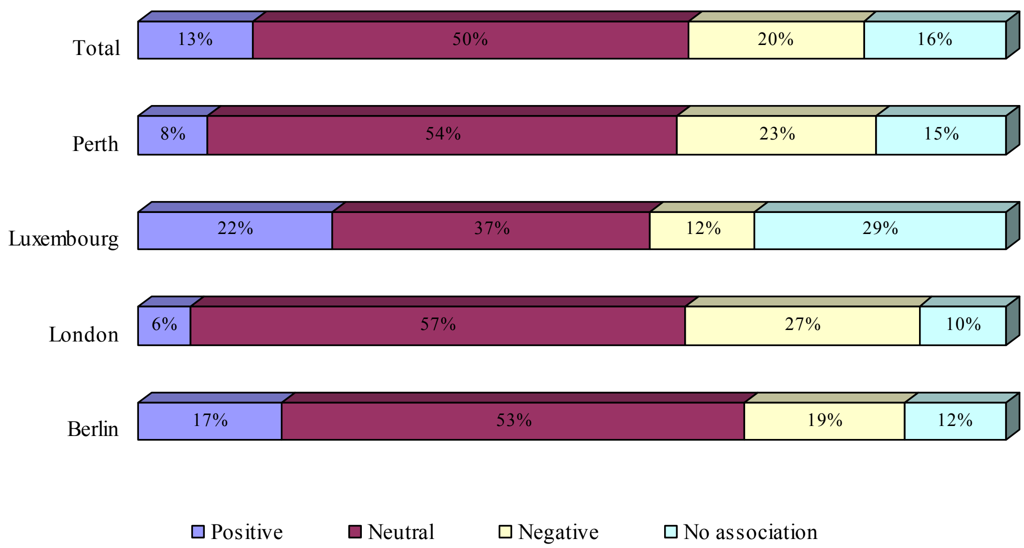


Figure 1: Hydrogen associations[2]

**Knowledge about hydrogen vehicles**

Prior to being given information about hydrogen and fuel cells, respondents were asked whether they knew that car companies were developing hydrogen vehicles. Just over half of the respondents (54%) claimed to know, while almost half (42%) did not know of the existence of hydrogen-powered vehicles, and a small number (4%) weren’t sure about it (Figure 2). Berlin interviewees were clearly the more informed (72% did know), while Londoners were the least informed (only 45% did know), and in general men were more familiarised than women. The main sources of information were television (36%) and newspapers/magazines (37%).

**Attitude towards hydrogen vehicles**

Respondents were also asked how they would feel about the introduction of hydrogen vehicles in their cities (Figure 3). A slight majority would support it (52%), but many would need more information (41%), and only a tiny number would oppose it (1%).

An interesting insight was that previous knowledge about hydrogen vehicles was determinant to the level of support granted, since the rate of support among those with previous knowledge was at least double the support rate of those without previous knowledge (Figure 4).

[2] Source for Figure Figure 1 to Figure 11: Neves, 2004

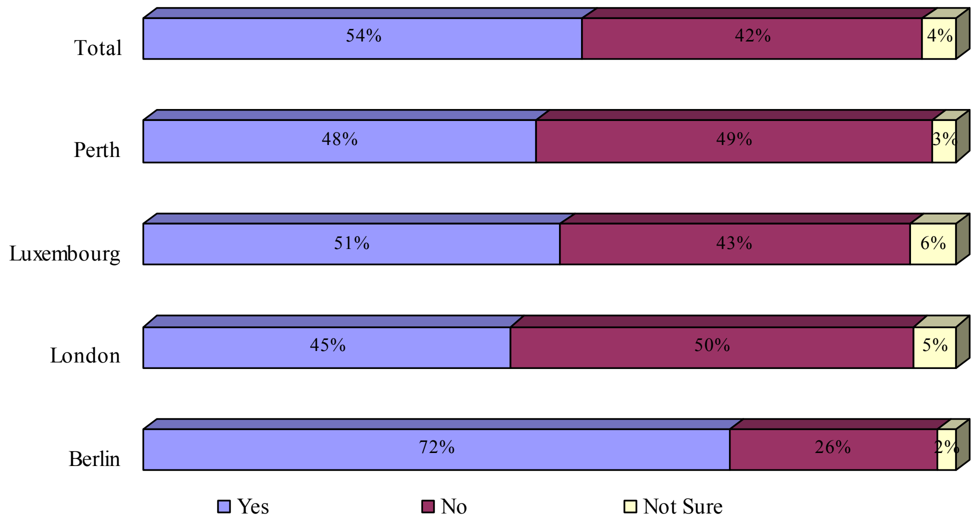


Figure 2: Did you know that car companies are developing hydrogen-powered vehicles?

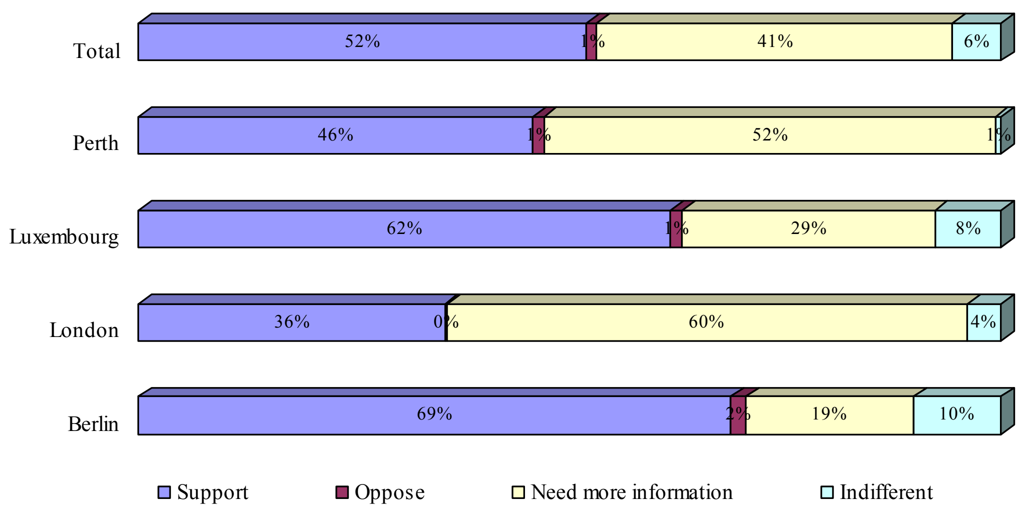


Figure 3: How would you feel about the introduction of hydrogen-powered vehicles in your city?

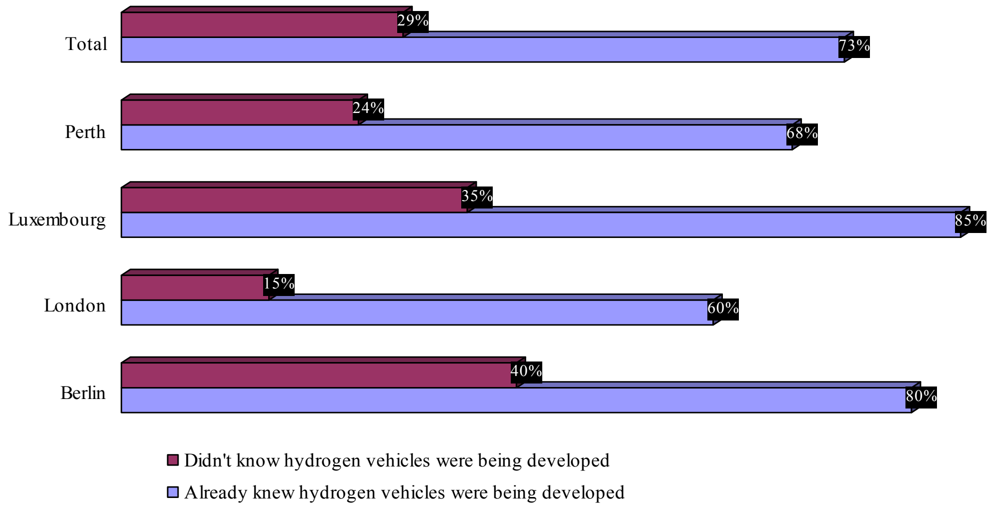


Figure 4: Importance of previous knowledge among supporters of hydrogen vehicles

**Attitude towards hydrogen buses trials**

After being given information about hydrogen, fuel cells and the hydrogen fuel cell bus trials, interviewees were asked if they thought the demonstration projects were a good idea (Figure 5). The rate of unconditional support – generally motivated by the potential of environmental benefits – was overwhelming (90%) and opposition insignificant (1%).

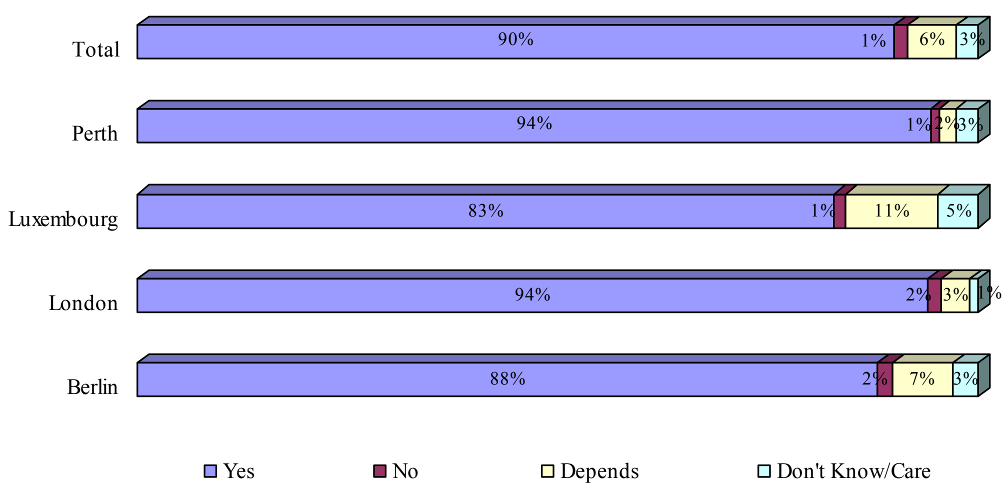


Figure 5: The trial of hydrogen buses in your city is a good idea?

**Attitudes towards large scale introduction of hydrogen buses**

Respondents were much more cautious towards the large-scale introduction of hydrogen fuel cell[3] buses (Figure 6), since unconditional support was down to 46%, while 44% conditioned support to the results of the trials and safety issues, and the opposition represented a mere 3%.

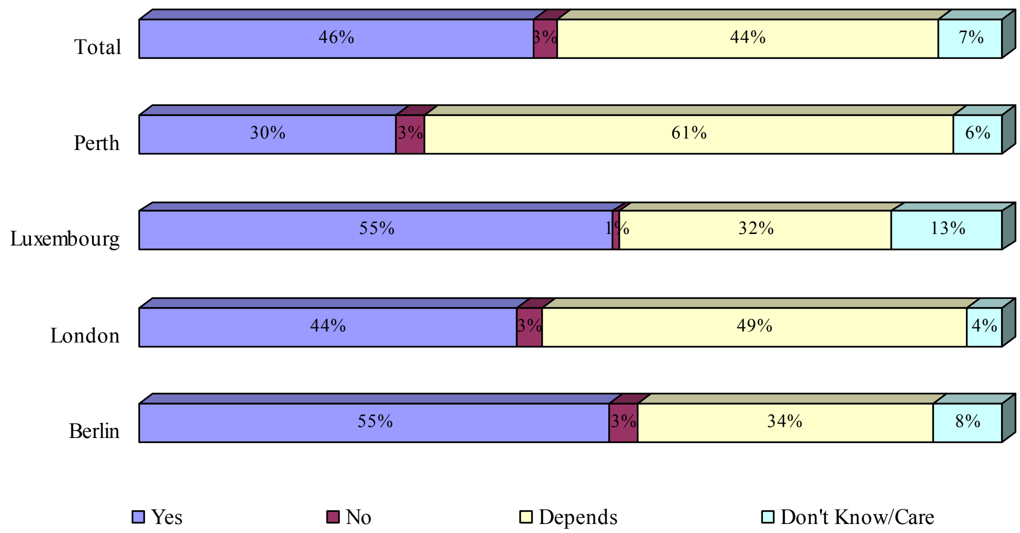


Figure 6: The large-scale introduction of hydrogen buses in your city is a good idea?

Respondents were also asked if they would try to take the hydrogen or the normal bus if there was a hydrogen bus covering their most common route. Logically, the majority (73%) would take the first bus that comes along, some (22%) would try to take the hydrogen bus out of curiosity, and only 1% said would try to take the normal bus. This indicates that the negative associations with the word hydrogen (Figure 1) did not materialize in fear of travelling in hydrogen vehicles, and thus are not a barrier to their large-scale introduction.

**Attitudes towards hydrogen storage**

A favourable perception of hydrogen storage at local refuelling stations is a crucial step towards setting up a hydrogen infrastructure that allows hydrogen to take-off in the private car sector. In Figure 7 it is clear that the majority (60%) of respondents would support local hydrogen storage, while opposition (2%) related with risk and fears of explosiveness was almost irrelevant. However there was a significant need for more information (26%) and once again previous knowledge of hydrogen vehicles increased the level of support granted.

3 Hydrogen internal combustion engine in Berlin

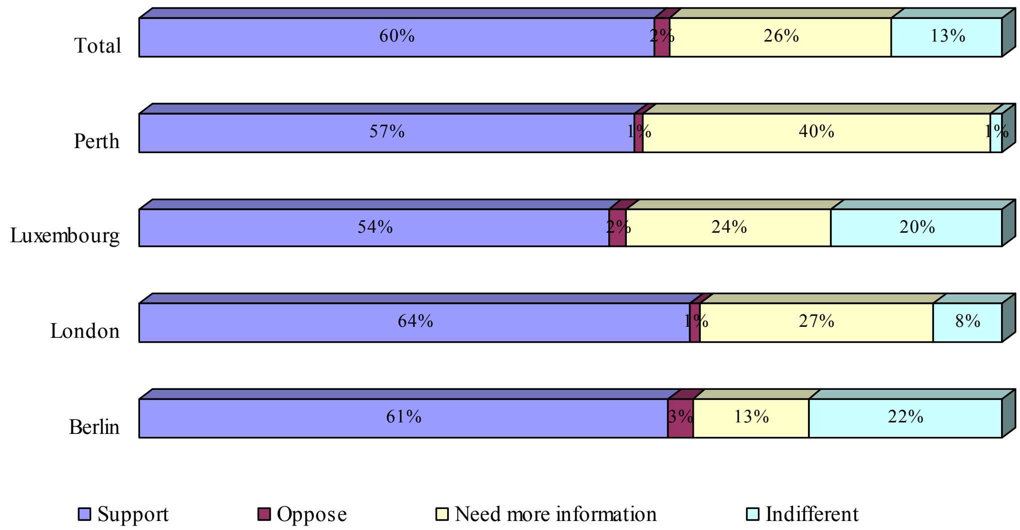


Figure 7: How would you feel about hydrogen being stored and included as a fuel option at your local petrol station?

### 2.3.2 Environmental knowledge and attitudes

**Environmental priority**

Since the respondents' environmental awareness might be a crucial factor that influences the acceptance of hydrogen-powered buses, three categories of environmental awareness were examined. First, the interviewees were asked which environmental issue should have priority in terms of public spending in their countries (Figure 8). Global warming (30%) was the unanimous choice, while urban noise (5%) was considered the least urgent issue to be tackled.

**Environmental knowledge and environmental attitude**

The second factor to be assessed was environmental knowledge/attitude (Table 1), with interviewees being asked to rate their approval of eight statements related with transport and the environment using the following five categories: 1 (strongly disagree), 2 (agree), 3 (neither agree nor disagree), 4 (agree), and 5 (strongly agree). Statements S1, S2 and S3 measured environmental knowledge, while environmental attitude was assessed by statements S4 to S8.

Respondents' environmental knowledge was not particularly strong, since although it was satisfactory in statements S1 and S2, many respondents' failed to reject the commonly held misconception that the hole in the ozone layer is the main cause for global warming.

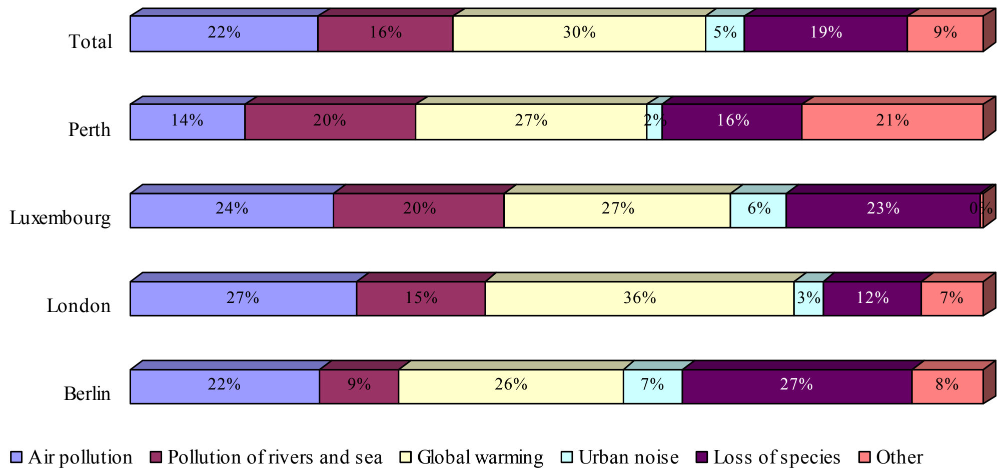


Figure 8: Which of these environmental issues should have priority in terms of public spending?

| | Environmental Knowledge | Berlin | London | Luxembourg | Perth | Average |
|---|---|---|---|---|---|---|
| S1 | Greenhouse gas emissions from transport are one of the 3 major causes of global warming | 3.67 | 3.88 | 3.60 | 3.49 | 3.66 |
| S2 | Car use is the main cause of air pollution in cities | 3.70 | 3.57 | 3.80 | 3.52 | 3.65 |
| S3 | The main cause of global warming is the hole in the ozone layer | **2.78** | 3.02 | **2.40** | 2.97 | 2.70 |
| | Environmental Attitude | Berlin | London | Luxembourg | Perth | Average |
| S4 | Science and technology are the key to solving environmental problems | 3.65 | 3.55 | 3.80 | 3.68 | 3.67 |
| S5 | Environmental problems, such as global warming and air pollution, have been over exaggerated | **3.87** | 2.10 | **3.17** | 2.23 | 1.82 |
| S6 | The decline in oil supplies around the world is a major problem that will cause petrol prices to rise significantly in the next few years | 3.14 | 3.73 | 3.00 | 3.62 | 3.37 |
| S7 | It is necessary for everyone to give up certain activities in order to protect the environment | 4.17 | 3.67 | 4.10 | 3.56 | 3.87 |
| S8 | Solving environmental problems should be one of the top priorities for public spending | 3.97 | 3.90 | 4.10 | 4.00 | 3.99 |

Scale: 1 - Strongly Disagree / 2 - Disagree / 3 - Neither Agree nor Disagree / 4 - Agree / 5 - Strongly Agree

Statements S3 and S5 were recoded in Berlin and Luxembourg. Thus the **values highlighted in bold have a opposite meaning** (is/have must be read is/have not). The averages presented for these questions (corrected by adding 10 and subtracting the values of Berlin and Luxembourg to the total that is divided by four) appear to biased, and the correct averages should be slightly higher (around 0.3 higher).

Table 1: Environmental knowledge and environmental attitude[4]

Respondents' environmental attitude was very positive with widespread agreement that "solving environmental problems should be one of the top 3 priorities for public spend-

4 Source for Table 1 to Table 6: Neves, 2004

ing" and that "it is necessary for everyone to give up certain activities in order to protect the environment".

This was reinforced by the strong environmental awareness of respondents, who predominantly disagreed with the claim that "environmental problems, such as global warming and air pollution, have been over exaggerated". The general perception that "the decline in oil supplies around the world is a major problem that will cause petrol prices to rise significantly in the next few years" and that "science and technology are the key to solving environmental problems" reveals awareness towards the drivers of change, but does not neglect the role of people's actions and habits.

**Environmental Behaviour**

The third factor measured was environmental performance (Table 2), with respondents being asked to assess between 1 (never) and 5 (always), the frequency with which they performed certain activities with significant environmental implications.

| | Environmental Behaviour | Berlin | London | Luxembourg | Perth | Average |
|---|---|---|---|---|---|---|
| Q1 | Recycle cans, glass or paper | 4.61 | 3.84 | 4.70 | 4.40 | 4.39 |
| Q2 | Avoid using your car for environmental reasons | 3.02 | 1.97 | 3.16 | 2.17 | 2.58 |
| Q3 | Buy shares specifically in environmental or ethical companies | 1.67 | 1.13 | 1.39 | 1.24 | 1.36 |
| Q4 | Selected one product over another due to environmental friendly ingredients or packaging | 3.60 | 2.98 | 3.42 | 3.12 | 3.28 |
| Q5 | Attend environmental rallies or protests | 1.69 | 1.23 | 1.36 | 1.29 | 1.39 |
| Q6 | Donate to environmental groups or organizations | 2.25 | 1.99 | 2.03 | 2.26 | 2.13 |
| Scale: 1 - Never / 2 - Rarely / 3 - Sometimes / 4 - Often / 5 - Always | | | | | | |

Table 2: Environmental behaviour

Overall, interviewees practically never attended environmental protests or had the concern to buy shares in environmentally engaged or ethical companies. Only rarely did they donate to environmental groups or organisations, but sometimes they avoided using the car for environmental reasons, and selected products due to environmentally friendly ingredients or packaging. But the most striking aspect of respondents' behaviour was the extraordinary commitment with recycling, which they claimed to perform always or very often.

However, this should be treated with caution since people might have answered according to the theoretical values they were expected to. Another possibility is that recycling habits have now become a daily routine, like in Germany for instance, where people are expected to separate household waste.

Finally, environmental membership was assessed and it was found that only 14% of the respondents were members of an environmental, conservation or wildlife organisation.

### 2.3.3 Willingness to pay for hydrogen fuelled buses

As the introduction of hydrogen buses will certainly involve extra costs, it is important to know whether bus users would be willing to support extra costs in exchange of the environmental benefits they would receive. Therefore, respondents were asked whether they would support the introduction of hydrogen buses if that meant a small increase in bus fares. As the results depicted in Figure 9 show, 46% of the respondents would support the decision, while 33% said it would depend on the actual amount of the increase, and 18% would be against. The Londoners were the most enthusiastic, with 67% supporting and just 9% opposing, while the Germans were the less encouraged with only 29% supporting and 31% opposing. However, this may have to do with the fact that bus fares in Berlin are almost double the level of other cities.

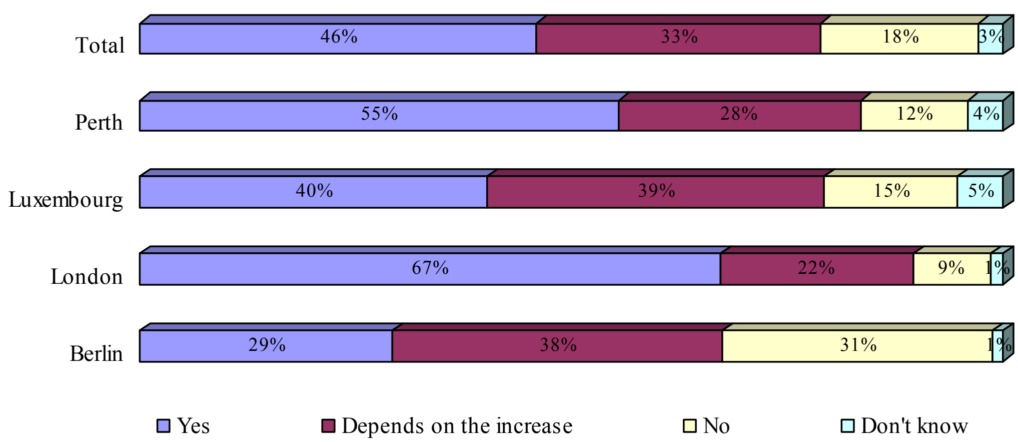


Figure 9: Would you support the introduction of hydrogen buses if that meant a small increase in bus fares[5]?

**Willingness to pay per fare**

In order to quantify the amount respondents were willing to pay (Table 3) they were asked how much more they would be willing to pay *per fare* to have hydrogen buses introduced in their cities. A total of 1,056 interviews were made, 233 stated a zero willingness to pay, but reasons given revealed that 150 were protest responses. Thus, only 83 valid zero statements were included into the analysis and, after removing 7 outliers, the analysis recognised only 899 answers as being valid. The estimated mean

5 These figures do include protests, but if they were removed, overall support would increase.

willingness to pay (Figure 10) per fare (£0.21 = €0.31 = A$0.54) represented 22% of the average bus fare (£0.93 = €1.40 = A$2.45).

| WTP SINGLE FARE | Berlin | London | Luxembourg | Perth | Average |
|---|---|---|---|---|---|
| Price of Single Bus Fare | 1,45 GBP | 0,70 GBP | 0,79 GBP | 0,76 GBP | 0,93 GBP |
| Mean WTP (no protest or outliers) | 0,18 GBP | 0,27 GBP | 0,18 GBP | 0,18 GBP | 0,21 GBP |
| Max WTP | 2,18 GBP | 1,50 GBP | 2,97 GBP | 0,95 GBP | 1,90 GBP |
| Price of Single Bus Fare | 2,20 EUR | 1,05 EUR | 1,20 EUR | 1,14 EUR | 1,40 EUR |
| Mean WTP (no protest or outliers) | 0,28 EUR | 0,41 EUR | 0,28 EUR | 0,28 EUR | 0,31 EUR |
| Max WTP | 3,30 EUR | 2,25 EUR | 4,50 EUR | 1,43 EUR | 2,87 EUR |
| Price of Single Bus Fare | 3,85 AUD | 1,85 AUD | 2,10 AUD | 2,00 AUD | 2,45 AUD |
| Mean WTP (no protest or outliers) | 0,49 AUD | 0,71 AUD | 0,49 AUD | 0,48 AUD | 0,54 AUD |
| Max WTP | 5,78 AUD | 3,96 AUD | 7,88 AUD | 2,50 AUD | 5,03 AUD |
| Sample | 341 | 282 | 287 | 146 | 264 |
| Protests and Outliers | 86 | 22 | 28 | 21 | 39 |
| Sample (no protests or outliers) | 255 | 260 | 259 | 125 | 225 |

Table 3: Willingness to pay – single fare

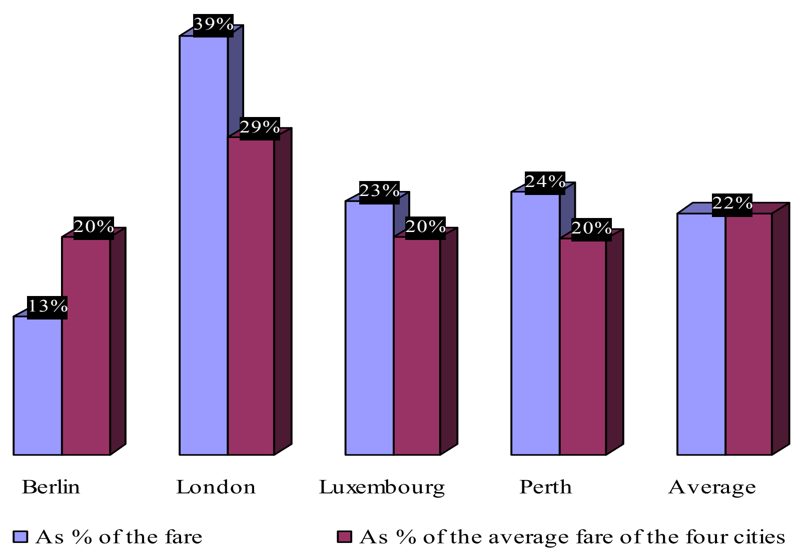


Figure 10: WTP per fare as % of the fare price

The highest mean WTP *per fare* (£0.27 = €0.41 = A$0.71) occurred in the city – London – with the lowest fare (£0.70 = €1.05 = A$1.85), this appears to suggest that the willingness to pay for (environmental) improvements in the service depends on the differential between the value people attribute to a certain service and the price they are charged. If that gap is narrow and viable substitutes are available (underground), the willingness to pay for improvements will also be narrow. However, this baseline view is challenged by the fact that Luxembourg, Perth and Berlin have the same mean WTP *per fare* (£0.18 = €0.28 = A$0.49) although the bus fare in Berlin (€2.20 = £1.45 = A$3.85) is around twice that of London, Luxembourg or Perth. Furthermore, the average income of Berlin respondents is about half of those in London.

### Willingness to pay extra taxes

Now under a different scenario, where the introduction of hydrogen buses would be dependent on a small tax increase – with bus fares remaining the same – the interviewees were asked how much more taxes they would be willing to pay *per year* to finance the large scale introduction of the hydrogen buses. Table 4 provides evidence of the negative public reaction to the taxes option, with 637 respondents (506 protests) from a total of 1297 refusing to pay more taxes. After including 131 valid zero statements and removing 46 respondents that don't pay tax anyway (e.g. students) from the analysis, the number of valid answers drops to only 745. The estimated mean WTP extra taxes (£15.37 = €23.18 = A$40.65) was considerably lower than the WTP *per fare*, either due to temporal embedding or to negative attitudes towards tax based payments. London had the higher mean WTP in both scenarios but was shortly followed by Berlin in the taxes option, while Perth had the lowest mean WTP in both cases (Figure 11).

| WTP EXTRA TAXES | Berlin | London | Luxembourg | Perth | Average |
|---|---|---|---|---|---|
| Mean WTP (no protest or outliers) | 19,19 GBP | 19,94 GBP | 13,61 GBP | 8,75 GBP | 15,37 GBP |
| Max WTP | 132,00 GBP | 1.500,00 GBP | 132,00 GBP | 19,00 GBP | 445,75 GBP |
| Mean WTP (no protest or outliers) | 29,07 EUR | 29,91 EUR | 20,62 EUR | 13,12 EUR | 23,18 EUR |
| Max WTP | 200,00 EUR | 2.250,00 EUR | 200,00 EUR | 28,50 EUR | 669,63 EUR |
| Mean WTP (no protest or outliers) | 50,87 AUD | 52,64 AUD | 36,09 AUD | 23,02 AUD | 40,65 AUD |
| Max WTP | 350,00 AUD | 3.960,00 AUD | 350,00 AUD | 50,00 AUD | 1.177,50 AUD |
| Sample | 341 | 414 | 242 | 300 | 324 |
| Protests and Outliers | 177 | 180 | 90 | 105 | 138 |
| Sample (no protests or outliers) | 164 | 234 | 152 | 195 | 186 |

Table 4: Willingness to pay – extra taxes

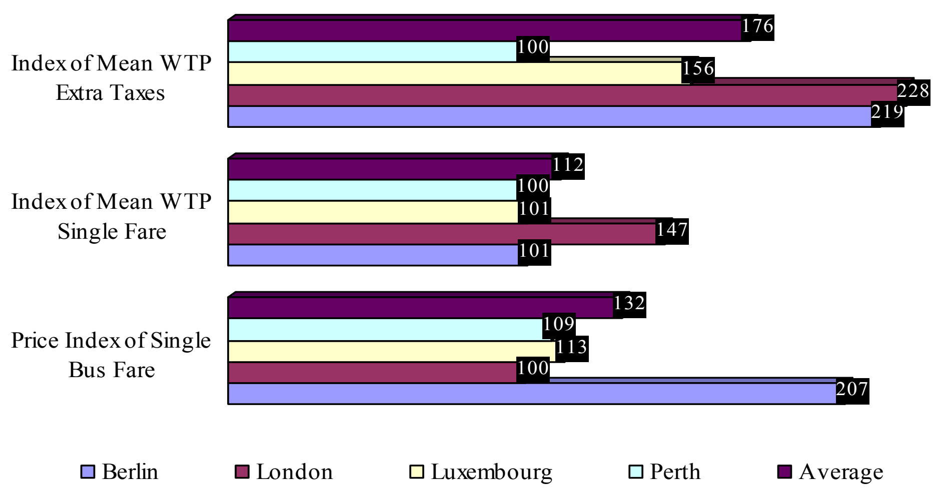


Figure 11: Price and WTP Indexes (Baseline =100)

*Bus Tickets*

The cost of a single bus ticket in Berlin was twice the price of a bus ticket in London, while prices in Luxembourg and Perth were slightly more expensive than in London. The average price of tickets (£0.93 = €1.40 = A$2.45) and more detailed information is presented in Table 5.

| WTP SINGLE FARE | Berlin | London | Luxembourg | Perth | Average |
|---|---|---|---|---|---|
| Price of Single Bus Fare | 1,45 GBP | 0,70 GBP | 0,79 GBP | 0,76 GBP | 0,93 GBP |
| Price of Single Bus Fare | 2,20 EUR | 1,05 EUR | 1,20 EUR | 1,14 EUR | 1,40 EUR |
| Price of Single Bus Fare | 3,85 AUD | 1,85 AUD | 2,10 AUD | 2,00 AUD | 2,45 AUD |

Table 5: Fares

### 2.3.4 Regression analysis

Ordinary least squares regression (OLS) was used to generate a model of WTP for each payment vehicle (single fare, extra taxes). Although from a theoretical perspective one would expect that the frequency of bus use and the perception of fumes and noise level of existing buses would be crucial factors to influence WTP, these variables proved of little importance and did not add significant explanatory power to the model (Table 6). In addition, some degree of correlation between variables such as age, education and income was found.

| Influence of Variables on WTP per Fare | Berlin | London | Luxembourg | Perth | Overall |
|---|---|---|---|---|---|
| Sex (male) | No Influence | No Influence | No Influence | No Influence | No Influence |
| Age | - | - | - | No Influence | --- |
| Income | + | + | + | No Influence | +++ |
| Education | - | No Influence | No Influence | No Influence | - |
| Knowledge of H2 Vehicles | No Influence | + | - | No Influence | No Influence |
| Satisfaction with existing buses | + | + | + | No Influence | +++ |
| Environmental Sensibility/Attitude/Behaviour | + | + | + | + | ++++ |
| Influence of Variables on WTP Extra Taxes | Berlin | London | Luxembourg | Perth | Overall |
| Sex (male) | + | + | No Influence | No Influence | ++ |
| Age | No Influence | + | No Influence | - | No Influence |
| Income | + | + | + | + | ++ |
| Education | - | No Influence | - | + | - |
| Knowledge of H2 Vehicles | No Influence | + | No Influence | No Influence | + |
| Satisfaction with existing buses | No Influence | No Influence | + | No Influence | + |
| Environmental Sensibility/Attitude/Behaviour | + | + | + | + | ++++ |
| R2 of the Model | Berlin | London | Luxembourg | Perth | Overall |
| WTP Per Fare | 0.19 | 0.14 | 0.25 | 0.19 | 0.19 |
| WTP Extra Taxes | 0.25 | 0.20 | 0.26 | 0.34 | 0.26 |

Table 6: Regression analysis

The coefficient of determination of both models was relatively weak ($0.14<R2<0.34$), but their robustness proved satisfactory (F-statistic significance $< 0.05$), thus the variation explained by the model was not due to chance. Environmental sensibility was the crucial variable to explain willingness to pay for the introduction of hydrogen powered buses, although income and satisfaction with existing buses were also relevant in 3 out of 4 surveys.

## 2.4 Conclusions

Existing studies concerning public acceptance of hydrogen technologies have been reviewed. It appears that they are mostly focused on transport, while stationary applications have not been specifically addressed so far. This does not mean, however, that there is no scope for future studies on these applications for hydrogen technologies, too.

In general, studies on public acceptance of hydrogen technologies to date are scarce, largely focused on a specific country (i.e.: Germany) and, apart from two (Mourato, 2004 and AcceptH2), they only investigate public perception but not public preference (i.e.: willingness to pay) for hydrogen technologies.

In this report we have mostly discussed recent results produced by the project AcceptH2, this being the most up to date and comprehensive study on the public acceptance of hydrogen technology to date. More results will be available by June 2005, when the project AcceptH2 is expected to come to completion. These results will also provide important indications for future research needs.

The results so far obtained as part of the project AcceptH2 are broadly in line with what found in previous studies, although they now give a closer picture of the public attitude and preference for hydrogen technologies and buses in particular, thus providing better insight into this issue.

Specifically, these results show a reasonable consistency across the different cities – Berlin, London, Perth and Luxembourg. Associations with hydrogen were mainly neutral and knowledge of hydrogen vehicles was relatively weak, but there was overwhelming support for the hydrogen buses trials; this confirms the somewhat unusual result already obtained by previous studies. Support for large-scale introduction of hydrogen buses and development of local refuelling infrastructures still requires additional information, but they are generally welcomed. These are good news for the hydrogen economy, since public approval of hydrogen infrastructure is critical to its success. In addition, and in accordance with previous studies, it was found that previous knowledge of hydrogen vehicles increased public acceptance of demonstration projects and hydrogen storage twofold. Therefore, fostering informational campaigns about hydrogen applications appears to be the right step towards an improved public perception of the technology and a wider market penetration.

The only previous study which assessed willingness to pay for hydrogen vehicles addressed taxi drivers in London; in that case, preferences appeared to be mainly driven by personal economic gains, at least in the short term. The case of public transport, though, is clearly different and AcceptH2 results show that willingness to pay for extensive introduction of hydrogen buses soared in the single fare option with a mean WTP (£0.21 = €0.31 = A$0.54) that represented 22% of the average fare, while willingness to pay using extra taxes was relatively lower (£15.37 = €23.18 = A$40.65). The main determinant to influence willingness to pay under both payment vehicles was environmental sensibility.

The fact that willingness to pay (on a yearly basis) is higher per fare than per extra taxes may suggest that the costs of large-scale introduction of hydrogen buses would be more efficiently offset by a fare increase, than by a tax raise. However, the universal nature of environmental and social-health benefits deriving from the introduction of clean buses can justify the option for taxation. Furthermore the fares of public transportation should be kept relatively low to incentive this form of transportation, which is justifiable by environmental (reduce pollution), efficiency (save resources) and equity (avoid social exclusion of the poor from public transport) arguments.

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# 3 An Overview of Identified Hydrogen-Related Knowledge Gaps

*ECN Energy research centre of the Netherlands*

## 3.1 Social impacts of the hydrogen economy

The research question for this task was composed of two parts: "*To evaluate potential problems associated with the potentially poor safety image that hydrogen has. And to evaluate the level of knowledge of the different market actors (policy makers, industry, educational entities and general public) on the subject.*" Three problems accompanied this second research question. Firstly the question was still very broad, secondly, it was expected that only limited information would be available that could be used for analysis. Lastly it was believed that a thorough analysis of this research question would require severe personal capacity (several man months) and would cover over 6 months in time, whilst the amount of man months that can be attributed to this topic is very limited (about 1/2 man month in total).

### 3.1.1 Methodology

The analysis on level of knowledge of different market actors was based on existing public available material. Bearing in mind that Hysociety is an accompanying measure and that the amount of man months that could be attributed to this topic were very limited (about 1/2 man month in total), no extensive new / additional research was conducted. The methodological approach was therefore rather straightforward, since it built on existing material rather than on developing a new approach. No questionnaires were developed, but only existing material was analyzed. First, a literature search was performed (internet). Complimentary, the Hysociety partners were asked whether they are aware of any material on this topic, however, no suggestions were made. Lastly ECN analyzed the results of WP1 on barriers related to "knowledge of relevant actors".

### 3.1.2 Output

The output for task 2.4 consists of a short overview of the available information on Internet, and an overview of the data of WP1 on barriers related to "the level of knowledge of key actors".

The approximately 12.000 hits that we analyzed in greater detail were in general however, not really adequate for in-depth analysis in terms of a thorough understanding of hydrogen related knowledge gaps to be closed to facilitate the achievement of a hydrogen economy. Most sites, links, PDF reports mentioned that to realize a future in which hydrogen plays a key role, many knowledge gaps needed to be closed or bridged. However, although a few links specified the content of the lack in knowledge, most merely identified the need to identify the knowledge that is missing. In the following two appendices highlights of available information on the Internet and in the Hysociety database on hydrogen related knowledge gaps are discussed. The information is subdivided to technological knowledge, socio-cultural knowledge, and political-institutional knowledge.

## 3.2 Hydrogen related knowledge gaps

### 3.2.1 Economic knowledge gaps

- Knowledge on technological and economic issues that identifies means to make hydrogen technologies (production, storage, distribution, conversion and end-use) more optimal and cost effective options. Ibidem for technologies that might facilitate the introduction of hydrogen such as carbon sequestration. [1]
- Need for business models that identify demonstration sites with the best commercial potential. It has to be proved that hydrogen as future energy carrier offers similar good business opportunities as existing business opportunities. [2]

### 3.2.2 Technological knowledge gaps

- More research is needed on materials for hydrogen production, separation, storage. [3]
- More research is needed on implication of then integration of hydrogen technologies in the energy system. [3]
- Need for a base case against which different scenarios could be modeled.[1]
- More knowledge on the impacts of the availability of renewable electricity to produce hydrogen on the landscape. [1]
- More research is needed on the possibility of atmospheric interactions (such as the possible impacts on ozone of releasing hydrogen in the troposphere), and the impacts of using resources such as platinum. [1]
- More research needed on membranes, energy efficiency, batteries, capacitors, start up time of automotive applications, compressing, harmonisation, production and management processes, electrolysis, size and weight reduction, rapid refuelling, operating temperatures. [3]
- There is more information necessary on the implications of the introduction of hydrogen for security of supply, share of renewables, CO2 ceilings. [1] [3]

### 3.2.3 Socio-cultural knowledge gaps

- What is missing is a web site and other public means to ensure the publics access to objective information on hydrogen related issues, experiences and demonstration projects. [2]
- Knowledge on the risk that high profile demonstration projects created false expectations among consumers about the likely timescale for the widespread introduction of hydrogen vehicles. [1]
- More research needed on the social acceptance of hydrogen as part of the energy infrastructure and on how to approach this public risk perception.[3]
- More knowledge on the key parameters (performance, luxury, safety, utility, range and refueling convenience) relevant to the consumers' choice of the fuel cell options? [4]
- More knowledge is needed on how to increase consciousness of link between recreational value of the environment and environmental policy through education and targeted information. [3] [4]
- Creation of expert groups, where people belonging to the different institutions can tackle the problems, establish the mutual responsibilities and find the effective measures. [8]

### 3.2.4 Political-institutional knowledge gaps

- Knowledge is required on the key (political and institutional) parameters to get the hydrogen economy underway. [1]
- Need for the creation of an organization responsible for public information on hydrogen. [2]
- More transparent knowledge is needed on what kind of technical and safety related information, on steps and time schedule of approval processes is required to obtain permission and certificates needed to start demonstration projects. [6]
- More dispersion of knowledge and expertise on hydrogen properties, safety and solutions is needed. This knowledge now is limited within competent notified bodies and organizations and public authorities responsible for CE marking. [6]
- Knowledge is required on how to harmonize and coordinate the development of both national and international standards to assure safety and minimize overlap between standards. [7]
- Emergency response agencies have to be trained. New procedures need to be developed taking into account the specific characteristics of hydrogen. [6]
- More knowledge is needed on possible policy measures that local authorities and governments can develop to effectively favour the adoption of the technology. [1]

- Knowledge on how to design and implement a different taxation system for fuels, either direct or indirect, which can reflect the actual carbon content and emissions over their life cycle. [8]
- Knowledge is required about which current restrictions will need to be removed. These include parking and travel restrictions on hydrogen-fuelled vehicles and restrictions on distribution and handling of gaseous fuels. [8]

## 3.3 Summarising the conclusions

The analysis on the level of knowledge of different market actors is based on an Internet search and on the data collected in work package 1 of the Hysociety project. The output for task 2.4 consists of a brief overview of the available information on Internet and in the WP1 Hysociety database, and conclusions on the existing knowledge gaps and the efforts the EC should undertake to bridge these gaps.

### 3.3.1 Overview of information on hydrogen and knowledge gaps/level of knowledge of relevant actors

The information on the Internet and in the Hysociety database on hydrogen-related knowledge demonstrates that there is a vast amount of knowledge available on research, development, and technological issues that deal with the pre-market phase of hydrogen related technologies. However, knowledge needed to facilitate a market entry is largely missing. For example, economic knowledge on cost effectiveness, commercial potential and effective partnerships is mostly lacking; the technological knowledge that is still largely missing is knowledge on the integration of hydrogen in and the interaction of hydrogen with energy systems; the socio-cultural knowledge that is missing relates to issues of social acceptance and needs and risk perception; the knowledge gaps on political and institutional aspects deal with responsibility and accountability issues, fiscal incentives, and standards. For a detailed overview of the missing knowledge see appendices 2 and 3.

It was only mentioned in very few instances which actors should fill the knowledge gaps. In general it can be concluded that the economical knowledge gaps have to be filled through cooperation between industry, R&D and economical scientists; the technological knowledge gaps require similar cooperation if the knowledge required deals with technologies that are dependent on economical aspects, otherwise the actions require only technical researchers. The socio-cultural and political-institutional knowledge gaps need to be filled by a cooperation between industry, R&D, governmental authorities and public representatives or consumers organizations, and gamma researchers. A need that was expressed many times was the need for coordination of knowledge development on an international level to prevent the constant duplication of already existing knowledge, since this aspect was one of the great hurdles in advancing a hydrogen economy.

### 3.3.2 Concluding remarks

Although an enormous amount of hits was provided with keys consisting of the words 'hydrogen, economy, knowledge, gaps' the content of these documents was mostly disappointing. Most of them merely mentioned the existence of knowledge gaps. However, some documents took the analysis one step further, and this provided us with the means to elaborate a little more in-depth on the existing knowledge gaps on technological, economic, political, institutional and socio-cultural issues. The main conclusion that can be drawn from the collected material is that most available information deals with the pre-market phase of hydrogen related technologies, and that the economic, political, and socio-cultural knowledge needed to facilitate a market entry is largely missing. In the description of the knowledge gaps, most detail was available on technological and economical knowledge gaps, whilst the description of the socio-cultural and political knowledge gaps did not go in more detail than "more knowledge needed on required standards". Research on required knowledge should therefore focus on these two issues. Coordinating and facilitating the international cooperation between scientists, industry and economists, and creating a transparent knowledge exchange system might be one of the most important and most pressing tasks for the European Commission, in terms of facilitating a successful market entry of hydrogen related technologies.

## 3.4 References Chapter 3

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[ 7] http://www.hydrogensafety.info/articles/02-may-07.asp

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# 4 Discussion of Impacts of Hydrogen on Defined Aspects of Quality of Life

*VTT Technical Research Centre of Finland*

## 4.1 Introduction

When we try to assess the implications that increased and finally wide-spread use of hydrogen as an energy carrier has, we are at first faced with the necessity to define, what aspects and parameters constitute the concept "quality of life" (QOL), as this is not self-evident.

At first we need to define, what ‘life’ we mean in this context, because in this case of 'quality of life', the object of evaluation is 'life'. According to [1], most often that life is an individual life, the quality of life of a person. However, the term is also used for aggregates and larger social entities, for instance we can speak about the quality-of-life of women. However, even if ‘individual life’ is in question, the term refers usually to the average of individuals, but sometimes the term is also used in reference to humanity as a whole.

In this context the object of our evaluation is mostly the average individual, and the long-term destiny of the species. The evaluation then concerns 'human life', rather than 'human lives'. We have assumed this kind of ‘semi-individual’ approach, as we need to assess the question mostly in view of the ‘EU citizens’ or ‘Europeans’, taking into account also non-member countries that will most likely evolve in synergy with the Community. In this case, the "quality of life" refers more to social systems, and we speak about the 'public wellbeing', and at a more collective level we mean, how well society functions and maintains itself.

Our study on the implications of wide-scale uses of hydrogen as an energy carrier (vector), often referred as "hydrogen economy" or "hydrogen society" revealed, that this was a relatively virgin topic, and not much scientific discussion could be found in the social science literature regarding quality of life issues. This clearly underlines the necessity of this kind of analysis, and shows that the topic has perhaps not yet penetrated the walls between the disciplines, social science vs. engineering and economy, where several studies has been made on the various implications of hydrogen use. However, "hydrogen economy" and "hydrogen society" are in their true nature very multidisciplinary, and therefore, social science should also be taken as an important arena for future deliberations and implementation of the research agenda.

In our study we were also able, after screening the methodology suggested and also used in social science to describe "quality of life", a suitable metrics to make – at least a first attempt – an assessment of the implications that wide-scale use of hydrogen would and should entail. However, we must bear in mind that this ranking is highly subjective, and should be re-visited in a larger scientific community that shall include members also from social and economical sciences, and not just engineers, like this first effort.

Furthermore, this analysis also revealed, that although the overall perception is that hydrogen economy is mostly associated with positive effects regarding quality of life, we could also point out certain areas, where also negative impacts could be expected, if not overall, but at least by some parts of the public or other stakeholders. Even if we can clearly see that most of those fears are unsubstantiated, we cannot ignore people's fears, even unwarranted, because those are true to them, and shall affect to their behaviour and decisions. Therefore, this is the focal point, where deliberations to educate public of the virtues of hydrogen use should be concentrated. Clear and easy-to-understand messages of the positive sides of the hydrogen economy should be produced and widely communicated in order to alleviate these negative associations.

## 4.2 Metrics used in "quality of life" assessments

### 4.2.1 The metrics and measures in QOL assessments

Everyone wants to have a good quality of life, and good life quality is often also taken by many as a sign of successful development. There is less agreement, however, about what promotes good quality of life. Several attempts has been made to make such definitions that could be used in studies, and even have some way to quantify the implications of some measures taken, like we are here trying to do about the use of hydrogen. In the following chapters, some examples of measures and metrics that are used in QOL assessments are introduced and their suitability to this assessment at hand is discussed and evaluated

#### 4.2.1.1 Example of a sociological measure of individual welfare

One if the very first attempts to chart quality of life in a general population was made in the Scandinavia under the direction of Erik Allardt (1976). He developed the following criteria to measure 'welfare', what can here regarded as a synonym for "quality of life":

- income
- housing
- political support
- social relations
- irreplaceable
- doing interesting things
- health
- education
- life-satisfaction.

Allardt classified these indicators using the classic distinction, between 'having', 'loving' and 'being'. This labelling was also introduced by him, and it was appealing at that time, because it expressed the rising conviction that welfare is more than just material wealth, and because it fitted modish notions drawn from humanistic psychology. Though it is well known, the classification has not proven to be very useful, and many contemporary social scientist does not support the use of it any more.

This measure of QOL on a individual level contains a few items that can be associated with the implications that we can expect the use of hydrogen in energetic purposes to possess. They would be mostly related to health (*air pollution/air quality*), but partly also to housing (*noise*) and maybe even life-satisfaction (*sustainability and freedom of mobility provided with non-polluting and renewable energy*). Even so, the metrics does not appear to be very functional in our case.

#### 4.2.1.2 Example of a measure of socio-economic development

Of systems mostly used in cross-national comparisons of quality of life, the most commonly used indicator is the 'Human Development Index', developed for the United Nations Development Program. This program describes the progress in all countries of the world in its annual 'Human Development Reports' [4].

The Human Development Index is the major metrics used in these reports. In the basic level, this measure involves only three items:

- public wealth, measured by buying power per head
- education, as measured by literacy and schooling
- life-expectancy at birth.

Later variants of the HDI involve two further items:

- gender-equality, measured by the so-called 'Gender empowerment index' which involves male-female ratios in literacy, school enrolment and income.
- poverty, measured by prevalence of premature death, functional illiteracy and income deficiencies.

We can see that the items considered in this scoring system are not suited to the assessment of hydrogen use.

#### 4.2.1.3 Example of a medical quality of life index

One of the most common measures in medical quality of life research is the 'SF-36 Health Survey' [5]. It is a questionnaire on the following topics:

- physical limitations in daily chores (10 items)
- physical limitations to work performance (4 items)
- bodily pain (2 items)
- perceived general health (6 items)
- vitality (4 items)
- physical and/or emotional limitations to social functioning (2 items)

- emotional limitations to work performance (3 items)
- self characterizations as nervous (1item)
- recent enjoyment of life (4 items).

Ratings on the first four topics are grouped in a 'Physical Component Sub-score', ratings on the last four topics in a 'Mental Component Sub-score'. These components are added into a 'Quality of life Total score'.

When assessing this example of methods, we can see that because this is a medical QOL index, the items considered are all health-related, and we feel that even if the majority of the expected positive implications of hydrogen use will fall in just that sector, it will not give adequate possibilities to rank all the relevant implications that can be surmised for our case.

#### 4.2.1.4 Multi-dimensional tools in QOL assessment

One common characteristic of quality of life (QOL) instruments is that they can encompass a large number of items. This is common with many other psychological test instruments. With the exception of some very short QOL instruments like those two referred above, they usually cover between 20 and 100 items. And the items do not usually have common 'metrics', so they need to be rated using multiple scales. Therefore, in order to use such instruments appropriately in quantitative research, some sensible form of data reduction is necessary, i.e., condensation of the total information contained in the complete set of items to a fairly small set of composite variables (subscores) reflecting the most important features of the instrument.

For this purpose various statistical techniques, both descriptive and analytical, can be exploited and associated with this issue. At a descriptive level, the method most commonly used is exploratory factor analysis [6, 7]. Less frequently applied techniques include cluster analysis (item clustering [8]) and various scaling procedures [9, 10]. In a recent paper [11] also a multidimensional scaling (MDS) is introduced and discussed as a graphical method to complement conventional descriptive and confirmatory methods in the validation and analysis of QOL data.

Even if these statistical and multi-dimensional tools could be of use in combining the scores, they are only means to make an assessment of the data, as such they, however, do not actually consider a set of topics/items or criteria. Therefore, they are only complementary tools.

## 4.3 Rating and classification of the QOL aspects

As can be seen from the short round-up of the methodology, social science has unfortunately not been able to agree on a single system for QOL assessment. Neither are they 'objective' and their scales unified, because it has also been argued, e.g. in [2] that many personality factors can significantly affect how the quality of life that is experienced. Therefore, we have tried in this assessment to take into account more such aspects that may be defined 'objectively', i.e. with some kind of metrics, and less those that will be based more on personal values and experiences, that are perceived as 'subjective', and usually interpreted as a matter of arbitrary taste, because the social values differ even among the nations of the EU countries, and on individual level even more.

We did not find among the candidates we reviewed, a suitable methods and metrics, and thus the one we choose to use remain very "self-made’ and can be easily contested. However, we have been able to find a kind of classification system to quite comprehensibly describe the whole concept of QOL, and help positioning of the various metrics and scores.

It is described in [1], and it proposes a classification based on two bi-partitions; between life 'chances' and life 'results', and between 'outer' and 'inner' qualities. Together these dichotomies imply four qualities of life: 1) livability of the environment, 2) life-ability of the individual, 3) external utility of life and 4) inner appreciation of life. They can be pictured as a "four field matrix", as is done in Table 7.

| | Outer qualities | Inner qualities |
|---|---|---|
| Life chances | Livability of environment | Life-ability of the person |
| Life results | Utility of life | Appreciation of life |

Table 7: "Four qualities of life" by Ruut Veenhoven [1]

The author in [1] has given some descriptions of what she assumes these quadrants to encompass. Those were:

**Life-ability of the environment**

The left top quadrant denotes the meaning of good living conditions. Often the terms 'quality-of-life' and 'wellbeing' are used in this particular meaning, especially in the writings of ecologists and sociologists. Economists sometimes use the term 'welfare' for this meaning. Another term is 'level of living'. The author thinks that 'Livability' is a better word, because it refers explicitly to a characteristic of the environment and does not have the limited connotation of material conditions. One could also speak of the 'habitability' of an environment, though that term is also used for the quality of housing in particular.

**Life-ability of the person**

The right top quadrant denotes inner life-chances. That is: how well we are equipped to cope with the problems of life. This aspect of the good life is also known by different names. The words 'quality of life' and 'wellbeing' are also used to denote this specific meaning, especially by doctors and psychologists. According to the author, there are, however, more names. In biology the phenomenon is referred to as 'adaptive potential'. On other occasions it is denoted by the medical term 'health', and in the medium variant of the word, or by psychological terms such as 'efficacy' or 'potency'. Even so, the author prefers the simple term 'life-ability', which contrasts elegantly with 'livability'.

**Utility of life**

According to Veenhoven, the left bottom quadrant represents the notion that a good life must be good for something more than itself. Apparently, this presumes some higher values. However, there is no current generic for these external turnouts of life. Often they are referred as 'transcendental' conceptions of quality of life. Another appellation is 'meaning of life', which then denotes 'true' significance instead of mere subjective sense of meaning. The author has chosen the more simple 'utility of life', admitting that this label may also give rise to misunderstanding. When making this choice, she also calls for our awareness that this external utility does not require inner awareness. A person's life may be useful from some viewpoint, without them knowing it.

In this very context (hydrogen issue) we might wan to take a special note of the author’s suggestion that the quality of a life is also linked to effects on the ecosystem. Ecologists see more quality in a life lived in a 'sustainable' manner than in the life of a polluter. In a broader view, the utility of life can be seen in its consequences for long term evolution. This notion is very relevant to our case, as sustainability and all positive environmental impacts related to it, are perhaps the most essential targets of the whole mission of creating the "hydrogen society".

**Appreciation of life**

Finally, the bottom right quadrant represents the inner outcomes of life. That is the quality in the ‘eye of the beholder’. As we deal with conscious humans this quality boils down to subjective appreciation of life. This is probably the field most commonly related to QOL issues, and usually referred to by terms such as 'subjective wellbeing', 'life-satisfaction' and 'happiness' in a limited sense of the word.

To facilitate easier use of the proposed topic/score classification, the author has also offered some more descriptive terms related to those quadrants. They are presented in Table 8.

We will later on use these items and descriptive terms to ‘classify’ the topics and items in our particular case and see, how widely we can encompass the implications of hydrogen use as energy vector to spread, i.e. can we claim that we will see improvements in scores that belong to all four main classes.

| | Outer qualities | Inner qualities |
|---|---|---|
| Life chances | Livability of environment | Life-ability of the person |
| | · Ecological e.g. moderate climate, clean air, spacious housing,<br>· Social e.g.. freedom, equality and brotherhood<br>· Economical e.g. wealthy nation, generous social security, smooth economic development<br>· Cultural e.g. flourishing of arts and sciences, mass education<br>· Etc… | · Physical health negative: free of disease positive: energetic, resilient<br>• Mental health negative: free of mental defects positive: autonomous, creative<br>• Knowledge e.g. literacy, schooling<br>• Skills e.g. intelligence, manners<br>• Art of living e.g. varied lifestyle, differentiated taste<br>• Etc…. |
| Life results | Objective: Utility of life | Subjective: Appreciation of life |
| | • External utility<br>• for intimates, e.g. rearing children, care for friends<br>• for society: beeing a good citizen<br>• for manking: leaving an invention<br>• Moral perfection<br>• e.g. authenticity, compassion, originality<br>• Etc… | • Appraisal of life aspects<br>• Job satisfaction<br>• satisfaction with variety<br>• Prevailing moods<br>• depression, ennui, zest<br>• Overall appraisals<br>• affective: general mood level<br>• Cognitive: contentment with life |

Table 8: Some sub-meaning within quality-quadrants, by Ruut Veenhoven [1]

## 4.4 The assessment and score classification

In this chapter we will enumerate the implications that we can conceive from the (gradually) widening use of hydrogen as a carrier of (renewable) energy.

### 4.4.1 Implications of the usage of hydrogen

#### 4.4.1.1 Human health effects

Of those QOL aspects that are quantitatively measurable, at least to some extent, the implications to one's health & well-being may be the foremost in terms of contributing to the scores of good life quality. Furthermore, numerous scientific research studies has been published of the relations between the air quality (one aspect that we expect the use of hydrogen to make a positive effect) and human health. Therefore, we have ranked this aspect as the most important parameter in our assessment.

The impact that use of hydrogen according to our scenarios A and B to local air quality, which is the most relevant parameter of air pollution adversely affecting human health, are discussed in Task 2.5. It seemed not feasible at this point of time to try to quantify the effects, but a general notion can be made that we expect, even and especially in the modest penetration scenario (B), that the use of hydrogen will most probably start from the population centres, and thus the emission reductions and improvements in local air quality will have maximum efficiency, because the locales usually are those that mostly suffer from bad air quality, usually resulting also form traffic-related emissions. Thus bringing in hydrogen fuelled vehicles with zero in-use emissions we claim that the impact will be most efficient.

#### 4.4.1.2 Other effects to human activity and habitat

Among those measurable items, where we trust the use of hydrogen will have a positive impact, are noise emissions. However, this area is perhaps less investigated and documented in relation to human well-being, because the mechanisms thru witch the noise affects to our person and especially our symptoms are less evident than the implications of air pollution. Therefore, we have chosen to take this in account, too, but with respect to human habitat, because it is known that traffic (and other) noise is perceived as "less desirable", and causing stress, although the dose/response functions may be very different among different people, and most likely these issues are regarded as parameters that affect things like quality and prices of housing and the overall esteem of certain human habitats. By bringing in fuel cell powered hydrogen vehicles we can positively influence the noise level of traffic, but we need to note here that noise is somewhat different emission than air pollutants, because with less pollutant emissions the air quality will improve, but with less noisy vehicles among the normal vehicles has less impact on overall level of noise, as the loudest of the vehicles will always mark the highest peaks, and those peaks are of the most irritating ones.

Deliverable D6 of the HySociety project also correctly reminds us that fuel cell vehicles are not noiseless, but the tone of the noise is different with more high-pitch noises related to electric components (inverters etc.) and traction devices. Therefore, we may need quite substantial share of fuel cell driven vehicles before meaningful changes can be expected to the noise level and spectrum in traffic environments.

#### 4.4.1.3 Economical implications

Welfare is also a concept that is often linked with QOL, and sometimes they are seen to mean the same thing. If we can develop the hydrogen production from renewable energy sources to a perfected level, the chances are that the price of energy would take a downward turn, in contrast to its usual upward swing.

Even if we don not reach that far, bringing up hydrogen as an energy vector to complement, and in long-term replace, today’s fossil fuels, should have stabilising effect to the world (energy) economy. This is expected to happen, because hydrogen can be produced from a great variety of raw materials via multiplicity of processes, and almost any primary energy can be turned into hydrogen. Thus hydrogen as an energy vector should be regarded as an "equaliser", freeing the world (energy) economy from the constraints and tension that the disproportionally divided fossil energy sources create. Of course this will take quite some time, but nevertheless, it remains as one of the most important ends for our deliberations to build a hydrogen economy.

However, in short term we expect that the economical implications will be mostly negative, i.e. large investment in infrastructure are necessary and costs of vehicles and their use will raise from their present level. On the other hand we need to take into account that because of the necessity to keep all emissions at a low level and simultaneously improve fuel economy for lower $CO_2$ and other GHG emissions, the cost of traditional technology will also become higher. Thus the difference may not be that high in the future. Indeed, this aspect is an important driver also for the development of hydrogen fuel cell drive for the vehicles used in the transportation sector.

The alternative like hydrogen is needed, not only because of cleaning the exhaust becoming too expensive, but also because this sector is gradually being more and more impaired by the fact that the fossil fuels are becoming more and more expensive, and if oil remains as the sole energy supply option, this starts to endanger the productivity of the sector. Quite many experts even see that the mobility sector, both the small scale portable applications and transport vehicle use, will be the main thrust towards the success in the upbringing of hydrogen economy and hydrogen society.

Another aspect of economical implications is derived for the noise issue, already discussed in pervious chapter as part of the human habitat. However, it has been proved that traffic induced noise has an important depreciation effect on prices of houses. Should the noise level become lower, the value of houses and other real estates could improve on those areas that are now hampered and under-rated by the traffic. The same effect is seen also in air quality, and if hydrogen use will improve local air quality, positive economical effects should be generated with the improvements of the human habitat.

#### 4.4.1.4 Life security and stability

Items that are more difficult to measure, but which often are mentioned, when people describe "qualities of good life" are things that bring continuity, stability or consistency to our lives.

What was implicated to happen to the energy economy and security of supply in Chapter 3.1.3, is a viable factor also under this title. Mainly, because along with the increased energy security, the political tension now felt quite strongly between countries that have large fossil energy resources and those that are using lots of fossil energy, and are thus strongly dependent on imports, should be alleviated and eased out, when hydrogen economy brings along more possibilities for employing the local, indigenious energy sources. This should be regarded as a major step towards increased life security and stability.

Furthermore, if pollution-free energy can be generated via hydrogen, it shall improve security and stability in our societies and personal life. Furthermore, if via hydrogen/fuel cell electric energy can also distributed more equally than in present system, the quality of life in terms of ‘ability to live’ will be improved in those areas where electricity is a non existent or at least a very scare resource. Bringing electricity to ‘all corners of the earth’ can positively impact the life in many societies now less developed.

However, within this quadrant, life security, we need to keep in mind the fact that the studies on the acceptance of hydrogen use as energy carrier, like the European-wide "acceptH2", presented in their conclusions that also fears and feelings of insecurity are associated with hydrogen by some groups of the general public and even amongst some of the stakeholders. They see that bringing hydrogen in transport as a fuel will threat their life, because they recognise strongly the associated dangers related to the explosive nature of hydrogen combustion and storage of high-pressure gas. These negative associations could implicate also distrust in using public transportation that is hydrogen-driven, or even fear of living in an environment, where hydrogen filling station is situated nearby. Like traffic noise, this could have serious negative effects on house prices in the vicinity of the hydrogen installations, and seriously impede the efforts of building this infrastructure.

Whether these negative associations are substantiated or not, is not the key issue, because not all human beings can be convinced with logical explanations that could prove their fears unwarranted. Nor can we ignore people’s fears, even unwarranted, because those are true to them, and shall affect to their behaviour and decisions. Also it is a fact that some of us cannot be convinced no matter what, but remains sceptics, and this scepticism is the enemy we must fight, because it is quite common among human communication that the "bad word" always travels faster than any counter-talk. We must bear in mind in these situations, that if we can’t convince them, we should certainly not confuse them, because that will only make things worse and create more anxiety. Clear and easy-to-understand messages of the positive sides of the hydrogen economy should be widely communicated in order to alleviate these negative associations.

#### 4.4.1.5 Appraisal of personal life aspects

Furthermore, we have assessed that such a topic as ‘freedom of choice for mobility’ is a personal life aspect that people may perceive as an issue they strive for. That is the prime mover of personal/passenger car sales and human behaviour in every developing country in the world has shown that it is a very strong incentive for efforts towards greater economic wealth. When peoples’ income is increased, usually a disproportional share of this increase is directed in achieving and raising the level of motorised transport.

If hydrogen fuel cell vehicles become affordable, chances are better that also in the future the ‘freedom of choice’ that people are now capable regarding their personal mobility, will continue, and we must not revert only to mass transportation systems. Thus, with all their positive effects, hydrogen fuel cell vehicles can become ‘weapons of mass salvation’.

However, we need also raise a warning related to this issue of pollution-free mobility: The increased feeling of freedom of mobility because people no longer feel that they are polluters when driving, might also lead to an enormous increase in mobility, with all the congestion problems that shall soon accompany it. That could seriously decrease the positive feelings of end-users towards hydrogen-driven mobility.

### 4.4.2 Scoring and classification of the impacts

We have taken the 'four quadrant classification' described in detail in Chapter 2, and tried to associate both the positive, as well as the negative implications presented above in those 'keywords' that were offered for the user to relate the various QOL issues to this case.

This 'scoring' is presented in Table 9 and Table 10, and the links that the perceived implications have with the key subjects is expressed in colour code. The ranking is done on a four-level scale, with strong, modest or weak relations or no relation at all (see legend below graphs). However, we must bear in mind that this 'scoring' and ranking is subjective, and based mainly on the authors own perceptions.

| | Outer qualities | Inner qualities |
|---|---|---|
| Life chances | Livability of environment | Life-ability of the person |
| | · Ecological e.g. moderate climate, **clean air,** spacious housing, | · **Physical health negative: free of diseases,** positive: energetic, resilient |
| | · Social e.g.. freedom, equality and brotherhood | • Mental health negative: free of mental defects positive: **autonomous, creative** |
| | · Economical e.g. wealthy nation, generous social security, smooth economic development | • Knowledge e.g. literacy, schooling |
| | · Cultural e.g. flourishing of arts and sciences, mass education | • Skills e.g. intelligence, manners |
| | | • Art of living e.g. varied lifestyle, differentiated taste |
| Life results | Objective: Utility of life | Subjective: Appreciation of life |
| | • External utility | • Appraisal of life aspects |
| | • for intimates, e.g. rearing children, care for friends | • Job satisfaction |
| | • for society: beeing a good citizen | • Satisfaction with variety |
| | • for manking: leaving an invention | • Prevailing moods |
| | • Moral perfection | • depression, ennui, zest |
| | • e.g. authenticity, compassion, originality | • Overall appraisals |
| | | • Affective: general mood level |
| | | • Cognitive: contentment with life |

| | |
|---|---|
| (bright green) | strong positive relation of the implications |
| (light green) | modest positive relation of the implications |
| (yellow) | weak positive relation of the implications |
| (white) | no positive relation |

Table 9: Relating the perceived positive implications within quality-quadrants

| | Outer qualities | Inner qualities |
|---|---|---|
| Life chances | Livability of environment | Life-ability of the person |
| | · Ecological e.g. moderate climate, clean air, spacious housing,<br>· Social e.g.. freedom, equality and brotherhood<br>· Economical e.g. **real-estate price depriciation because of the anxiety caused by hydrogen**<br>· Cultural e.g. flourishing of arts and sciences, mass education | · Physical health negative: free of disease positive: energetic, resilient<br>• Mental health negative: **fears associated with hydrogen**<br>• Knowledge e.g. literacy, schooling<br>• Skills e.g. intelligence, manners<br>• Art of living e.g. varied lifestyle, differentiated taste |
| Life results | Objective: Utility of life | Subjective: Appreciation of life |
| | • External utility<br>• for intimates, e.g. rearing children, care for friends<br>• for society: beeing a good citizen<br>• for manking: leaving an invention<br>• Moral perfection<br>• e.g. authenticity, compassion, originality | • Appraisal of life aspects<br>• Job satisfaction<br>• Satisfaction with variety<br>• Prevailing moods<br>• depression, ennui, zest<br>• Overall appraisals<br>• Affective: general mood level<br>• Cognitive: contentment with life |

| | |
|---|---|
| | strong negative relation of the implications |
| | modest negative relation of the implications |
| | weak negative relation of the implications |
| | no negtive relation |

Table 10: Relating the perceived negative implications within quality-quadrants

## 4.5 Conclusions

Our study on the implications of wide-scale uses of hydrogen as an energy carrier (vector), often referred as "hydrogen economy" or "hydrogen society" revealed, that this was a relatively virgin topic, and not much scientific discussion could be found in the social science literature regarding quality of life issues. This clearly underlines the necessity of this kind of analysis, and shows that the topic has perhaps not yet penetrated the walls between the disciplines, social science vs. engineering and economy, where several studies has been made on the various implications of hydrogen use. However, "hydrogen economy" and "hydrogen society" are in their true nature very multidisciplinary, and therefore, social science should also be taken as an important arena for future deliberations and implementation of the research agenda.

In our study we were also able, after screening the methodology suggested and also used in social science to describe "quality of life", a suitable metrics to make – at least a first attempt – an assessment of the implications that wide-scale use of hydrogen would and should entail. However, we must bear in mind that this ranking is highly subjective, and should be re-visited in a larger scientific community that shall include members also from social and economical sciences, and not just engineers, like this first effort.

Furthermore, this analysis also revealed, that although the overall perception is that hydrogen economy is mostly associated with positive effects regarding quality of life, we could also point out certain areas, where also negative impacts could be expected, if not overall, but at least by some parts of the public or other stakeholders. Even if we can clearly see that most of those fears are unsubstantiated, we cannot ignore people's fears, even unwarranted, because those are true to them, and shall affect to their behaviour and decisions. Therefore, this is the focal point, where deliberations to educate public of the virtues of hydrogen use should be concentrated. Clear and easy-to-understand messages of the positive sides of the hydrogen economy should be produced and widely communicated in order to alleviate these negative associations.

## 4.6 References Chapter 4


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# 5 Social justice

*Fraunhofer ISI – Fraunhofer Institute for Systems and Innovation Research*

## 5.1 Introduction

Since the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro 1992, the idea of sustainability has developed to a widely attended concept. For its success in the political practise, its concretion and operationalisation is of decisive importance. Therefore representative indicators are needed, which highlight the development in the single policy areas, make it interpretable from a sustainable point of view or can be used for target setting (Walter et al. 2001). The understanding of sustainability as a three-pillar-concept is widely spread. Hereby sustainability must be equally achieved in the three dimensions economy, environment and society. Impacts on society involve issues like public acceptance, the impact on quality of life (health and immissions), security aspects and social justice. This part of the study focuses on the social justice of a hydrogen based society.

## 5.2 Methodology

Based on a literature survey the criteria and indicators for the assessment of the social justice of an energy system are selected. In a second step the transferability of these criteria and indicators on a hydrogen energy system is examined. The indicators, which are suitable to characterise the social justice of a hydrogen based energy system are than analysed and discussed in detail.

## 5.3 Social indicators for a sustainable energy system

Currently various studies on indicators for sustainable energy systems are available on international as well as on national level[6]. Unfortunately the focus in most studies is very much on environmental aspects, while economic and especially social impact indicators are often not sufficiently considered. A good approach for the identification of social impact indicators of an energy system provide the following two studies: Sustainability: Criteria and Indicators for the energy sector (Walter et al. 2001) and Concretion of the model of a sustainable development for the energy sector (Enzensberger et al. 2002). These studies identify the following criteria and indicators for the social justice of an energy system.

6 Helio International 2000; IEA 1997; EEA 2000; Walter et al. 2001 – see the references at the end of this chapter.

**Access to fair-priced energy services**

In the sense of a high social compatibility, an energy supply system should allow each human being access to necessary energy services. Social justice involves further, that the price is appropriate with respect to the capacity to pay of the individual.

*Possible indicator:* Share of expenditures for energy services at the average disposable income.

**Freedom of choice**

In the European Society the individual freedom of action is of high significance. Interferences and regulations are normally not appreciated. Freedom of choice can for example involve the possibility to receive renewable electricity or hydrogen.

*Possible indicators:* Number of households, which have the possibility to choose between a conventional and a hydrogen energy system in the residential and transport sector. Number of households, which have the possibility to receive renewable hydrogen.

**Regional balance**

On the European level, the interregional balance, especially between congested areas and peripheries play an important role. Social justice involves here the equal access to energy supply with respect to prices (Harmonisation of regional price differences).

*Possible indicator:* Average price in the most expensive region in percent of the average price of the most inexpensive region.

On an international level the solidarity with world regions, which have so far consumed considerably less energy, yet also want to profit from (especially non-renewable) resources is in the middle of attention. Energy systems should contribute to a peaceful cooperation between countries and avoid destabilisation and interregional or international tension. Indicators are an equal access to energy resources and a fair compensation for depletion of resources in less developed countries, as well as the avoidance of unwanted social and economic side effects.

*Possible indicators:* Share of population with direct bus bar. Amount of compensation for depletion of resources in less developed countries. Degree of unwanted social and economic side effects.

**Participation**

Participation is the possibility to be involved in the shaping of processes and to influence decisions (political/ governmental decisions). An indicator can be the subjective satisfaction of different population groups with their possibility of co-determination in the energy sector.

*Possible indicator:* Share of adult population, which is satisfied with the possibility of co-determination in the energy sector.

**Protection of privacy**

Protection of privacy comprises aspects like data security. The rapid technical progress often provides the basis for the invasion of privacy (compare modern communication). A sustainable energy system should protect the consumer from such encroachments.

*Possible indicator:* Number of declarations to the data security agent, with relevance to the energy economy.

## 5.4 Relevance of the selected criteria and indicators for a future hydrogen supply system

Most of the criteria and indicators can not be applied for a future hydrogen energy system, as they are tailored to existing energy systems which supply precise data. The hydrogen energy system is not yet implemented but is so far only a conceptual construct and can not supply the needed information like for example regional price differences or the possibility of co-determination in the energy sector. Considerations and calculations could only be on the basis of vague assumptions and scenarios. Only one criteria can be appropriately discussed in the context of a hydrogen society. The access to fair-priced energy supply. For this criterion the indicator index can be calculated, thanks to a broad data collection in task 2.1 of the HySociety project.

It is not expected, that a hydrogen energy system performs worse than our present energy system with respect to social justice. On the contrary, as hydrogen can be produced from a wide range of feedstocks it can help to overcome political instabilities and regional difference. It is also expected that freedom of choice, the protection of privacy or participation will at least maintain its present standard.

## 5.5 Access to fair-priced energy services

The access to fair priced energy services is an important criterion to evaluate the social justice of a hydrogen based energy system. As indicator the share of expenditures for energy services at the average disposable income is used. In this study the energy services residential electrification and private transport (passenger cars and motorcycles) are considered.

### 5.5.1 Data and calculation

For the calculations residential electricity is assumed to be generated in fuel cells on hydrogen. Transport is also considered with hydrogen on fuel cells. For comparison reasons the indicator value is also calculated for a conventional energy system. The scope is EU 25 in 2000 and 2020. Basis data like electricity demand, transport fuel demand, average disposable income as well as specific data on electricity and fuel prices of a conventional system are taken from the Capros database (Capros 2003) (see Table 11 for the basis data).

| | Unit | Year 2000 | Year 2020 | Source |
|---|---|---|---|---|
| **Electricity demand/ capita** | [kWh/capita/a] | 1533 | 2118 | Capros 2003 |
| **Fuel demand/ capita transport (private cars and motorcycles)** | [kWh/capita/a] | 4042 | 4315 | own calculation |
| **Average net income/ capita** | [€/a] | 11382 | 17913 | Capros 2003 |

Table 11: Basis data from Capros 2003

All data concerning a hydrogen energy system derive from the HySociety database from task 2.1. This database provides information on hydrogen based residential electricity cost for various production, distribution and conversion pathways and also contains data for hydrogen based and conventional private transport options. The data reflect an estimation of the performance and cost of hydrogen and hydrogen technologies for the year 2020, thus learning effects and cost reduction resulting from technical improvement and mass production are included.

For the calculations in this study the cheapest, the most expensive and a moderate priced renewable hydrogen path has been selected, to illustrate the wide range of options. Results are presented in Table 12 (residential electricity) and Table 13 (transport). To achieve a fair comparison, the conversion system is included in the transport calculations.

| | Unit | Year 2000 | Year 2020 | Source |
|---|---|---|---|---|
| **Electricity conventional system EU-Mix** | | | | |
| Specific cost electricity | [c/kWh] | 9,10 | 8,20 | Capros 2003 |
| Total annual cost | [€/a] | 139,46 | 173,67 | own calculation |
| Share energy services (electricity) at average net income | [%] | **1.23** | **0.97** | own calculation |
| **Electricity fuel cell on H2 from natural gas reforming** | | | | |
| Electricity specific cost | [c/kWh] | | 14,83 | HySociety database |
| Total annual cost electricity | [€/a] | | 314,09 | own calculation |
| Share energy services (electricity) at average net income | [%] | | **1.75** | own calculation |
| **Electricity fuel cell on H2 from gasification of biomass** | | | | |
| Electricity specific cost | [c/kWh] | | 27,08 | HySociety database |
| Total annual cost (electricity from hydrogen) | [€/a] | | 573,54 | own calculation |
| Share energy services (electricity) at average net income | [%] | | **3.20** | own calculation |
| **Electricity fuel cell on H2 from electrolysis with wind electricity** | | | | |
| Electricity specific cost | [c/kWh] | | 40,70 | HySociety database |
| Total annual cost (electricity from hydrogen) | [€/a] | | 862,00 | own calculation |
| Share energy services (electricity) at average net income | [%] | | **4.81** | own calculation |

Table 12: Calculations for electricity

| | Unit | Year 2000 | Year 2020 | Source |
|---|---|---|---|---|
| **Transport conventional system (internal combustion engine on gasoline or diesel)** | | | | |
| Mechanical energy on the wheel/capita | [kwhmech/a] | 970,10 | 1035,49 | own calculation |
| Efficiency powertrain conventional | [%] | 24 | 24 | HySociety database |
| Specific cost fuel (without taxes) | [c/kWh] | 3,30 | 4,50 | Capros 2003 |
| Specific cost fuel | [c/kWhmech] | 13,75 | 18,75 | HySociety database |
| Specific cost powertrain | [c/kWhmech] | 24,00 | 24,00 | HySociety database |
| Total specific cost | [c/kWhmech] | 37,75 | 42,75 | own calculation |
| Total annual cost | [€/a] | 366,21 | 442,67 | own calculation |
| Share energy services (transport) at net income | [%] | **3.22** | **2.47** | own calculation |
| **Transport PEMFC on hydrogen from natural gas reforming** | | | | |
| Mechanical energy on the wheel/ capita | [kWh/a] | | 1035,49 | own calculation |
| Efficiency fuel cell | [%] | | 44,3 | HySociety database |
| Specific cost hydrogen | [c/kWh] | | 6,56 | HySociety database |
| Specific cost hydrogen | [c/kWhmech] | | 14,81 | HySociety database |
| Specific cost powertrain | [c/kWhmech] | | 59,00 | HySociety database |
| Total specific cost | [c/kWhmech] | | 73,81 | own calculation |
| Total annual cost | [€/a] | | 764,27 | own calculation |
| Share energy services (transport) at net income | [%] | | **4.27** | own calculation |
| **Transport PEMFC on hydrogen from electrolysis with wind electricity** | | | | |
| Mechanical energy on the wheel/ capita | [kWh/a] | | 1035,49 | own calculation |
| Efficiency fuel cell | [%] | | 44,3 | HySociety database |
| Specific cost hydrogen | [c/kWh] | | 15,28 | HySociety database |
| Specific cost hydrogen | [c/kWhmech] | | 34,49 | HySociety database |
| Specific cost powertrain | [c/kWhmech] | | 59,00 | HySociety database |
| Total specific cost | [c/kWhmech] | | 93,49 | own calculation |
| Total annual cost | [€/a] | | 968,10 | own calculation |
| Share energy services (transport) at net income | [%] | | **5.40** | own calculation |
| **Transport PEMFC on hydrogen from electrolysis with solar thermal electricity from North Africa** | | | | |
| Mechanical energy on the wheel/ capita | [kWh/a] | | 1035,49 | own calculation |
| Efficiency fuel cell | [%] | | 44,3 | HySociety database |
| Specific cost hydrogen | [c/kWh] | | 20,01 | HySociety database |
| Specific cost hydrogen | [c/kWhmech] | | 45,17 | HySociety database |
| Specific cost powertrain | [c/kWhmech] | | 59,00 | HySociety database |
| Total specific cost | [c/kWhmech] | | 104,17 | own calculation |
| Total annual cost | [€/a] | | 1078,66 | own calculation |
| Share energy services (transport) at net income | [%] | | **6.02** | own calculation |

Table 13: Calculations on transport

### 5.5.2 Results

The share of expenditures for residential electricity at the disposable income was in 2000 with 1.23 % quite low. Till 2020, the Share is even supposed to decrease to 0.97 %, due to a higher disposable income and lower electricity cost. In comparison to that the index of the cheapest hydrogen option: fuel cell on hydrogen with natural gas reforming is with 1.75 % slightly higher. The difference becomes much more evident with more expensive hydrogen production options like gasification of biomass (3.2 %) and electrolysis with wind electricity (4.81 %). Similar conclusions can be drawn for the transport sector. The share index is generally higher than for residential electricity. For conventional transport it was 3.22 % in 2000 and is supposed to drop to 2.47 % till 2020. Hydrogen based transport has – dependent on the hydrogen production option – an index of 4.27 % for natural gas reforming, 5.4 % for electrolysis with wind electricity and 6.02 % for electrolysis with solar thermal electricity from North Africa as the most expensive option.

When interpreting these data, one has to keep in mind, that the assumptions of the used data source for electricity and fuel price development – Capros – are fairly conservative. Other sources[7] estimate the availability of oil and natural gas more pessimistic which leads to higher prices for electricity and fuels in 2020. This would make hydrogen, even from more expensive renewable sources more attractive.

## 5.6 Summary

Social justice can be characterised by the following five criteria: Access to fair-priced energy services, Freedom of choice, Regional balance, Participation and Protection of privacy. Of all these criteria, the access to fair-priced energy services is the only one that can be appropriately discussed in the context of a hydrogen society. As indicator the share of expenditures for energy services at the average disposable income is used and the indicator index is calculated. Energy services comprise residential electricity and transport. In both categories the current supply is compared with a hydrogen based supply in financial terms. The data reflect an estimation of the performance and cost of hydrogen and hydrogen technologies for the year 2020, thus learning effects and cost reduction resulting from technical improvement and mass production are included. For the conventional system an estimation for the year 2020 is applied as well. For the calculations in this study the cheapest, the most expensive and moderate priced renewable hydrogen path has been selected, to illustrate the wide range of options. The main results are as follows: The share of expenditures for residential electricity at the disposable income is estimated to be 0.97 % in a conventional system in 2020. In comparison to that the index of the cheapest hydrogen option: fuel cell on hydrogen with natural gas reforming is with 1.75 % slightly higher. The difference becomes much more evident with more expensive hydrogen production options like gasification of biomass (3.2 %) and electrolysis with wind electricity (4.81 %). For conven-

7 compare Simmons et al. 2004; Zittel et al. 2003; Groppe 2002

tional transport the share is supposed to be around 2.47 % in 2020. Hydrogen based transport has – dependent on the hydrogen production option – an index of 4.27 % for natural gas reforming, 5.4 % for electrolysis with wind electricity and 6.02 % for electrolysis with solar thermal electricity from North Africa as the most expensive option.

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# 6 Risk Communication

*IC Imperial College London*

## 6.1 Introduction

Like all new technologies which the general public becomes exposed to, hydrogen as an alternative fuel as well as hydrogen-fuelled vehicles have attracted some suspicion as to their safety properties. While current fuels and conventional transport technologies are considered to be "safe" by almost everyone in the chain of production, distribution and end use, hydrogen has to work against the disadvantage of a perception as being potentially unsafe and dangerous. If left unaddressed, public anxieties about explosions or even poisoning might pose considerable barriers to the introduction of hydrogen as an alternative source of energy production and transportation.

The study of the processes involved in changing such adverse attitudes as well as the proposition of appropriate communicative material is the field of risk communication. Risk communication theory works upon the idea that what the public perceives as high or low risk in relation to specific issues (technologies, diseases, crime, food, health etc.) does not always reflect the real probabilities of being adversely affected by a particular threat, but rather the way different sections of the public make sense of specific risks.[8] Thus, "risk" is nothing that is fixed or has a stable meaning. Rather, risks need to be understood as floating communicative entities which are negotiated by all people involved in social networks that bring about change (decision makers, public, scientific community, media etc.) through channels that are open to the influence of altruistic or vested interests (pressure groups).[9]

In order to understand the way in which people internalize and make sense of their world with regard to perceived risks, it is necessary to first define people's understandings of a specific potential set of risks, the range of variables which contribute to that set of risks, their relative salience and the nature of interaction between them. The majority of risk communication theories now work on the assumption that only by exploring existing understandings of specific risks within target audiences and by interacting with

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8 See L. Frewer, C. Howard, R. Shepherd (1998), Understanding public attitudes to technology. Journal of Risk Research, 1(3): 221-235.

9 See the extensive literature from the 1980s on the social construction of risk and the cognitive turn that followed in the 1990s, which is working with the idea of mental models. Amongst others: L. Clarke (1989), Explaining choices about technological risks. Social Problems, 1: 22-35; W. A. Gamson, A. Modigliani (1989), Media discourse and public opinion on nuclear power: a constructionist approach. American Journal of Sociology, 95 (1): 1-37; D. Nelkin (1989), Communicating technological risk: the social construction of risk perception. American Review of Public Health, 10: 95-113; B. B. Johnson, V. T. Covello (eds.) (1987), The social and cultural construction of risk: essays on risk perception and selection. Dordrecht: Reidel; M. Ganger Morgan et al. (2002), Risk Communication – a mental models approach. Cambridge: Cambridge University Press.

these audiences it is possible to create successful communication strategies to overcome adverse attitudes.

In order to advance envisaged changes of public attitudes towards risks connected to particular technologies, most authors now work with a three-stage plan of risk communication. In this approach, an 'expert model' of a particular set of risks is developed. Drawing on technical insight, this model maps primary variables, interactions between the variables and their relative weighting. In a second step, lay understandings of that set of risks are explored, in order to get insight into how people dealing with a specific technology and potential end users comprehend and respond to perceived risks. In step three, these lay understandings are mapped onto the expert model in order to permit points of congruency and incongruity to be identified. From here, effective risk communication activities and material are developed together with an idea about the most effective risk communication media, tailored to the specific information needs of the different target audiences.

## 6.2 Enter the scientist: the "Expert" model

It is widely recognised that in any future hydrogen-based economy, key economic determinants will be the cost and safety of the fuel distribution system throughout the chain of on-site generation, distribution, storage and end-uses. While this is true of any fuel, hydrogen presents peculiar challenges due to its unique chemical and thermodynamic properties. For at least 50 years now, the chemical, transport and manufacturing industries all over the world have gained sufficient experiences with the safe handling of hydrogen in all its states of aggregation. Today, some 41 million tons of hydrogen are manufactured in the world annually and transported for chemical and fuel manufacturing as a low- or high-pressure gas via pipelines and trucks or as a cryogenic liquid.[10]

The uniqueness of hydrogen in terms of its chemical and thermodynamic properties defines the ways in which the risks involved in the application of hydrogen-based technologies are assessed by both scientists and the public. Hydrogen is characterised by a very low molecular weight and therefore high diffusion capabilities. Its great flammability is accompanied by its ability to form explosive mixtures over a wide range of concentrations. As a result, the release of any volume of hydrogen presents a larger probability of ignition than would be the case for a similar volume of other fuels commonly in use. Since hydrogen is colourless and odourless, it cannot be detected by human beings without the use of detectors. The unique chemical structure of molecular hydrogen results in extreme combustion characteristics praised by engineers (low ignition energy, low emissivity, and wide flammability limits), which at the same time causes safety concerns. These concerns are made worse taking into account that hydrogen can embrittle certain materials and cause them to become weak.[11]

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10 See National Academy of Engineering (2004), The Hydrogen Economy: Opportunities, Costs, Barriers and R&D needs. Washington, D.C.: National Academy Press, p. 2 (chapter 4) and p. 6 (chapter 9).

11 See D. Hart (2004), Hydrogen, end-uses and economics. Encyclopaedia of Energy, in press.

On the other hand, the same chemical and physical properties of hydrogen listed above lend a great deal of support to views which present hydrogen as a potentially safer fuel for daily use by end-consumers. Hydrogen is nearly 15 times lighter than air, which means that it disperses rapidly when accidentally released. While conventional fuel tends to puddle when leaked and builds up potentially dangerous concentrations of poisonous mixtures with air, hydrogen is not only non-toxic but also tends to diffuse easily, thus being less likely to build up dangerous concentrations. It is therefore actually extremely difficult to cause a mixture of air and hydrogen to explode. On top of that, hydrogen vehicles are safer than petrol vehicles in collisions as hydrogen dissipates so quickly in the air. Even in cases of outright explosions hydrogen performs better as its high buoyancy results in a high flame speed, which in accidents would cause the flames to go upwards. Because of that, hydrogen burns in a much more controllable manner than does petrol. In cases of complete tank ruptures, hydrogen immediately burns vertically rather than horizontally, thus less affecting people or cars around. Research has shown that in such cases hydrogen tends to deflagrate speedily upwards into the air rather than causing a shattering explosion known from conventional fuel.[12] Contrary to popular belief, the explosive power of hydrogen-air mixtures is also 22 times weaker than that of fuel vapour. While conventional fuel is known to be a hazard because of the smoke and emissions it produces, hydrogen poses little if any such threat to human environment.

**Hydrogen Production**

More than 50 years of industrial experience with hydrogen shows that the safety record of professionally produced and managed hydrogen compares favourably with that of similar industrial processes. Hydrogen is already manufactured and used by trained professionals under controlled conditions with acceptable safety. Incidents involving hydrogen on industrial production plants are extremely rare and usually involve other, conventional fuels. The few reported cases could all have been prevented if *existing* safety management systems had been followed.[13] This impressive amount of experience gathered under the conditions of centralised industrial production of hydrogen has been made available via industrial accidents databases and therefore feeds back into the processes of drawing up safety standards for the everyday commercial use of hydrogen.[14] This fact together with the expectation that in the near future distributed rather than centralised production of hydrogen will be a driver for the continued expan-

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[12] In such experiments, conventional fuel cars were completely destroyed by an explosion and the subsequent burning down of the car. Hydrogen cars remained largely intact without causing any danger to passengers. See B. Vincent (2004), Hydrogen and the law: safety and liability. Presentation given at George Washington University Law School, June 11 2004.

[13] See B. D. Kelly (1998a), Investigation of a hydrogen compressor explosion. Journal of Loss Prevention in the Process Industries, 11 (4): 253-6; B. D. Kelly (1998b), Investigation of a hydrogen heater explosion. Journal of Loss Prevention in the Process Industries, 11 (4): 257-59; H. Janssen, J. C. Bringmann, B. Emonts, V. Schroeder, Safety-related studies on hydrogen production in high-pressure electrolysers. International Journal of Hydrogen Energy, 29 (7): 759-70.

[14] See C. Kirchsteiger (1999), Status and functioning of the European Commission's major accident reporting system. Journal of Hazardous Materials, 65 (1-2): 211-31.

sion of fuel cell vehicles suggests to shift the focus away from the generation of hydrogen towards safety assessments of its distribution, storage and end-use.[15]

**Hydrogen Distribution**

The shipment and storage of hydrogen also offers an impressive amount of experience gained in industries around the world over several decades. There are well-established procedures which govern the distribution of hydrogen via trucks or pipeline systems. Hundreds of tons of hydrogen are transported in European Union states every week in trucks on motorways and in high-pressure pipeline systems which span many hundreds of kilometres.[16] As was the case with the on-site production of hydrogen, its professional distribution for industrial purposes offers a highly acceptable safety record due to the existence of a well established set of standards and safety procedures developed and supported by industries and industrial standards organisations.[17] Some potential risks in relation to hydrogen distribution via pipelines which clearly need to be addressed in future are on the one side the danger of terrorism. Potentially, terrorist attacks could destroy distribution systems and on-site storage tanks, resulting in the disruption of supply. While this is true for all other energy generation and distribution systems and even for the public water system, a relatively young and untested energy source such as hydrogen would suffer far more from the entailing psychological damage in terms of loss of confidence.[18] On the other side, a potential risk in a wider sense stemming from hydrogen pipeline systems are undiscovered leaks. Hydrogen leaking from pipeline systems in great amounts would further deplete ozone in the stratosphere, thus adding to the greenhouse effect, a problem which advocates of the "hydrogen society" initially had set out to combat.[19]

The thermodynamic properties of hydrogen also indicate that some risks are involved in the distribution and storage of hydrogen especially in enclosed and poorly ventilated spaces, such as garages or tunnels. Due to the high buoyancy and wider flammable concentration range of hydrogen, the geometry of the confining space strongly influences the likelihood of detonations. Trucks involved in heavy crashes in tunnels or private FCV being parked in enclosed spaces (private garages, car parks at airports or shopping centres) are therefore areas which now attract most of the attention of risk

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15 See National Academy of Engineering (2004), p. 4 (chapter 9); G. Berry (2004), Hydrogen production. Encyclopaedia of Energy, Vol. 3, in press.

16 See Royal Academy of Engineering (ed.) (2004), Realising the Hydrogen Economy. Transcript of seminar held on Thursday, 4th December 2003. London: Royal Academy of Engineering.

17 See the activities of the US National Hydrogen Association, the International Energy Agency as well as the International Standards Organization (ISO) on the development of hydrogen standards.

18 See National Academy of Engineering (2004), p. 3 (chapter 4).

19 Hydrogen in the vapour coming from hydrogen-fuelled airplanes is also thought to be a critical issue with regard to ozone depletion and the greenhouse effect. See A. Contreras, S. Yigit, K. Ozay, T. N. Veziroglu (1997), Hydrogen as aviation fuel: a comparison with hydrocarbon fuels. International Journal of Hydrogen Energy, 22 (10-11): 1053-60.

assessments with regard to the daily use of hydrogen.[20] Existing safety procedures governing the road transportation of hydrogen already work on this knowledge by disallowing drivers to park trucks in enclosed spaces or to use certain tunnels or roads through densely populated inner-city areas. This, in its turns, implies that further safety assessments will have to focus on the private consumption of hydrogen in FCV rather than on the generation and distribution of hydrogen. In respect to the use of hydrogen in private FCV, the possible risks arising from undetected leaks in enclosed spaces as well as the risks coming from car crashes and accidents warrant further attention.

**Hydrogen End-uses**

As the discussion has hitherto shown, the consumption of hydrogen by private end-consumers engenders the development of new risks which are not covered by the existing industrially oriented codes of standards and safety procedures. Leaks in on-board tanks of FCV for example might allow the build-up of dangerous concentrations of hydrogen in unventilated garages. This problem is known and potentially easily to be rectified: currently, a great deal of research is being conducted into the development of sensors for hydrogen.[21] Moreover, future safety standards for the private use of hydrogen-fuelled vehicles will have to make the proper ventilation of garages and underground car parks compulsory.[22]

The risks coming from FCV involved in car crashes are not seen with the same unanimity in the scientific community. A recent report published by the US National Academy of Engineering states that not only the economic disadvantages of on-board storage of molecular hydrogen in high-pressure tanks, but also safety concerns might render this way of hydrogen end-use a less viable option. This particular report proposed the use of metal hydrides as the way forward: "The principle game-changing features of these materials are the elimination of most safety and cost issues that high-pressure or cryogenically liquefied molecular hydrogen has, and the possibility of a major safety and range enhancement for on-board storage of hydrogen." [23]

Other studies, however, have questioned the use of metal hydrides, which, when reacted with water, emit hydrogen, from an economic point of view and also do not agree

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20 See for example M. N. Carcassi, F. Fineschi (2004), Deflagrations of H2-air and CH4-air lean mixtures in a vented multi-compartment environment. Energy, in press; M. R. Swain, P. Filoso, E. S. Grilliot, M. N. Swain (2003), Hydrogen leakage into simple geometric enclosures. International Journal of Hydrogen Energy, 28 (2): 229-48; M. R. Swain, E. S. Grilliot, M. N. Swain (1999), Experimental verification of a hydrogen risk assessment method. Chemical Health and Safety, 6(3): 28-32.

21 Hydrogen is odourless and therefore undetectable for human senses. Odorising hydrogen as done with town gas is likely to make hydrogen use in internal combustion engines and fuel cells ineffective or even impossible. See B. K. Miremadi, K. Colbow (1998), A hydrogen selective gas sensor from highly oriented films of carbon, obtained by fracturing charcoal. Sensors and Actuators, B: Chemicals, 46 (1): 30-4.

22 Ventilation systems in multi-storey car parks are already compulsory in European Union member states.

23 See National Academy of Engineering (2004), p. 7f. (chapter 4).

with safety concerns raised by the US report.[24] The use of hydrogen-storage materials, as opposed to liquid or compressed hydrogen, has itself its hidden environmental and technical risks. Some of the proposed metal hydrides are for example very rare which, with rising consumer demand for FCVs, could lead to a race for raw materials in areas of the Third World where such races for oil, diamonds, gold etc. have already fuelled civil wars and given rise to dictatorships. Metal hydrides could also pose potential risks if they are not disposed of properly by consumers or local re-fuelling agents. Chemical carriers such as Nitrogen (NH3) have also two major drawbacks: chemical reactivity with certain metals and their toxicity.[25]

Hydrogen vehicle studies in the US as well as Europe have provided abundant evidence that liquid and compressed hydrogen not only can be handled safely in an environment catering for private mass end-consumption, but also that the safety features of such hydrogen vehicles in crashes are actually better than those of petrol vehicles. [26] In crash tests, vehicles with cylinders of compressed gas and liquid-hydrogen tanks have been exposed to extreme forces which resemble those at work in car crashes; FCV even have been dropped from cranes from high altitude; vessels with high-pressure hydrogen as well as fuel cell vehicles have been subjected to other safety tests, such as the exposure to bonfire and gunfire: in none of these tests has hydrogen been released which could have caused the danger of an explosion.[27]

The discussion of the existing "expert model" of the risks involved in the production, distribution, storage and end-use of hydrogen has shown that the actual, measurable risks are known and relatively low in comparison to the everyday management of conventional fuel in industry and private lives of consumers. The scientific community generally does agree that risks which could prove to become barriers for the introduction of a hydrogen economy are less likely to come from the background of the industrial production and distribution of hydrogen, but do lie in the storage and end-use of hydrogen

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[24] For a balanced discussion of the possible options of storage materials see R. Harris, D. Book, P. Anderson, P. Edwards (2004), Hydrogen storage: the great challenge. The Fuel Cell Review, 1 (1): 17-23.

[25] Although NH3 is lethal above a certain concentration it is easily detectable by smell and lighter than air. See Berry (2004), ‘Hydrogen storage and transportation’.

[26] See Parliamentary Office of Science and Technology (ed.) (2002), Prospects for a Hydrogen Economy. London: HMSO; J. M. Ogden (1999), Prospects for building a hydrogen energy infrastructure. Annual Review of Energy and the Environment, 24: 227-79; J. Hord (1976), Is hydrogen a safe fuel? International Journal of Hydrogen Energy, 3 (1): 157-76; J. T. Ringland et al. (1994), Safety issues for hydrogen-powered vehicles. Livermore, CA: Sandia National Laboratories (SAND-94-8226); Ford Motor Company (1997), Direct hydrogen fuelled proton exchange membrane fuel cell system for transportation applications: hydrogen vehicle safety report. Contract No. DE-AC02-94CE50389; R. Rhoads Stephenson (2004), Crash-induced fire safety issues with hydrogen-fueled vehicles. In: Hydrogen Safety Report (www.hydrogensafety.info). For a critical review of safety studies see J. L. Alcock et al. (2001), Compilation of existing safety data on hydrogen and comparative fuels. Deliverable report by the European Integrated Hydrogen Project. Contract No. ENK6-CT2000-00442.

[27] Such extreme experiments have included bonfire tests, gunfire tests, crash tests, drop tests, vibration and permeation tests. See Berry (2004), Hydrogen storage and transportation; Vincent (2004); K. A. Adamson, P. Pearson (2000), Hydrogen and methanol: a comparison of safety, economics, efficiencies and emissions. Journal of Power Sources, 86 (1-2): 548-55.

by consumers. Even though there is no complete unanimity in scientific opinion, evidence supports the safety of FCV for daily use, while the problem of leaking tanks in unventilated, enclosed spaces is generally acknowledged.

An area which needs to be addressed more specifically is the question of refuelling stations. As interface between the industrial distribution of hydrogen and its everyday use by consumers, refuelling stations are also points of transition between two safety management regimes. While industrial safety procedures governing the generation and distribution of hydrogen are well established and supported by a great deal of experience, there are no widespread, established records of consumer applications of hydrogen. Due to the unique circumstances of a refuelling station, with technically inexperienced consumers expecting a simple and safe act of purchase, professional safety standards developed for large industrial plants can not simply be applied to an everyday-life retail environment. On the other hand, experience with the everyday-use of hydrogen by bus and taxi drivers at test and demonstration sites is mounting: existing refuelling stations in the US, Canada, Australia, Germany, Spain, Iceland, Singapore and other countries provide valuable long-term insight into the issues arising from the translation of industrial safety standards into safety codes for consumer end-use of hydrogen.[28] The experience of these sites also shows that the track record of these refuelling sites can successfully be translated into safety codes and codes of practices for consumers.[29]

Thus, the discussion so far has provided us with three crucial insights which will determine the ways in which risks involved in the introduction of the hydrogen economy might have to be communicated in the near future. Firstly, it has been shown that scientific opinion is guided by an existing mental model of risks which is open to challenge, amendments and critical discussion. Secondly, this model associates potential risks with the storage of hydrogen rather than with risks from explosions caused by ruptured tanks due to car crashes or other sudden vehicle accidents in traffic situations. Thirdly, it was shown that due to the unique properties of hydrogen, safety practices and skills developed over many years of handling of other fuels can not be applied uncritically to the management of hydrogen. Nor can existing industrial standards regarding the on-site production and distribution of hydrogen simply be utilised as safety codes for the everyday consumption of hydrogen. All indicators point in the direction of a need to develop a unique set of safety codes and practices to cater for the use of hydrogen by individuals in non-industrial parts of public life.

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28 S. Mourato, B. Saynor, D. Hart (2004), Greening London's black cabs: a study of driver's preferences for fuel cell taxis. Energy Policy, 32: 685-695.

29 See for example the case of BP in London and in Singapore. In 2003, local councillors in the north-east London Borough of Havering rejected the installation of a hydrogen pump due to the lack of safety standards for the end-use of hydrogen for non-industrial purposes. In Singapore, on the other hand, BP was allowed to install a hydrogen pump next to conventional fuel pumps due to the fact that safety codes and standards of practice for the retail use of hydrogen existed in the south-east Asian state. See (2003) Planners reject London hydrogen station. Fuel Cells Bulletin. 9: 4 and Angelo Amorelli (2004), The Challenge of Developing a Hydrogen Infrastructure. Presentation given at Imperial College, May 19 2004.

## 6.3 Enter Mr. Everyman: the "Lay" model

In order to assess the public perception of hydrogen it is important to differentiate between three types of "publics" depending on their exposure to hydrogen. People with no knowledge about or exposure to the issue of hydrogen are thought to be usually very sceptical, sometimes even adverse to hydrogen. Especially the perceived danger of uncontrollable, powerful explosions features prominently in this sub-section of the public. This attitude has been attributed to the lack of familiarity with hydrogen infrastructure, very low market demand and consequently low consumer understanding. This fact is only made worse by the virtual non-existence of publicly accessible information about the benefits and the safety record of hydrogen technologies.

On the other hand, a second sub-section of the public is growing now which is characterised by a more positive attitude towards hydrogen. This part of the public has had a chance of changing its opinion after being exposed to hydrogen demonstration projects. Studies conducted in the UK, Germany, the US, Iceland, Australia and Canada have found that people do welcome the introduction for example of new hydrogen buses and show surprising openness even towards large-scale demonstration projects.[30] Both sections of the public, however, are still defined by their essentially passive role in dealing with hydrogen. While a great deal of educational work could be achieved by simply extending demonstration projects, it does not necessarily follow that people who like to travel on a hydrogen bus would be equally happy to drive around several kilograms of hydrogen in their own cars. This third public, the active private end-consumer of hydrogen, however, is an attitude stage which in the long term drives demand, thus facilitating the transition towards a hydrogen economy. Risk communication projects therefore will have to focus on the question of enabling ever more people to move upwards on these three different stages of attitudes towards endorsing hydrogen as a future transport fuel.

It needs to be taken into account, however, that people as consumers of a specific technology also understand the term "risk" differently from the scientific community. In the scientist’s "mathematical mind", all risks are measurable and therefore open to managerial manipulation. The scientific mind for example perceives the risk of a plane crash as a question of scale and probability, where the individual components of a risk-setting are each identifiable and manageable. The "public mind", on the other hand, facing the option of either to use or abandon a specific technology, simplifies the myriad of factors and boils complex risk-settings down to preferably simple decisions. The public, "decision-making" mind therefore positions itself not within a setting of risks, but reduces the complexity of modern technology-based life to the decision to either trust a

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[30] See I. Schulte, D. Hart, R. v. d. Horst, Issues affecting the acceptance of hydrogen fuel. International Journal of Hydrogen Energy, 29: 677-685; LBST (1997), The acceptance of hydrogen technologies: a study carried out by Ludwig-Boelkow-Systemtechnik GmbH in co-operation with Ludwig Maximilians University of Munich. (http.www.hydrogen.org/accepth2/execsumm.html) and S. Mourato et al. (2004). Anecdotal evidence from Canada and Germany shows that hydrogen buses are particularly welcomed in inner-city areas for their greater silence and cleanliness (no emissions) to the extent that people let conventional buses pass by and waited for the hydrogen bus.

certain technology or withdraw trust.[31] Thus, rather than perceiving the issue of a plane crash on a risk scale of probabilities, average consumers will simply offer their trust in advance and usually decide that flying on a plane is "safe enough".

Within this mind-set, which is geared to reduce complexities, people often subconsciously resume to the strategy of making trade-offs in order to decide in favour of a certain technology.[32] For example, while driving a car is known to involve the risk of accidents, people accept these risks in order to enjoy the freedom of transportation. Sometimes, risks are ignored or simply not realised any longer. For example, people gain a lot from the existing energy infrastructure and will not perceive it as unsafe or risky. At the same time, actual accidents involving natural gas, propane gas, conventional fuel and electricity are occurring in their thousands every year resulting in hundreds of fatalities.[33] Thus, gaining a picture of the "lay" understanding of risks involved in hydrogen is complicated by the fact that when scientists and consumers talk about "risks", they are talking in different languages and use different definitions of risk.

Unlike in the cases of GM food, nuclear power, AIDS etc., a lack of personal experience and secondary exposure to and information about risks via the media with regard to hydrogen has resulted in a situation where "borrowed knowledge" has replaced clear, identifiable sets of attitudes and opinions. Rather than being whole-heartedly in favour or against hydrogen, the public mind has filled the void with powerful symbols and icons such as the Hydrogen Bomb, the Hindenburg catastrophe or the Challenger explosion. These substitutes, although having no relevance for the discussion of hydrogen as a potentially safe or unsafe transport fuel, are being used to enable and simplify decision-making processes about whether or not to put trust in a new technology. This indicates that successful risk communication strategies will have to make information accessible in order to replace this "borrowed" knowledge and eventually disassociate hydrogen cars from ideas about Hydrogen Bombs and the Hindenburg catastrophe. What’s more, effective communication material needs to outline some advantages of hydrogen-based transport technologies over conventional fuels in order to help people making trade-offs between perceived initial risks and possible gains.

The discussion of the corresponding "lay" model of risks with regard to hydrogen has led to three insights, which eventually provide the starting point for a risk communica-

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31 N. Luhmann (1979), Trust and Power. [translated from the German by Howard Davis, John Raffan and Kathryn Rooney]. Chichester: Wiley; N. Luhmann (1997), Modern society shocked by its risks. University of Hong Kong. Social Sciences Research Centre, Occasional Papers, No. 17; U. Beck (1992), Risk Society: towards a new modernity. London: Sage.

32 See P. Slovic (1987), Perception of risk. Science, 236: 280-5; P. Slovic, B. Fischhoff, S. Lichtenstein, S. Read, B. Combs (1978), How safe is safe enough? A psychometric study of attitudes towards technological risk and benefits. Policy Studies, 9: 127-52; D. von Winterfeldt, R. S. John, K. Borcherding (1981), Cognitive components of risk ratings. Risk Analysis, 1: 277-80.

33 Figures published by the US Department of Transportation (USDOT) and the US Office of Pipeline Safety (OPS) for example show between 1986 and 2003 some 360 fatalities involving natural gas and ca. 40 fatalities involving fires of fuel pipelines and fuel stations. In 1998 alone, 40 US citizens died in propane gas fires, 284 died in home electrical fires while in 2000 some 400 people in the US died from electrocution. See Vincent (2004).

tion strategy. Firstly, the decision making on part of the end-consumer is governed by the need to reduce the complexity involved in such decisions. Often, such decisions are made on the grounds of long-term experiences which are translated by consumers into the language of trust. Trust has been defined as a strategy to avoid the high costs (time, money, personal energy) involved in understanding and assessing the likeability of being adversely affected by failures of a specific technology. Secondly, the actual exposure to and experience with hydrogen technologies such as buses in the public transport system has been seen as very positive by the majority of people. Thirdly, the only identifiable parts of a mental model of risks with regard to hydrogen pointed at fears of explosions.

## 6.4 Enter the consumer: a communication project

Any successful risk communication strategy will have to take as its starting point the notion of the consumer as citizen. Consumer citizenship encapsulates the idea of a world where people are offered choice between technologies while at the same time are being enabled and educated to make informed decisions about the different qualities of these choices. Such an understanding, however, also points at a necessary shift from perceiving new technologies simply as better technical solutions with possible end-users attached to it towards the realisation that hydrogen-fuelled cars will have to be competitive in a mature and desire-driven consumer society. This consumer-centred rather than technology-centred approach works on the assumption that consumer choices and goodwill will eventually decide over the fate of new hydrogen-based transport and energy technologies.[34]

**Identifying specific target groups**

Perceptions of risks with regard to hydrogen depend on the experience and the professional background of different target groups. Following the three steps of generating, distributing and using hydrogen, several key audiences can be identified: workers on production plants (production); drivers of trucks, workers at refuelling stations, maintenance workers at bus or car repair stations, local resident communities, council and local government officials (distribution); taxi drivers, bus drivers, drivers of private cars (consumption).

One of the most essential tasks in communicating the risks to these more specific groups will be the development and communication of a unique set of safety codes and standards of practice with regard to the use of hydrogen. As examples in the US and Singapore have shown, planners as well as consumers will offer their support only if unique safety codes have been developed specifically for a certain type of industry-to-

[34] See I. Schulte et al. (2004): 680-1. For some of the wider issues of risk communication and democracy see also P. Slovic (1993), Perceived risk, trust and democracy. Risk Analysis, 13 (6): 675-82; S. Jasanoff (2002), Citizens at risk: cultures of modernity in the US and EU. Science as Culture, 11 (3): 363-80.

retail transition of hydrogen (for example a bus refuelling station).[35] To this end, zoning codes which restrict the location of hydrogen facilities will have to be devised and communicated to a variety of constituencies, such as local councillors and local government officials.

In order to support decision-making on a local level, the proven track record of industrial hydrogen management needs to be translated into a set of standards for the commercial/retail application of hydrogen. Safety policy goals will have to be formulated and communicated to decision-makers and stake holders in local government processes. The development of rigorous safety programmes needs to be funded by governments in order to assist local communities and administrators in assessing potential risks. Furthermore, the involvement of the public in early stages of any planning processes is paramount. Rather than trying to convince people at a later stage of a planning process that a specific hydrogen distribution-site will be safe, existing safety concerns need to be incorporated into these processes from the first moment.[36] This public involvement and the creation of a local dialogue has the crucial side effect of providing for high levels of tangible controllability and familiarity with a new technology. That is to say that people are less concerned about risks if they feel they have accepted something voluntarily as well having the feeling of familiarity with a potential source of risk.[37]

The standards set out in these newly to be established safety codes as well as codes of practices will not only have to be developed in collaboration with the fire service, the police and public health officials, but also be incorporated into the formal training schedule of these services. Local hospital and paramedical staff should be provided with introduction courses about the properties of hydrogen and the actual risks coming from the nearest distribution site. Generally, target groups such as civil servants, teachers or firemen etc. are usually easier to be educated about potential risks coming from new technologies as their professional role demands the unbiased assessment of risks from very specific and well-defined point of views. Specially designed training and education courses focussing on these target groups are therefore very likely to yield positive results.

Moreover, it needs to be taken into account that some of these groups (for example police officers and firemen) enjoy a great deal of respect and trust amongst the wider community. What is true for these professions is also true for certain institutional ac-

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35 See US Department of Energy (2004), Hydrogen posture plan: an integrated research, development and demonstration plan. Washington, DC: Department of Energy, pp. 8, 14, 17.

36 Long-term comparisons of risk communication projects have shown that the public in a wider sense needs to be engaged as an equal partner in all stages of planning processes. See B Fischhoff (1995), Risk perception and communication unplugged: twenty years of progress. Risk Analysis, 15 (2): 137-45; W. Leiss (1996), Three phases in the evolution of risk communication practice. Annals of the American Academy of Political and Social Science, 545: 85-94; P. Slovic, D. MacGregor (1994), The social context of risk communication. Eugene OR: Decision Research.

37 For the difference in the perception of involuntary vs. voluntary risks and unfamiliar vs. familiar risks see Slovic (1987) and R. E. Kasperson, O. Renn, P. Slovic (1988), The social amplification of risk: a conceptual framework. Risk Analysis, 8 (2): 177-87.

tors. While governments and private companies (such as Shell and BP) are most interested in educating the public about the future possibilities of hydrogen as a fuel, they are usually not very trusted. Other institutional actors, such as schools, museums and public broadcasting services, which all enjoy greater trust, will eventually have to be made the mouthpiece of industrial and governmental education and information campaigns about the prospects of hydrogen.

**Engaging the general public**

Campaigns to educate the wider public about future possibilities of hydrogen which could dispel myths about being affected by uncontrollable risks would ultimately have to start in school. The chemical and physical properties of hydrogen and information about the potentially lower risks coming from new hydrogen technologies will have to be incorporated into school curricula, which are still dominated by inefficient and outdated energy and transport technologies. These educational efforts should be accompanied by exhibitions in institutions such as science museums or other learning institutions. The European national science museums, for example, should be encouraged to run special sections devoted to hydrogen. These could be used to invite school classes for extra-curricular education. Both curricular as well as extra-curricular courses, however, should be carefully devised as regards the issue of safety and risk. While the phenomenon of the noisy deflagration of hydrogen gas produced from water is a popular school experiment, it leaves its mark with generations of potential consumers of hydrogen technologies. Experiments such as this create long-lasting associations between hydrogen and images of explosions and noise which work to the disadvantage of coming technologies. Thus, a great deal of educational work would have to focus for example on explaining that such mini-explosions are actually *not* the technological basis of fuel cells.

It has to be recognised that while schools and special exhibits in museums are probably the most effective risk communication channels in the long-term, they mainly reach generations that are currently in formal education. Those generations which have left the formal education system will have to be reached by more decentralised communication campaigns. In order to accomplish that, hydrogen risk communication could learn from awareness-raising strategies of other sectors of science and technology. The 1990s, for example, were declared by the US Congress to be the "Decade of Brain Research", while the year 2000 was announced to be the "Year of the Brain". Similarly, national governments and the European Commission should declare the year 2010 the "Year of Hydrogen" and the following decade until 2020 the decade of the breakthrough of hydrogen-based technologies. Such initiatives receive wide media attention and, most crucially, are able to keep this attention alive over a time span of many years. The positive effect of dedicating a special year or a decade to hydrogen can not be overestimated in terms of public awareness and the creation of goodwill. Ideally, a whole series of travelling exhibitions, festivals, lectures etc. could accompany the announcement.

As a more immediate and short-term communication activity, a fleet of mobile information centres (obviously using hydrogen cars, caravans or buses) should be created. These information centres should be placed in central locations such as city centres, shopping malls etc. or university campuses in order to reach people with a receptive mind which have already left the school education system. Rather than just handing out leaflets, these centres should invite people to express their concerns and encourage them to get a first "feeling" for the issue of hydrogen. In order to extend the little passive knowledge that people have and push it into areas of more proactive experience, these information centres should also allow people to drive a hydrogen-fuelled car for a few minutes.[38] In these moments, people are being taken seriously as citizens while being re-created as potential consumers of a car which they will find not only safe but also capable of fully replacing their present, conventional car.[39] Such activities ensure that people are actively involved in the transition process towards a new technology. As a result, such a safety campaign would not be a top-down form of communication from "experts" to an inert "lay public", but a form of dialogue between all those involved in such a transition process.

Eventually, the idea behind such campaigns is to allow people to make trade-offs in favour of a new and unfamiliar transport fuel. Information centres and car shows create interest and stimulate curiosity in people. This in its turns creates awareness, which is one of the most precious goods in modern, media-saturated consumer societies. Awareness, on the other hand, creates "affectedness". Engaging with questions about hydrogen and even having the opportunity to drive a car oneself means that people more or less *have* to create an opinion and a certain mind-set in relation to hydrogen. This makes them more receptive of all kinds of information which is offered to them about hydrogen. Exhibitions, festivals, information centres etc., thus first create demand for information which is then supplied.

As an ultimate communication event, public "safety stunts" could be envisaged to finally convince people about the higher safety properties of hydrogen cars. Under the supervision of the fire service and health and safety officials, two cars – one conventional and one hydrogen car – complete with passenger dolls so familiar from televised tests should be subjected to a public safety test. The aim would be to show that in incidences of a car crash or accidental fire the hydrogen car is the potentially safer transport device by not exploding or burning down as the conventional car would do. Event marketing and information campaigns should also make use of small appliances of fuel cells, such as mobile phones, laptops, bikes, lawn mowers, video cameras etc. as incentives in order to raise interest. By touching and using small appliances, people again get an idea of what new hydrogen-based technologies can deliver in terms of technical performance while at the same time all these appliances literally "feel" safe.

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38 This could also be used to familiarise the public with the existence of Codes of Practice, such as issued by the Society of Automotive Engineers in the US. See SAE (2002), Recommended practice for general fuel cell vehicle safety. SAE J-2578. For similar codes and regulations already available in the EU see M. N. Carcassi, N. Grasso, Safety, standards and regulations. In: M. Marini, G. Spazzafumo (eds.) (2003), Hydrogen power: theoretical and engineering solutions. Padua: Servizi Grafici Editoriali, pp. 569-79.

39 On the importance of communicating the performance potentials of internal combustion engine or fuel cell vehicles see again I. Schulte et al. (2004): 683 and G. Dinse (2000), Akzeptanz von wasserstoffbetriebenen Fahrzeugen. Eine Studie über die Verwendung eines neuen und ungewohnten Kraftstoffs. Berlin: Institut für Mobilitätsforschung.

Here again, touching and seeing a technical appliance changes the place of hydrogen on the mental maps of people: actual, physical experience replaces ignorance or "borrowed" knowledge (Hindenburg disaster etc.) with more specific ideas. This, eventually, helps people reducing the complexity of decision-making concerning hydrogen as a new energy source.

Last but not least, the new, hydrogen-based technologies should be endorsed by celebrities. Testimonials from the world of sports or "society" should be persuaded to speak out on behalf of a safer and cleaner technology and associate themselves with the "cause" of hydrogen. In the United States, this movement has already gained considerable impetus from Hollywood actors. In California, hybrid cars with a fuel consumption of only one gallon per 40-60 miles are currently a must-have consumer good, with Leonardo DiCaprio driving already three of these cars.[40] Such celebrity endorsement creates market demand and helps projecting virtually unquestioned trust onto a new technology. This mechanism could also be employed by placing hydrogen cars in popular television soap operas (product placement). Getting two famous characters of a popular soap to talk about a new hydrogen delivery van used by someone on "Lindenstrasse" (Germany) or "Coronation Street" (Britain) would be a standard PR exercise which again creates credibility and lends a great deal of trust to hydrogen as a future consumer good for Mr. and Mrs. Everyman.

## 6.5 Conclusions

‘Expert’ risk assessments perceive hydrogen as a transport fuel which is just as safe as conventional fuels. What’s more, the physicochemical properties make hydrogen a potentially safer transport fuel than its current alternatives. Especially its behaviour in collisions has been pointed out as being advantageous. Its better performance in explosions and collisions resulting in tank ruptures is added to the fact that hydrogen is non-toxic (as opposed to conventional fuel). Potential hazards in the daily use of hydrogen could occur in situations where hydrogen is stored in enclosed, unventilated spaces, such as private garages. Little evidence exists as to the long-term hazards and risks stemming from problems of the storing of hydrogen by private individuals. Thus, potential dangers involved in the introduction of hydrogen as a transport fuel are not identified in areas such as the production and industrial distribution of hydrogen, where long-term experience has proven hydrogen to be safely manageable. Rather, the storage and commercial use of hydrogen by end-users in a day-to-day/retail environment has been tagged by the scientific community as a key area of necessary accident prevention. As a result, the need for the formulation and implementation of unique hydrogen safety codes and standards of practice governing the private end-use of hydrogen has been recognised.

Public perception of risks involved in the daily use of mass-marketed hydrogen applications, however, has sedimented around the idea of hydrogen being potentially hazardous not in areas of storage, but in areas which were seen as specifically advantageous

40 See Peter Viles, CNN News, October 23 2002 and Maggie Shiels, BBC News, June 1 2004.

for hydrogen, most prominently fears of explosions on generation sites and through tank ruptures or car collisions. Therefore, future risk communication strategies will have to disassociate hydrogen as a transport fuel from icons such as the "Hindenburg" disaster or the Hydrogen Bomb as well as mental images of uncontrollable explosions. To this end, an information as well as an active "experience" campaign (demonstration projects) for future consumers of hydrogen is necessary which brings ‘expert’ and ‘lay’ models of risk in closer congruence. The involvement of formerly detached sections of the public in the emergence of a hydrogen society creates a sense of controllability and familiarity within these sections. This positively reinforces the public acceptance of new and unfamiliar technologies and encourages consumers to make trade-offs in favour of hydrogen applications.

Resulting from the differences in the risk assessments by public and scientific community, a number of risk communication strategies have been proposed. First of all, a unique set of standards, practice and zoning codes needs to be developed and communicated to the target groups in local government, healthcare, emergency services, staff at fuelling stations as well as taxi and bus drivers. These codes and standards of practice need to be backed up by specialised training and education courses targeting the fire, police, public transport and health services. As a long-term education measure, schools and museums have to be used as communication platforms to breed generations of pupils accustomed to the idea of being surrounded by daily-life hydrogen applications. In the short term, awareness-raising strategies known from communication campaigns relating to AIDS, breast cancer etc. should be utilised. Industry- and government-sponsored PR campaigns should promote hydrogen initiatives, long-term events such as a "Hydrogen Year" could be organised, travelling exhibitions could tour the countries supported by local festivals and event weeks. In addition, national fleets of mobile information centres should create awareness and provide information to the general public. More commercial marketing devices, such as event marketing (e.g. performing public safety tests), celebrity endorsement and product placement will have to be incorporated into the communication mix in order to reach unaffected sections of the public.