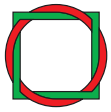

Wuppertal Institute
for Climate, Environment
and Energy

Maria Yetano Roche, Susana Mourato, Manfred Fischedick, Katja Pietzner, Peter Viebahn

Public attitudes towards and demand for hydrogen and fuel cell vehicles: A review of the evidence and methodological implications

Originally published as:

M. Yetano Roche, S. Mourato, M. Fischedick, K. Pietzner, P. Viebahn (2010):
Public Attitudes Towards and Demand for Hydrogen and Fuel Cell Vehicles: A Review of the Evidence and Methodological Implications.
In: Energy Policy 38 (10): 5301-5310

(DOI:10.1016/j.enpol.2009.03.029)

This article was published as: Yetano Roche, M., Mourato, S., Fischedick, M., Pietzner, K., Viebahn, P. (2010) Public Attitudes Towards and Demand for Hydrogen and Fuel Cell Vehicles: A Review of the Evidence and Methodological Implications. Energy Policy 38 (10): 5301-5310 (doi:10.1016/j.enpol.2009.03.029).

Public attitudes towards and demand for hydrogen and fuel cell vehicles: A review of the evidence and methodological implications

Yetano Roche, María[†‡]*, Mourato, Susana[‡], Fischedick, Manfred[†], Pietzner, Katja[†], Viebahn, Peter[†]

[†] Wuppertal Institute for Climate, Energy and Environment, PO BOX 100480, 42004 Wuppertal, Germany

[‡] Department of Geography & Environment; London School of Economics and Political Science, Houghton Street, London WC2A 2AE.

*Corresponding author: maria.yetano@wupperinst.org, Tel: +39 347 194 04 51, Fax: +49 202 2492-198

Abstract:

It is now widely recognized that effective communication and demand-side policies for alternative energy require sound knowledge of preferences and determinants of demand of the public and consumers. To date, public attitudes towards new transport technologies have been studied under very different conceptual frameworks. This paper gives an overview of the various conceptual frameworks and methodologies used, where four main approaches can be distinguished: general attitudinal surveys, risk perception studies, non-market economic valuation studies, and other approaches such as those based on semiotic theory. We then

review the findings of the recent literature on acceptance, attitudes and preferences for hydrogen and fuel cell end-use technologies, focusing on vehicles. These studies are then contrasted with related research into alternative fuel vehicles. The paper finally discusses the main trends in research and avenues for further work in this field. We recommend, among other things, the use of approaches that build knowledge and familiarity with the technology prior to the exploration of attitudes, and the set up of studies that take a whole-systems perspective of hydrogen technologies and that look at hydrogen in the context of other competing clean technologies.

Keywords: Attitudes; Preferences; Hydrogen and Fuel Cells

1. Introduction

The large scale introduction of hydrogen and fuel cell technologies into energy systems is considered by some to be desirable for the achievement of long-term climate policy objectives (DoE 2007; EC 2007). Nonetheless, a number of techno-economic obstacles still need to be overcome before successful penetration of hydrogen technologies in the transport or stationary energy sectors can occur (DoE 2007). If and when hydrogen and fuel cell technologies become viable for introduction into national energy systems, then social research into public attitudes towards and preferences for hydrogen technologies will have an important role to play in informing policy design in this area.

There is moreover a concern among decision-makers that public alarm (chiefly on safety – i.e. associations with the Hindenburg disaster – and environmental impacts – i.e. green *vs.* black hydrogen[1]) could arise during the development of hydrogen energy systems (Edwards 2008; Webster 2008). Research suggests that an accident during the introduction phase of a new technology, albeit small, can disproportionately damage its uptake (Slovic*, et al.* 1984). For

example, public opposition to the sitting of hydrogen refueling facilities in London in 2003 was attributed by the media to safety concerns (FCB 2003). Although this was more likely a consequence of previous local opposition to a conventional refueling station (O'Garra*, et al.* 2008), it could nevertheless be seen as an early sign of possible social acceptance barriers. Whilst it is recognized that the vast majority of hydrogen refueling stations currently functioning or planned in the world (approximately 300, according to LBST (2008)) have not given rise to public opposition, it is not unlikely that opposition could arise in a scenario of increasing penetration of hydrogen.

While not all negative attitudes necessarily translate into active opposition, concerns should be acknowledged as a sign of the need for communication and debate. Indeed, understanding public attitudes towards hydrogen as an energy carrier falls within the wider context of engaging the public in the debate regarding the transition to sustainable energy systems and technologies. Moreover, it is also important to be able to identify cases where the social costs of, for example, a new energy infrastructure might potentially outweigh its social benefits.

There is a wealth of literature, and indeed a discipline (environmental psychology), which studies the determinants of attitudes, preferences and behaviour towards the environment, within which a considerable amount focuses on energy and transport. It is important to review the results and methodological lessons from this research in order to design future studies into hydrogen and fuel cell technologies and apply the relevant guidelines to communication and public engagement strategies.

The attitudes of consumers towards hydrogen end-use technologies, whether in the transport or residential sectors, will be fundamentally different to the attitudes of local populations who face the building of hydrogen production and distribution infrastructure in their communities. To keep the scope of this paper manageable, this review focuses solely on the former.

Moreover it focuses on vehicles as the majority of recent studies in the hydrogen realm have been based on demonstration projects in the transport sector[2].

This paper is organized as follows. First, we introduce the main conceptual frameworks and methodological approaches used in studies of attitudes towards and preferences for new technologies. Second, we review recent attitudinal and preference studies of hydrogen and fuel cell vehicles (HFCVs), followed by a comparison with related research in other alternative fuel vehicles (AFVs). Finally, we discuss the key conclusions from our review and propose avenues for further research.

2. Overview of main conceptual frameworks and methodologies

This section provides a summary introduction to the conceptual frameworks and methodological approaches which are applied in the studies reviewed in the paper. It is beyond the scope of this paper to comprehensively review the large body of research that critically analyses the theoretical foundations of the various approaches that have been used to explain attitudes, preferences and demand for new technologies. For our purposes, it suffices to describe briefly the main theoretical backdrops commonly used, together with a synthesis of the main concerns arising, allowing the reader to see "the big picture", including the links between the different concepts and methods.

2.1. Attitudinal research

Attitudes are a central concept to social psychology, and hence to environmental psychology. They are defined as "a psychological tendency that is expressed by evaluating a particular

entity [or attitude object] with some degree of favor or disfavor" (Eagly and Chaiken 1993). There are numerous theories regarding how the "evaluation" occurs, giving rise to attitude formation and attitude change.

The dominating trend in environmental psychology for the study of the relationship between attitudes and intended behaviour is the use of the Theory of Planned Behaviour (Ajzen 1991). It stipulates, to put it very briefly, that the main determining factors of behavioural intention are: first, the attitude towards the specific behaviour (attitudes are influenced by knowledge, experience and other factors); second, the subjective norms (what the actor believes is approved by society) and, third, the perceived behavioural control (the perception of the impact that the behaviour will have) (Ajzen 1991). In this context, an individual's acceptance of a technology, although not strictly a psycho-sociological term, can be regarded as an intention to adopt or use the technology, or to consent or actively support its development.

Methodological approaches to measuring attitudes, behaviour and intended behaviour in environmental psychology include quantitative (attitudinal surveys) and qualitative methods (e.g. semi-structured interviews, focus groups).

Limitations can be found in most models that aim to explain attitude formation and the attitude-behaviour relationship. The theory of planned behaviour, for example, does not account for all the variance observed, and has higher predictive power when behaviour measures are self-reported than when they are objective or observed (Armitage and Conner 2001). Alternative models in heuristics (Kahneman*, et al.* 1982) have also been used in the environmental psychology field (e.g. Yamamoto, *et al.* (2008)) and can be more accurate in explaining how people make complex decisions, especially when lacking complete information. In terms of data collection, the challenge to researchers is the design of tools to elicit the nature of attitudes and other behaviour measures and evaluate their strength. The

choice of survey questions or study designs for measuring attitude, perceived behavioural control or social norm, are subject to a wide range of biases (e.g. framing, cognitive burdens).

2.2. Risk perception studies

A subset of the environmental psychology literature has been concerned with the dynamics of behaviour in the face of risk (Slovic*, et al.* 1984; Slovic 1987). Although this is based on a socio-psychological framework, it can be regarded as a different application to that of general attitudinal surveys, especially for the large part it plays in the study of perceptions towards nuclear (Smith and Michaels 1987; Drottz-Sjoberg and Sjoberg 1990), climate (Cameron 2005) and other environmental risks (Lee 1986). The premise of this approach is that whilst experts rely on complex risk assessments for their decisions, the general public make judgements based on their experience, emotions, the media or other non-technical sources (Slovic 1987; Sjoberg 1998). Research in this field aims to quantify and predict perceived risk by studying the factors that underlie the perceptions of risk, such as information, its presentation, public trust in sources, or the impact of accidents (Slovic*, et al.* 1984). The methodological approaches used in risk perception studies are generally those available in social psychology (heuristics experiments, quantitative surveys).

Some of the models proposed by risk perception studies have been criticised for their low explanatory power (Sjoberg 1998). As in the attitudinal studies, researchers risk omitting key variables among the large number of factors that can influence perceived risk.

2.3. Stated preference studies

Modern welfare economic models stipulate that individuals will choose options that maximize utility subject to their preferences, knowledge of alternatives and budget. Consumers are assumed to be rational decision-makers with well-defined preferences. Preferences for environmental goods and services which are not usually traded within the market mechanism can be inferred by revealed preference and stated preference techniques (Champ*, et al.* 2003; Pearce*, et al.* 2006). Arguably, survey-based stated preference techniques that look at intended behaviour in hypothetical or constructed markets are the most commonly used in the environmental and energy fields (Bateman*, et al.* 2002; Champ*, et al.* 2003). These techniques analyse the trade-off that individuals would be willing to make between the good in question and some other good (usually money). The inferred economic preferences can be used for estimating the monetary values of environmental goods and can inform a wide range of policy decisions.

Two main stated preference methods are contingent valuation (CV) and choice experiments (CE). In the CV method, respondents are directly asked for their willingness to pay (WTP) for a hypothetical change in the quantity of a good, assuming that stated WTP is a measure of the respondents' underlying preferences (Mitchell and Carson 1989; Bateman*, et al.* 2002). In CE, goods are assumed to be made up of different attributes that vary at different levels. Sets of goods with different attributes are presented to the respondents, who are asked to choose between the alternatives (Louviere*, et al.* 2000; Bennett and Blamey 2001). The implicit price of each attribute can be indirectly inferred from the choices if price is included as an attribute. Choice experiments for economic valuation have been widely used in transportation research and marketing.

Information also plays a crucial role in stated preference methods. The values elicited by such methods are contingent to the information provided in the hypothetical market. There is a large body of literature exploring the effects of information in the formation of preferences (Blomquist and Whitehead 1998). Moreover, the measurement of the economic value of

information itself has been the subject of analysis with recent studies focusing on measures of effort in searching for information and its effect on economic values. For example, Berrens *et al.* (2004) have correlated the time spent accessing extra information on global climate change through online surveys with the resulting WTP estimates.

The critics to the stated preference approach argue that individuals react to hypothetical markets in fundamentally different ways to how they would make decisions in a real market. Another commonly mentioned problem is embedding (or scope insensitivity), which occurs where WTP does not reflect the scope of the qualitative and quantitative changes in the good being offered. For comprehensive reviews of potential sources of bias see Mitchell and Carson (1989), Carson *et al.* (2001), Bateman *et al.* (2002) or Champ *et al.* (2003).

2.4. Other methodological approaches

The three main research approaches presented above (attitudinal research, risk perception, and stated preference techniques for economic valuation) contain elements of the "rational actor" research philosophy. A fundamentally different approach to understanding behaviour towards the environment is that of symbolism, widely used in consumer research. Heffner *et al.* (2007b) have recently taken up the seminal literature and lessons of recent studies exploring the symbolic meanings of cars, and have produced empirical results regarding the purchase of hybrid cars. These studies are based on the assumption that vehicles symbolize ideas related to self-identity and that the choice of a vehicle is used to communicate interests, beliefs, values, and social status. Studies of symbols rely usually on ethnographic interviews. A possible caveat in the use of this approach for the study of new technologies such as hydrogen fuel cell or other alternative fuel vehicles is that new symbolic meanings take time to appear and be communicated among consumers.

Other innovative research approaches (which can be used in combination with the previously described methods) include experimental studies (involving direct or virtual driving/use or purchasing of vehicles) or activity analysis. Activity analysis relies on a combination of interactive interviews and the use of household travel diaries, activity location maps, videos and other information material that allow the respondents to develop awareness of their needs and familiarity with the technology in question (Kurani, *et al.* 1994; Kurani, *et al.* 1996).

The next section will first summarize the results from the various research studies which have taken place in the last five years relating specifically to hydrogen and fuel cell end-use technologies. It will then relate them to other recent research on the attitudes and preferences towards AFVs.

3. Recent research on hydrogen and fuel cell vehicles

Early research into public acceptance and attitudes towards hydrogen and fuel cell technologies for transport was reviewed by Altmann *et al.* (2003) and contrasted with research into attitudes towards alternative fuel vehicles. Research by Altmann and Graesel (1998), Dinse (2000), Lossen *et al.* (2003) and others revealed that public attitudes towards hydrogen were largely positive, that knowledge of the subject was low and that safety concerns were not an issue. These exploratory studies generally investigated attitudes but not intended use or purchasing behaviour.

Five years later, the review by Altmann *et al.* (2003) has been complemented by new research in the field of hydrogen fuel cell vehicles, which has offered fresh insights and a wide range of methodological approaches. The results of a number of key research projects, such as the AcceptH2 project (O'Garra, *et al.* 2005; O'Garra 2005; O'Garra, *et al.* 2007a; O'Garra, *et al.* 2007b; O'Garra and Mourato 2007), as well as the Store-HY, UKSHEC, CreateAcceptance and other projects, have made a substantial contribution to knowledge on the subject.

3.1. AcceptH2 project

The first of the main European projects in this area was the EU-funded AcceptH2 project (2003-2005), a transnational comparative survey-based study of public acceptability of hydrogen fuel cell buses and preferences for their environmental attributes in several cities hosting hydrogen bus trials through the CUTE, ECTOS and STEP demonstration projects[3]. A survey questionnaire was implemented by telephone in Berlin, London, Luxembourg and Perth (Australia). The survey, carefully designed and piloted in all four cities, gave a succinct explanation of the technologies, and their costs and benefits, prior to asking respondents for their opinions and preferences. Over 1,350 people were interviewed. The results of the study corroborated previous work in that awareness of the technologies was very low, with just over half of all respondents claiming to have heard about hydrogen vehicles. Results also showed that the general public displayed an overall support for the technologies: 46% of respondents unconditionally supported the large-scale introduction of fuel cell buses in their cities, while 44% indicated that their support was conditional on the results of the trials and proof of safety (O'Garra*, et al.* 2005; O'Garra*, et al.* 2007a). Opposition (mostly due to safety concerns) was negligible (3%). The respondents also expressed overwhelming support (90% overall, 1% opposition) for the continuation of trials of hydrogen buses. The attitudinal part of the survey showed some concern for safety, but the risk perception was not particularly high.

Of note, this study used the contingent valuation method for the economic valuation of the environmental benefits of introducing hydrogen fuel cell buses. Respondents were asked for their maximum WTP per single bus fare and also in taxes, for a hypothetical introduction of fuel cell buses in their cities. As mentioned above, CV assumes that stated WTP is a measure of the respondents' underlying preferences for the benefits brought about by fuel cell buses. Bus users across the four cities were found to be willing to pay an extra € 0.29 to € 0.35 (adjusted value) per single bus fare for riding a hydrogen bus. Additionally, residents of

London and Perth (not just bus-users) were willing to pay between € 15 and € 24 (adjusted value) in extra taxes to support the large-scale introduction of hydrogen buses in their cities.

Statistical analyses revealed that determinants of WTP other than income were different for each city. For example, pro-environmental attitudes had a significant positive influence on WTP extra fare in London and Perth, while the frequency of donation to environmental causes was the key determinant in Luxembourg and Berlin. Being male and having prior awareness of hydrogen had an influence in the WTP via taxes in London, whereas having university studies was correlated with paying extra taxes in Perth. This study is particularly important for its focus on public transport, for its combined methodology (measurement of attitudes and economic preferences, for both bus users and non-users) and the fact that the public was surveyed across different regions (sample sizes ranged from 200 to 414 for each city's survey).

3.2. Stor-HY project

The second project to have investigated attitudes of the general public towards hydrogen and fuel cell vehicles was the survey which took place in France as part of the Stor-HY project[4] (CEA/Cohesium-Études 2005). This is the only known (and yet unpublished) study into the attitudes towards different types of on-board hydrogen storage and again showed, in line with the results of AcceptH2, that there was little knowledge of the technology. A mix of positive and negative beliefs about hydrogen was observed, which pivoted between the idealisation of a "natural" and "clean" solution to energy-related problems and safety fears. The authors argue that these polarised beliefs risk becoming embedded in public opinion unless tailored communication is used in the early phases of the introduction of hydrogen and fuel cell technologies.

In addition to a quantitative survey of 200 members of the general public and fifteen interviews with a sample of fleet managers, the Stor-HY study carried out thirty individual and

six group semi-structured interviews with members of the general public (young and middle-aged Parisians). This allowed a closer examination of the process of attitude formation and revealed that the complexity of the technology was a major barrier to the creation of firm attitudes. Personality-type analysis (in terms of "early technology adopters", "environmentally friendly" and other personality types) was carried out to differentiate the cycle of attitude formation among the respondents. The respondents struggled to see hydrogen as a concrete solution in a way that was not the case for other alternative technologies. They lacked reference points and welcomed examples of the "tangible reality" of hydrogen, e.g. pictures of hydrogen prototype cars, in order to establish a link with present technologies.

The provision of comprehensive technical information, followed by a time lapse of a few weeks to allow reflection, resulted in the evolution of respondents' positions towards the technology, after which the original spontaneous positive attitudes evolved into a more reserved judgement. In this phase, many individuals perceived the technology as complex, unstable and difficult or impossible to control (women were found to express these fears more often than men). Respondents evolved finally to a matured opinion, usually overall positive (but still very undecided). It is important to note that, following the provision of information, the majority of the public preferred liquid storage over other forms of storage, reflecting the importance of "reference points" linking the known technologies (in this case, liquid petrol and diesel) to the new one. Young individuals, and those who reported concern for the environment, were seen to favour solid storage as the safest, most efficient and innovative.

3.3. UK Sustainable Hydrogen Energy Consortium project

The third project to have taken place in a European context is the UK Sustainable Hydrogen Energy Consortium (UKSHEC[5]), an ongoing multidisciplinary project which has carried out a number of studies on the perceptions of hydrogen technologies among the public (Bellaby*, et al.* 2007; Ricci*, et al.* 2008). This research takes a global view of hydrogen as an energy

carrier, i.e. it encompasses both end-use, production and distribution infrastructure. The first step of the study was a telephone poll administered to about 1,000 members of the public in three different areas of contrasting transport characteristics in the UK (Norwich, Sheffield and Southampton). The poll showed that level of knowledge about hydrogen as an energy carrier was at best moderate and variable, and that men, the younger, and those with higher incomes tend to know more about hydrogen.

In the next step, Bellaby *et al.* (2007) carried out twelve focus groups for which they designed a 15 minute documentary film on the role of hydrogen energy in the wider energy system and its implications for everyday life. The findings coincide with those of other studies in that clear attitudes are not yet formed, and they are conditional on further information. Following the showing of the film, participants showed varying support for the technology depending on the different elements of hydrogen systems: on the topic of production, they were often critical of the use of non-renewable primary sources to generate hydrogen. Regarding storage and distribution, there was demand for more information on the risks, and some safety-related concerns. While no significant opposition was found on the basis of these concerns, the participants needed to know what changes in their behaviour would hydrogen imply.

Earlier research by the same team carried out nine focus groups in areas where hydrogen projects are being planned and/or developed (Teesside, South Wales and London) (Ricci*, et al.* 2006, 2007a; Ricci*, et al.* 2007b). Participants were invited to discuss general energy and environment issues, and were allowed to frame the debate about hydrogen in the way that was most relevant to them. The findings showed that attitudes towards hydrogen were neither wholly positive nor wholly negative, that awareness of hydrogen varied widely and that more detailed and impartial information was needed. Concerns about risks did appear but did not dominate the debate. People welcomed the idea of public engagement in energy and technological issues, and expressed support for the increased use of public consultation, although they recognised that governments would ultimately need to make decisions. The

authors proposed a more active engagement with the public by hydrogen advocates and government and the use of deliberative methods such as citizen juries.

3.4. CreateAcceptance project

Taking a similarly broad perspective, the recently concluded CreateAcceptance[6] project produced an analysis of the factors influencing social acceptance of new energy technologies (Hodson, *et al.* 2007; Heiskanen, *et al.* 2008). It reviewed five case studies of social acceptance towards different hydrogen and fuel cell initiatives, including the fuel cell buses deployed in Berlin and Reykjavik and the London hydrogen refuelling station. The methods used in most case studies were in-depth interviews with local residents, and local as well as global stakeholders. Content analysis of literature, media and publication materials was also carried out. The comparison of the three demonstration projects reveals that the effects they had on public opinion were very unequal. For example, the successful Berlin project went relatively unnoticed whilst the debate on the London refuelling station caused delays and a fall in the operator's reputation. The study makes a qualitative evaluation of the factors influencing these outcomes, such as the relationships between project initiators and stakeholders, the scale of the projects and the operators' risk management strategies. Heiskanen *et al.* (2008) argue, among other things, that demonstration projects should focus on managing expectations and giving the public a sense of shared benefits.

3.5. Fuel cell taxi project

In an earlier study, Mourato *et al.* (2004) used contingent valuation methods to investigate the preferences of potential drivers of fuel cell fleets, namely London taxi drivers. The study investigated attitudes towards hydrogen as a fuel, potential demand for joining a fuel cell hydrogen taxi demonstration project and the purchase intention of a future production fuel cell vehicle. In the CV survey, administered to about 100 taxi drivers, respondents were presented

with the specifications of a fuel cell taxi in terms of autonomy, costs, emissions, etc. and then offered an opportunity to join a demonstration project where they would be assigned a fuel cell taxi, in return for an annual payment. Drivers would incur the same running costs as they did with conventional petrol, and would receive maintenance, insurance and a breakdown service free of charge. The environmental advantages (zero emissions and silent operation) were highlighted. It would, however, also have a reduced range, no rear boot space, and its hydrogen fuel would only be available from two refuelling stations in London.

Both in focus groups and in the survey, there was overwhelming support for the introduction of cleaner fuels and technologies in the taxi industry although just over half of all drivers said they had heard about fuel cells beforehand. The proposal for participating in a fuel cell demonstration project was considered a good deal by 65% of the respondents, while 14% did not wish to drive a FC taxi because of reduced range, refuelling restrictions, or because they considered the technology to be unproven. Of those willing to participate in the project, 69% were willing to pay a premium for the FC taxi. The WTP of London taxi drivers to participate in the pilot project was driven principally by considerations of own personal financial well-being (i.e. reduced running costs) and showed no correlation with level of environmental or health concerns or familiarity with fuel cells. In contrast, however, environmental considerations and knowledge of the technology were found to affect taxi drivers' longer-term vehicle purchasing decisions. The qualitative part of the research (focus groups) revealed that drivers were not concerned over safety issues.

3.6. Other research

Other smaller-scale surveys that have taken place in the last five years, related specifically to HFCVs, provide similar results to the above studies in terms of finding generally positive attitudes towards hydrogen. These include a survey in Stockholm (Haraldsson*, et al.* 2006; Saxe*, et al.* 2007), which provided similar results to those of other participating cities surveyed

within AcceptH2, as well as some insights into the opinions of bus drivers. Surveys of hydrogen bus passengers in Reykjavik were also marked by positive opinions (Maack and Skulason 2006). Maack (2007) carried out a small series of focus groups where youth and energy experts gave their opinions about hydrogen. In a follow-up to the surveys carried out in the AcceptH2 project, Heinz and Erdmann (2008) carried out a study of public attitudes through brief face-to-face interviews and an online survey to university students which revealed an overall support for the hydrogen technologies. The only study found on attitudes towards hydrogen ICE (Internal Combustion Engine) buses (in Winnipeg, Canada) showed similar positive attitudes (Hickson*, et al.* 2007). However, it is important to note that some of these studies present no clear theoretical framework for the investigation of attitudes and behaviour. Although the insights they provide into the decision making process and the underlying values that determine behaviour are still useful, the inability to put the empirical findings in an explanatory theoretical framework might lessen their contributions.

Most of the studies presented above focused on either public transport or broad technological aspects of FCVs, and were based chiefly on attitudinal and stated preference surveys and/or qualitative interviews and focus groups. In contrast, Heffner *et al.* (2007a) have recently offered an alternative approach to studies on and information campaigns for the adoption of fuel cell cars, based on their experience in research into symbolism in California's market for hybrid electric vehicles. The details of their study are described below, when we review research on AFVs. Heffner *et al.* (2007a) argue that analysts err in assuming that it is always the objective functional, economic or environmental benefits that attract new buyers. It is not only a matter of households finding the calculation of these benefits complex – they find that households bought the hybrid electric vehicles (HEVs) for the *meanings* they provided about the buyers towards society (the HEV symbolizes environmental preservation, financial responsibility, independence from petroleum producers) as well as the connotations linked to these meanings, such as "behaving ethically", "being intelligent" or "unique".

Heffner *et al.* (2007a) recommend that, just as early buyers of HEVs looked for meanings that were unavailable in other types of vehicles, messages of "environmental preservation" and "advanced technology" should be clearly linked to FCVs in order to differentiate them from other types of vehicles. They also propose that future research concentrates on the ability of FCVs to symbolise the idea of "extended personal territory", as they could potentially be able to provide electricity independently.

Lastly, it is worth noting here the existence of one nation-wide effort to understand better what the public knows about hydrogen. The United States' Department of Energy (DoE) carried out a national survey in 2004 with the aim of gauging public knowledge about hydrogen, which showed low awareness and relatively high concern for safety (Cooper 2006). Repeat surveys are planned to measure changes in knowledge and opinions over time. This is an example of a large-scale initiative that, if implemented in the European context, would allow temporal monitoring of the evolution of attitudes, as well as comparison of the findings of local studies to larger contexts.

3.7. Final remarks

In sum, the last five years have witnessed the emergence of an increasing number of studies, both quantitative and qualitative, investigating public attitudes and preferences towards hydrogen technologies. A thorough and structured comparative analysis between all existing studies is hindered by methodological caveats – such as small and unrepresentative samples – and widely varying methodological frameworks. Moreover, several of the studies remain unpublished in peer-reviewed format. Nevertheless, a few summary remarks are possible.

Some of the quantitative studies reviewed have used careful research designs and relatively large sample sizes (e.g. AcceptH2 project). While some of the in-depth qualitative studies using focus groups and in-depth interviews have been helpful in revealing the stages in

evolution of attitudes in a way which quantitative methods are unable to do (e.g. Stor-HY and UKSHEC projects). A few studies looked at professional users (e.g. taxi drivers, fleet managers), some targeted end-users such as bus users and several focused on the general public (which include both potential users and non-users of the technologies). Notably, all studies but one (UKSHEC) appear to be somewhat limited in scope in that they focus on the attitudes and preferences towards specific parts of the technology (e.g. the vehicle, the storage technology), rather than on a whole-system perspective, encompassing end-use, production and distribution.

Moreover, with the exception of the AcceptH2 survey which included some individuals who had ridden on a fuel cell bus, there appear to be no structured experimental analysis of preferences for hydrogen, involving direct or virtual driving, use or purchasing of HFCVs. Therefore, currently, it is not possible to assess whether experienced utility – related to an actual use of the hydrogen technology – differs from decision utility – as elicited in stated preference surveys, attitudinal and risk perception research from people yet to experience the technology.

Arguably, the key recurring themes appear to be a somewhat positive albeit reserved public support for hydrogen vehicles and the technology in general, low awareness and moderate concerns about safety issues. Furthermore the effect of increased knowledge and familiarity with the technology on attitudes has been explored, either through the provision of written documentation on the technologies (Stor-HY) or audiovisual materials describing hydrogen in the context of other energy options. This information has been shown to kick off an evolution of attitudes towards a cautious judgement and a clear demand for extra information and tangible experience of the technology.

4. Lessons from alternative fuel vehicles research

The empirical literature related to public attitudes and preference for AFVs for transport was also reviewed by Altmann *et al*. (2003), as part of the review done for HFCVs. This review found that most of the research on attitudes and preferences towards AFVs carried out in the 1980s and 1990s focused on electric vehicles (EVs), with an emphasis on passenger cars, although some treated commercial fleets, or even AFVs generically. These were predominantly published in the United States, where scholars have a tradition of studying preferences and purchase intention for transportation, with an emphasis on households – rather than individuals – as targets of research.

The predominant methods used to estimate public views on clean transport were attitudinal surveys, stated preference surveys and experimental analysis (involving direct or virtual driving or purchasing of vehicles), or a combination of all three. In line with the some of the findings of the stated preference studies on HFCVs described above, attitudinal studies indicated that positive attitudes towards the environmental benefits of EVs are not generally accompanied by higher purchase intentions, and especially so in the presence of increased information about and experience of EVs (Golob and Gould 1998; Gould and Golob 1998). Even when a correlation is found between environmental concerns and attitudes towards cleaner vehicles or WTP for cleaner vehicles (e.g. Brownstone *et al.* (1996)), the correlations with price or performance are stronger.

Within stated preference surveys, there is a predominance of choice experiment methods, which aim to discern the roles of unique attributes of EVs on purchase decisions (Bunch*, et al.* 1993). The most important attributes that distinguish EVs from conventional vehicles have been found to be (apart from cost of vehicle purchase and operation): range between refuelling, availability of fuel, dedicated vs. multiple fuel capacity and, less importantly, reduction in emissions. Other attributes such as vehicle size – the electric car usually being the

smallest car within the overall fleet of vehicles that a household owns (Beggs and Cardell 1980) – or maximum speed and cost of delay in case of battery rundown (Cheron and Zins 1997), have also been explored. The identification and description of unique attributes and their effects on purchase is an approach that offers advantages in the study of future adoption of FCVs.

An alternative to the stated-preference approach is found in Kurani *et al.* (1994; 1996). They frame EV purchase decisions in terms of a household's entire stock of vehicles (following Beggs and Cardell (1980)), car purchase behaviour and travel behaviour. Through activity analysis, interactive interviews based on household travel diaries, activity location maps, videos and other information material are combined with stated preference surveys. As we saw in some of the findings of the studies on hydrogen and fuel cells (e.g. Stor-Hy and UKSHEC), this increased knowledge and familiarity with the technology plays a crucial role in the process of evaluation and formation of attitudes.

These same researchers developed the concept of "hybrid households", a term which refers to households that own various vehicles to satisfy different travel needs, and in which at least one person has consistently shorter travel needs (such as taking children to school). This narrowed down the population of California to 7-18% of its residents. The results of the study showed that hybrid households would not be discouraged by the limited driving range of EVs once they become aware of their needs and, again, that environmental concern is not necessarily a characteristic of potential early buyers.

Five years since the review carried out by Altmann *et al.* (2003), a number of additional major studies have taken place. Potoglou and Kanaroglou (2007) examined the factors and incentives most likely to influence household choice for cleaner vehicles in Hamilton, Canada. This web-based survey had a sample of almost 500 people and used choice modelling. It showed that dwelling-location characteristics such as land-use mix and population density were important

determinants of choices. The results also indicated that reduced costs, tax incentives and low emissions rates would encourage households to adopt a cleaner vehicle, while limited fuel availability was a concern. Willingness to pay extra in next vehicle purchase for a vehicle that would only emit 10% of a present average car was between USD 2000 and USD 5000, although the authors point out that stated environmental concerns could be higher than real ones. Although this study did not consider HFCVs, the use of land use and other urban form variables could be of interest for future studies which include HFCVs.

Noblet *et al.* (2006), examined the role of information provision in vehicle eco-labels on purchasing behaviour through a survey of 1,200 people. They distinguished two phases in the purchase decision: the choice of vehicle class (car, van, SUV, truck) and the choice of vehicle. Perhaps not surprisingly, the authors find that consumers do not react to emission information presented on labels at the class level but rather at the vehicle level. The effect of ecolabelling in the vehicle choice stage is weak and dependent on prior knowledge. Finally, through choice experiments, Ahn *et al.* (2008) investigate the preferences of 280 drivers in South Korea with regard to AFVs where factors such as vehicle usage and ownership are taken into account. Their results indicate that consumers favour compressed natural gas (CNG) or liquid petroleum gas (LPG) vehicles over HEVs.

Another recent piece of research already noted above was carried out by Heffner *et al.* (2007b), who took up semiotics (the study of symbols) as a basis for their survey of Californian households. Past research signalled towards the fact that symbolic meanings were important for buyers of EVs and HEVS (e.g. a survey quoted by them indicated that 31% of current HEV owners said they purchased an HEV because the vehicle "makes a statement about who they are"). The study of symbols, widely used in marketing studies, was thus considered to be a powerful alternative to conventional stated-preference and "rational actor" research approaches.

The results of analysing the narrative of 25 ethnographic interviews with households which had purchased an HEV, resulted in four sets of "semiotic maps" which represent the palette of symbols typically found in HEV-owning households. These maps show the links between a wide range of meanings HEVs have for their owners, and their accompanying connotations, such as "ethics", "intelligence", "independence" and "uniqueness". For example, some households were often not interested in economic savings for the financial reasons that welfare economics would propose, but because they regarded frugality as an "ethical obligation". Similarly, care for the environment did not have the same connotation for all: some were even concerned that their hybrid vehicle could portray them simplistically as "tree-huggers", rather than sensible buyers with a wide range of other concerns such as national energy independence. Other interesting meanings include the links between efficiency and intelligence of the buyers ("Hybrids are intelligence and SUVs are stupidity").

The authors go on to argue that new meanings will continue to emerge, especially as HEVs gain popularity in markets outside the US, and that this should be monitored and understood in order to best promote the market for products which bring about social or environmental benefits. As mentioned above, the emergence of new meanings is also expected for HFCVs.

Overall the key findings from these studies on AFVs appear to be that in comparison with performance and convenience attributes, environmental benefits are of relative little importance in vehicle purchase decisions, and that variables such as household characteristics and urban form play a role in the attitudes and preferences towards AFVs.

5. Conclusions and recommendations

This review aims to inform future research on public attitudes and preferences towards HFCVs. For this purpose, this section synthesizes the main theoretical frameworks and methodological approaches which have been used to date, summarises the empirical findings reviewed, and concludes by presenting a number of specific recommendations for future research.

5.1. Theoretical frameworks and methodological approaches

The main theoretical frameworks and the methodological approaches used in the studies reviewed are summarised in Table 1. The frameworks include social psychology (models for attitude formation and behavioural intention), risk perception and economic valuation of non-market goods. As an alternative to the previous three rational-actor approaches, we have found interesting the use of semiotic theory for the study of symbols related to AFVs.

Regarding research methods, the predominant trend for both HFCV and general AFV studies is the use of quantitative and qualitative attitudinal surveys. Stated preference surveys (both CV and CE) have also been used in AFVs research, although only once in relation to HFCVs (AcceptH2 project). A handful of studies have used experimental and activity analysis techniques while there is only one instance of the use of ethnographic interviews within semiotics research.

[INSERT TABLE 1 ABOUT HERE]

The weaknesses of each theoretical framework and methodological approach have been examined briefly. A key weakness of the behavioural intention models often used in attitudinal and risk perception studies is that they overlook key variables such as emotions. Alternative

(or complementary) approaches include the study of heuristics, or "rules-of-thumb" used for decision making in complex situations. On the other hand, the critics of economic valuation methods question the correlation between individuals' true economic preferences and the stated values elicited in CV surveys or choice experiments.

With regards to the data collection methods used in the studies reviewed, the authors find that while quantitative methods can provide more generalisable and conclusive results, qualitative methods render themselves more useful for achieving in-depth insights into the underlying factors affecting attitude formation and the evolution of attitudes with increased information.

In terms of their use in the field of HFCVs, a common problem faced by all the methodological approaches reviewed is that hydrogen technologies (be it production, distribution or end-use) remain mostly unknown to the consumer. There is therefore a need to build up respondents' familiarity with the object of the study prior to exploring public attitudes and preferences. Some authors explicitly address this need by providing respondents with extensive information materials about the technologies (e.g. UKSHEC and Stor-HY). Others, in the field of EVs and HEVs, have gone further and have conducted experimental analysis, involving real or virtual use of the technology, and activity analysis, entailing use of information, travel diaries and mobility maps.

5.2. Key findings

The main results from the studies reviewed in this paper are summarised in Table 2. The quantitative studies on HFCVs revealed low awareness about the technology but generally positive attitudes towards it. Opposition, where studied, was negligible. The findings also suggest that the "public" is rather a set of "publics", where differences in attitudes are seen

across gender, age, income or education groups. Willingness to pay, where studied, was positive but not generally influenced by the level of environmental awareness of respondents.

[INSERT TABLE 2 ABOUT HERE]

The qualitative research revealed a more complex mix of positive and negative attitudes. It also provided insights about how attitudes towards the technologies evolve with provision of additional information. The key results however are in line with the findings from quantitative surveys: there appears to be no significant opposition to the technologies and safety concerns were at best moderate. Only one qualitative study, UKSHEC, revealed some concern about the environmental impact of hydrogen production. This study used a "whole-system" approach to information provision, where deliberation of wider system implications of the transition to sustainable energy preceded the debate on hydrogen, and where hydrogen technologies were described from production to end use. This approach seems therefore promising in its capacity to reveal underlying public concerns.

Notwithstanding the fairly different approaches used, a comparison between HFCVs studies and AFVs research, sheds some light into other issues that could be of interest to consumers in early hydrogen vehicle markets. Choice modelling studies carried out in the 1980s and 1990s (mainly on EVs and HEVs for private use) reveal, unsurprisingly, that cost is the paramount attribute governing car purchase decisions. Performance and convenience attributes (such as range and fuel availability) follow in the ranking of attributes, with environmental benefits consistently found to be of relative little importance. This latter result is comparable to findings of HFCV studies where no consistent correlation between environmental concerns and attitudes towards HFCVs was detected. An alternative view of the drivers behind purchase of AFVs was given by the study of car purchasing behaviour through semiotics. The approach revealed the wide range of connotations that HEVs have for their owners, such as "ethics", "intelligence", "independence" and "uniqueness".

5.3. Recommendations for future research

Our review suggests a number of recommendations for use of theoretical frameworks and methodological approaches, and also for the scope and strategic objectives of future research.

Developing further the use of social psychology and non-market valuation approaches for investigating the determinants of attitudes and demand for HFCVs on a large scale is recommended, as strong and robust quantitative evidence is still relatively scarce. On the other hand, there is also the need for continued in-depth qualitative research as well as for deliberative methods (such as citizen juries) that may allow a more active engagement with the public and facilitate debate on the implications of new technologies to society. We would also argue that the adoption of more unusual theoretical frameworks such as heuristics and semiotics holds promise for a more in-depth understanding of preferences in this field. All these approaches are complementary and should be encouraged in future research in the field of hydrogen. Moreover, the proliferation of studies with no clear theoretical framework for the investigation of attitudes and behaviour (such as some of the ad-hoc surveys taking place in hydrogen vehicle demonstration projects) should be discouraged.

Given the widespread low technology awareness found by all studies and the role of information provision on the development of attitudes, it would appear that a combined use of data collection approaches (quantitative and qualitative surveys, combined with information provision, experimental or activity analysis) will yield the best results for the future study of public attitudes towards HFCVs.

We found a gap in the scope of the studies conducted so far in that they appear to focus solely on preferences for a single technology and fail to consider the broader context where substitute (or complementary) technologies might be available. We recommend that future studies take a

whole-system perspective, looking at hydrogen technologies as part of the whole energy system and in the context of other competing clean technologies.

Increased monitoring of nation-wide knowledge of and general attitudes towards hydrogen and fuel cell technologies over time would be very useful for researchers to better tailor local studies and to guide public engagement and communication strategies in a European context. The effectiveness of educational campaigns and the impact on attitudes and demand of environment-related information presented in the media could also be studied through such monitoring systems.

Of course, there are a number of caveats in our review. The field of attitude and preference studies is a vast one, and we only reviewed studies that specifically dealt with hydrogen or alternative fuel vehicles. Moreover, we have attempted to synthesize what are extensive and complex studies in a rather brief way, which has not allowed an in-depth evaluation of all the existing debates. Nevertheless, our focused review of attitude and preference studies towards HFCVs and AFVs has highlighted several existing gaps in knowledge whilst identifying a number of promising methodological approaches and avenues for further research. The existing uncertainties about the development of attitudes towards hydrogen and fuel cells in the future seem to warrant a continued research effort in this field.

6. References

Ahn, J., Jeong, G. and Kim, Y. (2008). "A forecast of household ownership and use of alternative fuel vehicles: A multiple discrete-continuous choice approach." Energy Economics **30**(5): 2091-2104.

Ajzen, I. (1991). "The theory of planned behavior." Organizational Behavior and Human Decision Processes **50**(179-211).

Altmann, M. and Graesel, C. (1998). Die Akzeptanz von Wasserstofftechnologien (The Acceptance of Hydrogen Technologies). Available online at: http://www.hyweb.de/akzepth2/summ.html. Accessed 12 April 2008.

Altmann, M., Schmidt, P., Mourato, S. and O'Garra, T. (2003). Analysis and comparison of existing studies. Final Report Work Package 3 of AcceptH2 project. Available online at http://www.accepth2.com/results/docs/WP3_final-report.pdf. Accessed on 12 October 2007.

Armitage, C. J. and Conner, M. (2001). "Efficacy of the theory of planned behaviour: A meta-analytic review." British Journal of Social Psychology **40**: 471-499.

Bateman, I. J., Carson, R. T., day, B., Hanemann, W. M., Hanley, N., Hett, T., Jones-Lee, M., Loomes, G., Mourato, S., Ozdermiroglu, E., Pearce, D. W., Sugden, R. and Swanson, J. (2002). Economic Valuation with Stated Preference Techniques: a Manual. Cheltenham, UK, Edward Elgar.

Beggs, S. D. and Cardell, N. S. (1980). "Choice of smallest car by multi-vehicle households and the demand for electric vehicles." Transportation Research Part A: General **14**(5-6): 389-404.

Bellaby, P., Upham, P., Flynn, R., Dresner, S., Fish, R., Goldring, J., Hughes, N., Ricci, M., Speakman, D. and Tomei, J. (2007). Public Engagement with Hydrogen Infrastructures in Transport. D. H. R. Programme.

Bennett, J. and Blamey, R. K. (2001). The choice modelling approach to environmental valuation. Cheltenham, Edward Elgar.

Berrens, R. P., Bohara, A. K., Jenkins-Smith, H. C., Silva, C. L. and Weimer, D. L. (2004). "Information and effort in contingent valuation surveys: application to global climate change using national internet samples." Journal of Environmental Economics and Management **47**(2): 331-363.

Blomquist, G. C. and Whitehead, J. C. (1998). "Resource quality information and validity of willingness to pay in contingent valuation." Resources and Energy Economics **20**(2): 179-196.

Brownstone, D., Bunch, D. S., Golob, T. F. and Ren, W. (1996). "A transactions choice model for forecasting demand for alternative-fuel vehicles'." Research in Transportation Economics **4**: 87-129.

Bunch, D. S., Bradley, M., Golob, T. F., Kitamura, R. and Occhiuzzo, G. P. (1993). "Demand for clean-fuel vehicles in California: A discrete-choice stated preference pilot project." Transportation Research Part A: Policy and Practice **27**(3): 237-253.

Cameron, T. A. (2005). "Updating subjective risks in the presence of conflicting information: An application to climate change." Journal of Risk and Uncertainty **30**(1): 63-97.

Carson, R. T., Neil, J. S. and Paul, B. B. (2001). Resources and Environment: Contingent Valuation. International Encyclopedia of the Social & Behavioral Sciences. Anonymous. Oxford, Pergamon**:** 13272-13275.

CEA/Cohesium-Études (2005). Étude StorHy, Étude de la dimension Sociétale, Présentation orale des principaux résultats. Results not published.

Champ, P. A., Boyle, K. J. and Brown, T. C. (2003). A Primer on Nonmarket Valuation. Dordrecht Kluwer Academic Publishers.

Cheron, E. and Zins, M. (1997). "Electric vehicle purchasing intentions: The concern over battery charge duration." Transportation Research Part A: Policy and Practice **31**(3): 235-243.

Cooper (2006). The DoE Baseline Knowledge Survey: Measuring "H2IQ".Available online at: http://www.hydrogen.energy.gov/pdfs/review06/cooper_education_survey_tues_lunch_may16.pdf, Accessed on: April 14, 2008

Dinse, G. (2000). Akzeptanz von wasserstoffbetriebenen Fahrzeugen. Eine Studie über die Verwendung eines neuen und ungewohnten Kraftstoffs (Acceptance of hydrogen vehicles - A

study on the use of a new and unusual fuel). Berlin, Institut für Mobilitätsforschung (ifmo-studien).

DoE (2007). Hydrogen, Fuel Cells & Infrastructure Technologies Program - Multi-Year Research, Development, and Demonstration Plan.

Drottz-Sjoberg, B.-M. and Sjoberg, L. (1990). "Risk perception and worries after the chernobyl accident." Journal of Environmental Psychology **10**(2): 135-149.

Eagly, A. H. and Chaiken, S. (1993). The Psychology of Attitudes, Harcourt Brace Jovanovich College Publishers.

EC (2007). "Communication from the Commission: A European strategic energy technology plan (SET-Plan) – 'Towards a low carbon future', Brussels, 22 November 2007, COM(2007) 723 final."

Edwards, P. P. (2008). Our fear of hydrogen fuel stations. The Times.

FCB (2003). "Planners reject London hydrogen station." Fuel Cells Bulletin **2003**(9): 4-9.

GHC. (2003). "Statement of The Green Hydrogen Coalition." Public Citizen Retrieved 13 August 2008, from http://www.citizen.org/cmep/energy_enviro_nuclear/renewables/articles.cfm?ID=10703.

Golob, T. F. and Gould, J. (1998). "Projecting use of electric vehicles from household vehicle trials." Transportation Research Part B: Methodological **32**(7): 441-454.

Gould, J. and Golob, T. F. (1998). "Clean air forever? A longitudinal analysis of opinions about air pollution and electric vehicles." Transportation Research Part D: Transport and Environment **3**(3): 157-169.

Haraldsson, K., Folkesson, A., Saxe, M. and Alvfors, P. (2006). "A first report on the attitude towards hydrogen fuel cell buses in Stockholm." International Journal of Hydrogen Energy **31**(3): 317-325.

Heffner, R. R., Kurani, K. S. and Turrentine, T. (2007a). "Symbolism and the Adoption of Fuel-Cell Vehicles." World Electric Vehicle Association Journal **1**: 24-31.

Heffner, R. R., Kurani, K. S. and Turrentine, T. S. (2007b). "Symbolism in California's early market for hybrid electric vehicles." Transportation Research Part D: Transport and Environment **12**(6): 396-413.

Heinz, B. and Erdmann, G. (2008). "Dynamic effects on the acceptance of hydrogen technologies--an international comparison." International Journal of Hydrogen Energy **33**(12): 3004-3008.

Heiskanen, E., Hodson, M., Mourik, R. M., Raven, R. P. J. M., Feenstra, C. F. J., Alcantud, A., Brohmann, B., Daniels, A., Fiore, M. D., Farkas, B., Fritsche, U., Fucsko, J., Hünecke, K., Jolivet, E., Maack, M., Matschoss, K., Oniszk-Poplawska, A., Poti, B., Prasad, G., Schaefer, B. and Willemse, R. (2008). Factors influencing the societal acceptance of new energy technologies: Meta-analysis of recent European projects. Available online at: http://www.createacceptance.net/fileadmin/create-acceptance/user/docs/E07058.pdf. Accessed on: 15 February 2008.

Hickson, A., Phillips, A. and Morales, G. (2007). "Public perception related to a hydrogen hybrid internal combustion engine transit bus demonstration and hydrogen fuel." Energy Policy **35**(4): 2249-2255.

Hodson, M., Marvin, S. and Simpson, V. (2007). Technological transitions and public engagement: competing visions of a hydrogen fuel station Risk and the Public Acceptance of New Technologies. R. Flynn and P. Bellaby, Palgrave MacMillan.

Kahneman, D., Tversky, A. and Slovic, P. (1982). Judgment under Uncertainty: Heuristics & Biases. Cambridge, Cambridge University Press.

Kurani, K. S., Turrentine, T. and Sperling, D. (1994). "Demand for electric vehicles in hybrid households: an exploratory analysis." Transport Policy **1**(4): 244-256.

Kurani, K. S., Turrentine, T. and Sperling, D. (1996). "Testing electric vehicle demand in `hybrid households' using a reflexive survey." Transportation Research Part D: Transport and Environment **1**(2): 131-150.

LBST. (2008). "Hydrogen Filling Stations Worldwide." Retrieved August 13, 2008, from http://www.netinform.net/h2/H2Stations/Default.aspx.

Lee, T. R. (1986). "Public attitudes towards chemical hazards." The Science of The Total Environment **51**: 125-147.

Lossen, U., Armbruster, M., Horn, S., Kraus, P. and Schich, K. (2003). "Einflussfaktoren auf den Markterfolg von wasserstoffbetriebenen Fahrzeugen (Factors influencing the market success of vehicles powered by hydrogen)." Expert verlag.

Louviere, J., Hensher, D. A. and Swait, J. (2000). Stated choice methods: analysis and applications. Cambridge, Cambridge University Press.

Maack, M. H. (2007). Energy and alternative fuel types. Preferences of young Icelanders, as presented in a focus group discussion, WP5 (social research) report for HYFLEET:CUTE project.

Maack, M. H. and Skulason, J. B. (2006). "Implementing the hydrogen economy." Journal of Cleaner Production **14**(1): 52-64.

Mitchell, R. C. and Carson, R. T. (1989). Using Surveys to Value Public Goods: the Contingent Valuation Method. Washington, Resources for the Future.

Mourato, S., Saynor, B. and Hart, D. (2004). "Greening London's black cabs: a study of driver's preferences for fuel cell taxis." Energy Policy **32**(5): 685-695.

Mumford, J. G. (2006). Improving risk communication - Strategies for public acceptance of new technology involving high impact low frequency risk. School of Management, University of Surrey. **PhD**.

Noblet, C. L., Teisl, M. F. and Rubin, J. (2006). "Factors affecting consumer assessment of eco-labeled vehicles." Transportation Research Part D: Transport and Environment **11**(6): 422-431.

O'Garra, T., Mourato, S., Garrity, L., Schmidt, P., Beerenwinkel, A., Altmann, M., Hart, D., Graesel, C. and Whitehouse, S. (2007a). "Is the public willing to pay for hydrogen buses? A comparative study of preferences in four cities." Energy Policy **35**(7): 3630-3642.

O'Garra, T., Mourato, S. and Pearson, P. (2005). "Analysing awareness and acceptability of hydrogen vehicles: A London case study." International Journal of Hydrogen Energy **30**(6): 649-659.

O'Garra, T., Mourato, S. and Pearson, P. (2008). "Investigating attitudes to hydrogen refuelling facilities and the social cost to local residents." Energy Policy **36**(6): 2074– 2085.

O'Garra, T., Pearson, P. and Mourato, S. (2007b). Public Acceptability of Hydrogen Fuel-Cell Transport and Associated Refuelling Infrastructure. Risk and the Public Acceptance of New Technologies. R. Flynn and P. Bellaby, Palgrave MacMillan.

O'Garra, T. (2005). Full Analysis Report: Comparative analysis of the Impact of the Hydrogen Bus Trials on Public Awareness, Attitudes and Preferences: a comparative study of Four cities. Final Report of AcceptH2 project. Available online at: http://www.accepth2.com/results/docs/AcceptH2_D9_Full-Analysis-Report_050804.pdf. Accessed on 12 October 2007.

O'Garra, T. and Mourato, S. (2007). "Public Preferences for Hydrogen Buses: Comparing Interval Data, OLS and Quantile Regression Approaches." Environmental and Resource Economics **36**(4): 389-411.

Pearce, D. W., Atkinson, G. and Mourato, S. (2006). Cost-Benefit Analysis and the Environment: Recent Developments. O. f. E. C.-o. a. D. (OECD). Paris.

Potoglou, D. and Kanaroglou, P. S. (2007). "Household demand and willingness to pay for clean vehicles." Transportation Research Part D: Transport and Environment **12**(4): 264-274.

Ricci, M., Bellaby, P. and Flynn, R. (2006). 'Telling it as it is': typical failings in studies of lay opinion about a Hydrogen Economy World Hydrogen Energy Conference. Lyon, France.

Ricci, M., Bellaby, P. and Flynn, R. (2007a). Stakeholders' and Publics' Perceptions of Hydrogen Energy Technologies. Risk and the Public Acceptance of New Technologies. R. Flynn and P. Bellaby, Palgrave MacMillan.

Ricci, M., Bellaby, P. and Flynn, R. (2008). "What do we know about public perceptions and acceptance of hydrogen? A critical review and new case study evidence." International Journal of Hydrogen Energy **33**(21): 5868-5880.

Ricci, M., Newsholme, G., Bellaby, P. and Flynn, R. (2007b). "The transition to hydrogen-based energy: combining technology and risks assessments and lay perspectives." International Journal of Energy Sector Management **1**(1): 34-50.

Saxe, M., Folkesson, A. and Alvfors, P. (2007). "A follow-up and conclusive report on the attitude towards hydrogen fuel cell buses in the CUTE project--From passengers in Stockholm to bus operators in Europe." International Journal of Hydrogen Energy **32**(17): 4295-4305.

Sjoberg, L. (1998). "Risk Perception: Experts and the Public." European Psychologist **3**(1): 1-12.

Slovic, P. (1987). "Perception of risk." Science **236**: 280-285.

Slovic, P., Lichtenstein, S. and Fischhoff, B. (1984). "Modeling the Societal Impact of Fatal Accidents." Management Science **30**(4): 464-474.

Smith, V. K. and Michaels, R. G. (1987). "How did households interpret chernobyl? : A bayesian analysis of risk perceptions." Economics Letters **23**(4): 359-364.

Webster, B. (2008). Hydrogen fuel stations for cars land in Britain. The Times.

Yamamoto, Y., Suzuki, A., Fuwa, Y. and Sato, T. (2008). "Decision-making in electrical appliance use in the home." Energy Policy **36**(5): 1679-1686.

Table 1. Summary of main theoretical frameworks and corresponding methodological approaches in attitudinal and consumer preference studies on alternative fuel vehicles

<table>
<tr><td rowspan="2"></td><td colspan="2">Social Psychology</td><td>Economics</td><td>Selected others</td></tr>
<tr><td>Conceptual frameworks</td><td>Attitudinal and Intended Behaviour Models (e.g. Theory of Planned Behaviour)</td><td>Risk Perception (models of behaviour in the face of risk)</td><td>Non-market Valuation (inferred economic preferences)</td><td>Semiotic Theory</td></tr>
<tr><td rowspan="2">Methodological approaches</td><td colspan="2">Attitudinal surveys (quantitative - structured questionnaires; qualitative - focus groups, in-depth interviews)</td><td>Stated Preference surveys (Contingent Valuation, Choice Experiments)</td><td>Ethnographic interviews</td></tr>
<tr><td colspan="4">Experimental Analysis, Activity Analysis</td></tr>
</table>

Table 2. Summary of main findings in studies reviewed

Hydrogen and Fuel Cell Vehicles		Alternative Fuel Vehicles
Quantitative studies	**Qualitative studies**	
Public attitudes largely positive Negligible opposition Low awareness Positive WTP (extra bus fares, taxes) Safety concern relatively low or absent No clear correlation with awareness, environmental attitudes or demographic variables	Mix of positive and negative attitudes No significant opposition Liquid storage favoured over gaseous, solid Concerns about environmental impacts of hydrogen production and storage risks Demand for information and public engagement	Ranking of EV attributes on purchase decisions: Vehicle and operation costs Range between refuelling Availability of fuel Multiple fuel capacity Reduced emissions "Hybrid households": different travel patterns influence likelihood of purchasing EV HEVs as symbols of ethics, intelligence, etc.

Footnotes

[1] Green hydrogen refers to hydrogen produced with renewable energy sources or through processes that reduce emissions of greenhouse gases (e.g. carbon sequestration), whilst black hydrogen is a term used to refer to the hydrogen produced from fossil fuels, with higher well-to-wheel emissions. Also, hydrogen produced from nuclear energy is usually considered black hydrogen (GHC 2003).

[2] The attitudes towards sitting of hydrogen refueling infrastructure have recently been treated by O'Garra *et al.* (2008), who compare the results of an exploratory survey of the population neighbouring possible locations for hydrogen refueling stations in London with other cases of controversial sitting of energy and environment-related infrastructure. A more in-depth study of the Hornchurch refueling station controversy has been undertaken by Mumford (2006) and Hodson *et al.* (2007).

[3] Clean Urban Transport for Europe (CUTE) was a European Union project which saw the development and testing of 27 fuel cell buses - three in each of nine cities in Europe – over two years (2003- 2005). The ECTOS project tested three fuel cell buses in Reykjavik, Iceland. STEP tested another three buses in Perth, Australia. The current HyFleet:CUTE project arose from the collaboration of the CUTE, ECTOS and STEP project partners and aims to operate a total of 47 hydrogen powered buses in regular public transport service in 10 cities on three continents (www.global-hydrogen-bus-platform.com).

[4] The Stor-HY Project was an R&D project focused on hydrogen storage technologies. The project was co-financed by the European Union and terminated in 2008 (www.storhy.net).

[5] UK-SHEC is funded by the UK Department of Transport Horizons Programme (www.uk-shec.org.uk). A second phase of the project has begun from which further results are expected in 2009.

[6] The CreateAcceptance project was co-financed by the European Commission and ended in 2008 (www.createacceptance.net). The findings of this project are being followed up by the Change Behaviour project (www.energychange.info).