

Is hydrogen safe? An approach to the study of perceptions of risk among those who may have a stake in a future hydrogen economy¹

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A hydrogen (H₂) economy is not a present reality, but a future prospect. Much about the technology required to bring it about is uncertain. Informed stakeholders tend to present a positive, consensual image of the H₂ future, but on closer inspection have varied, sometimes conflicting interests in it. Among the wider public, knowledge of the probable benefits, costs and risks is decidedly limited.

In principle, if technology currently under development could be scaled up for mass production and distribution, and if it were competitive in cost at the right time, H₂ might be substituted for fossil fuels. So might the H₂-powered fuel cell for the internal combustion engine. H₂ is not available in nature in isolation in significant amounts, but has to be generated by other power, and so can only be

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an energy carrier. It might become the carrier in future energy systems, and, if it did so, that could be on many levels, ranging from the national electricity grid through transport and domestic heating to the mobile phone. If H₂ were generated from nuclear or renewable primary power or else the CO₂ emitted in generating H₂ from hydrocarbons were sequestered, H₂ would help bring global warming under control.² If it were generated from almost any other non-fossil fuel than nuclear power, it would be clean and healthy in the long term. Moreover, H₂ could be generated in so many different ways from so many different primary energy sources that all parts of the world could become self-sufficient in energy. This might improve the economic status of poorer regions and remove an incentive for interference by powerful states that are net consumers of fossil fuels in the internal affairs of states that are net producers (Bellaby 2003).

One of the acknowledged potential obstacles to H₂'s acceptance by the public is whether it is safe in normal use as a fuel. Safety will be the focal concern of this paper. We conclude with an attempt to understand the likely relation between the risk assessment of science and the risk perceptions of those who are or may become stakeholders in a future hydrogen economy.

² It has been argued that H₂'s impact on global warming could be negative, since leaks are likely and would contribute to greenhouse gases (Tromp et al 2003). This would also be likely if it were used to power aircraft, at least at high altitudes, for water vapour left after combustion of hydrogen in air is itself a greenhouse gas. Damage to the ozone layer has also been mooted. The scale of these effects is hotly contested (see Flynn, Bellaby & Ricci 2005 and Ricci 2005 for further discussion).

Lessons for a Hydrogen Future from IT History

Geels & Smit (2000) have drawn 'lessons' for the development of all new technologies from the history of information technology (IT). In introducing our topic, we seek to apply their lessons to H₂ energy. We focus here on just two of the seven that occupy the authors.

1. *'Cultural concerns' and the promise of new technologies*

Both IT and H₂ energy have been represented as solutions to what Geels & Smit (2000) call 'cultural concerns' of the times. Some proponents see one or both new technologies as agents for decentralising the power of states and corporations and distributing it to those who are unable to control their own situations and are excluded from opportunities that others have. In similar vein, both have been viewed as means to recover social capital or 'lost community', albeit in different ways: H₂ energy by restoring the local self-sufficiency lost to dependence on geographically concentrated fossil fuels; IT, through the internet, by enabling virtual communities that have no geographic limits. These are key elements of what we shall call the 'green' agenda. An emphasis on global warming and the climate changes that might flow from it also form part of this agenda, but have a part in different agendas.

For other proponents of the two new technologies, the issue is more likely to be globalisation and whether it can be sustained. Globalisation is the diffusion of the

capitalist way of life of the West across the world. It is two-edged for, while it may sustain Western dominance by opening new markets for both goods and relatively cheap labour, it also generates competition for Western capital. After the fall of Communist regimes, the West may eventually cease to view ideological opposition as an underlying threat to globalisation, and instead focus on other threats. They are the depletion of the sources of energy on which globalisation depends, political instability in remaining oil- and gas-producer states and the prospect of climate change. Opponents of Western dominance, in turn, may favour the new technologies on the grounds that they might help displace the power of Western states and the multinational corporations that advance under their protection, and allow non-Western countries to gather the material benefits of globalisation. These are the main factors in a 'globalisation' agenda that is very different from the green agenda but itself contains significantly different opinions.

Finally, there is more diffuse 'cultural concern' about risks associated with new technology *per se*. While the issues of class and 'alienation' that remain in the green agenda would have had resonance for the Marxist C.Wright Mills (1959), Beck (1992, 1999), and Giddens (1991, 1998) have argued that 'abstract' risks, remote and out of control, that arise from the seemingly inexorable progress of technology, are supplanting class in public consciousness and becoming the new basis for inequality. The internet is beset with debate about 'safety': some of it about criminal fraud perpetrated through email, much of it about the exposure of

the public to images, opinions and personal influence that might corrupt them morally. In the energy arena, parallel issues are public perception of the uncertainties attaching to the health and safety and environment impacts of both fossil fuels and also the alternatives that some champion.

2. The 'performative value' of high claims for new technologies

Geels & Smit (2000) suggest that the promise of new technology for a distant future is typically embellished when the technology is in the 'niche' stage of development: relatively protected in a kind of nursery and not yet rolled out to an external mass market. This is because high claims for the new technology tend to help secure the necessary funding to progress the development.³

Demonstration prototypes are meant to engage the imagination of the public, and so to make charities, government agencies or venture capital confident that they will have public support in making funding available. The prototypes do not need to show a commercial return. High claims for the new technology may be tempered as they become mainstream, because they are of less value to producers and may generate expectations among consumers and investors that cannot be met.

It is in such a context as this comparison with the history of information technology suggests that we should seek to understand the perceptions

³ This is well illustrated in the case studies our colleagues are making of current niche developments of H₂ technologies in the UK (Hodson & Marvin 2004).

shareholders are likely to have of the benefits, costs and risks of H₂ technology at this niche stage of its development.

Various Informed Appraisals of Benefits, Costs and Risks of an H₂ Future

Figure 1 outlines the positions currently taken to the project of an H₂ future by those who are relatively well-informed, as proponents (green or globalisation), or as sceptics and opponents.

Proponents of globalisation envisage that H₂ would allow the current energy-intensive way of life in developed countries to survive the depletion of reserves of fossil fuels in politically unstable countries without threatening growth of the global economy or the planet itself (Jones 2003). Others project a green future in which decentralised control of H₂ would halt the global diffusion of the Western or capitalist way of life, and transform social structures and the distribution of political power (Rifkin 2002).

On the other hand there are those who adopt a more pragmatic approach to an H₂ future and are sceptical of some of the claims made for it (MacLean and Lave 2003), and still others who oppose it, having concluded that the claims are without foundation (Shinnar 2003).

These are the issues raised in Figure 1:

1. Balance of benefits/risks to life on the planet
 - a. Is H₂ safe in normal use as fuel (not liable to explode or cause fire)?
 - b. Is H₂ healthy should it escape in use (compared with fossil fuels of course, but also other alternatives, including nuclear power, and bearing in mind that H₂ has to be generated by other fuels)?
 - c. Is H₂ benign to the environment, especially for climate change (again comparatively, and in light of the same proviso)?
2. Economic viability of the project
 - a. In light of the depletion of fossil fuel reserves.
 - b. How competitive is H₂ technology now, is it likely to become competitive, and can it be made so by state intervention in the energy market?
3. Politics, or, who controls energy?
 - a. Regulation. What forms of regulatory regime – for price, supply, environment, health and safety - are likely be acceptable to policy-makers, other stakeholders and publics?
 - b. Control of energy. Is it to be individual/communal or does it remain corporate/centralised?
 - c. Geopolitics. Which countries have reserves, have the military/economic power to command those of others or must endure unequal exchange in the world market to get energy?

<i>Issues</i>	Informed appraisal of an H2 future			
	Proponent		Sceptic	Opponent
	Green	Globalisation		
<i>Benefits/Risks</i> re: Safety. Health. Environment.	√ √ √	√ √ √	? √ ?	X ? X
<i>Economics</i> re: Fossil fuel reserves. Costs of production, distribution and use - short and long term.	√ ?	√ ?	? X	X X
<i>Politics</i> re: Regulation – price, supply, environment, health & safety. Control to individual/communal from corporate/central. Access to energy in all parts of the world.	√ √ √	√ √ (but opposite to green) Relevance?	? Relevance? Relevance?	X Relevance? Relevance?

Figure 1: Sketch map of informed appraisals of benefits, costs and risks of an H₂ economy

Legend: √ = positive; X =negative; ? = uncertain

These, then, are the broader issues surrounding H₂ energy. While acceptance of such a future will depend on the trade-offs eventually made between benefits, costs and risks, we shall focus now on only one of these issues – risk – and only one aspect of it – safety. We hypothesise that safety is critical in the early stages of public exposure to this emergent technology.

Safety of H₂ as Fuel

1. Risk assessments in the science⁴

Current knowledge about the *safety* of H₂ in use is all but limited to specific industrial practices that may have little or no relevance to future applications of H₂ 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).

Near-term risks to safety are addressed by the available literature more than other potential hazards, as they have an immediate, visible effect. Moreover, safety hazards are investigated and discussed principally in the context of H₂ storage, transportation and final use, while less information is available regarding potential safety hazards of H₂ production technologies (Janssen et al, 2003).

⁴ A more comprehensive treatment of risk assessments for hydrogen as fuel is presented in Ricci, M. (2005) ..

According to Dorofeev (2003), although numerous studies have addressed safety issues related to H₂, “no solutions are available in terms of widely accepted standards, methodologies, mitigation techniques, and regulations”. Accumulated experience with H₂ is regarded as presently limited to a number of industrial applications whose scale and proximity to the general public are small.

The widespread diffusion of H₂ as an energy carrier would necessarily require that people use it with the same level of confidence and familiarity as its fossil fuel counterparts, such as natural gas and petrol. H₂, however, is rather different from those conventional fuels in terms of physical and chemical characteristics (NASA, 1997; Cadwaller and Herring, 1999; Lanz *et al.*, 2001; HSE, 2004), so that its behaviour in leakages, fires and explosions, and consequently prevention and mitigation procedures, are significantly different.

All the documents we have reviewed agree on some fundamental technical issues. As regards to risks to safety, unintentional H₂ leaks are considered serious hazards. In the presence of ignition sources, such as electric sparks, flames or high heat, H₂ 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 H₂ may lead to fire and explosion if no detection systems or venting are in place. H₂ 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.

H₂ embrittlement of metal and non-metallic materials, such as steel and plastics, is also a potential hazard. This involves the ability of H₂ to penetrate into the molecular structure of certain materials, where it can cause a severe loss of strength and catastrophic ruptures of H₂ containment systems. Liquid H₂ entails other types of hazards. Given its very low cryogenic temperature (-253 °C), it can cause severe frostbite. H₂ gas can also be asphyxiant if released in large amounts, as it can displace oxygen.

The most recent comparative study of fuel safety (Alcock *et al.*, 2001), aimed at collating existing safety data related to H₂ and other conventional vehicle fuels, analyses the physical and chemical properties of H₂ to discuss their possible implications in terms of risks to safety. Unfortunately, this study does not offer detailed practical guidance. It is suggested that H₂ safety should take into account several factors: the specific context in which an unintentional release of H₂ may occur; the specific form of H₂ being handled (liquid or gaseous); and its particular ignition and explosion modalities under those particular circumstances. The report concludes that H₂ may be either safer or less safe than conventional fuels depending on the context in which it is used.

Different authors take varied approaches to assessing H₂ safety, often leading to contradictory results. This reflects, both the absence of an accepted way to tackle this issue, and also the profound uncertainty that characterises early-stage H₂ energy technologies. Some focus on only a few H₂ properties to deduce general statements about its comparative safety, others take into account a combination of those properties and attempt to draw conclusions valid in specific technical situations.

In a study funded by the National Hydrogen Association (discussed in Cadwaller and Herring, 1999), a qualitative assessment of the relative safety of H₂ as compared to other fuels concluded that H₂ is more dangerous than methane and less dangerous than propane. Significantly different conclusions are presented in Barbir, who analyses the possible consequences of unintended H₂ leaks and compares them to those of conventional fossil fuels, by considering only the relative energy content of the fuels. It is argued, for example, that a H₂ leak would be less dangerous than a natural gas leak. Analogously, it is claimed that a H₂ explosion would be less severe than in the case of other fuels.

Another study (DTI, 1997) developed a risk assessment of several H₂ accident scenarios, namely fuel tank fire or explosion in unconfined spaces, fuel tank fire or explosion in tunnels, fuel line leaks in unconfined spaces, fuel leak in a garage, and refuelling station accidents. The study concluded that in a collision in open spaces, a H₂ FC car would be safer than either natural gas or petrol

vehicle. In a tunnel collision, a H₂ fuel cell car should be *nearly as safe as* a natural gas vehicle, both being *less dangerous* than petrol and LPG cars.

Uncertainties and knowledge gaps become particularly evident when disastrous events involving H₂ are considered, such as explosions with high-pressure gas. Limited experience of severe accidents has been accumulated so far and chiefly within industrial settings, so that H₂ explosion phenomena following high-pressure releases and their likelihood of occurrence are poorly understood. To overcome this deficit of knowledge and to evaluate the comparative behaviour of H₂ and hydrocarbon fuels on ignition, a number of tests and simulations have been conducted (Swain et al, 2003; Parsons Brinckerhoff Inc, 2004), while others are currently being executed (Dorofeev *et al.*, 2004) and planned (www.hysafe.org).

A recurring theme emerging from technical sources (DOE, 2004) and H₂-supporting web sites (examples include: www.fuelcellstore.com, www.hydrogennow.org, www.hydrogensociety.net, www.hydrogenus.org) is that prospective safety hazards posed by hydrogen-based technologies can be addressed with the aid of proper design, engineering and operation; the development and application of appropriate standards and regulations; and the familiarisation of consumers through education and communication initiatives.

To date, few opponents have raised their voice. Apart from expressing serious doubts about the economic and technological feasibility of a H₂-based economy, Shinnar (2003) also questions its safety characteristics, claiming that “hydrogen is the most dangerous of all known fuels” and H₂ “cars would be a boon to terrorists”. Without disclosing his criteria, Shinnar ranks diesel as the safest vehicle fuel, followed by petrol, natural gas and propane.

Less severe criticism is expressed by Cherry (2004), who is concerned that the “unspoken consensus” among the scientific community supporting H₂ may cause important risk issues to be overlooked. However, he acknowledges that H₂'s potential benefits “are well known and convincing”, making it “an attractive answer to a significant problem” (he implies global warming).

Romm (2004) does not oppose H₂ development, but calls for a gradual introduction of H₂-based technologies and stresses the need for more basic research to solve technical difficulties of producing, storing, delivering and using H₂. He also warns about yet unsolved safety issues related to H₂ as a fuel.

Romm agrees with Moy (2003), who interprets the data collected by NASA on H₂ safety records in a far different fashion from the generally optimistic response of others. Those data (NASA, 1997) show that 22% of industrial H₂ accidents have been caused by undetected leaks, “despite the special training, operating procedures, protective clothing, and electronic flame and gas detectors”. With

this track record, Moy argues, “it is difficult to imagine how hydrogen risks can be managed acceptably by the general public”.

2. *Scientists as stakeholders: factors affecting their perceptions of risk*

Scientists working in the field of H₂ energy are themselves stakeholders in its future and often have links with commercial stakeholders and/or environmental lobby groups. The authors’ vantage point as social science members of an interdisciplinary consortium committed to this innovation in science and technology demands that they be reflexive about their role.

Whether in science or outside it, and no less in H₂ technology than any other topic, proponents are more likely than those who oppose or are indifferent to the innovation, to consider that its benefits outweigh its costs and risks. For instance, Dutton (2002, 4) argues: ‘Hydrogen is safer than commonly held perceptions might suggest...Hydrogen is broadly similar to the fuels it might replace’. As we have seen, this conclusion has to be qualified by the fact that H₂ has distinctive risks associated with it, and that consumers, car mechanics and central heating installers are currently familiar only with the different risks posed by petrol and natural gas. The tendency to understate risks and costs is a well-established finding in risk perception research (Finucane *et al* 2000).

This tendency may be compounded by the fact that scientists and technologists themselves operate in a policy environment where they are engaged in

influencing public debate (see for example Watson *et al* 2004). Science is part of the culture and embedded in universities, government departments and laboratories and company R&D departments where networks of actors link it to where policy is made and public opinion is led. Ironically, these networks ensure that science is as much influenced by as it influences what goes on outside itself (Latour, 1996).

The pressures to 'champion' the cause of H₂ are palpable. It can be seen in the unusual degree of concentration of publications in a single international journal (*Hydrogen Energy*). Leading scientists in the field also find themselves lobbying policy-makers for the cause, are approached by and entreat support from producers and distributors with a stake in H₂, and respond to media requests to translate the science for lay audiences.

The safety issue is a sensitive one for science proponents of H₂. The fate of the airship Hindenburg in 1937 and the tests of and threat of war-use of the H-bomb during the cold war have been given varied attention. Addison Bain (who had a connection with NASA's Hydrogen Program at the time) re-opened the case of the Hindenburg in an effort to demonstrate that the gas was not responsible for the fire that consumed the airship (Bain and van Voorst 1999).⁵ By comparison,

⁵ The disaster was not investigated at the time to a standard that would now be considered adequate in such cases. The hardest data available appear to be a newsreel of the event and fragments of the airship, including its fabric covering. On the basis of this, Bain and Van Vorst conclude that H₂ itself had no part in the fire that destroyed the airship. The fire was attributable to a flammable dope used to coat the fabric skin of the dirigible.

the association of H₂ with the H-bomb is less often addressed. The H-bomb is about the physics of hydrogen fusion at very high temperature and pressure in the midst of a nuclear reaction triggered by an atom bomb, not the chemistry of hydrogen mixed with air at normal temperature and pressure, which (so far at least) applies to proposed use of H₂ as fuel.⁶

Currently even the wider class of stakeholders in H₂ beyond science and engineering is small and well networked. Should H₂ become mainstream it will become heterogeneous and less cohesive. In the market, they will be producers, distributors and consumers of energy and (more remotely) the same in the arena of uses of energy, to which may be added policy makers, regulators, financiers and employees of the firms. In terms of social status, we shall in future need to distinguish those who, by virtue of income from capital or employment, will lead affluent life-styles from those who, for lack of income on such a scale, lead relatively deprived life styles. Finally, in power relations, we shall need to separate those who are parts of organised arrangements for the exercise of political power at local, regional or national levels, including through lobbies, unions and other voluntary associations, from those who are excluded from power. For the present, however, the arena is comprises an elite of 'experts' and a mass of 'laypeople'.

⁶ Notoriously so among the better informed, President Bush confused nuclear fusion research with the development of H₂ as fuel in transport and similar applications when announcing increases in spending on R&D by his administration in the Spring of 2003.

3. *Lay perceptions of risks*

As Thompson (1994) has argued of 'rubbish', analysis of lay perceptions of the safety of H₂ might start by considering how 'safety' is represented in contemporary Western culture with respect to things that are experienced in everyday life. Dirt can be conceived anthropologically as 'matter out of place'. If the analogy works, safety is likewise a question of order. What is unsafe is not readily contained, does not fit, within the categories by which we symbolically order our world.

Whether H₂ is 'safe' is also a relative not an absolute matter. Fischhoff et al (2000) in asking "How safe is safe enough?" note that 'acceptable' risk for a new technology involves trade-offs of risks and benefits, where higher levels of risk are tolerated if such risks are voluntary, immediate, known precisely and familiar and controllable.

Petrol and natural gas set the standard in our culture for 'safe' fuel, because, though many fires and explosions have been associated with them, the materials are familiar and have been habitually used for what have been considered indispensable purposes. Consumers sit alongside petrol in tanks inside moving vehicles that might collide, and use natural gas for cooking and heating in their homes.

What then are the qualities attributed to fire and explosion in this culture? Fire has long been considered constitutive of the physical world. Traditionally, along with water, air and earth, fire was one of the four elements, in a natural philosophy that is at least as old as classical Greece. In this concept, fire is ever-present and can be a danger, but is normally contained or channeled in useful ways. It is not necessarily an uncontrollable hazard. On the contrary, domestic cooking and heating from earliest times have depended on fire, but fire contained in a hearth or beneath an oven.

Latterly, internal combustion engines of all kinds have depended on a spark to ignite and cause an explosion in a mix of an oil-based fuel and air, but that explosion is contained within a small compression chamber. When they are contained, fire and explosion are not only accepted, but also ignored. We do not normally think of the engines of our cars as involving fire and explosion. We take this function for granted.

Danger is perceived in what is otherwise useful fire and/or explosion when it is no longer contained and channeled in forms that are defined as orderly. These 'normal bounds' can occasionally be a matter for dispute and then seem arbitrary not natural. For instance, the convention that fire and explosion are contained when bonfires are lit and fireworks exploded in British gardens or parks to celebrate the detection of the Gunpowder Plot on 5th November, is disputed

every year by professional fire fighters and raises a flurry of debate about whether the custom should be put under tighter regulation or even banned.

Against this cultural background, it has taken prolonged familiarisation to gain acceptance for new ways of channeling fire and explosion for useful purposes. For instance, the major early proponents of the steam engine, Boulton and Watt, deferred the adoption of the high pressure design, pioneered by Trevithick, in spite of its much greater efficiency, for long after their earlier design was outmoded, because their customers thought the high pressure design unsafe. In the USA, however, the benefits of the more efficient design were more likely to be taken to out-weigh safety considerations (Leveson 1994).

These varied responses suggest another layer of culture that, unlike the basic idea of what is safe and unsafe, differentiates rather than unites such countries as the UK and the USA: namely, the more entrepreneurial culture and social organisation of the USA and the more hierarchical culture and social organisation of the UK (Douglas and Wildavsky 1983). Culture, then, influences not only what counts as safe, but also the disposition to set the threshold at which benefits might be considered to outweigh risks. Finally, our stress on how perceptions of risk associated with this new technology are grounded in longstanding cultural traditions, is a counter-weight to the tendency of theorists of 'risk society', such as Beck and Giddens, to assume that 'late modern' risk-perceptions are wholly emergent phenomena.

How Might Expert and Lay Judgements of Risk Relate?

Much of the large literature on the complex relationship between scientific evidence and lay experience has focused on the precarious nature of lay trust in expertise. Lidskog (in Cohen 2000) reasons that, if risks are incomprehensible to non-experts, and only represented through scientific assessments, public perceptions must be conjectural. He outlines four ideal-type situations where expert and public judgements of risk are variously conjoined. *Situation One* consists of hazards that both scientists and laypeople agree constitute high risk (for example nuclear radiation). *Situation Two* comprises activities or materials that experts regard as a risk, but laypeople do not. *Situation Three* covers activities or materials that experts do not regard as high risk, but laypeople do. *Situation Four* obtains when there are phenomena that neither scientists nor the public see as a current risk - though future judgements might change in this as in other situations. Currently, H₂ energy appears to fit Lidskog's *Situation Three*. However, this is only a first approximation, and in this concluding section, we consider its limitations.

First, we must take a more nuanced view of knowledge, both expert and lay, than does Lidskog. All life forms behave *as if* they know the future, though they are not necessarily equipped to adapt to every contingency that the future might bring. Human minds know the future to the extent that they can extrapolate from what has happened to date and act accordingly. Imprecision in their estimates

confers *uncertainty* on the future. Much is also *unknown* (as opposed to uncertain). The unknown includes whether the conditions on which current knowledge rests might persist or change.⁷

Critics of the way public consultations have been conducted around new technologies and the risks of disposing of waste, point to the fact that policy makers and the scientists that advise them typically assume that the science is known and that publics do not know it. Among the deficits that are attributed to lay people is inability to understand uncertainty. According to its critics, however, the 'deficit model' neglects the extent to which risk assessment in the science is 'framed', that is, focuses on a delimited view of the adverse consequences that are relevant. The public may consider a different set of adverse consequences to be relevant and often reasonably so (Shackley *et al.* 1996).

To follow on from, but also go beyond this critique of the deficit model, we wish to argue that there can be both *differences* in forms of knowledge of the 'same' object and *deficits* in knowledge in each form on the part of types of actor. This argument is familiar to those who study expert and lay knowledge of ill health. In this context, it is customary to distinguish between 'disease' - learned knowledge of the psycho-biological process that appears to produce disease in the organism, and 'illness' - experiential knowledge of the consequences of disease (real or imagined) for one's self. In addition, some writers distinguish from

⁷ In parallel, when writing about public perception of risk, Slovic (2000a) distinguishes two axes: the nature and extent of 'dread' of the unknown, and the degree of uncertainty

disease and illness, 'sickness' - the socio-cultural representation of ill health and its consequences for the society of which the sick person is a part (for instance, Frankenberg 1980, Turner 1995, Bellaby 1990a).

One can make broader distinctions between abstract knowledge, practical know-how and representation. Where ill health is concerned, disease, illness and sickness would respectively belong with such actors as (disease) medical scientists and health professionals, (illness) patients and carers, and (sickness) the general public and opinion leaders. Analogously in the energy field:

1. Abstract knowledge would belong with science, engineering and technology
2. Practical know-how with stakeholders who are producers, distributors, consumers and regulators, also policy-makers
3. Representation with disinterested citizens and the media.

The proposed relation between types of agent and types of knowledge of energy is suggested in Figure 2. There are both differences in forms of knowledge and also 'deficits' on all sides - wherever that form does not 'belong' to the type of actor. To qualify the model, it is *modus operandi* (or role) not only individual background that is likely to determine whether one is a scientist, stakeholder or citizen in different phases of a course of action. Policy-makers, for instance, may be briefed in the abstract knowledge and act alternately as stakeholders and

shapers of public opinion. Publics⁸ may double as consumers (that is, stakeholders) and also seek to acquire some of the abstract knowledge that is of interest to them.

Knowledge of the physical world is at some level necessary for all who act in it, but tends to be limited by what one can get by with. For practical purposes no one needs to understand the thermodynamics and mechanics of the internal combustion engine in order to start a car and drive it. Conversely, the physicist abstracts from or 'frames' the field, even discarding 'practical' considerations, not arbitrarily but in order to make study of the field manageable.

You have to be a 'stakeholder' (e.g. health professional/producer or patient/consumer) for subjective experience and preference to be relevant to your actions. Everyone is likely to be a stakeholder in health or in energy at some level, but the chronically ill and the car manufacturer are a different case from scientists and engineers and also from those who have neither abstract knowledge nor a practical interest in the field.

Finally, publics and opinion formers are – comparatively speaking – 'onlookers' with respect to the other forms of knowledge, yet may construct sense of either or both. Lidskog (in Cohen, 2000) has observed that publics tend to become conscious of environmental risks in the abstract just as the threats in question

⁸ Not 'the public' because publics are plural and heterogeneous not singular and homogeneous.

Types of Agent		Different Objects of Knowledge/ Varying Degrees of Knowledge of Each		
		Abstract Knowledge	Practical Experience	Representation
Expert	Science	Assessed Risks	Deficit In Experiential Knowledge	Deficit In Cultural Knowledge
In-between	Stakeholder (consumer, producer)	Some Deficit In Science	Preferences and Perceived Risks	Some Deficit In Cultural Knowledge
Lay	Opinion Formers/Publics	Deficit In Science	Deficit In Experiential Knowledge	Culturally Constructed Risks

Figure 2: Difference and deficit in knowledge: type of actor and form of knowledge

become further removed from their individual control.

Non-medical and non-patient onlookers may have an interest in the implications of, say, AIDS or cancer for the wider society, and so tend to confer meaning on them. In some cases they may stigmatise the condition or taboo it – so ensuring that the diseases have social as well as health consequences for those who suffer from them - causing them to enter the sick role and excluding them from employment.

In an energy context, representation may stigmatise a form of energy, as it has done in the case of nuclear power in the last twenty years or so in the USA and

UK. Flynn J *et al* (2001) highlight the exceptional stigma associated with nuclear technologies in the USA; Kaspersen *et al* (in Slovic, 2000) demonstrate the impact of such stigma and its media representations in, and effects on, the social amplification of risk. Representation may also associate a form of energy with such value-laden, affective qualities as 'clean/dirty' or 'safe/ unsafe'.

Different approaches to risk analysis are associated with each of these forms of knowledge. Thus, risk assessment conventionally belongs with abstract knowledge. The psychology of decision-making belongs with actors' strategies, preferences and perceptions of risk.⁹ Cultural theory takes 'representation' in society and culture as its starting point (Douglas 1992, Bellaby 1990b). Figure 2 implies the relevance of all three approaches and that they are not opposed and may be complementary.

There may be a struggle between advocacy coalitions (Sabatier 1999) that vie with each other to define how the 'risk' in question should be represented. Hogenboom *et al* (in Cohen, 2000, 91) emphasise that risk definition is a complex social process involving many different groups: 'risk-producing institutions, government agencies, scientists and environmental organizations. Each of these ...has particular interests and tries to influence risk definition and control in accordance with its unique perspective'.

Figure 2 suggests that difference and deficit in knowledge among the various actors in such an arena as consultation about the safety of a new technology are likely to be in a dynamic relation to each other.

Finally, we wish to observe that, while it is an over-simplification to attribute miscommunication about risk between experts and laypeople to a *deficit* of knowledge on the part of laypeople, it is also an over-simplification to view 'knowledge' as one-dimensional and thus to ignore the extent to which different interests accentuate the relevance of one form of knowledge over another and make people relatively blind to other forms of knowledge.

Discussion

If H₂ technology is to become mainstream, it will have to be acceptable to the public, who will be the citizens that influence planning permissions, and, in increasing numbers, the stakeholders who consume H₂ as fuel, produce it and distribute it, or sell and service vehicles and plant that use it. It will become acceptable for a mix of (perceived) benefits, low risks and affordable costs.

⁹ Slovic (2005) has developed a provocative approach to affect in risk perception, arguing that it is not antithetic to reason, but on the contrary plays a necessary part in arriving at decisions between alternative courses of action.

We have focused attention in this paper on risks and only in one area: safety. Evaluation of the safety risks of H₂ appears currently to divide most experts from most lay people. Summarisers of the science, who are also proponents of H₂ as energy of the future, tend to claim that, on balance, H₂ would be no less safe in use as fuel than are petrol or natural gas. However, we have argued that not enough is known that is relevant to widespread use of H₂ as a substitute for petrol and natural gas for us to be confident about that risk assessment. Moreover, H₂ is qualitatively different in the hazards it presents and so the comparison can be misleading.

The suggestion that proponents of H₂ energy for the future tend to be parties to an unspoken consensus about how safe it is, has prompted us to examine the interests that might shape the coalition that shares that view. We have concluded that scientists in this area are stakeholders in its future, and that their over-stated claims at this stage of the development of the project are typical of niche developments in new technologies.

On the other side, we have considered the factors that might shape public perception of the safety of H₂ as energy, concluding that these need to be sought, at least in part, in the main themes of the Western cultural tradition. We have evaluated the view that miscommunication about risk between experts and laypeople is attributable to a deficit of lay knowledge about science. We have attempted to carry further the analysis that has been developed by critics

of the 'deficit model', arguing that there are both differences and deficits in forms of knowledge among scientists, stakeholders and publics alike, and that these are in a dynamic relation to each other.

Finally, such is the difficulty of trying to foresee development in H₂ energy from its current state of niche development to a possible mainstream energy system of the future that we have used comparators, starting with information technology and including medical and lay knowledge of health that might allow us to find our bearings.

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