Risk Perception of an Emergent Technology: the case of Hydrogen Energy

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Introduction

Concerns over global warming and climate change and the depletion of fossil fuels have intensified interest by scientists, industries and governments in the feasibility of alternative energy sources. Hydrogen can be an energy-carrier and may become an effective substitute for hydrocarbons, especially in transport. It has to be generated from other energy sources. The benefits of hydrogen lie in any savings it may make in carbon dioxide emissions or in use of scarce fossil fuels. The gains are greatest where renewable primary sources – such as wind, wave, tide or solar - are used in generating hydrogen, and also where nuclear power is the source. Various alternative scenarios, 'visions' or hydrogen futures have been identified (Hodson and Marvin, 2004; McDowall and Eames, 2004;Watson et al, 2004) using different assumptions about the economy and factors affecting technological innovation and diffusion and different timescales. Currently hydrogen energy systems are an *emergent* technology about which there is considerable scientific uncertainty and relatively little public awareness.

One way of gauging likely public perception of risks, benefits and costs of a potential hydrogen economy is to consider public perceptions of similarly new, uncertain and largely unknown technologies as studied to date. We have picked out studies of carbon storage and sequestration (CSS); genetically modified food (GM) and nanotechnology (NT). The purpose of the analysis is to examine whether lessons learned from such studies – empirical insights, concepts and methods - can be used in conducting work on public awareness of, and attitudes towards, hydrogen energy and a hydrogen economy. We have to use parallel cases because we do not know how a hydrogen future might progress and how people might perceive it as it does unfold.

Alternative parallels would be historical ones, that is, innovations that have been diffused already, even if they did not fulfil their original promise (Geels et al. 2000), or else never took off (Latour 1996). We might get a more tempered and rounded view of these than of contemporary parallels. But then we probably would not have the public consultations to examine that are in these case studies.

First, we outline the concepts of 'risk' that inform our approach to public perceptions of hydrogen and also the use we make of the three parallel case studies. This is followed by a summary of expert assessments of risks associated with hydrogen (based on reviews of the relevant scientific literatures). The case studies of public perceptions of the risks and benefits of CSS, GM and NT are then considered. Finally, the paper discusses implications for the communication of risks between experts and lay people, and broader ('upstream') questions about so-called public engagement in any emergent technology.

The Semantics of 'Risk'

(i) *Types of Risk*

'Risk' is a term of several meanings, which all too easily tend to slip into each other but need to be kept separate. They fall into three broad types. Type 1 is associated with the

closed off debate about the long-term environmental impacts of nuclear power as compared with the short-term risk of melt-down in power stations.

Ideology also intervenes by causing risk to be evaluated in relation to a familiar benchmark, such as petrol or natural gas in the case of hydrogen. This has distorting effects. It invites us to compare things on similar dimensions that are not altogether alike. Thus it is often claimed that hydrogen is as safe as or safer than petrol, whereas there are critical differences in what is required to handle each of the very different materials safely.

In managing Type 2 risk, stakeholders too restrict their vision of the future - by whatever interests they are allied with. In the case of hydrogen as energy, there is a division among proponents between those whose main interest is security of energy supply and the continuation of global capitalism as it is, and those who see hydrogen as the foundation for a new economy and polity in which control of energy is distributed, not centralised or dominated by big business (Rifkin 2002).

Where there is Type 3 risk – assured threat *or* safety – the shared culture that underpins many varied perceptions lies close to the surface and permits its examination. Concepts of ‘dirty’, ‘unhealthy’ and ‘unsafe’ and their opposites have their roots in the largely tacit ways in which culture orders our world. It is a familiar dictum that dirt is ‘matter out of place’. Similarly ‘safe’ may mean everything contained in its proper place, and ‘healthy’ the exclusion of what is unwholesome (Douglas 1964). The fact that they carry dense alternatives. In a fully rational process of decision-making, every conceivable alternative should be considered.

In taking a rational choice approach, no one element in the choice, including risk perceptions, can be adequately understood without attending to the others. Cost might be an inhibitor, even if benefits were judged to outweigh risks. Similarly, risks might inhibit choice even when benefits were high and costs low.

Uncertainty on the one hand and values on the other, tend to'bound' the scope to act rationally (Simon 1976). One way in which uncertainty is made more tractable is to avoid judging between several relatively unknown options and focus on a comparison of hydrogen with one that is familiar. Values also enter in. Thus, if benefits of hydrogen seemed marginal, even though it was competitive on costs and carried an acceptable risk, people might not part with the familiar option – 'sooner the devil we know'. Also, the new might be attractive or unattractive in itself, depending on the person's values.

We assume that publics are most likely to have been exposed to representations of hydrogen and that these refer primarily to whether hydrogen is safe in use. Benefits for environment and health are more often referred to in the representation of hydrogen as energy than are risks. Costs are relatively invisible in this early stage of development. Even if publics know that they are high, they probably expect them to fall in the future.

iv) Limitations of 'information'

The rational choice model rests on the assumption that knowledge is the basis of choice and that actors make choices that suit their interests, for example as producers or consumers. Its proponents often assume that subjects have only to be adequately informed to make appropriate choices. But this is a flawed view (Ajzen and Fishbein 1980).

First, greater *knowledge* might make subjects more sceptical, less inclined to decide for or against an option. They might say they 'don't know', even though the basis for that judgement is knowing more than they did when they felt they could make up their mind previously! Second, subjects might entertain *beliefs* that combine elements of knowledge and ideology and/or culture. Typically where knowledge is thin, it is patched with ideology. For instance, the lack of evidence to support a connection between global warming and climate change has long been patched up with a widely shared belief that extreme events are becoming or will become more common. Beliefs may be based on authority, including 'the evidence' as scientists accept it. They may also be built on own experience or on rumour, for instance having encountered a hydrogen demonstration.

green option, such as heat pump or fuel cell for central heating, in spite of the costs of each, because they value one or the other for their own particular reasons.

Fourth, *affect* often plays a part alongside cognition and value in making decisions. For instance, choice of green energy might be made ‘for the sake of my children/grandchildren’, as might choice of an SUV that seems to offer security on the school run. It has also been observed that affect tends to distort judgements about the risks associated with benefits. It is rational to perceive a combination of benefits and risks in an option, but affect (including fear) can cause people to see only risk and no benefit or only benefit and no risk (Finucane et al 2000).

Fifth, *norms* influence judgements. They are the rules that subjects are constrained by, which might be law and regulation or informal expectations. Regulation has indirect effects on consumer’s options in the energy field – notably on price - and they are probably unaware of how this happens. A relevant informal expectation that they might be aware of would be that one should not pollute the air or one should recycle scarce or toxic materials when the product that contains them is done with.

Public Perceptions of Risk

Slovic’s pathbreaking work (Slovic 2000) on perceptions of risk has shown some recurrent patterns in the social and psychological contexts of assessing risks and benefits. The most important findings include the consensus that: perceived risk is influenced by the ‘imaginability’ and memorability of a hazard; experts and laypeople tend to have different perceptions of how risky certain technologies are; disagreements about risk do not necessarily reduce or disappear in the face of ‘evidence’; fear and dread are the major axes of preference – and for any given level of benefit, higher risks may be tolerated by the public if those risks are controllable, familiar, immediate, known precisely and voluntary (Fischhoff et al, 2000). Slovic (2000a) has also shown that people’s beliefs and attitudes about risk vary along the dimensions of ‘dread’ and degree of knowledge. The extent to which risks are known or unknown is a crucial variable: people’s perceptions vary according to whether the risk is observed or observable, whether it is known to those exposed to it, whether the effect of the hazards immediate or delayed, whether it is a new risk, and whether it is known or unknown to science. Thus for example, according to Slovic, nuclear power (and nuclear weapons) have the highest ‘dread’ risk, but chemical technologies score the highest ‘unknown’ risk.

Johnson and Slovic (1995) examined public reactions to (Type 1) scientific estimates of risk uncertainty in relation to radiological and toxicological hazards. They found that people were unfamiliar with (and uncomfortable with) uncertainty in risk assessment. Low ratings of risk were treated cautiously and sceptically. How much trust the public had in government was an important mediating factor. They concluded that it should not be assumed that the lay public cannot understand uncertainty, but it should also not be assumed that explaining such uncertainties would increase people’s trust. Johnson and Slovic (1998) showed in another study of public reactions to information about environmental and health risks that it was very difficult to convey uncertainty in risk estimates. Organisations communicating information about uncertainty were seen as either honest or incompetent. Where 'low' risk levels were presented, these were regarded by laypeople as preliminary to higher estimates in future, or simply distrusted. Johnson (2003) has noted that uncertainty in environmental risk estimates raises questions in the public's mind about honesty and trustworthiness. Disagreement among experts is often ascribed to their self-interest rather than the inherent uncertainty of science itself.

In such situations, numerous researchers have identified public trust as a crucial factor. Siegrist and Cvetkovich (2000) investigated the role of social trust and knowledge in the case of ‘extreme events’). Where there is an imbalance between the low probability of the events and the scale of the hazard they present, the extreme event may seem to the public to be an ‘assured threat’ (Type 3). He notes that in situations of such indeterminacy risk communication and risk management are highly problematic.

Communication of uncertainty is, to say the least, problematic, especially when there is an elision of what we previousl lc9.6(emccpe/TTand reatand ran ess8(gwe p)-1t bas0.tlisic.)]TJTD0.0011 Tc

ii) Safety

With respect to safety (Bellaby et al 2004), current knowledge is all but limited to specific industrial practices that may have little or no relevance to future applications of hydrogen as an energy carrier, in particular in the transportation sector. In a report issued by the U.S. Department of Energy (DOE, 2003) it emerges that “hydrogen is well known as a chemical, but its use as energy carrier on a large-scale commercial basis is largely untested and undeveloped”. This is also confirmed by several documents published within the European Hydrogen Integrated Project II, which addressed the development of comprehensive safety standards and regulations for hydrogen. A general remark emerging from these reports is that “the current knowledge about hydrogen safety is less thorough than the knowledge of safety of conventional fuels”, compounded by a “general lack of data on frequency and size of hydrogen release” (EHIP II, 2002).

All the documents we have reviewed agree on some fundamental technical issues. As regards to risks to safety, unintentional hydrogen leaks are considered serious hazards. In the presence of ignition sources, such as electric sparks, flames or high heat, hydrogen leaks can cause combustion in air. This in turn may generate an explosion in specific circumstances. In fact, most of the technical reports agree that the greatest potential risk to the public appears to be a slow leak in a confined space, such as a home garage, where accumulation of hydrogen may lead to fire and explosion if no detection systems or venting are in place. Hydrogen has no odour. Its flames are almost invisible in daylight and emit less heat than other fuels, so that human senses alone are less able to detect them.

Hydrogen embrittlement of metal and non-metallic materials, such as steel and plastics, is also a potential hazard. This involves the ability of hydrogen to penetrate into the molecular structure of certain materials, where it can cause a severe loss of strength and catastrophic ruptures of hydrogen containment systems. Liquid hydrogen entails other types of hazards. In fact, hydrogen can be stored as a liquid only at very low, or cryogenic, temperature (-253 ºC). If spilled, it can cause severe frostbite. Hydrogen gas can also be asphyxiant if released in large amounts, as it can displace oxygen.

iii) Public health

As far as direct and immediate risks to public health are concerned (Bellaby 2003), all sources agree that hydrogen is non-toxecperny P10(uwln.3(o)-10.e)3(ni)e-8d.3(o)-10urcn3(o)-10o9(g)-0mos practice. The public health consequences of not following this course are most deleterious effects on the climate, including enhancing global warming and jeopardising the ozone layer.

The issue is not new to climate change experts. The International Panel on Climate Change Third Assessment Report (IPCC, 2001) points out that hydrogen can negatively interfere with the atmospheric chemistry responsible for abating methane and other major greenhouse gases, although it does not consider molecular hydrogen a direct greenhouse gas. It clearly states that "in a possible fuel-cell economy, future (hydrogen) emissions may need to be considered as a potential climate perturbation".

The Tromp et al paper received strong criticism, mostly directed at the assumed hydrogen leakage rates of 10-20%, which in the authors' opinion "should be expected". More

Grove-White and colleagues (Grove-White et al, 2000) carried out a qualitative study by interviewing twenty experts and stakeholders, and undertaking six focus groups with members of the public about the introduction of GM crops and food. This was done in the context of considerable public debate about GM during the late-1990s in Britain. First, it was observed that the professionals and specialists, who were interviewed, saw providing information to the public as conveying 'facts', not indicating areas of ignorance or uncertainty. Experts assumed that 'consumers' made judgements on the basis of what was positively known. Second, the focus groups with members of the public revealed 'widespread suspicion' of GM foods (and the motives of those promoting them) and a feeling that they had little influence over these new technologies. However, attitudes did vary between technologies – more favourable views were displayed towards Information Technology than towards GM, for example. Trust in information about GM supplied by business and government officials was limited and conditional.

Members of the public interpreted information in relation to their own experience as consumers and their trust in the information source. There was great public concern about the uncertainties surrounding the impact of GM, but this was not mirrored in expert/specialists' approach to communication of information. Grove-White and colleagues noted a 'deep cultural dislocation' between the expert framing of relevant knowledge, and typical public perceptions. Whereas the experts tended to ask 'What are the risks?' (Type 1), the public extended that question to probe 'What might be the unanticipated effects' (Type 2), and also 'Who will be responsible? ', 'Can they be trusted?' As Grove-White et al concluded, the public expected greater acknowledgement of scientific uncertainty, but:

> 'Again and again, public demands for "the facts" or "fuller information" about particular controversial products or processes have been patronised by official scientific advisors and spokesmen as misguided pleas for "absolute certainty" that "no risks exist"'
> (Grove-White et al, 2000, 29).

Public attitudes to genetically modified food were one of the five major 'risks' studied by Poortinga and Pidgeon (2003) using a large-scale nationally-representative (face-to-face interview) survey. Within a generally supportive position towards science, 39% of the respondents said that people put too much trust in science; 51% thought that scientists often try out new things without thinking about the consequences; 67% believed that scientists should listen more to what ordinary people think; and 69% replied that there is so much conflicting information that it is difficult to know what to believe. Among the five risk issues – climate change, radiation from mobile phones, radioactive waste, genetic testing and GM food - the least interest was in GM food and radiation from mobile phones. Forty-one percent considered GM food to be of importance. When asked which of the five risks posed the most risk to themselves individually (rather than to society as a whole) climate change and radioactive waste were seen as posing the greatest threat, genetic testing and mobile phone radiation as posing the least, and GM food was in the middle. When asked about different dimensions of risk, GM food (and climate change) scored most highly in terms of unknown consequences (Type 2). Generally, the least trusted sources of information were national government, business and industry, and there was scepticism about the capacity of government to manage and regulate risks. Overall, from the survey, it was shown that ‘people appeared to be less concerned about

The Royal Society study commissioned a large-scale representative sample survey (face-to-face interviews were carried out with 1,005 people) and qualitative workshops with samples of the public in Birmingham and London (carried out by BMRB) at which experts and scientists were introduced to provide information to assist the focus-group discussions. In the workshops, public awareness of NT was low, but after participants had been given more detailed information, there were some signs of positive interest in, and support for, some applications of NT. The technical report (BMRB, 2004) on these workshops demonstrated that members of the public were generally positive towards new technologies, except that GM food, embryo selection and human cloning were viewed negatively.

Even with technologies where there was public support, however, laypeople identified negative features. They went through a mental 'weighing-up' process, 'trading-off' positive and negative effects of new technologies. People concluded that no technology was intrinsically good or bad: much depended on the uses to which it was put. Indeed, participants in the workshops 'found it difficult to react to nanotechnology as a concept without seeing some of the ways in which it could be used' (BMRB, 2004, 35). However, when provided with information by scientists, respondents found it difficult to react to - some found it 'very confusing and difficult to understand' (op cit, 33). In general, participants strongly favoured control and regulation over the development of NT but were unsure how this was to be put into practice. They were nonetheless certain that the public should be involved in future regulation: it was expressed that government and scientists did not have the right to make decisions about NT without effective public

assessments are deemed desirable and the degree to which those assessments are accepted. To identify public values and integrate them in decision-making about risk management, Renn strongly advocated a communication process based on intensive dialogue and ‘mutual social learning’ or ‘co-operative discourse’ between members of the public, the scientific community and risk managers.

Similar proposals have been made in Britain in the aftermath of the public consultation about GM food. Grove-White and colleagues (2000) identified the need to move from a deficit-model of public understanding of science and simplistic notions of communicating factual information to more sophisticated approaches to ‘interactive understanding’. This was seen to be most important because of ‘the immediate practical need … to incorporate more socially sensitive antennae into the very processes of technological innovation

– for example BSE, rail safety, terrorist threats. If officials and experts wish to know what people think about a technology and its risks, Hunt et al argue, then they can neither assume public ignorance nor disregard these other contextual issues.

and citizens demanded more detail about specific applications and uses in order to judge its benefits and risks.

Conclusion

Public awareness of hydrogen energy and a potential hydrogen economy is yet to be investigated systematically. For communicating information about these issues to the lay public or engaging the public in dialogue, the (Type 1) risk assessment evidence is somewhat inconclusive; there is only early-stage provisional planning for Type 2 risks that involve the unexpected; and there is room for concern that perceived Type 3 risk – the sense of assured threat from a combustible and explosive gas - may be amplified, should a serious accident involving hydrogen occur as current niche development is rolled out to the consumer market .

As we have seen from other emergent technologies such as CCS, GM and NT, the uncertainties of science are perceived in varying ways. Different stakeholders and different publics may focus on the different types of risk. Even attempting to move public consultation further 'upstream' does not avoid this, as the framing of risks and benefits is necessarily embedded in a cultural and ideological context, and is subject to change as experience of the emergent technology unfolds.

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