Exploring public attitudes towards hydrogen energy: Conceptual and methodological challenges

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Abstract

This working paper addresses a series of fundamental issues related to our research task of exploring public awareness and attitudes towards new developments in hydrogen energy. In particular, it seeks to identify and discuss outstanding conceptual and methodological challenges underlying this research undertaking.

Our study has two interlocked challenges to tackle. The first challenge lies in the nature of the topic – hydrogen energy - about which public responses are to be elicited. To clarify this point, the paper discusses the complexities and uncertainties associated with hydrogen futures which are revealed across various expert accounts.

The other major challenge is to devise an appropriate methodology for probing public views on this complex topic and integrating them in meaningful public engagement mechanisms. The paper reviews the available literature on public awareness, attitudes and acceptability of hydrogen, discusses their methodologies and assumptions, and attempts to draw lessons for current and future investigations in this area.

Objectives and challenges of the study

Our study has two main objectives. Broadly, it aims to contribute to the current debate on upstream public engagement in the process of innovation and technological change. More specifically, by focusing on three areas of the UK (Teesside, South Wales and Greater London) where hydrogen energy developments are being proposed, planned or implemented, it attempts to explore public awareness of and attitudes towards the prospective role of hydrogen as an energy carrier. In particular, our research seeks to shed light on the various ways in which different sections of the public might frame the risks, costs and benefits of different hydrogen technologies and applications.

The study addresses the following research questions, which also are the issues we would like to put forward as topics for public discussion:

1. Are people aware of hydrogen energy in general and of hydrogen technology developments in their regional area?
2. Are people aware of the broader issues about energy and the environment, which also have a bearing on the increasing interest in hydrogen? What are their attitudes and behaviour in this respect?
3. What do people think of hydrogen-based technologies when given more information about them? Do they suggest any alternative?
4. What would be the main drivers (and barriers) to supporting and/or adopting hydrogen-based technologies?
5. Is there a difference between their roles as consumers and citizens?
6. What concerns (including risk issues) are raised, in which contexts are they discussed, and what role do they play? How do people frame the risks of hydrogen and their relevance to their everyday life?
7. What are the value and beliefs that shape those concerns? How do public attitudes and concerns compare with those of interested parties, such as industrial and public sector stakeholders?
8. Who should decide and act about developing hydrogen as a fuel of the future? Do people want to be involved in the broader debate about energy?

Eliciting public attitudes towards hydrogen energy carries significant challenges. *Firstly*, the technical nature of the subject is complex and associated with major uncertainties. Hydrogen energy is at a very early stage of development and can be used in rather different future technological configurations, depending on various factors. As an energy vector, hydrogen must be produced by consuming a primary source of energy. The multiplicity of production routes, the level of centralisation in production and use, the diversity of storage technologies and distribution infrastructures, and the myriad potential end-uses all concur to increase the complexity and uncertainty associated with this technology.

Looking at potential applications, hydrogen energy can be embedded in radically different technologies and products which have distinctive patterns of consumption or interaction with society. The degree of uncertainty about its future deployment and diffusion across society is great. Expert accounts are not unanimous in this respect. Some hydrogen-based technologies are nearer to commercialisation than others and a great deal of research is still needed to improve both theoretical and practical understandings.

Secondly, evidence from recent studies suggests that public knowledge and awareness of new developments in hydrogen technologies are significantly low. As argued by Shackley *et al.* (2004), who in particular refer to carbon storage and sequestration technology, major difficulties arise when presenting (and encouraging public debate about) complex technical issues which are remote from people's everyday experience and for which people have no immediate reference points.

Hydrogen energy: what does it mean and how will it look like?

The study of public awareness and attitudes towards hydrogen energy has to address, firstly, what "hydrogen energy" means and relates to. Citizens may be aware of some particularly publicised technologies based on hydrogen, such as fuel cell buses and cars, which in some cities have been part of demonstration projects. However, those popular examples represent just the "tip of the iceberg" in the wide-ranging portfolio of prospective technologies based on hydrogen. Additionally, it is not clear whether prototypes will eventually be mass-produced and whether they will look the same as today.

Focusing only on the end-uses of hydrogen leads to missing the importance and significance of the whole picture of hydrogen energy systems, which also include all the facilities and infrastructures needed for hydrogen production, storage, distribution and delivery; the knowledge base, skills and human capital required to develop and deploy those technologies; the institutional, political and organisational settings in which those developments take place; and the social, cultural and symbolic meanings associated with them.

In other words, "hydrogen energy" cannot be simply reduced to a cluster of advanced technologies and/or innovative consumer products and services, but should be regarded as a complex "socio-technical system" (Bijker *et al.*, 1987) composed by tangible technological artefacts and less tangible social, political, organisational and cultural components.

The level of complexity becomes evident as soon as the principal characteristic of hydrogen is taken into account: as an energy carrier, molecular hydrogen has to be produced because it is not available naturally as a stand-alone substance. Hydrogen can be produced by electrolysis of water or directly from coal, natural gas, biomass and nuclear power plants, by using chemical or biological processes. In all cases, a primary energy source, or feedstock, must be deployed and primary energy must be consumed to run the hydrogen production process.

There are profound differences among hydrogen production routes if they are evaluated against distinctive criteria, such as environmental sustainability, cost-effectiveness, security of supply, proximity to commercialisation, etc. This leads to a multiplicity of different scenarios of hydrogen production, and associated environmental, economic and social implications, which can be presented to the public.

Hydrogen production systems may also need to rely on additional technologies. An example is carbon dioxide (CO2) capture and storage (CCS). If hydrogen is produced from fossil fuels, by steam reforming of natural gas or coal gasification, CO_2 emissions at the production stage could outweigh the benefits of hydrogen at the point of use. CCS technology, however, is still being studied and many unknowns need to be tackled before it becomes technically mainstream.

Indeterminacy adds to complexity. Expert accounts reveal great uncertainty as to what the future holds for hydrogen production. There are contrasting expectations concerning not only the primary source and associated technologies that will be used, but also the level of centralisation in hydrogen production.

Currently, hydrogen is employed as an intermediate product, or feedstock, in a number of industrial applications, especially in the ammonia production, petrochemical refining and food industries. Virtually all hydrogen is consumed at the site of production, where steam reforming of natural gas is the most established technique. Being a well-understood production route, steam reforming is also the most cost-effective. However, it is not unanimously considered as a suitable option for long-term production of hydrogen as an energy carrier (Adamson, 2004; Romm, 2004).

A report commissioned by the WWF in co-operation with Fuel Cell Europe (Pehnt and Ramsohl, no date available) makes the same remark and adds that nuclear power and coal should be ruled out. The use of coal, even associated with CSS, "is not seen as a successful climate strategy for the next decades". As for CSS itself, it is argued that "carbon disposal remains an open issue" whereas "the safe storage of CO_2 cannot be guaranteed presently". Hart (2004) highlights the technical challenges associated with converting large-scale industrial hydrogen production processes into small-scale commercial units for distributed generation. Instead, the National Academy of Sciences (2004, p.3) believes that "the transition to a hydrogen fuel system will best be accomplished initially through distributed production of hydrogen" and envisages the diffusion of "small hydrogen-production units located at dispensing stations", based initially on steam reforming or electrolysis.

Some commentators envisage the renaissance of nuclear power, which could produce emission-free electricity for electrolysis or directly produce hydrogen via thermal processes. Others expect that hydrogen will be mostly produced by renewable sources (either directly or through electrolysis of water), in particular wind, solar and biomass. To date, there are no commercial plants that produce hydrogen from renewable energy. Moreover, operating electrolysers with intermittent renewable electricity still represents a technical challenge affecting conversion efficiency and long-term durability (Adamson, 2004).

Once produced, hydrogen must be stored and distributed to the locations of its subsequent use. Likewise production, hydrogen storage and distribution can be realised, in terms of technical possibilities, in a variety of forms.

Hydrogen storage is a particularly challenging area fraught with significant uncertainties. Being the lightest element of all, hydrogen has a very low energy-to-volume ratio. This means that storing hydrogen energy requires far more space than any other conventional form of energy. Currently, hydrogen is stored either as a gas, in pressurised cylinders, or as a liquid in specially-manufactured containers at a very low temperature (-253 °C). Although the use of hydrogen in industry and, as a fuel, in prototypes or demonstration projects is almost unequivocally considered successful, currently available storage technologies would fall short of the desired performance and cost-competitiveness necessary for a large-scale commercial roll-out, especially in the transportation sector (Harris *et al.*, 2004). Solid-state and other advanced storage technologies capable of releasing hydrogen on demand are currently being studied and tested in the laboratory, but they are still far from commercialisation.

A distribution infrastructure, comprising pipelines and tankers for road transportation, already exists in a very limited form and serves current hydrogen utilisation in industry. In the UK, for example, there is a 30 km long hydrogen pipeline network in Teesside, currently serving the local petrochemical industry. The total hydrogen pipeline system amounts to 1500 km in Europe and to 750 km in the US (Risoe, ISI, ENEA, 2005). However, to be able to sustain a future economy based on hydrogen, this (almost invisible to the public) infrastructure must be extended, either by converting that built around conventional energy technologies, or by developing new infrastructure.

Finally, hydrogen energy can be incorporated in a wide range of different products and uses, most of which are currently at laboratory or prototype scale. As any other form of energy, in principle it could be used to power anything that requires electricity or a fuel to work. The range of hydrogen-powered technologies that could be commercially available in the future is huge and comprises stationary, portable and mobile applications. They span very different products and services, from high-tech, small fuel cell-powered laptops and electronic devices, portable power for remote areas not connected to the electricity grid, to combined heat and power (CHP) units, capable of providing electricity and heat to homes, offices and businesses. In the transportation sector, hydrogen could be used as a fuel to power public buses, individual cars and any other type of heavy- and light-duty vehicles. None of these applications has reached the consumer market and costs are still dramatically high. Power from prototype fuel cells costs, in fact, roughly 100 times as much as that from a conventional petrol engine (Crabtree *et al.*, 2004; Bianucci, 2006).

The picture that has emerged so far portrays “hydrogen energy” at the core of a complex network which connects different primary energy sources to multiple end uses. Various interrelated technologies and consumer products could become part of this system, such as hydrogen refuelling stations, small residential CHP units, fuel cell cars or high-tech fuel cell-powered electronic devices. As it claimed by Andrews and Weiner (2004, p.27) in relation to the difficulty of clearly positioning hydrogen systems in the broader energy context, “the closer one looks, the more ambiguous this vision of the hydrogen economy becomes”.

At this time there is no certainty that current technological options will be maintained also in the future. Actual demonstration projects could develop into commercial products with little change, but they may well be replaced by different technologies should unexpected circumstances demand so. As stated by the NAS study (2004, p.3), the ultimate hydrogen infrastructure “cannot yet be fully identified and defined”.

Expert assessments and visions on this matter are far from consensual. A report published by the American Physical Society (2004), which develops a critical assessment of the US Hydrogen Initiative, underlines fundamental problems associated with hydrogen production, storage and use and warns that “major scientific breakthroughs are needed” (p.1). Among the recommendations, it clearly emphasises the need for funding more basic research on hydrogen technologies, while advancing research in energy efficiency and renewable energy areas. In similar vein, the NAS study (2004) identifies current barriers and research needs facing the transition to a future (and mostly desirable) hydrogen economy and calls for increased government funding on "breakthroughs in on-board storage systems, in fuel cell costs, and in material for durability" (p.4). The report also underlines uncertainties and unknowns in many areas of hydrogen technologies, including safety.

Opposite views are expressed by Amory Lovins (Motortrend, 2004), who instead claims that "light, efficient vehicles remove any need for a new hydrogen storage material or for liquid or solid storage, both of which are far costlier than simple compressed-gas storage" (p.106).

The overall desirability of a future hydrogen economy is questioned by several commentators, who express serious doubts about the ability of hydrogen to become a credible and effective competitor in the future fuel and energy landscape (Crea, 2004; Kreith and West, 2004; interview with P. MacCready, Motortrend, 2004; D.Hammerschlag and Mazza, 2005).

Further evidence of the broad spectrum of visions and expert views about the future of hydrogen energy is provided by McDowall and Eames (2004) in their detailed review of hydrogen futures literature within the UK SHEC. This study reviews a number of forecasts, scenarios, visions, backcasts and roadmaps to the hydrogen economy in order to produce a set of realistic, credible hydrogen futures, roadmaps and pathways to them, and to identify key decision and actions points along those routes. What emerges from this review is an extremely complex landscape populated by diverging views of drivers, barriers and challenges shaping a wide range of possible "hydrogen economies".

Given such a heterogeneous depiction characterised by contested assumptions and expectations, it becomes quite difficult to present the public a comprehensive and stable overview of a future hydrogen energy system.

The multiplicity, diversity and uncertainty characterising these future technologies and products bear significant consequences on the way in which the public will react to them. Important decisions of a social and political nature will have to be taken to support any of the diverse configurations of a hydrogen economy: decisions about the types of production routes to privilege (with the possible renaissance of nuclear power); the prospective large-scale adoption of such novel technologies as CCS; land use, in the case of hydrogen from biomass; and a massive increase (doubling) of the current electricity production capacity to meet future hydrogen demand (Dutton *et al.*, 2005).

To date, no study on public perceptions and attitudes towards hydrogen has addressed all these issues exhaustively. Most studies focus on transport applications and address specific projects, either existing or planned. The following section presents and summarises their findings.

Public awareness of hydrogen as a new fuel: evidence from past studies

The way people feel about a future development of a hydrogen economy may depend on their current awareness and knowledge about hydrogen, which they might have gained from media reports or other publicly available information. Hydrogen is usually presented under a positive light, and associated with global benefits to the environment (hydrogen would help reducing our dependence on fossil fuels and secure the use of domestic and renewable energy sources) and local benefits, such the improvement of air quality, and reduction of pollution and noise from vehicles and power-generating technologies. Being represented as the 'ultimate solution' to many of the energy and environmental problems afflicting the world, hydrogen and its associated technologies have so far enjoyed a favourable profile across the media and policy agendas. This contrasts with the largely negative social response to other new, unfamiliar technologies such as biotechnology, which has caused public anxiety due to its potential to 'play with nature' and create problems, rather than solving them.

Some websites supporting the development of a future "Hydrogen economy" insist that people would make a link between hydrogen and the H-bomb or the Hindenburg disaster (whereby a hydrogen-fuelled dirigible caught fire minutes before landing and caused the death of many passengers), and fear public opposition on safety grounds.

However, intensified attention at local, national and international level on the use of hydrogen as a "clean" energy carrier and fuel has not been matched by a comparably high degree of public engagement. Few studies on public attitudes towards hydrogen have in fact been published so far, the majority of which point to a general lack of awareness and knowledge of hydrogen among the lay public. Most studies consist of quantitative surveys, based on questionnaires, and just a few adopt qualitative techniques, such as interviews and discussion groups (or focus groups). Moreover, the principal focus of most studies is on public attitudes and perceptions of hydrogen as a transportation fuel, in such applications as buses and cars.

One of the few publicly available studies on public perception and acceptance of hydrogen technologies was carried out by Ludwig-Bölkow-Systemtechnik (LBST) in co-operation with the Ludwig-Maximilians University of Munich (Altmann and Graesel, 1998). The study, conducted through a questionnaire, comprises three separate investigations addressing the level of awareness, knowledge and acceptance of hydrogen technologies among the German public and the need for more information. Study 1 specifically targeted secondary school students, Study 2 targeted passengers of the first H2 bus in Munich in operation in 1997, and Study 3 compared responses given by secondary school students on the H2 bus with those given by students in the classroom in Study 1.

Study 1 elicited the views of 410 students and found that acceptance is influenced by gender and age: girls were more likely to give a negative opinion than boys and older students tended to show greater acceptance. Attitudes and behaviour towards the environment appeared to slightly increase the likelihood of acceptance. Knowledge about hydrogen was extremely low and spontaneous associations were mostly neutral. Students with prior knowledge of hydrogen had been mainly informed through the mass media. Most students pointed to the school as the principal source of information they would use to gain more knowledge about hydrogen.

Study 2 addressed the opinions of 145 passengers on board the H2 bus in Munich. Again, an overall acceptance of hydrogen emerged despite low levels of awareness and knowledge among the public. Environmental sensibility was linked to acceptance. Prior knowledge was gained through the mass media and demand for more information about hydrogen emerged.

Study 3 presents a comparative analysis of the responses from students from Study 1 (N=188) and Study 2 (N=24) to assess whether direct experience of riding the H2 bus influence perceptions and acceptance. This analysis concludes that students interviewed on the H2 bus showed greater acceptance and were more likely to associate "hydrogen" with positive assessments, such environmental benefits.

In conclusion, the authors claim that hydrogen technologies enjoy a good public reception and demonstration projects should be developed to reinforce public familiarity and trust. It is suggested that issues of safety should be the subject of research and development, but they should not be regarded as appropriate topics for public debate.

Several relevant studies exploring public attitudes to and perceptions of hydrogen-based transport technologies have been carried out within the EU-funded project AccepH2. The research investigation conducted within this project, funded by the European Commission, consists of a cross-continental study addressing public attitudes and preferences for H2 buses in London, Berlin, Luxembourg, Perth (Australia) and Oakland (USA).

Among the reports published within AcceptH2, particularly relevant is a detailed review of earlier studies on public acceptability of hydrogen which have not been published in journals or made publicly available on the internet (Altmann *et al.*, 2003). This report presents a comprehensive review of studies on public perception of hydrogen technologies and other clean vehicles and fuels, among which there are 4 investigations carried out in Germany and one in the US. These studies significantly differ in their sample size and characteristics and the methodologies used.

Dinse (1999) reports the outcome of a series of face-to-face interviews conducted in Berlin in 6 different public locations, with 150 randomly selected people in the street. The survey, based on a few open-ended questions, addressed spontaneous associations with the word "hydrogen", awareness, knowledge and attitudes towards hydrogen-powered transportation. Associations were mainly neutral and very few people recalled the Hindenburg accident. When asked for possible uses of H2, 40% of respondents mentioned energy-related uses; 61% knew about H2 vehicles, mainly through school, the press and television. Of those with prior knowledge on H2 vehicles, 71% expressed a positive opinion and interest about this technology, depending on costs, fuel consumption, environmental performance, driving autonomy and engine power. Gender differences emerged, with men more knowledgeable about H2 than women.

Another study by Dinse (2000) concerns a large-scale survey conducted with randomly-selected BMW employees across Germany, with the majority operating in Munich. Respondents (N=593) were asked about their general attitudes, interests and knowledge of H2 technology, their perception of risks and benefits, word associations, the influence of the media and issues of trust. Acceptance was found to be high, especially for males with higher qualifications. Respondents perceived the risks of H2 to be higher than those of conventional fuels; nevertheless they supported a future shift to H2 as a fuel provided it would entail comparable prices and a sufficient refuelling infrastructure. High-tech vehicles were identified as the more appropriate forms for rapid diffusion of H2 technology. Recommendations were made to increase information diffusion through schools and the media, and to improve visibility and public trust.

A passenger poll carried out by the local bus operator in Nürnberg, Germany, is also reviewed by Altmann *et al.* (2003) although the study was only reported in a press release. For this reason, details on socio-economics characteristics of the respondents (N=156) and methodological issues are not available. The main findings point to a general positive reception of the H2 bus, despite a generalised lack of knowledge on this technology. Low emissions and low noise levels were the main features of the bus which attracted positive judgements. Most respondents claimed to support the introduction of H2 as a fuel and accepted moderate increases in fare price. A similar poll was conducted by the Chicago Transit Authority and very few details are provided. Reactions to the H2 bus were mostly positive, by both drivers and passengers. The interviewed drivers expressed positive assessment of the bus performance in terms of driving and low fumes emissions and noise.

One of the most recently published studies (O'Garra *et al.*, 2005a) investigates public attitudes towards the introduction of hydrogen buses in London and attempts to identify key factors underpinning public acceptance. This study is part of a much larger investigation conducted at international level within the EU-funded AcceptH2 project. Discussing past evidence on this issue, the paper argues that despite a generalised lack of public awareness, hydrogen vehicles do attract relatively high public support. However, it is claimed that past studies have mixed results. Overall, previous findings point at prior knowledge, experience, safety and environmental concerns as having relevant influence on supportive attitudes.

By administering a telephone questionnaire to a sample of 414 London residents prior to the introduction of H2 buses, the authors found that over a third of the respondents were supportive of the introduction of hydrogen vehicles in London, whilst the remaining two-thirds needed more information to form their views. Free associations with the word 'hydrogen' were mainly neutral, followed by positive and negative associations. According to the authors, "these results suggest that public concerns with hydrogen safety are not likely to be widespread". Safety concerns, instead, appear to preoccupy the experts more than the surveyed population. The study concludes that prior knowledge about hydrogen appears to increase the likelihood of acceptance, whereas environmental concerns did not seem to influence public support for hydrogen vehicles.

Evidence that attitudes towards the environment may not have a significant role in this respect is in line with previous findings of economic research (some of which are reviewed by Mourato *et al.*, 2004) investigating purchasing intentions and actual choices of transport technologies. Cost, performance and personal benefits emerge as key factors influencing preferences for private transport.

The research investigation conducted within the AcceptH2 project, funded by the European Commission, consists of a cross-continental study addressing public attitudes and preferences for H2 buses in London, Berlin, Luxembourg, Perth (Australia) and Oakland (USA). In each city, surveys were carried out about one year prior to the introduction of H2 bus trials and compared with the results of similar surveys carried out after the H2 buses had been introduced. The objectives of these studies were to investigate public knowledge, perceptions and attitudes towards H2 fuel cell buses in each city, to estimate willingness to pay (WTP) for the large-scale introduction of H2 buses and refuelling facilities (assuming these would bring significant environmental benefits and reduce pollution and noise in participating cities), and to assess the relative influence of the bus trials on public responses by comparing ex-ante with ex-post results.

The findings from the ex-ante surveys (Neves and Mourato, 2004), conducted mainly through telephone interviews with bus users (and a number of non-users in London and Perth), indicate that perceptions about hydrogen were predominantly neutral and knowledge of hydrogen and fuel cells was relatively limited. In particular, the level of awareness of hydrogen vehicles was highest in Berlin and lowest in London, probably due to previous H2 trials in Berlin in the past. Despite this widespread lack of knowledge and awareness, support for the H2 bus trials was pretty strong. Less enthusiastic responses and the need for more information emerged when attitudes towards a large-scale introduction of H2 buses and refuelling infrastructure were investigated. Willingness to pay for a hypothetic extensive introduction of hydrogen buses was elicited by using the "contingent valuation method" via two different payment vehicles, namely the WTP per bus fare and the WTP extra taxes per year. The aggregate results show that respondents were willing to pay on average £0.21 per bus fare (approximately equivalent to 22% of the average bus fare) and £15.37 extra taxes annually, with the latter result representing a remarkably lower level of WTP. It was also found that the main variable that significantly influenced WTP was environmental sensibility.

Ex-post surveys, carried out in the same cities (except Oakland) six months after the introduction of the H2 bus trials, revealed (O'Garra, 2005) that awareness level in Berlin and London did not change significantly, whereas in Luxembourg and Perth awareness levels did increase and respondents were the most aware of H2 bus trials taking place in their city. This might have been the consequence, it is claimed, of a greater exposure to both the bus trial, more visible in a small city, and of a more extensive public dissemination campaign and media coverage than those in London and Berlin. Berlin and Luxembourg respondents showed the strongest environmental attitudes, whereas London and Perth showed the weakest attitudes towards the environment. Unconditional support for the large-scale introduction of H2 buses increased significantly six months after the commencement of the trials in all cities. Statistical analysis points to prior knowledge of hydrogen as the major driver for support in Berlin, Luxembourg and Perth. In contrast, willingness to pay for the large-scale introduction of H2 buses did not increase in most cases, being similar to that elicited in the ex-ante survey. Overall, attitudes towards the storage of hydrogen in local refuelling stations were positive.

It is concluded that, although attitudes towards hydrogen buses became more positive in all cities after the trials had begun, respondents' preferences remained almost unchanged. Spontaneous associations with the word "hydrogen" did not provide any meaningful insights into public attitudes, in fact no clear patterns of answers could be identified across cities by comparing ex-ante with ex-post results. Another interesting finding is that respondents with direct experience of H2 buses did not seem more favourable or more willing to pay than those with no direct experience, in all cities. In particular, in Luxembourg respondents interviewed on board the H2 bus appear to be less likely to unconditionally support the large-scale introduction of H2 buses and more likely to say that their support is conditional to the outcome of the bus trial. Differences in the WTP through the two proposed payment mechanisms also emerged across cities: in Luxembourg and Berlin, for instance, respondents' WTP extra taxes is significantly lower than in the other cities, whereas their WTP extra bus fare is not significantly different.

In summary, the study concludes that the public does not seem to be particularly concerned about hydrogen, thus confirming findings from previous empirical investigations on public attitudes towards hydrogen. Prior knowledge seems to have a significant influence on acceptability, but this can be a consequence of the largely positive information that is publicly available on hydrogen. Although the public is generally willing to pay for the large-scale introduction of H2 buses, preferred mechanisms of payment are different across countries. Acceptability and WTP are driven by distinctive factors across cities. Environmental concern appears to be one important driver in all cities except Luxembourg.

In another study carried out prior to the introduction of prototype hydrogen buses in Amsterdam (Van den Bosch, 2003), a very small sample (22 people) of bus passengers was interviewed. Respondents placed great importance on the environmental impact, smell and noise level of conventional buses and expected that hydrogen buses would make improvements in those areas. Safety was not thought to be a problem by most respondents, suggesting that people were confident that hydrogen buses would be at least as safe as conventional buses.

An EPSRC-funded study addressing the development of a hydrogen energy infrastructure in London investigated public acceptability of hydrogen storage, with the aid of a written questionnaire distributed to 346 households near existing refuelling station in Greater London (O'Garra, 2004 and O'Garra *et al.*, 2005b). Initial feelings about the hypothetical storage of hydrogen at the local petrol station were of a more cautious nature compared with those expressed for H2 buses, with more respondents demanding for more information to be able to give an answer. When given more information, the share of respondents who would not be concerned roughly equals that of respondents who would be concerned and that of the undecided.

Another study conducted by the Imperial College and commissioned by BP (discussed by O'Garra *et al.*, 2005b) comprises a longitudinal investigation of public acceptance of H2 refuelling stations in 3 London boroughs (Bromley, Havering and Redbridge). The study commenced in 2004 and it will address 600 households through a telephone survey, every 6 months over 3 years.

From these 2 studies supportive attitudes towards H2 facilities in London are most likely amongst younger males with prior knowledge of hydrogen. Opposition is likely to come from older people who distrust regulations, people who have already taken individual actions to influence planning and from people with scarce environmental sensibility. Among opponents, awareness and knowledge of hydrogen are low but they are no more likely to associate hydrogen with negative assessments (such as explosions, bomb and the Hindenburg accident). Most opponents also claim to be very motivated and willing to proactively oppose local H2 storage.

By assessing the findings from the London studies on H2 buses and infrastructure, risk does not emerge as a serious issue in relation acceptability of H2 buses, but it could be a sensitive issue in relation to H2 storage and refuelling facilities. Opposition, it argued, is driven by many different factors and it is suggested that the provision of more information on hydrogen could significantly change public attitudes for the better.

An empirical study has been conducted in Wales (Cherryman *et al.*, 2005) as part of a programme of activities having the goal of building a regional sustainable economy through the use of hydrogen energy. The fieldwork consisted of a series of focus groups with members of the public living in South East Wales, an area where hydrogen demonstration projects are being planned. The main objective of the research was to understand public perception and acceptability of hydrogen as a fuel. Participants were found to be generally supportive of science and trustful of the regulation of science. They also appeared to be aware of a looming energy crisis, although they were not sure about the timescales involved. Participants were not aware of hydrogen projects in Wales, neither were they informed about hydrogen buses already running in some cities around the world, including London. Different views on safety emerged. Some people felt that transportation technologies would be thoroughly tested before being put on the market, whereas others expressed more concerns about the fact that hydrogen is classified as a "highly flammable" substance. Some people were concerned about accidental releases of hydrogen and other unexpected consequences of water emission from fuel cells. Cost was the principal factor people would consider if they were to choose hydrogen technologies personally. This was true also for participants who were particularly concerned about the environment. People identified government financial support measures as a means to facilitate the uptake of hydrogen, but feared tax increases as hydrogen adoption would be left to market forces alone. People did not welcome a prospective increased fare for hydrogen buses. When faced with the prospect of a massive move to hydrogen in Wales, participants expressed general support, as that would create jobs and put the region on a more visible level. In summary, the study showed that men (and not women as in other studies) were more sceptical about hydrogen. The two main concerns were safety (both of hydrogen use and in production) and cost, which in particular seemed to override environmental considerations. Biological and renewable energy sources were identified as the most desirable options for hydrogen production.

Hydrogen energy developments are currently undergoing on the Shetland island of Unst, where a renewable energy scheme uses wind power to supply storage heaters and to produce hydrogen from water electrolysis. The scheme, called PURE (Promoting Unst's Renewable Energy), is aimed at serving the local population, thus representing the first community-owned hydrogen production facility in Europe. An EPSRC-funded project within the Supergen Programme is investigating the social representations of hydrogen in Unst and the role they play in the context of community-owned renewable energy (Sherry-Brennan *et al.*, 2005). The on-going study, based on the "social representations theory", seeks to understand how people in Unst make sense of an unfamiliar technical issue such as using hydrogen for electricity storage. Selected samples of local population and stakeholders are being interviewed about what they feel about hydrogen developments in their area, including aspects of perceived risks and benefits. The picture emerging from preliminary results is one characterised by a general lack of knowledge but positive assessment of the scheme, which is seen as a way of improving employment and economic prospects of the island.

Discussion

Very few studies have been conducted so far on public perceptions of and attitudes towards hydrogen. Of those, only a few have been published. Research on public attitudes to hydrogen has been conducted mostly through questionnaire surveys, targeting different countries and sections of the public, by employing a variety of market research methods, including contingent valuation. Largely inspired by a 'consumer behaviour' perspective, most studies have addressed only specific applications in the transportation sector. Research addressing perceptions of hydrogen infrastructure and refuelling facilities has just begun and more investigation should be done to cover relevant unexplored areas such as hydrogen production and storage facilities, and stationary and portable applications.

Given the scarcity of background information on methodologies and sample characteristics in some of the reviewed studies, it would be misleading to generalise their findings and attempt to make conclusive remarks. What clearly emerges, however, is that despite a widespread low level of public awareness and knowledge of hydrogen and its associated technologies, the public appears to support the introduction of hydrogen as a transportation fuel.

Less conclusive evidence concerns the determinants of supportive attitudes. In some cases, knowledge has been found to be positively correlated with support, although there are no indications about the depth of this knowledge (simple awareness or articulated knowledge). It must also be noted that public beliefs about hydrogen might have been largely influenced by the positive image portrayed by the media. Environmental beliefs and attitudes have no clear impact on attitudes towards hydrogen or the willingness to pay for the introduction of hydrogen technologies. Moreover, the only longitudinal study available has shown that direct experience may not increase unconditional support.

Spontaneous associations with the word 'hydrogen', neutral in most cases, seem to offer little insight into actual attitudes and acceptance. Questionnaires, despite their ability to provide statistically significant data, fail to understand the complex nature of public perceptions and understandings of unfamiliar technologies such as hydrogen. Although safety does not appear to be prominent among public responses, the qualitative research carried out in Wales indicated that concerns about safety are an important component of public perception of hydrogen, as well as broader considerations about costs and the energy scenario.

It is important to acknowledge the motivations behind all those studies. Some have been conducted to provide a useful analysis of ex post response from the general public for agendas and policies on which decisions have already been made, such as hydrogen demonstration projects in the transportation sector. The focus, scope and depth of each study are in fact largely determined by the type of agenda within which the study is performed. If hydrogen is to become an important part of the future energy landscape, public engagement should become an integral part of energy policy and hydrogen futures should become themes for open debate. Moreover, as hydrogen cannot be viewed in isolation but must be placed in the context of a multiplicity of energy sources and options, the public should be engaged in discussions about the whole range of energy possibilities and alternative paths, not just about specific, but limited, hydrogen applications.

As for the methodological approach and assumptions, in most studies 'the public' is usually referred to as generic consumers, who make decisions and choices on the basis of 'information' they receive. No considerations are made as to what role is played by the source of such information, the ways in which information is interpreted and understood, and issues of public trust in information sources. Especially in the development and diffusion of new technologies – the case of hydrogen energy makes no exception - the public is considered as the last barrier to overcome, once major technical and economic challenges have been dealt with.

Moreover, the public is generally considered as a homogeneous, uninformed or ill-informed entity which needs to be educated in order to appreciate new technologies. The underpinning rationale is the belief that more information dissipates doubts, puts an end to controversies and encourages rational decision-making by the individual. An increasing number of studies have gradually re-framed the concept of "the public" and proposed a new way of addressing and interpreting public reactions to new technologies.

An upstream question relates to the extent to which public self-reported attitudes to specific imaginary or prototype hydrogen-based technologies (such as vehicles) still hold significance in different practical contexts where other technologies in the hydrogen system play a more prominent role. As already explained, a future hydrogen economy would necessarily comprise not only clean vehicles and smart electronic devices, but also new production facilities and infrastructures for hydrogen storage and distribution. Public reactions to those potential technological developments have not been systematically studied to date, although there are a few attempts to shed light on this area (presented by Pearson *et al.*, 2005, ESRC Seminar).

Another question is linked to the temporal validity of such attitudes. In fact, there is the possibility of change over time as the hydrogen economy, whatever that will be, unfolds. Energy shortages coupled with increased fuel prices might, in the not so distant future, have a significant impact of public perception of energy issues and mediate the process whereby people negotiate the trade-off between benefits, costs and risks of new energy technologies and their inevitable infrastructures.

The "social constitutions" of hydrogen energy

Scientific discoveries and new technological developments have encountered various and contrasting public responses, ranging from enthusiasm to concern or open opposition. Recent findings from studies on public responses to new technologies (Grove-White *et al.* 2000, 1997) consolidate the idea that each technology and its associated products become embedded with a distinctive host of values and social assumptions, which Grove-White *et al.* (2000) term "social constitution". Different technologies thus have radically different social constitutions as a consequence of their specific historical development and of particular social, cultural and symbolic meanings associated with their consumption in society. According to these studies, however, this perspective about technology is widely under-recognised across industry, government and the media.

By drawing upon empirical evidence concerning public attitudes to GM organisms in the UK, Grove-White *et al.* (2000) give important insights on issues related to the development of new technologies in general. Technological advancements and novelties are framed in substantially different ways by informed stakeholders or experts and lay publics on the other side. Technical and economic assessments of benefits, costs and risks associated with new technologies often fail to address wider concerns emerging in public debates. Among those, particularly relevant are concerns over the motivations underlying the development of new technologies, the actors controlling the content and direction of technological change, and their roles and liability in case of unexpected consequences or unknown effects.

Although not every new technology may give rise to such concerns (the mobile phone is a classic example), it is nevertheless important to acknowledge the broader context in which technological development takes places and the different socio-cultural meanings associated with it.

Three important considerations developed by Grove-White *et al.* (2000) are particularly significant here. Firstly, information about new technologies, and products or services based upon them, tend to be of a positive nature, while occluding indeterminacies, unknowns or uncertainties. Secondly, people are often conceptualised generically as “consumers”, whose ability to make rational choices about new services and products predominantly depends upon the information they receive. Thirdly, trust in information providers and those who have control over new technologies is seldom accounted for as a key determinant of people’s attitudes.

Findings from their work suggest that, in some cases, people may actually become more reluctant to support new technologies after receiving more information; areas of unclear or contested knowledge, which are deliberately occluded to the public, may increase public unease with new technologies; and that trust in the actors involved in technological developments may be as important as factual evidence in shaping public reactions.

Taking these insights together, it appears that public responses to a large-scale move to hydrogen may vary significantly according to what specific hydrogen-related technology is considered. Attitudes towards the construction of new hydrogen production facilities, the siting of new fuelling stations or the introduction of hydrogen-powered public buses in highly congested cities may turn out to be radically different. The social constitutions of those technologies are in fact profoundly different, as are the risks that might be perceived in relation to each development.

Some commentators have introduced the concept of “risk signature” (Petts *et al.*, 2003) in trying to explain the different public responses to distinctive technologies that raise risk issues. Each technology or technological development may be perceived as “risky” in different ways, according to the specific nature of the risk, the group that could be potentially affected, and to whom control and responsibility are assigned. The benefits that people gain, or perceive to gain, from using certain technologies are an additional factor which can outweigh or attenuate perceived risks.

Attitudes towards hydrogen as a fuel for transportation, for example, may coexist with attitudes towards a particular type of infrastructure that needs to be developed to sustain a hydrogen energy system.

Particularly important in this context is the issue of hydrogen production. If hydrogen is to become a mainstream energy vector, it will need to be produced in far higher amounts than today. According to Macdonald (2004), the current US hydrogen production of 9 billion tons per year should be increased around 200 times to meet the entire annual energy demand of the country. New production facilities will need to be developed. Choices will need to be made in relation to the primary energy to be used to produce hydrogen. Renewable sources attract huge interest as long-term sustainable options and many public and private sector commentators suggest that it will not be difficult to take the public onboard. However, concepts like “sustainability” and “renewable” cannot simply be determined by scientific appraisals and are open to scrutiny on political, social and moral grounds. Nuclear power is sometimes referred to as a potential renewable and sustainable source of hydrogen. However this view is far from being widely shared. Wind power is another example of “benign technology” facing in some cases public opposition. This suggests that “friendliness to the environment” is a disputable (and actually disputed) concept and other interrelated factors should be accounted for when trying to understand public reaction to new technologies. The specific local context in which a ‘green’ project is planned, and the ways in which decisions are made about its implementation, do matter in understanding public reactions.

The case of the BP planning proposal rejection for a hydrogen refuelling station to be built in Hornchurch, London (discussed in Mumford, 2005), warns us that good intentions towards the environment are not sufficient to ensure unconditional support by the local public. Past controversies and incomprehension around an existing BP petrol station had in fact largely contributed to creating negative expectations on the public part, with consequent opposition. The lesson that can be learnt from this and other similar experiences is that public positive reactions to having public transport running on hydrogen might go hand in hand with public opposition to a specific hydrogen project contrasting with local communities’ needs and concerns.

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