Unfamiliar fuel: how the UK public views the infrastructure required to supply hydrogen for road transport

Paul Bellaby, Paul Upham, Rob Flynn and Miriam Ricci

Corresponding author:
Paul Bellaby, Former Professor, Centre for Social Research, University of Salford, Greater Manchester M5 4WT
Home: New Barns Farm, Hollinsclough, Buxton, Derbyshire, UK, SK17 0RQ; phone +44(0)1298 83444
paul@bellaby.plus.com

Brief biography:
Paul Bellaby graduated in both history and also economics and political science and gained his PhD at Cambridge University. He taught sociology successively at Keele, East Anglia and Salford Universities, before retiring as full-time Professor in 2008. Having published research on schooling, health at work and public health issues, in 2003 to 2012 he became a leading social-scientist in the cross-disciplinary EPSRC-funded Supergen consortium on sustainable hydrogen energy.

Other authors:
Paul Upham, Senior Research Fellow, Centre for Integrated Energy Research and Sustainability Research Institute, Energy Building. University of Leeds, Leeds, LS2 9JT
p.upham@leeds.ac.uk

Brief biography:
Dr Paul Upham is a cross-faculty Senior University Research Fellow at the Centre for Integrated Energy Research and Sustainability Research Institute, University of Leeds. He has been Visiting Professor in Governance of Energy Systems and Climate Change at the Finnish Environment Institute, Helsinki, and is an affiliate of the Tyndall Research Centre for Climate Change Research. He works on energy research R&D governance and policy, particularly socio-technical transitions theory and public and stakeholder behaviour, attitudes and practices in relation to energy system change.

Rob Flynn, Former Professor, Centre for Social Research, University of Salford, Crescent House, The Crescent, Salford, Greater Manchester M5 4WT
robflynn1@btinternet.com

Brief biography:
Rob Flynn, until retiring in 2011, was Professor of Sociology at Salford University. He published widely in urban and medical sociology and the sociology of risk and public engagement with new technologies, especially hydrogen energy. He was co-editor, with Bellaby, of ‘Risk and the Public Acceptance of New Technologies (2007, Palgrave Mamillan).

Miriam Ricci, Research Fellow, Centre for Transport & Society, Faculty of Environment and Technology, University of the West of England, Frenchay Campus, Coldharbour Lane, Bristol BS16 1QY
miriam.ricci@uwe.ac.uk

Brief biography:
Dr Miriam Ricci is Research Fellow at the Centre for Transport & Society, University of West England, Bristol. A physicist by training, she gained an interdisciplinary PhD in innovation studies at the Universities of Turin, Italy, and Manchester, with an EU Marie Curie grant. Her research interests concern the interconnections and interactions between science, technology and society, with a focus on energy, sustainability and environmental challenges.

ABSTRACT

In 2007, under contract to the UK Department for Transport, we engaged with the public about the infrastructure to supply hydrogen for transport.

We combined a quota-sample survey of 1003 across three disparate 'travel-to-work areas' in England with focus groups representative of them. We informed the groups 'at arm's length' through a purpose-made video, composed with advice from a hydrogen scientist and made by professional broadcasters.

Participants saw benefits in hydrogen energy. None rejected it on safety grounds, though many discussed the risks. The costs were considered a problem.

'The public' was not of one mind. Regular car drivers were unwilling to reduce their car use. Bus users, cyclists and walkers often sought improvements in air quality. Motorists knew more than others about hydrogen energy.

In discussion we seek psychological and socio-cultural explanations for these results. We conclude by drawing out implications for the future of hydrogen in transport.

Keywords

hydrogen-in-transport infrastructure; public engagement; contrasting travel-to-work-areas; psycho-social explanations

ACKNOWLEDGEMENTS

The project was funded by UK Department for Transport (DfT) Horizons Research Programme – Contract Number PPRO 4/54/2. The interpretation of the findings offered is the authors' and does not necessarily express the views of the DfT. Malcolm Eames was co-investigator in the original bid for funding, but unfortunately had to withdraw before fieldwork began. His place was taken by Paul Upham and all the authors took part in designing the study. They are indebted to Keith Ross, the materials scientist, for his advice on the script of the video and the 'FAQs' list for the focus groups. Creative Concern of Manchester developed the video with us. British Market Research Bureau (BMRB) conducted the survey and set up the focus groups. Rob Fish facilitated them and Nick Hughes took a turn as 'expert', as did Bellaby and Upham among the authors. The author Ricci and Dorian Speakman analysed the transcripts initially and John Goldring conducted an independent analysis. Alongside Bellaby, Julia Tomei developed the area profiles and Simon Dresner analysed the quantitative data. Rose Baker, the statistician, advised on our methods. Andrew Clark commented on the final version of the paper in the light of a study with Bellaby of public engagement with the Hydrogen Centre in South Wales in 2011. We owe a wider debt to colleagues in the EPSRC-funded Sustainable Hydrogen Energy Consortium, and especially to the members of the public in Norwich, Sheffield and Southampton who took part.

HIGHLIGHTS

1) Reports lay-public engagement with visions of hydrogen energy in road transport presented ‘at arm’s length’ from investigators
2) Focuses on infrastructure required for hydrogen’s generation, storage and distribution, both micro- and centralised
3) Based on sample survey in three travel-to-work areas with12 representative focus groups deliberating about the visions
4) Psychological and socio-cultural explanations and implications for the take-off of hydrogen energy in road transport

WORD COUNT

Text	7428
Tables	112
References	1304
Notes	0
(Subtotal:	8844)
Title Page	127
Brief Biographies	270
Acknowledgements	241
Abstract	150
Keywords	8
Highlights	89

1. Introduction

In 2013, the UK Department for Business, Innovation and Skills (BIS) published a 'roadmap' for developing hydrogen fuel-cell road vehicles and the refuelling points and other infrastructure they would need, anticipating as many as 1.5mn on UK roads by 2030 [1]. It aims for the target set by the Climate Change Act (2008): to reduce UK Green House Gases (GHGs) that contribute to global warming and so threaten climate change, by 80% of 1990's level before 2050. This comes at a time when transport is playing an increasing part in those emissions [2].

In advance of the publication of the BIS roadmap, McDowall [3] argued that such roadmaps are too often 'one-offs': they should conform to established standards and be rigorously evaluated. Part of the evaluation should be deliberation 'upstream' of implementing new technology, conducted among engineers and scientists in the field and business and other stakeholders. Arguably it should include dialogue between members of the general public and experts in the field, for the public will be affected as consumers and citizens and might push for or else resist the new technology. According to Williams and Edge [4] two-way dialogue could 'socially shape' the technology so as to form a better fit than otherwise with the demands of everyday life.

In 2006 the UK Department of Transport (DfT) Horizons Programme commissioned the project reported here. Our remit was wider than hydrogen's end-use in vehicles. It was to engage the public with the infrastructure that would be required to produce, store and distribute the considerable volume of hydrogen needed to replace oil. Subsequent studies in both Germany [5] and Norway [6] have addressed this issue with the public.

Since 2000, the UK government has advocated engagement with the public upstream of implementing new technology [7] [8]. This follows a wider trend in Europe and beyond [9] and also responds to public resistance in the UK to earlier developments, such as genetically modified crops and measles, mumps and rubella vaccination [10]. In 2000 public engagement was carried out on nanotechnology by the Royal Society and the Royal Academy of Engineering [11].

2. Background

How might hydrogen provide energy, in particular fuel for transport? [12] Our principal source for the summary that follows is long-term 'visions' for hydrogen energy drawn from an interdisciplinary panel of experts and stakeholders that did 'deliberative mapping', evaluating each vision on multiple criteria [13] [14].

Hydrogen is the most abundant of elements, but on Earth, unlike in the Sun, hydrogen is found in chemical compounds, such as water formed with oxygen and the several that with carbon form hydrocarbons - among them coal, natural gas and oil (all fossil fuels), and also biomass in plant life. Releasing hydrogen from these compounds to serve as energy in its own right requires other forms of energy: for instance, heat to 'coke' coal so as to release the mix of hydrogen and methane known as 'coal gas'; heat from nuclear reactors or geothermal processes to release hydrogen from steam; the heat in steam to reform natural gas; dark fermentation of biomass such as energy crops; and electricity to separate hydrogen from oxygen in water by electrolysis.

Hydrogen can fuel transport so long as it is converted into heat, as is petroleum in the internal combustion engine, or else into electricity to power electric motors. The latter is achieved by a hydrogen 'fuel cell', which in effect reverses the electrolysis by which hydrogen is released from oxygen in water. It leaves a residue of nothing but water.

Like both oil and electricity as sources of power in vehicles, hydrogen must be stored on board and that store has to be refilled when nearly empty. The on-board store needs to hold sufficient for a practical gap between refills. Hydrogen is gaseous at 'room' temperature and the lightest of elements. If it is to fit in a tank compact enough to sit on board a vehicle, it has to be highly pressurized, liquefied at near to absolute zero, or stored in solid state - by chemical absorption into or physical adsorption onto suitable materials.

Re-fuelling stations need to be spaced at intervals. Each might be a 'micro-generator' of hydrogen, steam-reforming natural gas fed by the national pipeline or producing hydrogen from renewable sources on-site. Otherwise it might deliver hydrogen carried by pipeline or tanker from a 'central-generator'. Like the vehicle, the re-fuelling station must store hydrogen ready for use.

Oil - in the form of petrol or diesel - is used more by far than any other fuel in transport. Electricity is in use too, but on a much smaller scale. Substituting hydrogen for oil or for electricity in transport would carry benefits, costs and risks.

They have to be weighed in the balance with the benefits, costs and risks of the fuels it might replace.

The benefits of hydrogen as compared with petroleum are that it produces no air, land and sea pollution in use [15]; that hydrogen fuel cells make no noise; and that hydrogen-in-use produces no greenhouse gases (GHGs) [16]. The same benefits apply to electrically powered vehicles. However, electricity merely carries energy from various sources, but hydrogen can also serve as a store of electricity which, when supply exceeds demand, would otherwise go to waste: whether produced intermittently from such renewable sources as wind, tide/wave and the light of the Sun, or else produced constantly from nuclear or geothermal power.

Currently, a secure supply of electricity relies on power stations in the national grid that can be turned on when demand exceeds supply. These are usually powered by natural gas, which contributes to global warming and pollution. Like other fossil fuels, natural gas is not renewable. Moreover, fossil fuels are not evenly distributed in Earth's crust. Thus countries which have to import them adversely affect their balance of trade, while suppliers of fossil fuels – national or corporate – have a vested interest in maintaining others' dependence upon them. Hydrogen energy, by contrast, can be produced sustainably from whichever low carbon energy is in abundance in any locality.

Currently, the costs of powering transport by hydrogen are high. This is largely attributable to the fact that hydrogen technology is yet to be fully developed and so gain from the economies of scale that stem from mass production. Should reserves of oil become scarcer, so the price advantage that oil has over hydrogen should diminish.

Hydrogen carries risks to the user, but not necessarily as great as often perceived [17] [18] [19]. It is the lightest element. This has the advantage that, should it escape into an open space, it will ascend rapidly, unlike petrol, which is liquid and, if spilled, can spread out on the ground and readily ignite. However, if hydrogen were to escape in an enclosed space – say a garage - it would probably explode. Like the risks associated with petrol, those of hydrogen must be controlled by technology and handling practices tailored to the fuel.

Hydrogen energy is by no means as familiar a fuel to the general public as oil. In the 2000s, prototype hydrogen buses were introduced into several world cities and researchers surveyed how the public reacted to them: in the UK [20] [21] [22]; elsewhere in the EU [23] [24]; and in other countries [25] [26]. Car manufacturers – among them BMW and Honda - have launched hydrogen cars.

Reviews of available studies have concluded that the public has slight knowledge of hydrogen energy, but, when informed, expresses little opposition and some support [24] [27]. Fewer than half of London residents polled for the Clean Urban Transport for Europe (CUTE) hydrogen fuel-cell bus project had even heard of hydrogen as a fuel and only 20% of bus users and 15% of non-users were aware of the demonstration buses then in service [20]. Professional drivers were better informed, yet only half the London taxi drivers interviewed had heard of hydrogen fuel-cells [21]. The situation was similar in many other European countries [24].

Once aware, a third of the general public questioned in the London CUTE bus project were in favour of hydrogen's introduction. Unprompted negative connotations were less frequent than expected. Interviewees mentioned positive associations (alternative fuel, clean) marginally more frequently than negative ones (the bomb, toxic) [28]. In other cities around the world, people were generally positive towards hydrogen fuel-cell buses and felt safe with the technology [25]. Nevertheless, concern for the environment had weaker influence on willingness to use cleaner transport than did price and performance [27] and a positive response seemed to depend on already trusting in science and technology and then hearing positive rather than negative reports about hydrogen energy [28].

Our project for DfT was carried out in 2007. Following feedback late in 2007 to members of Sustainable Hydrogen in Future Transport (SHIFT) at the Said Business School, Oxford University, we reported to civil servants at DfT [29]. The findings have been published passim in book chapters [30] [31]. This paper revisits the DfT project of 2007 in the wake of a recently published examination in 2011 of how neighbours of the Hydrogen Centre in the South Wales Valleys reacted to tours guided by scientists and engineers [32] [33].

That Centre is a prototype for sustainable micro-generation of hydrogen energy on a local scale for multiple uses, including refuelling vehicles. In future, viewing central-generation and distribution could be an option, but, because there is as yet no working prototype to compare with that of micro-generation at the Hydrogen Centre, the hypothetical ‘visions’ we presented to members of the public in 2007 help to fill a gap.

Moreover, the 2011 project was necessarily confined to one place, but that of 2007 had the merit of covering three disparate regions and of combining focus groups with a large-scale social survey of which the focus groups were representative. However, the project of 2011 compared reactions by age-group: adults with tertiary (18-19) and secondary (14-15) students. That of 2007 involved only adults.

In what follows, the Results section reports participants’ views not only on the benefits, but also the costs of hydrogen in transport and the safety risks it might present. Having conveyed our understanding of people’s views, in Discussion we seek to explain why they might have reacted as they did, drawing on psychological and socio-cultural theories. In Conclusion we seek the implications for the future of hydrogen energy in road transport and for further public engagement research. We begin, however, by discussing the Methods we used.

3. Methods

From its first attempts, the UK Sustainable Hydrogen Energy Consortium (UKSHEC) treated public engagement with hydrogen energy as a matter of enabling similar deliberation and dialogue among lay people to that of an expert panel. It modeled its presentation of what the public would probably find unfamiliar upon an expert panel’s ‘visions’ [14]. It also treated ‘the public’ not as if ‘one’, but as likely to be divided by gender, age, social class and place [19]. At first, UKSHEC focused on areas of England and Wales already somewhat exposed to hydrogen energy in action. It revisited the CUTE Bus demonstration in London, and also investigated more integrated, if embryonic, 'hydrogen economies' [12] on Teesside and in South Wales, on the assumption that the adult members of 'Citizens' Panels' whom we recruited for focus groups were likely to take a particular interest in such developments in their own region [34] [35] [36]. That assumption was less well-supported than we had expected.

Given the focus of our funding body, DfT, for the 2007 study we sought areas that had disparate transport patterns rather than embryonic hydrogen economies or even a hydrogen vehicle demonstration. We combined a large-scale social survey of 1003 adults in three clusters - each a travel-to-work area - with representative sub-samples of 4 focus groups in each area, making 12 in all. Quota samples from each area were recruited by British Market Research Bureau (BMRB), which conducted interviews by phone. The survey was confined to this topic, not - as often – forming part of an 'omnibus' survey, which could have diverted respondents' attention to other topics. The telephone poll was concentrated in the three areas so that we could form focus groups among those living relatively near to each other.

We selected three travel-to-work-areas (TTWAs) from the then-latest 2001 Census. A TTWA is such that, of the resident economically active population, at least 75% work in the area, and also, of everyone working in it, at least 75% live there. The TTWAs chosen differed in how people typically travelled to work. In what follows the name of the city stands for the wider travel-to-work-area of which it is the centre. Norwich is a city in the east of England with a large rural hinterland, which, in 2001, more than doubled its population in working hours with commuters. Sheffield is a northern industrial centre with a predominantly local urban daytime population that was a high user of public transport in 2001. Southampton is a major transport hub in the south, by sea, air and rail as well as road, but local-urban in its daytime population, which was a low user of public transport in 2001.

The survey questionnaire drew on previously published surveys on the public's views on hydrogen energy to enable comparisons to be drawn and was designed by the academic team. Interviewees were asked about their existing knowledge of hydrogen, their actual and intended transport behaviour and their opinions about transport and the environment in general.

The survey was sub-sampled to form the twelve focus groups: four per area. Our criteria ensured that in every area each group of 8 to 10 people was differentiated from other groups by both age (21-44 or 45 and over) and social class (manual or non-manual), and also had a balance of men and women and a spread of regular modes of mobility and opinions about transport and the environment. As a result, the focus groups were broadly representative of the wider population. Our proposal had approval from a Research Governance and Ethics Committee, on condition that participants were informed about its purpose and what it would entail for them, and were invited to give or withhold their consent to take part. After the survey interview, 80% gave informed consent to take part in focus groups: thus refusal is unlikely to have biased the groups' composition.

We modelled the focus groups on established practice in sociology [37]. Our aim was that participants should be comfortable with strangers of similar background to themselves, yet sufficiently diverse in their regular modes of mobility and opinions to be stimulated into discussion. We avoided giving the impression of 'selling' hydrogen energy. Survey respondents were given no prior information about it. The subsequent focus groups received information 'at arm's length' from the research team in a purpose-made video in familiar TV documentary style, scripted to reflect the 'visions' of the expert panel [14] and made by a media firm with voiceover by an experienced broadcaster. Pauses were built in for discussion to take place. One researcher, familiar with the TTWA, was present in each group and answered questions from the same list of Frequently Asked Questions (FAQs). Finally, the one independent chair, appointed by BMRB, chaired all the groups.

The 12 focus groups were carried out in May and June 2007 in local hotel conference facilities. Members were offered refreshments, travel costs and a small reward, which was not known to them in advance. All sessions were digitally audio-recorded, then transcribed professionally. Each focus group met once for about 90 minutes. Detailed qualitative analysis of the transcripts was undertaken by two trained respectively in the physical and environmental sciences, using a thematic approach rather than by coding and quantifying words or phrases. Their analysis of half the groups was verified by a sociologist who was independent of the research team.

4. Results

4.1. The Survey

4.1.1. Knowledge of hydrogen

One item in the survey asked participants elementary factual questions about hydrogen. Following a previous Netherlands survey [38], the questions referred both to hydrogen's transport uses and its physical properties. Answers were combined to form a scale, ranging from 0 to 8. There were extremes: over a third (35.7%) got everything wrong or just one right, and a quarter (25.3%) got everything or all but one right.

Another item was about belief in science's capacity to solve problems. While one might expect knowledge of hydrogen to be correlated with this belief, there was no such relation, rather there was large variance from linearity between the belief in science responses and mean scores on the hydrogen knowledge scale ($p<.897$). A further puzzle is that knowing about hydrogen was not significantly related to concern about climate change or being prepared to drive or fly less, and the less concerned people were about air pollution, the more likely they were to know about hydrogen ($p<0.5$). Further, while favouring charges on cars to enter cities in order to boost public transport ($p<.05$), and a higher price for petrol $p<.01$) were significantly related to knowledge of hydrogen, views on a further six potential ‘green’ changes in policy on transport derived from a poll carried out in 2000 [39] were not related to that knowledge.

4.1.2. Willingness to refuel more often

Because of limited storage capacity on board cars for cryogenic-liquid and especially compressed-gaseous hydrogen, until solid-state storage is developed it might be necessary for users to refuel up to twice as often as they do in using petrol or diesel. The survey asked drivers whether they would be willing to do this. Even the 38.6% with no ‘green’ responses at all among the eight on offer were willing to refuel more often if necessary. This suggests that driving less seemed more of a social cost to most people than refuelling twice as often.

4.1.3. Personal mobility and hydrogen knowledge

The survey asked what mode of mobility people used ‘at least 4 out of 7 days a week’. Their answers had a bearing on their knowledge, attitudes and intentions towards hydrogen energy in transport, as Table 1 shows.

[PLEASE INSERT TABLE 1]

The 64% who used their own cars regularly were less likely than others to be concerned about climate change and less likely to find air pollution and noise arising from traffic to be problematic. Slightly more walked for 15 minutes or more at least four times a week: 68.6%. Many walkers were frequent car drivers, but car drivers were less likely to walk than were bus or train users and cyclists. Walking was associated with being more likely to be concerned about both climate change and air pollution, and, for those who also drove, being willing to drive less.

The 24% who relied on buses and 16.4% who used cycles were in most respects the opposite of car drivers: they were more likely to be concerned about air and noise pollution from traffic, and those who also drove cars were prepared to do so less. It is also notable that frequent bus users were more likely than others to see science as holding the key to traffic and environment problems.

The fact that car drivers were significantly more likely than others to know about hydrogen energy is probably explained by the attention that the motoring media give to hydrogen energy. Here the hydrogen car appears, with the all-electric car, as a 'green' alternative to oil, which, of course, would enable car use to continue and at the same time allow government targets for reducing GHG emissions to be met (e.g. BBC TV 'Top Gear' [40]).

4.2. Focus Groups

The TV documentary-style video was shown while the focus groups ran. It covered the infrastructure for production, distribution and storage as well as end-use of hydrogen in transport. It also addressed safety issues.

4.2.1. Producing hydrogen

The video depicted the expert visions of hydrogen summarised in the Background section. Like electricity, hydrogen would be an energy carrier but one able to store electricity produced intermittently – as by solar, wind and marine power, or, for efficiency's sake, constantly – as by nuclear power. Storing energy produced when demand for it is low would enable its use when demand was high, so reducing the infrastructure required. Hydrogen would be emission-free in end use and so would reduce both global warming and air pollution. Also explored were the difficulty of producing enough hydrogen to meet demand in transport and the need to produce hydrogen sustainably from renewable and/or low carbon sources.

At a pause in the video, the focus groups debated what means of production would make hydrogen 'sustainable' with respect to the environment. In all three areas, groups opposed nuclear power as a source, citing the unsolved problem of radioactive waste and the threat of another Chernobyl. One person said that these defeated the object of producing hydrogen and another that nuclear power might be a target of terrorism. One group in Sheffield objected to a government proposal to overturn planning controls so as to enable nuclear expansion. Nevertheless, a group each in Norwich and Sheffield said that nuclear power was the most feasible way of tackling both energy insecurity and carbon emissions worldwide.

There was still wider opposition to using fossil fuels such as coal and natural gas for producing hydrogen. This was partly on the grounds that both were in limited supply. Most coal today in Britain was said to be imported and thus an energy security problem. Likewise it was noted that natural gas reserves in the North Sea were running out. Coal was also remembered for its toll on miners and for producing smog that was bad for health. Moreover, without efficient carbon capture and sequestration (CCS) to prevent global warming, coal was thought an inappropriate source of sustainable hydrogen. Yet some considered CCS to be impractical and perhaps unsafe.

Throughout the three areas, renewable energy - in the form of wind power - was favoured for generating hydrogen, though not accepted without question. Solar and marine sources were little discussed. Wind power was sometimes criticised on the grounds that turbines tend to occupy scenic sites and are noisy to live next to. Wind farms are relatively common in Norfolk, both on land and offshore. Here on the whole focus groups minimised the problems they posed and someone castigated the UK for being slow to develop them. A Sheffield group, however, pointed to the problem of producing enough output from wind to meet demand for power and stressed that wind is intermittent.

The groups knew relatively little about biomass as a primary source for hydrogen and often asked questions about it. The idea appealed to one participant in Norwich, who said that coppicing was traditional in Norfolk. On the other hand, it took land that might otherwise grow food. Fermenting waste, including sewage, seemed to avoid this, though in Sheffield this was associated with bad smells.

In a Sheffield group, there was some scepticism about producing hydrogen via electricity from other forms of energy, rather than using electricity directly:

> Just *throw in a sideways question which is, I'm assuming that the* amount of *electricity that you'd have to use to create hydrogen is less than the amount of electricity you'd use to power electric cars, because* otherwise why do you need hydrogen?

Issues of efficiency and cost were also raised in a group each in Southampton and Norwich. This participant represents that view:

> Expensive is the only thing that comes to mind when I see it. *Everything that's involved in converting your car, in setting up the plants, I mean, where's the point? If we've got the energy and it's* working for us now – *all right I want a better future for my son, I don't want global warming and everything else, but it's just so expensive. And what do we know about it? You're using one energy to make another* energy, I mean why not just use that energy, why make another energy from using it?

In spite of reservations that many had expressed about generating hydrogen via electricity from fossil fuels and also from nuclear power, few seemed to connect the use of electricity to power vehicles to the same sources or to understand that hydrogen could serve as a store for electricity generated from intermittent sources and/or efficiently constant sources when demand is too low to put that electricity to use.

4.2.2. Central- and micro-generation of hydrogen

The next section of the video explored contrasting scenarios for generating hydrogen: a central national-grid-like system and micro-generation on the garage forecourt. The video suggested that centrally produced hydrogen might be stored underground and distributed down existing natural gas pipelines, or else moved by tankers.

There was no overall consensus in the focus groups about central- as opposed to micro-generation. Typically individuals saw pros and cons to each. For micro-generation the scale of plant required was an issue. So too was the location of plants in relation to where people live. From one point of view the local economy might benefit from micro-generation in terms of jobs and self-sufficiency in energy (Southampton). But energy security might be impaired if locales were dependent on limited production (Sheffield). On the other hand, central generation would require distribution by tanker which would worsen congestion on the roads: the more so, the bigger and more numerous the tankers (Norwich). Compressing hydrogen to store on a road vehicle would be costly and rail distribution would be preferable (Sheffield**).** Norwich people drew attention to the complexity and potential costs of setting up a central distribution infrastructure for hydrogen. Because transporting hydrogen would consume energy, efficiency favoured use of existing infrastructure, such as the natural gas pipelines, as Southampton participants knew from local experience of the Fawley petro-chemical plants. They added that mixing hydrogen with natural gas to facilitate pipeline transportation might involve loss in efficiency.

Safety concerns were also raised. Living near micro-generation plant and equally storing centrally generated hydrogen underground and distributing it by pipeline were seen to carry the risk of explosion, because hydrogen was likely to leak undetected and its low density and high volatility meant it might have to be pressurised.

A group in Norwich concluded that people would adapt to a new infrastructure so long as they could be persuaded of its benefits:

> People could be made to understand the necessity to have the energy: people liked gas because it was convenient to them and if they can see the advantages to it in some way, *presumably eventually you'd want the* hydrogen piped into their house in the same way as (natural) gas is now.

4.2.3. End-use: benefits, risks and costs

The last section of the video showed hydrogen powering a motorcycle and implied that all vehicles could be powered by hydrogen. Hydrogen would reduce emissions. The video also highlighted the quietness of the motorbike.

On the whole, focus groups concurred with the benefits of hydrogen in transport that the video suggested. Participants in Norwich acknowledged and welcomed the absence of carbon emissions and air-polluting fumes. They felt that the silence of hydrogen fuel-cells was a benefit, as did counterparts in Sheffield and Southampton.

At the same time, the focus groups felt that hydrogen energy could carry social costs. In spite of the result the survey yielded, Norwich groups discussed three possible disadvantages - longer filling-up time, larger tank and shorter range - with constant reference to everyday experience of conventional fuels and vehicles. The consensus was that these were not major inconveniences and that hydrogen technologies would eventually be improved. In Sheffield, on the contrary, a group reacted unfavourably to the expectation that hydrogen fuel capacity of cars would be in the region of 200 miles. The size of the hydrogen storage tank was raised as a problem, citing reduced boot space for cars powered by LPG. Frequent refilling would require more hydrogen stations than petrol stations and could lead to queues. According to a Southampton group, the longer queues at filling stations could incur the impatience typical of drivers.

The economic costs of the new hydrogen technology were discussed in the younger, manual group in Southampton:

> As unemployed people, you do have to go for the second-hand market and *you have to get an old car. [There are]… people who can afford new cars* and other people who can go out, say tomorrow, [and] get one of these new *hydrogen ones, but people like me can't do that, I can't suddenly say to someone, 'Oh yes, I am going to buy a new car because it's greener'*.

However, the older non-manual group suggested that economies of scale reaped through mass production were likely to reduce costs.

Participants felt there could be risks, mainly to safety, in resorting to hydrogen. They could include noiseless engines, which many saw as a benefit. Some people in Norwich observed (jokingly) that the lack of noise would not appeal to younger 'motorbike-lovers'. (Seriously) it could raise issues of safety for blind people. A motorcyclist in Sheffield said the near-silent running would not be a problem, except for warning other road users of his approach. In Southampton, it was pointed out that cyclists and pedestrians relied on noise to know the whereabouts of motor vehicles on the road. Some sort of noise would have to be engineered into the vehicles, particularly for the sake of children.

The threat of the fuel tank of a motorbike or car exploding was a worry in Southampton. In the older non-manual group there was concern about the pressurised hydrogen in the fuel-cell of the motorbike shown on the video. Others in the same group described the motorbike as a ‘bomb on wheels’. An engineer noted that hydrogen-based cooling systems required stringent precautions, which had implications for making hydrogen-powered vehicles safe. The trial of hydrogen-powered buses in London prompted a question: what had been learned about safety? There was another query about the safety of fuel-cells in the event of a failure. The older non-manual group in Southampton questioned how recyclable the materials used in hydrogen energy vehicles might be, including the materials used in fuel-cells. The life span of fuel-cells was another issue.

In Norwich, it was suggested that introducing hydrogen as a fuel for bus fleets would increase public awareness and build familiarity. Similarly, endorsement by a celebrity would attract public attention. In Sheffield, it was noted that the look of a car was likely to be an important factor. The older manual group in Southampton observed that hydrogen cars needed to prove that they benefited the environment. Then, if hydrogen cars were attractive as commuter vehicles, they could be phased in, for many households had more than one vehicle.

4.2.4. Perceptions of risk

Risk connected with hydrogen energy was raised separately in the scripted video, but – as noted above - discussed by the groups under other heads. ‘Risk’ here implies mainly safety concerns. Health risks appeared rarely. Investment risks for end-consumers were referred to. But risks to business were not discussed.

In Norwich it was said that people needed to know how hydrogen should be handled. A Sheffield group was concerned about the explosion hazard arising from a proposal in the video that hydrogen might be mixed with methane and share pipelines, seemingly unaware that this approximated to coal gas and how it was distributed. In Southampton, one participant feared that an overland network of hydrogen pipes could be vulnerable to terrorist attack. In Sheffield, a risk from individual cars running on hydrogen fuel was thought to arise if cars were maintained as poorly as they often are today.

Many argued that the risk was relative. A Sheffield group noted that, while hydrogen in cars would entail an element of risk, it seemed no greater than for petrol. In due course the risk of hydrogen would be accepted, as was that of petrol. Similarly, in Southampton one group compared the apparent risks of hydrogen with current risks in road transport fuel, and the risk of having large storage facilities for hydrogen was put in the same context as the currently well-understood risk of the Fawley oil-refining facility. Here it was noted that the risk to the public would be minimised by assigning responsibility for managing it. In all contexts safety risks had been exaggerated by the prevalence of litigation in the United States and this had influenced the UK. People might not have sufficient knowledge of hydrogen to associate any risks with it, and, with appropriate marketing strategies to advertise its benefits, hydrogen could be made attractive. The same group added that by introducing hydrogen-fuelled vehicles into public transport, potential hazards could be discovered before hydrogen was introduced into private cars.

4.2.5. The role of science

Hydrogen energy was presented in the video as, in effect, a ‘technical fix’ for the problems which oil-based transport poses for the environment. A Norwich woman in the older non-manual group gave voice to a ‘bottom-up’ rather than this ‘top-down’ approach:

> A lot of people are ready to change. The population are thinking more ahead: if the products were there for us to use, we would be using them. (But) a lot of technology has been around for many years and certain political (interests) and the big car companies have kept on making their petrol motors, combustion engines etc, because they are making huge amounts of money. The new technology is being squashed back.

In Southampton, the type of solution science might offer was much debated, but, understandably, existing technologies were given more attention than hydrogen. A member of the older non-manual group advocated the introduction of more efficient vehicles. Another suggested that trolley-buses and electric light rail systems should be brought into use. The younger non-manual group evoked Germany where solar power was better exploited, and noted that existing technology could be better used in oil-based transport:

> Technology is not just the method of transport. *There's the whole information* side of things. A lot of the bus stops now have 'real time' timetables, yet there are other bus stops in the city, which have never [had them]*… The* technology has been around for ten years, so why has that not been rolled out?

5. Discussion

Why did focus-group members react as we have reported to having visions of hydrogen energy presented to them by the video and having an opportunity to discuss them? We seek psychological and socio-cultural explanations from the wide range available for attitudes and behaviour in relation to the environment at large [41]. We focus on three: 'cognitive dissonance', 'social representations' and 'society, culture and risk'.

5.1. Cognitive dissonance

The use of audio-visual cues in presenting hydrogen energy to the focus groups was designed to help participants connect with information about a technology that none was likely to have experienced directly.

According to learning theories, individuals usually attend to information that supports their existing cognitive schema and ignore or reject contradictory information [42]. Kearney and Kaplan [43] refer to ‘cognitive ownership’: how an individual might use a concept in such a way that it becomes part of their cognitive map, and how familiar ideas and knowledge gained through experience are more likely to be incorporated than are those newly encountered. Related to this is the theory of ‘cognitive dissonance’ [44]: that people tend to adopt attitudes consistent with their behaviour and that, if there is a conflict between the two, they reduce dissonance by changing their attitudes to justify their behaviour, perceiving themselves to have little or no choice but to act as they do, or else denying any inconsistency.

In spite of the fact that regular motorists were more likely than others to know about hydrogen energy in transport, they did not appear to have ‘cognitive ownership’ of it. In focus groups many expressed ‘cognitive dissonance’ between knowing oil was adverse for the environment and not feeling able to change the behaviour that contributed to the damage. Though substituting hydrogen for oil would enable motorists to keep their cars and protect the environment, several said that hydrogen seemed not to compare with oil on price or that investment in a hydrogen car was out of their range.

5.2. Social representations

Moscovici’s thinking [45] places cognition in a socio-cultural context and has been discussed in relation to public understanding of hydrogen energy by others

[46]. Cognition is not just an individual process, but shaped by drawing on society's 'stock of ideas' in order to make sense of complex issues [47]. 'Anchoring' is posited as the process by which new ideas become part of the existing, socially shared stock, so becoming normalised and taken for granted. 'Objectification' aids this process by associating tangible examples and instances with abstract ideas. These cognitive frameworks arise from shared culture and are often 'normative' [48, p.166].

Accordingly, while our participants readily connected hydrogen energy to their everyday transport concerns, they tended to stay with the familiar, unless the facilitator brought the discussion back to hydrogen and the infrastructure it would require. Continuing with a car, as opposed to a switch to public transport or to cycling or walking, seemed at least convenient, given the normative responsibilities to which motorists referred - to seek employment, transport children or care for elders, and probably inescapable because of how services and workplaces had become removed from where people lived.

5.3. Society, culture and risk

The sociologists Beck [49], Beck, Giddens and Lash [50] and Giddens [51] have argued that the perceived threat that modernization presents for life, health and well-being has become dominant. Beck speaks of an emerging 'Risk Society' in which the degree to which people are exposed to risks, great or small, is supplanting inherited social divisions by class, gender and ethnicity. He distinguishes risks that are ‘familiar’ from those that are ‘unfamiliar’ to participants and also risks that seem ‘imminent’ from those that seem ‘remote’.

Oil in transport was more familiar than hydrogen energy, including to motorists who followed the media, and it was the comparator in the background. Use of existing technology, including electricity to power cars, seemed more viable to many than a radical change to unfamiliar hydrogen. However, one threat - air-pollution - that oil presented did seem imminent, though largely to cyclists and walkers. By comparison climate change seemed a remote prospect.

The social anthropologist Douglas [52], [53] (see also Douglas with Wildavsky [54]) developed a theory of risk, culture and society that is not focused on modernity, but aims to be general to societies past and present and at all stages of development. She identified four cultures of risk: vulnerability, individualism, solidarity and hierarchical.

A culture of solidarity, centred on selfless commitment to protecting the environment and based on a society of strong shared boundaries and weak internal divisions, implies ‘environmental citizenship’ [55]. On entering discussion with each other, many focus group members expressed guilt at not being good environmental citizens. However, only one had made a principled decision to live within walking distance of her work and give up having a car.

Beck’s ‘Risk Society’ implies a widespread sense of vulnerability. Douglas aligned this with a weak sense of shared boundaries and marked internal divisions – say, in wealth and/or as between motorists and others. Cyclists, walkers and bus-users came nearest to a sense of vulnerability, for they were more likely than motorists to be exposed to air-pollution from oil-burning transport, especially on congested roads.

Among the majority in our samples, who were motorists, there seems to be a good fit for individualism, which favours competition and applies to societies where both shared boundaries and legitimated internal divisions are weak. Regular car-drivers were less concerned than others about the traffic congestion, noise, air pollution and global warming to which their motoring contributed. They were disinclined to accept curbs on their freedom to drive.

On the other hand, many motorists had picked up more information from the media about hydrogen replacing oil in transport than those who regularly used other modes of travel and many were no less likely than others to accept the inconveniences, costs and risks that hydrogen energy in transport might bring – including refuelling twice as often. Hierarchical culture fits the latter. It corresponds to a society with a sense of strong boundaries and widely accepted internal lines, the members of which take responsibility for their own actions and already obey shared disciplines, such as the highway-code and insuring against third party risks.

Further support for the prevalence of hierarchical culture is that the state of public transport in the UK attracted criticism from motorists and non-motorists alike. Many felt that, through poor planning, access to employment and services had become more distant from where people lived. They looked to a lead from government, implying that, if the costs were favourable, they would follow it.

6. Conclusion

None of our survey sample had encountered hydrogen energy ‘for real’. Accordingly the 2007 DfT project relied on science and engineering ‘visions’ gained from deliberation by experts and stakeholders. On the other hand, it encompassed a wider view than the live prototype of micro-generation of hydrogen at the South Wales Hydrogen Centre opened in 2008 subsequently allowed us [32] [33]. The 2007 project represented, as well as micro-generation, the option of a centralised national-grid-like infrastructure that might be required to introduce hydrogen energy into transport on the scale BIS [1] now envisages.

The research design could be a model for public engagement with visions of hydrogen energy. It combined an extensive survey of attitudes and behaviour involving mobility and the environment with intensive focus group discussions. The focus groups were to an unusual degree representative of the wider population in the areas surveyed. Though the survey shed light on how little many members of the public already knew about hydrogen as a potential transport fuel, the focus-groups had an opportunity to learn about it from a purpose-made TV-documentary-style video and by asking questions which were answered from a FAQs list by an ‘expert’. They then formed judgements by deliberating with other lay men and women who had varied modes of mobility and varied opinions on transport and the environment. Lest the research team seemed to be ‘selling’ hydrogen, the video presented it ‘at arm’s length’ from them. In turn the group discussions were independently chaired.

The findings of the survey and focus groups together suggest perceived benefits, costs and risks that might encourage or deter eventual acceptance of hydrogen energy in road transport. The majority surveyed were regular motorists, who were more likely than others to know about hydrogen's potential uses in transport from the motoring media. They were seldom willing to reduce use of their cars. The benefits for the environment of substituting hydrogen for oil in transport were largely agreed by motorists and non-motorists alike; the costs – whether of hydrogen itself or the technology to apply it in transport – seemed prohibitive to some, even if likely to fall; the risks – principally of the gas's explosion and fire – occupied a substantial share of the focus groups' discussion, though many considered them likely to be brought under control.

At the outset, most people seemed unaware of how hydrogen in the quantity required might be produced, stored and distributed and the merits and demerits of central- and micro-generation. The project points to some obstinate 'blind spots' in the public's science knowledge. Even after viewing the video and discussing it, participants did not seem to grasp that hydrogen might store electricity for future use when produced from sources that are either intermittent or constant, and that mixing hydrogen and methane in distribution pipelines was what coal gas used to do with relative safety.

However, participants were familiar with vehicles that are fuelled by oil and how to refuel them and in the groups many pooled their limited knowledge of current production, storage and distribution of oil and natural gas to address the infrastructure hydrogen would probably require. They accepted a share of responsibility for damage to the environment that oil in road transport caused but looked to government and business for the lead in finding a remedy. Some participants sought major improvements in the system of public transport and in planning the locations of housing, employment and services.

The project confirmed that the public have views on what they consider to be the problematic relationship between energy, transport and the environment, which invite genuine dialogue with scientists and engineers, policy-makers and business. This suggests that intensified public engagement with hydrogen energy might lead to a response that could materially improve its fit with the needs of its prospective users, as Williams and Edge have envisaged for upstream engagement with all new technologies [4].

TABLES

Table 1: Personal mobility by opinions on traffic and the environment, willingness to change, trust in science and knowledge of hydrogen

OPINIONS ON ENVIRONMENT /TRANSPORT	1) DRIVING OWN CAR P=64%	2) USING LOCAL/LONG DISTANCE BUS P=23%	3) BY OWN MOMENTUM i) Walking 15 mins + P=68.6%	3) BY OWN MOMENTUM ii) Cycling P=16.4%
Concerned about climate change	-.136**	+.109**	+.072*	NS
Air pollution a problem	-.117**	+.094**	+.092**	+.118**
Traffic noise a problem	-.124**	+.081*	NS	+.083**
Would drive less	-.261**	+.159**	+.245**	+.203**
Would refuel more	NS	NS	NS	NS
Science will solve the problem	NS	+.074*	NS	NS
Knowledge of hydrogen	+.079*	-.088**	NS	+.109**

Product moment correlations **p<.01; * p<.05; NS not significant

REFERENCES

[1] UK Department for Business, Innovation and Skills (BIS) (2013) https://www.gov.uk/government/publications/uk-h2mmobility-potential-for-hydrogen-fuel-cell-electric-vehicles-phase-1-results, accessed 23.02.2015.

[2] Retallack, S., Lawrence, T. & Lockwood, M., (2007), Positive Energy: Harnessing people power to prevent climate change, Institute for Public Policy Research.

[3] McDowall, W. (2012) Technology roadmaps for transition management: The case of hydrogen energy, Technological Forecasting and Social Change, 79, 530–542.

[4] Williams, R., & Edge, D. (1996). The social shaping of technology. Research Policy, 25, 856-899.

[5] Zimmer, R. & Welke, J., (2012), Let's go green with hydrogen! The general public's perspective, Int J. of Hydrogen Energy, 37.22: 17502-17508.

[6] Tarigan, K.M., Bayer, S.B., Langhelle, O., & Thesen, G., (2012), Estimating determinants of public acceptance of hydrogen vehicles and refueling stations in greater Stavanger, Int J. of Hydrogen Energy, 37.7: 6063-6073.

[7] House of Lords, (2000), Session 1999-2000, Science and Technology Third Report.

[8] www.sciencewise-erc.org.uk, accessed 25.02.2015.

[9] Hagendijk, R., & Irwin, A., (2006), Public Deliberation and Governance: Engaging with Science and Technology in Contemporary Europe, Minerva, 44.2, pp 167-184.

[10] Bellaby, P., (2003), Communication and miscommunication of risk: understanding UK parents' attitudes to combined MMR vaccination, British Medical Journal, Sep 2003; 327: 725 - 728.

[11] Royal Society and Royal Academy of Engineering, (2004), Nanotechnology and Nanoscience, www.nanotec.org.uk, accessed 24.02.2015.

[12] Rifkin, J., (2002),The Hydrogen Economy. New York: Tarcher/Putnam.

[13] Burgess, J., Stirling, A., Clark, J., Davies, G., Eames, M., Staley, K. & Williamson, S., (2007), Deliberative mapping: a novel analytic-deliberative methodology to support contested science-policy decisions, Public Understanding of Science, Vol. 16 (3): 299-322.

[14] McDowall, W. & Eames, M., (2007), Towards a sustainable hydrogen economy: A multi-criteria sustainability appraisal of competing hydrogen futures, Int.J. of Hydrogen Energy, 32.18: 4611-4626.

[15] Kunzli, N., Kaiser, R., Medina, S., Studnicka, M., Chanel, O., Filliger, P., … Sommer, H., (2000), Public-health impact of outdoor and traffic-related air pollution: a European assessment, The Lancet 356 (9232): 795-801.

[16] IPCC, (2013), United Nations Intergovernmental Panel on Climate Change, Fifth Report.

[17] Ricci M., Bellaby, P., Newsholme G., & Flynn, R., (2006), Hydrogen: too dangerous to base our future upon? Institute of Chemical Engineers, Seminar Series No 151.

[18] Ricci M., Bellaby, P., Newsholme G., & Flynn, R., (2007), The transition to hydrogen-based energy: combining technology and risk assessments and lay perspectives, International Journal of Energy Sector Management, 1.1:.34 – 50.

[19] Flynn, R., Bellaby, P., & Ricci, M., (2006), Risk perception of an emergent technology: the case of hydrogen energy, Forum Qualitative Research/Forum Qualitative Sozialforschung Vol 7, Iss 1, Art 19.

[20] O'Garra, T., Mourato, S. & Pearson, P., (2004), Analysing awareness and acceptability of hydrogen vehicles: a London case study, Int. J. of Hydrogen Energy, 30.6: 649-659.

[21] Mourato, S., Saynor, B. & Hart, D., (2004), Greening London's black cabs: a study of driver's preferences for fuel cell taxis, Energy Policy, 32.5: 685-696.

[22] Anable, J., Lane, B. & Kelay, T., (2006), An Evidence-Based Review of Public Attitudes to Climate Change and Transport Behaviour, Report for the UK Department for Transport, London.

[23] Altmann, M., Schmidt, S., Murato, S. & O'Garra, T., (2003) Analysis and Comparison of Existing Studies. Final Report, Public Acceptance of Hydrogen Transport Technologies (AcceptH2). European Commission.

[24] Hynet, (2004), Towards a European Hydrogen Energy Roadmap, HyWays Coordination Office, Ottobrun, Germany. http://www.hyways.de/hynet/ accessed 25.02.2015.

[25] Haraldsson, K., Folkesson, A., Saxe, M. & Alvfors, P., (2006), A first report on the attitude towards hydrogen fuel cell buses in Stockholm. Int J. of Hydrogen Energy, 31.3: 317-325.

[26] Momirlan, M., & Veziroglu, T.N. (2005). The properties of hydrogen as fuel tomorrow in a sustainable energy system for a cleaner planet. Int. J. of Hydrogen Energy, 30, 795-802.

[27] Altmann, M. & Gräsel, C., (1998),The Acceptance of Hydrogen Technologies, Ludwig-Bölkow-Systemtechnik GmbH and Ludwig-Maximilians University of Munich, European Commission. http://www.hyweb.de/accepth2/index.html, accessed 3.03.2015.

[28] Achterberg. P., (2012), Knowing hydrogen and loving it too? Information provision, cultural predispositions, and support for hydrogen technology among the Dutch, Public Understanding of Science, 0963662512453117, first published online, September 10, 2012.

[29] Bellaby P. & Upham P., (2008), Public Engagement with Hydrogen Infrastructures in Transport, Report for the UK Department for Transport, contract number PPRO4/54/2.

[30] Ricci, M., Bellaby, P., Flynn, R., Dresner, S., & Tomei, J. (2010), Public attitudes to hydrogen energy: evidence form six case studies in the UK. In P.Ekins (Ed.) Hydrogen Energy: Economic and Social Challenges, London & Washington DC: EarthScan.

[31] Flynn R, Ricci M, & Bellaby P., (2010), The limits of upstream engagement in an emergent technology, In P.Devine-Wright (Ed.) Renewable Energy and the Public: from NIMBYism to participation, Earthscan.

[32] Bellaby, P., & Clark, A., (2014), Lay discourse about hydrogen energy and the environment: discussion by young people and adults following a first visit to a Hydrogen Research and Demonstration Centre, Int. J. of Hydrogen Energy. 39.27: 15125-15133.

[33] Bellaby, P., & Clark, A., (2015), Might more harm be done than good when scientists and engineers engage with the public about new technology before it is fully developed? The case of hydrogen energy, Int. J. of Science Education, on-line

[34] Ricci M., Bellaby P. & Flynn R., (2007), Stakeholders' and publics' perceptions of hydrogen energy technologies. In: Flynn R. & Bellaby P., (Eds) Risk and the Public Acceptance of New Technologies, Basingstoke: Palgrave-Macmillan.

[35] Ricci, M., Bellaby, P. & Flynn, R., (2008), What do we know about public perceptions of and acceptance of hydrogen? A critical review and new case study evidence, Int. J. of Hydrogen Energy, 33.2: 5868-5880.

[36] Cherryman, S.J., King, S., Hawkes, F.R., Dinsdale, R. & Hawkes, D.L., (2008). An exploratory study of public opinions on the use of hydrogen energy in Wales, Public Understanding of Science, 17.3: 397-410.

[37] Morgan, D. (1997). Focus Groups as Qualitative Research, 2nd edition, London: Sage Publications.

[38] Zachariah-Wolff, J.L. & Hemmes, K., (2006), Public acceptance of hydrogen in the Netherlands: two surveys that demystify public views on a hydrogen economy, Bulletin of Science, Technology and Society, 32.4: 339-345.

[39] CfIT/MORI (2000) The CfiT Report: public attitudes to transport in England. A survey carried out by MORI for the Commission for Integrated Transport, London, http://www.cfit.gov.uk/index.htm and http://archive.cabinetoffice.gov.uk/servicefirst/2001/panel/newsletter8/cfit_report.pdf

[40] BBC TV 'Top Gear'. http://www.topgear.com/uk/tags/Hydrogen, accessed 25.02.2015.

[41] Upham, P., (2009), Applying environmental behaviour concepts to renewable energy siting controversy: reflections on a longitudinal bioenergy case study, Energy Policy 37.11: 4273-4283.

[42] Resnick, L.B. & Chi, M.T.H., (1988), Cognitive psychology and science learning. In M. Druger (Ed.), Science for the fun of it: A guide to informal science education (pp. 24-31). Washington, DC: National Science Teachers Association

[43] Kearney, A.R. & Kaplan, S., (1997), Toward a methodology for the measurement of k**no**wledge structures of ordinary people. The Conceptual Content Cognitive Map (3CM) Environment and Behavior, 29.5: 579-617.

[44] Festinger, L. (1957), ATheory of Cognitive Dissonance, Stanford, Cal., Stanford University Press.

[45] Moscovici, S., (1988), Notes towards a description of social representations, European Journal of Social Psychology, 18: 211-250.

[46] Sherry-Brennan, F., Devine-Wright, H., & Devine-Wright, P., (2010), Public understanding of hydrogen energy: a theoretical approach, Energy Policy, 38.10: 5311-5319.

[47] Höijer, B., (2011), Social representations theory. A new theory for media research, Nordicom Review, 32.2: 3-16.

[48] Moscovici,S., (1993), The Invention of Society, trans W.D.Halls, Oxford: Polity Press.

[49] Beck, U. (1992) Risk Society: Towards a New Modernity. London: Sage. (Translated from the German, 1986).

[50] Beck, U., Giddens, A. & Lash, S., (1994) Reflexive Modernization. Cambridge: Polity Press

[51] Giddens, A., (1999), Runaway World: how globalization is reshaping our lives. London: Profile.

[52] Douglas, M., (1966), Purity and Danger: An analysis of concepts of purity and taboo, London: Routledge & Kegan Paul.

[53] Douglas, M., (Ed.) (1992) Risk and Blame, London, Routledge.

[54] Douglas, M., & Wildavsky, A., (1982), Risk and Culture, Berkeley and London: University of California Press.

[55] Flynn, R., Ricci, M. & Bellaby, P., (2008), Environmental citizenship and public attitudes to hydrogen energy technologies. Environmental Politics, 17.5: 766-783.