Sustainability, foresight and contested futures: exploring visions and pathways in the transition to a hydrogen economy

Prof. Malcolm Eames[(1)] & William McDowall[(2)]

[(1)] Brunel Research in Enterprise, Innovation, Sustainability & Ethics (BRESE), Brunel University

[(2)] Centre for Health and Environment Research, University of British Columbia

Correspondence address: Professor Malcolm Eames, BRESE, Brunel University, Uxbridge, UB8 3PH, UK

phone: ++44(0)1895 266837

fax: ++44(0)1895 269775

e-mail: malcolm.eames@brunel.ac.uk

Abstract

This paper reports an innovative foresighting study which aimed to construct a small number of credible hydrogen futures and pathways to them, in order to inform the prospective transition to a sustainable hydrogen economy. Combining backcasting and multi-criteria appraisal the authors developed a novel participatory expert stakeholder-led methodology to build and appraise a set of visions, which sought to acknowledge the diversity of possible hydrogen futures and contested claims as to their sustainability. Drawing upon insights from recent work on systems innovation a set of transition scenarios where then developed exploring the dynamics and governance of the large-scale socio-technical changes that would be required for the emergence of the different visions. Whilst various aspects of this project have been reported in detail elsewhere, this paper seeks to: i) locate the work with respect to broader developments in the fields of foresight, expectations and socio-technical transitions to sustainability; ii) provide an overview and description of the methodology as a whole; and, iii) reflect on some key insights and challenges for research and practice.

1. Transition management, foresight and contested futures

In recent years a growing international community of academics and opinion formers have argued for fundamental transformation in the socio-technological structure of human society to address the twin challenges of climate change and sustainable development. As Shove & Walker (2007) note, *"for those concerned with sustainability, the idea of transition – of substantial change and movement from one state to another – has powerful normative attractions".* Indeed the concept of transitions and transitions management are central to the emerging discourse of reflexive governance of sustainable development.

Drawing inspiration from ecology, systems and complexity science, transition theory seeks to develop an evolutionary perspective on societal change. With this perspective, addressing the inherently 'wicked' problem of sustainability becomes *"…a learning-by-doing exercise: experimenting with partnerships, new institutions, new technologies and new regulations within…ecological limits*", informed by a co-evolutionary, non-linear, multi-level conception of systems innovation and socio-technological transition (Kemp & Loorbach, 2006). Transition management is by its very nature flexible and adaptive. However, processes of foresight, experimentation, evaluation and social learning, built upon stakeholder engagement and participation are central. Particular emphasis is placed on the development of **shared** problem definitions, normative visions (including long-term goals) and prospective transition pathways.

"The vision, in combination with the images, the transition paths and experiments, forms the joint transition agenda…This is where coalitions come together around specific options or expectations" (Kemp & Loorbach, 2006: 114)

In other words, transition management consciously seeks to mobilise and exploit the performative power of visions and expectations: facilitating the alignment of actors around common goals; defining research priorities; stimulating resources for R&D and deployment; reducing uncertainty in decision-making for technology developers; promoting political support for necessary institutional and regulatory change; etc. (Van Lente, 1993: Dierkes et al, 1996).

Moreover, within the burgeoning transitions management literature a clear stream of work has emerged (of which this present study is a part) which has sought to provide a more theoretically grounded and informed set of foresight tools and methodologies (see for example: Elzen et al, 2004; Voss et al, 2006; Anderson et al 2005; Spath et al 2006; Mattias Weber, 2006). These approaches have built upon two bodies of literature: transitions theory and expectations dynamics.

However, some authors have questioned the politics of transition management (and the role of foresight therein). In particular, authors have challenged the role of shared normative vision(s) (Berkhout et al, 2004), and argued that transition management fails to adequately address the operation of power by vested interests, and the deeply political and contested character of sustainable development (Shove & Walker, 2007). Stirling (2006) has argued for what he terms 'precautionary foresight'. He suggests using a variety of 'heuristic' tools to facilitate more pluralistic forms of 'iterative participatory goal formation', and radical institutional means to achieve greater reflexivity over the role of power through 'opening up' previously closed processes of strategy development.

This paper reports the development of an innovative methodology which has been designed to: i) 'open up' the foresighting process; ii) work with multiple and contested visions of the future and understandings of sustainability; iii) and explore the social and political choices framing alternative transition pathways. The work was undertaken as part of the UK Sustainable Hydrogen Energy Consortium (UKSHEC).

Specifically the study aimed to construct a small number of credible hydrogen futures and pathways to them, in order to inform the prospective transition to a sustainable hydrogen economy. Combining backcasting and multi-criteria appraisal the authors developed a novel participatory expert stakeholder-led methodology to build and appraise a set of visions, which sought to acknowledge the diversity of possible hydrogen futures and contested claims as to their sustainability. Drawing upon insights from recent work on systems innovation a set of transition scenarios where then developed exploring the dynamics and governance of the large-scale socio-technical changes that would be required for the emergence of the different visions.

Section 2 below provides a brief overview of expectations of the hydrogen economy and the hydrogen futures literature. Section 3 outlines provide an overview and description of the methodology as a whole. Section 4 briefly describes the UKSHEC Transition Scenarios. Section 5 draws together some key insights from the work for the future of hydrogen, whilst section 6 provides some reflections on the methodology and future challenges for research and practice.

2. Contested futures and the hydrogen economy

At first sight the notion of a 'hydrogen economy' may appear to provide an unproblematic normative vision of a sustainable energy system. After all, everyone from George Bush to large sections of the green movement and the industrial giants of the global energy and auto industries have come out in favour of a hydrogen economy. However, upon closer inspection we find that there is not one guiding vision of a hydrogen economy but many. Reviewing the literature reveals diverse range of possible hydrogen futures for both transport and energy. These range from decentralised systems based upon the small-scale renewables, through to heavily centralised systems reliant on nuclear energy or fossil fuels with carbon-sequestration (McDowall & Eames, 2006a). Indeed, like the concept of sustainable development itself, once we scratch the surface it becomes apparent that the notion of a hydrogen economy in fact encompasses multiple contested socio-technological futures, value judgements and problem framings (Eames et al, 2006).

3. The UKSHEC Hydrogen Futures Methodology

An overview of the novel participatory foresight methodology developed for the UKSHEC hydrogen futures project is provided in figure 1 below. Essentially the research was structured around four main phases: i) scoping and literature review; ii) vision development; iii) multi-criteria sustainability appraisal; iv) transition pathways and scenarios development.

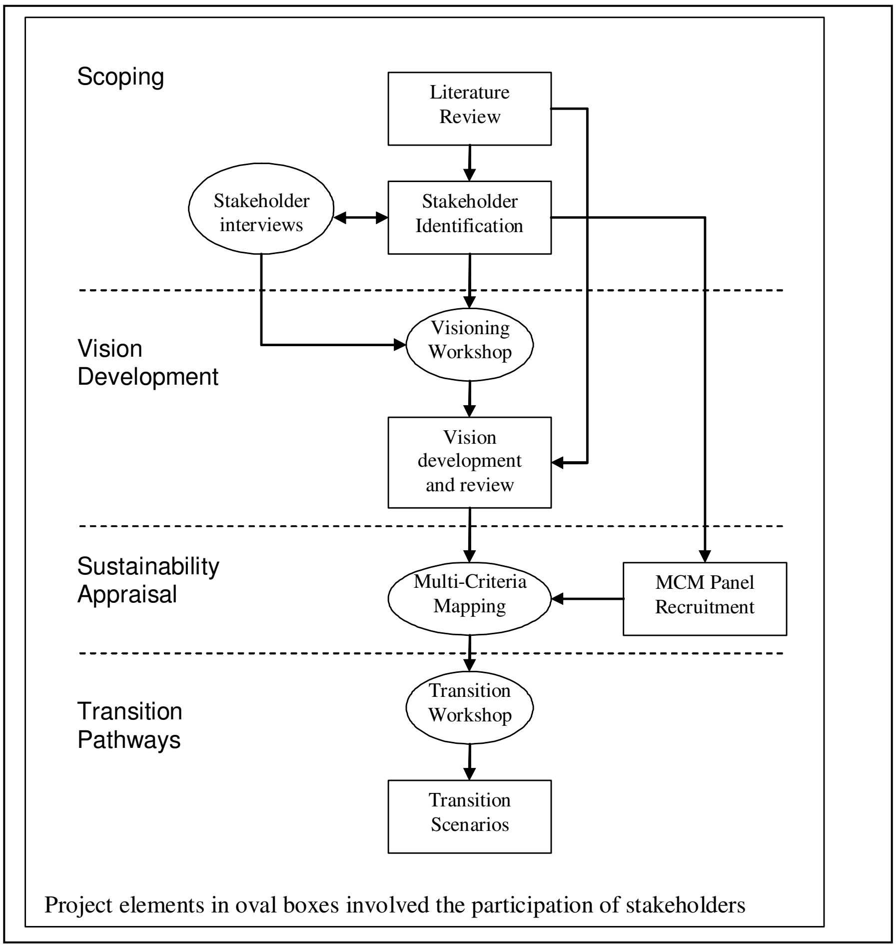


Fig 1: Overview of UKSHEC hydrogen futures project (Source: Eames & McDowall, 2007)

Phase 1: Scoping

The initial scoping phase of the project comprised a detailed literature review (McDowall & Eames, 2006) and process of stakeholder identification and recruitment, including a small number of exploratory interviews. Stakeholders were identified by 'mapping' the key actors involved in hydrogen production, supply and end-use chains, and by reviewing relevant UK steering groups, partnerships and hydrogen networks. A 'snowballing technique' was also used with key informants to ensure broad participation from all relevant sectors, including academia, industry, government and civil society.

Phase 2: Vision Development

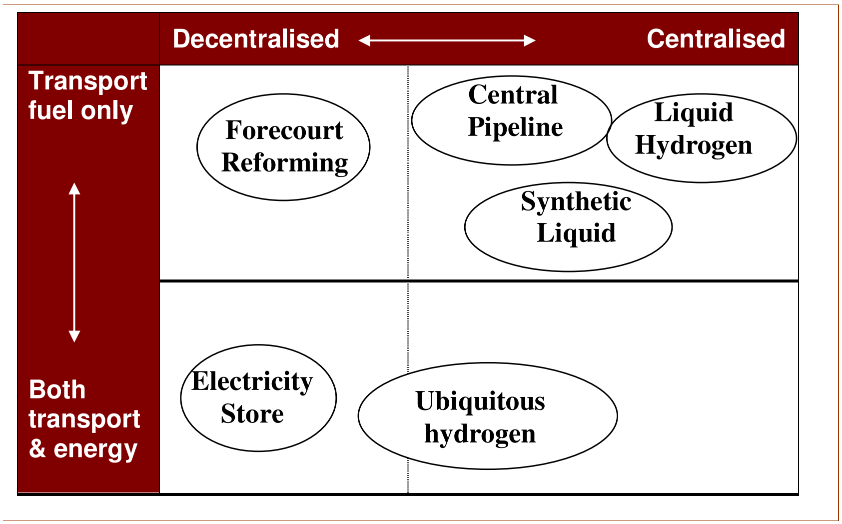
A *Hydrogen Visions* workshop was held in September 2004. This day-long workshop involved some forty leading UK hydrogen experts and stakeholders in the first stages of a backcasting process, exploring and articulating visions of desirable hydrogen futures. The workshop was structured around four breakout groups, each exploring a different theme or driver with respect to the 'hydrogen economy'. These different themes (*Climate Change; Energy Security; UK Competitive Advantage*; and *Empowering Consumers*) reflected key drivers and priorities drawn from the hydrogen futures literature and the UK Government's 2003 Energy White Paper (DTI 2003). Each group undertook three participatory 'brainstorming' exercises: i) working with a series of technological 'building blocks' to develop long-term visions of a hydrogen economy; ii) exploring the socio-economic dimensions of these visions; and, iii) exploring how change might come about. The outputs from the workshop were written up and circulated to the participants for review (McDowall & Eames, 2004).

The UKSHEC Visions

Building on the insights from the stakeholder workshop and literature review, the research team developed a set of six visions which sought to capture the diversity of stakeholder expectations about what a hydrogen future might or should look like. A key objective at this stage was to ensure that the set of visions as a whole encompassed the broad 'possibility space' and that no relevant future was excluded from the subsequent analysis. The credibility, transparency and internal consistency of the draft UKSHEC visions were again refined in consultation with the projects stakeholders.

The six visions differ both in relation to the role of hydrogen (transport fuel only, or providing both transport and broader energy services), the means of hydrogen generation and storage, and the degree of centralisation/decentralisation of its production and supply (see fig 2 below). The visions were set around 2040-2050: far enough into the future that substantial infrastructural changes are conceivable, but not so far that the technologies envisaged today will be obsolete.

Fig 2: The UKSHEC Hydrogen Visions



Source: Eames & McDowall, 2005

Each vision comprised: i) a structured narrative storyline describing archetypal configurations of hydrogen production, infrastructure (storage and distribution) and end-use technologies; ii) indicative quantitative indicators of the scale of primary energy demanded by the vision; and, iii) a systems diagram providing pictorial representations of each vision. For full account of the UKSHEC visions see (Eames & McDowall, 2005). Headline summaries of each vision are given in the table 1 below.

		Table 1: Headline Summary of the UKSHEC hydrogen visions
Transport Futures (hydrogen only used as a transport fuel)	Central Pipeline	Hydrogen has become the dominant transport fuel, and is produced centrally from a mixture of clean coal and fossil fuels (with C-sequestration), nuclear power, and large-scale renewables. Hydrogen is distributed as a gas by dedicated pipeline.
	Forecourt Reforming	Hydrogen produced locally from natural gas is the dominant road transport fuel. The existing natural gas network provides the delivery infrastructure, and hydrogen is generated on-site by steam methane reforming at the refuelling station.
	Liquid Hydrogen	Liquid hydrogen produced by nuclear power and large scale renewable installations has become the dominant transport fuel. There is an international market in liquid hydrogen. This is largely a scenario of substitution, with current energy and transport paradigms remaining unchanged.
	Synthetic liquid fuels	Renewably produced hydrogen again provides the dominant transport fuel. In this case, however, it is 'packaged' in the form of a synthetic liquid hydrocarbon, such as methanol, to overcome the difficulties of hydrogen storage and distribution. The carbon for fuel synthesis comes from biomass and from the flue gases of carbon-intensive industries.
Transport & Energy Services Futures	Ubiquitous Hydrogen	Gaseous hydrogen is not only the dominant road transport fuel. Many buildings also use fuel cell CHP systems running on hydrogen. Distributed renewable generation predominates, reducing need for long distance transmission and distribution, and allowing hydrogen to compete directly with electricity as the main energy vector for the provision of domestic and commercial heat and power. Regional grids of hydrogen pipelines connect (predominantly local) hydrogen supplies with local needs.
	Electricity Store	Hydrogen is not only the dominant road transport fuel, it also plays a vital role providing distributed energy storage to overcome the intermittency problems of renewable electricity generation. Hydrogen is produced locally in small scale electrolysis units for forecourt refuelling and onsite storage for use in domestic and commercial CHP units at times of peak electricity demand/limited supply.

Source: Eames & McDowall, 2005

Phase 3: Sustainability Appraisal

This study adapted the Multi-Criteria Mapping (MCM) technique, originally developed by Stirling (Stirling & Mayer 1999, Stirling 1999) as a tool for participatory technology assessment. MCM is designed to 'open up' debate by mapping the performance of alternative options according to different stakeholder perspectives, uncertainties and framing assumptions, rather than identifying a single 'best' solution.

MCM is conducted through in-depth one-to-one interviews using a dedicated software package. The interview consists of a structured series of stages: i) Discuss Visions; ii) Define Criteria; iii) Assess Scores; iv) Explore Uncertainty; v) Assign Weights; vi) Consider Ranks. Finally, the software produces a visual 'map' of the option rankings, using a weighted sum method. For this study, the qualitative material was transcribed and explored using NVivo and the quantitative outputs were analysed with the MCM Analyst software tool developed at SPRU. Further details of the method are available from the MCM Manual and Interview Protocol (Stirling 2004; Stirling 2005). A number of adaptations to the MCM method were made, as it has not been previously used to assess long-term visions in the context of a backcasting exercise.

First, in previous MCM work the options assessed are elicited directly from the expert participants. In this exercise, the core set of visions to be assessed were the product of the extensive stakeholder consultation process set out above. However, in order to ensure that significant futures were not excluded, participants were offered the opportunity to appraise additional visions during their individual MCM interviews.

Second, in order to keep the appraisal process as open as possible, MCM has previously avoided imposing any ex ante assessment criteria. However, in the current study, a set of ex ante criteria groupings were used to explicitly prompt participants to define criteria in relation to all three (environmental, economic, and social) dimensions of sustainability, as well as energy security. Participants were also provided with the opportunity to define criteria outside of that framework if they felt it appropriate.

Third, in addition to the six UKSHEC visions, a 'status quo' or reference scenario, describing the current systems for energy and transport in the UK was also appraised, as a way of providing a benchmark comparison for the different visions.

Finally, in order to more fully explore participants' framing assumptions, at the end of the interview participants were confronted with two short external "sideswipe" scenarios - *rapid climate change* and *sustained oil and gas crisis*. They were then asked to comment on how such sideswipe might change their appraisal. This allowed some insight into the importance of tacit framing assumptions in the appraisal, and the robustness of the 'desirability and plausibility' of the visions in the light of these major uncertainties. The opportunity to explore the importance of such sideswipes is often cited as one of the advantages of scenario approaches, although it is rarely done in practice (Van Notten et al 2005).

The interdisciplinary panel which undertook the MCM appraisal comprised some 15 experts from a range of professional and disciplinary backgrounds.[1] Participants took part on the basis of their individual expertise and particular effort was made to ensure that sceptical as well as pro-hydrogen viewpoints were represented.

Phase 4: Transition Pathways and Scenario Development

Having developed and appraised the sustainability of a set of long-term hydrogen visions, the next stage of the backcasting process was to articulate a series of plausible pathways through which these futures might be achieved. To this end the research team convened a further expert-stakeholder *Hydrogen Transitions* workshop in September 2005. Prior to the workshop, the project team drew on a range of sources to sketch outlines of a number of 'prototype' transition pathways which might each lead to one or more of the UKSHEC visions. These were circulated in advance of the meeting. Working in breakout groups and plenary sessions, participants worked through a series of structured questions in order to develop a picture of how each transition might take place. Drawing loosely on the multi-level perspective heuristic, these questions were organised around three themes: e.g. i) Technologies, niches, and early markets; ii) Diffusion and market growth; iii) Context and timescales. The outcomes from the workshop were again written up and subject to stakeholder review. For a full account see (McDowall & Eames, 2005).

In the final stage of the project the team developed an integrated set of transition scenarios, combining a revised set of four end-visions, with theoretically informed pathways describing a prospective transition to each of these hydrogen futures.

The structure and key dimensions of these integrated scenarios drew heavily upon i) the multi-level perspective (MLP) (niche; regime; and landscape) on socio-technological transitions (Geels 2002); ii) SPRU's work on transition contexts (Endogenous Renewal; Re-orientation of trajectories; Emergent Transformation; Purposive Transition) (Berkhout *et al* (2004); and, iii) IVM's work on governance paradigms (Governance by government; Governance by policy networking; Governance by corporate business; Governance by challenge) for long-term technological change (Hisschemoller *et al* 2006).

The rational for reducing the number of end-visions from six to four was twofold, being driven both by insights obtained from the earlier sustainability appraisal and by the need to work with a more limited set of visions which could be reconciled with the transitions framework adopted for the final phase of the project. *Forecourt Reforming* was dropped from the final scenarios set as many of our expert stakeholders saw this vision as a shorter-term intermediary step, part of a transition, to a hydrogen economy. The

[1] (i.e.: Nuclear Industry Expert; Carbon Trust Analyst; Department for Trade and Industry (DTI) Policy Maker; Fuel Cell Industry Participant; Sustainable Energy Policy Consultant; Industrial Gases Industry Participant; Energy Technology Researcher; Environmental Campaigner; Health & Safety Regulator; Energy Policy Researcher; Senior Oil Industry Participant; Department for Transport (DfT) Policy Maker; Automotive Industry Participant; Regional Government Policy Maker; and Climate Scientist).

Central Pipeline and *Liquid Hydrogen* visions were merged to form a *Central Hydrogen for Transport* end vision (see below).

4. The UKSHEC Transition Scenarios

The UKSHEC transition scenarios are not predictions. They are intended to shed light on possible innovation processes and transition pathways by which a future hydrogen economy might be achieved. They seek to illustrate different ways in which the large-scale socio-technological changes required for the establishment of a hydrogen economy might come about, and so highlight the choices and policy options facing the research community, business, policymakers and civil society alike on the road to a sustainable hydrogen economy. Whilst the scenarios have a UK focus, they seek to place the prospective developments they describe in a broader European and global context.

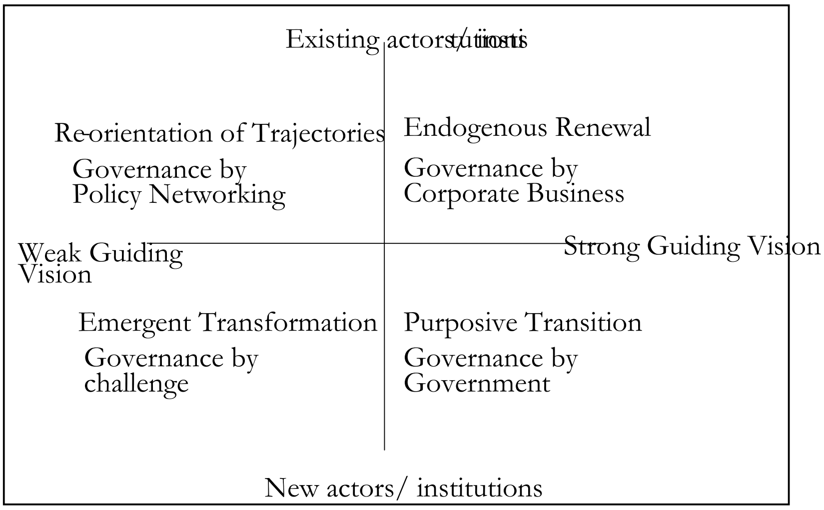
The UKSHEC Transition Scenarios are framed by two key dimensions of change, adapted from work by Berkhout *et al* (2004), which developed a quasi-evolutionary model of systems innovation: These dimensions are:

The degree to which ***innovation is shaped by a shared normative guiding vision***. In the past, large scale transitions of energy and transport infrastructures have usually occurred as an emergent result of interacting drivers and activities, rather than as the outcome of a managed transition. This axis allows us to explore how hydrogen might emerge without a coherent action plan, as well as through concerted efforts to bring about a hydrogen future.

The extent to which ***innovation is driven by existing actors and institutions, or by new actors and institutions*** (or existing actors taking on new roles in driving innovation). This axis invites us to think through the various possible roles of the different actors and institutions that will be involved in any possible transition: local, regional, and national governments; major industries; new entrants and entrepreneurs, and so on. The axis helps us to consider the interplay of different interests and agendas, and avoid assuming that any particular actor alone holds the key to the development of hydrogen energy.

Each quadrant was also associated with one of the four governance paradigms developed by Hisschemoller *et* al (2006), in order to help enrich the institutional and policy dimensions of the narrative storylines developed for each scenario.

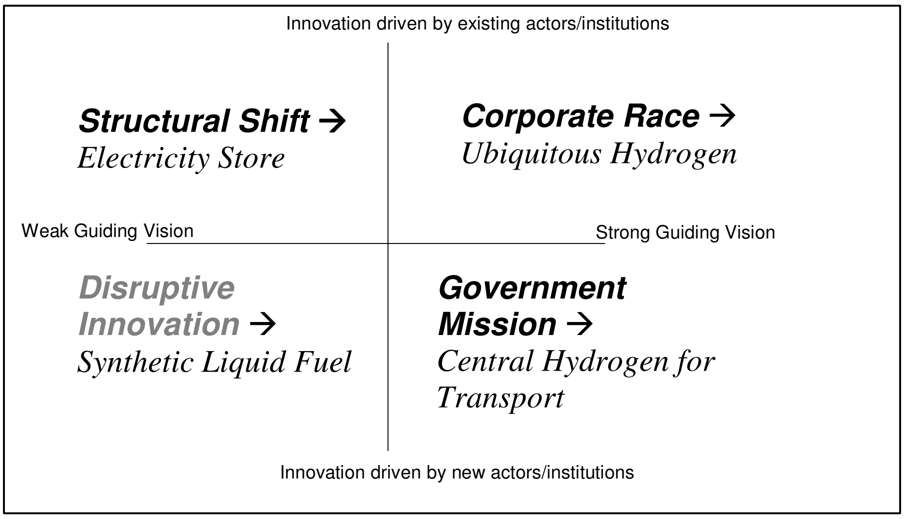
Fig 3: Mapping of the transition contexts and governance paradigms



Source: Eames & McDowall, 2006

The four UKSHEC transition scenarios are shown mapped onto this 2x2 grid below.

Fig 4: The UKSHEC transition scenarios



Source: Eames & McDowall, 2006 Note: Disruptive Innovation → *Synthetic Liquid Fuel* is shown in the diagram in lighter text to highlight its status as an alternative or 'wild card' scenario.

Of course the particular mapping of the transition pathways to the end visions presented above is only one possibility. There will be many other ways in which a transition to any particular hydrogen future could play out. Our purpose was not prediction, but to stimulate imaginative and critically informed thinking about how the future might unfold.

The four quadrants provide a useful way to distinguish different types of transition pathway. Each scenario is also described in terms of a second, multi-level, structure, adapted from the MLP on socio-technical transitions[2]. During a transition, developments take place on the three levels: here termed niches, system and landscape. New technologies first enter use in 'niches': demonstration projects, niche markets, and among enthusiasts. For the technology to enter the mainstream, the conditions must be right at higher levels – both within the industries and mainstream markets that make up the middle 'systems' level, and at the 'landscape level' of long term social and economic context. Most of the time, the conditions are not right, and existing systems resist the entry of newcomers. But there are times when windows of opportunity emerge for new technological systems to develop: particularly when innovations at the niche level combine with pressures of shifting landscape conditions, such as concerns about energy supplies; or when firms look to radical new technologies to provide competitive edge.

Fig 5: Multi level perspective on socio-technical transitions

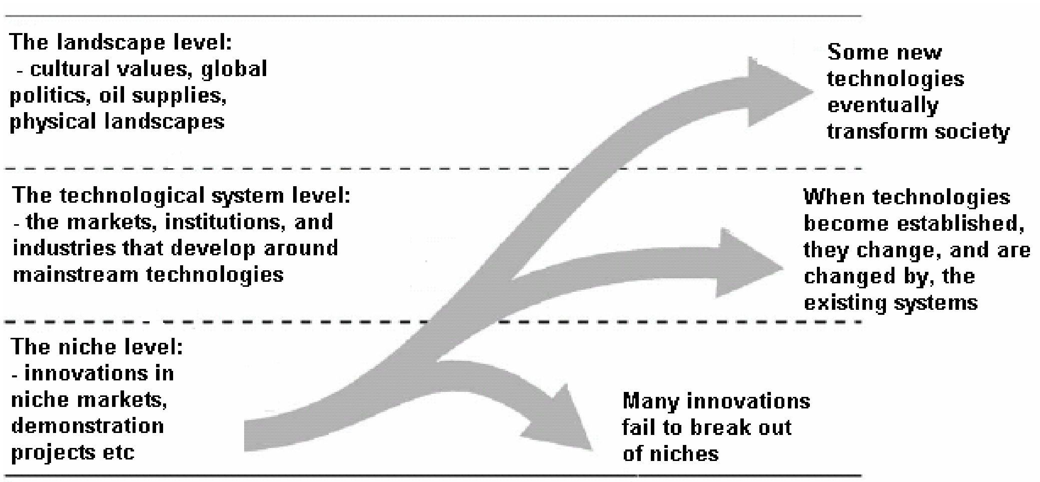


Figure showing multi-level perspective. Adapted from Geels 2002

The diagram represents the path of a new technology as it first develops in niches, and later diffuses into mainstream markets. By simultaneously focusing on how technologies develop in niches; on the dynamics of the incumbent systems; and on the wider changes for society, we can get a better insight into the possible future for hydrogen. All of the UKSHEC transitions scenarios are therefore described in terms of developments at the niche, landscape and systems level.

The major drivers for hydrogen at a landscape level, climate change and security of primary energy supplies, are well established. To a lesser extent local air quality and regional or national competitiveness also provide drivers for policy-makers to consider support for the development and diffusion of hydrogen technologies. In addition, landscape level drivers for the energy system more broadly include rates of economic growth (and hence of energy demand), and the social values that prevail.

[2] In order to make the scenarios more accessible to a UK policy audience unfamiliar with the concept of the socio-technical regime the multi-level structure is described in terms of the niche, **system,** and landscape instead of the niche, **regime** and landscape.

In addition to these landscape level policy drivers, it is important to consider drivers at the systems and niche level that influence the dynamics of change by either articulating, or responding to, changes at the landscape level, such as the: strategic activities of firms and industries; national and regional energy and transport policies (e.g. carbon trading, Zero Emissions Mandates, etc); lobbying by hydrogen and fuel cell associations, activists, NGOs, etc; the activities of scientists and engineers in advancing the state of hydrogen and fuel cell technologies; the growth in portable and on-vehicle power demands, leading to funding, support, and the creation of niche markets for fuel cell products; etc. These drivers interact in different ways in the four transition scenarios.

Each scenario comprised: i) a short description of a distinctive hydrogen future (or end vision); ii) a 'storyline' summary; iii) a set of qualitative indicators; iv) a detailed 'multi-level' narrative describing the transition pathway in terms of landscape, niche and systems changes; v) a 'transition diagram' providing a visual representation of the innovation dynamics and key developments along the individual pathway. For details of the full UKSHEC transition scenarios see (Eames & McDowall, 2006).

Table 2: Summary for the four UKSHEC Transition Scenarios

	Structural Shift	Corporate Race	Government Mission	Disruptive Innovation
Dimensions	Innovation driven by existing actors/ institutions Weak guiding vision	Innovation driven by existing actors/ institutions Strong guiding vision	Innovation driven by new actors/ institutions Strong guiding vision	Innovation driven by new actors/ institutions Weak guiding vision
Drivers	Strong UK Government and social concern for climate change and energy security Greater social awareness of need for demand reductions Societal rejection of nuclear and carbon capture and storage	Strategic positioning by big auto and big oil in the face of climate change and energy security concerns High demand and volatile supplies for oil and gas lead to increasing prices	Strong UK/EU government concerns over climate and energy security Societal acceptance of nuclear and carbon capture and storage, and greater social trust in science and technology	Emerging climate and energy concerns Emphasis on building competitive markets and high innovation Social preference for liberalised markets and consumer economy
Key technologies	Fuel cells Storage & handling Electricity grid updates Smart metering Renewables	Gas separation Fuel cells Onboard storage Gasification Pipelines & metering Carbon capture and storage Waste, biomass gasification Renewables	Storage & handling Fuel cells High temperature nuclear Pipelines & liquefaction Gasification technologies Carbon capture & storage (CCS) New nuclear power	Direct Methanol Fuel Cells (DMFC) Synthetic liquid fuel synthesis Fuel reformers or scale up of DMFC Renewables Carbon capture

Decision points and milestones	Renewables reach a high enough proportion of grid electricity to require buffering of supply and demand	Nuclear & CCS go/no-go decisions Commercialisation decisions of big auto Hydrogen injected into natural gas grids Collapse of Kyoto?	'Go' decision on major hydrogen programme, and on nuclear	'No-go' decision on major government hydrogen programme
End vision	Electricity Store	Ubiquitous Hydrogen	Central Hydrogen for Transport	Synthetic Liquid Fuel

Source: Eames & McDowall, 2006

5. Insights into the future of hydrogen

This section briefly outlines some of the headline results for the future hydrogen flowing from this work. The key insights from the sustainability appraisal and from the final transitions scenarios are dealt with in turn.

Insights from the Sustainability Appraisal

The MCM process produced a qualitatively and quantitatively rich picture of the panel's expectations of the sustainability of the visions: their assessment criteria (environmental, economic, social and energy security criteria); the relative weightings attributed to these; and overall performance and rankings of the visions and associated uncertainties.

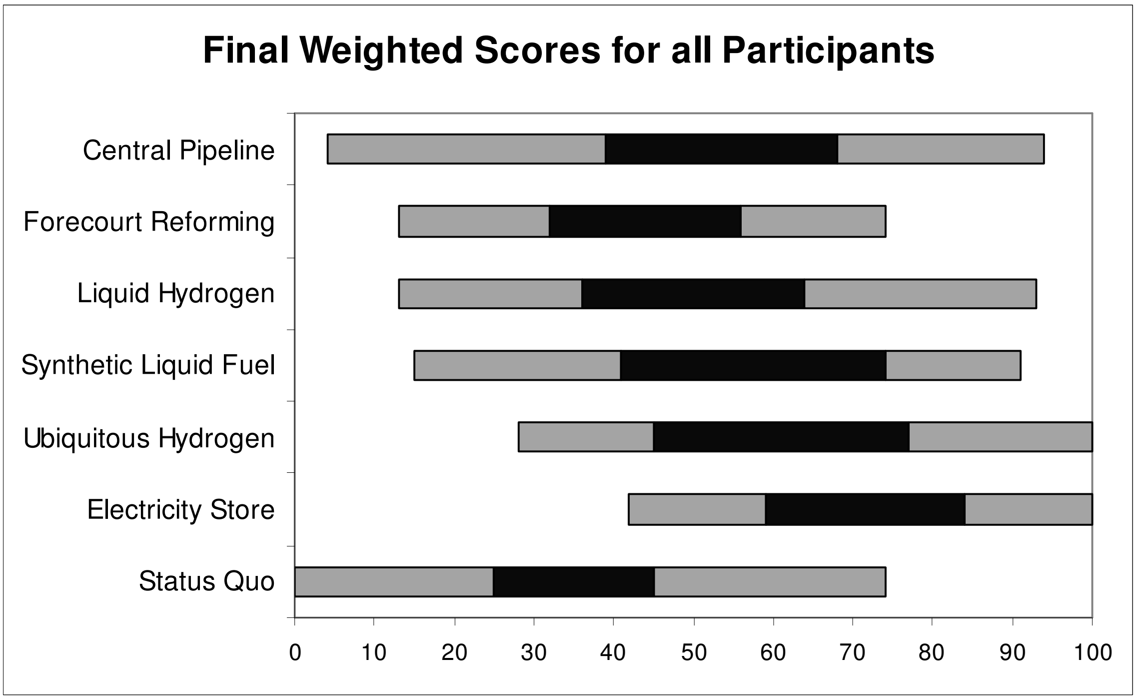
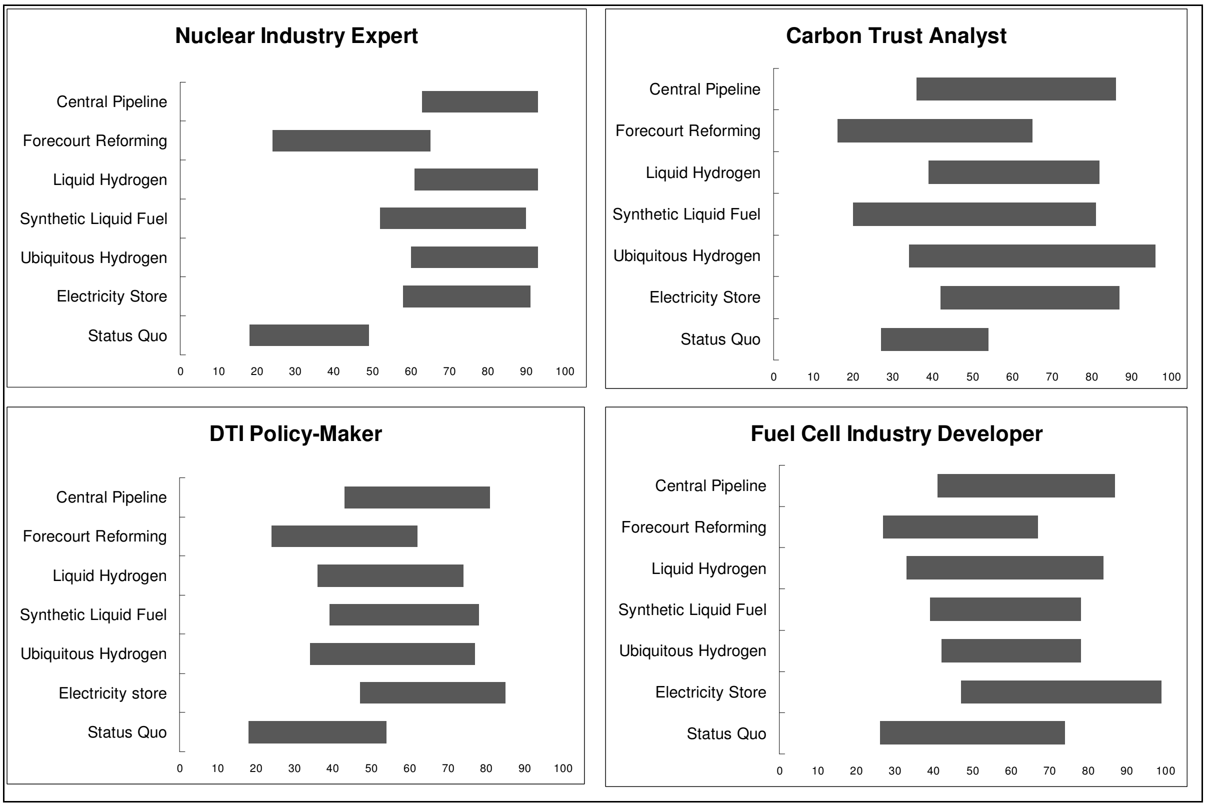
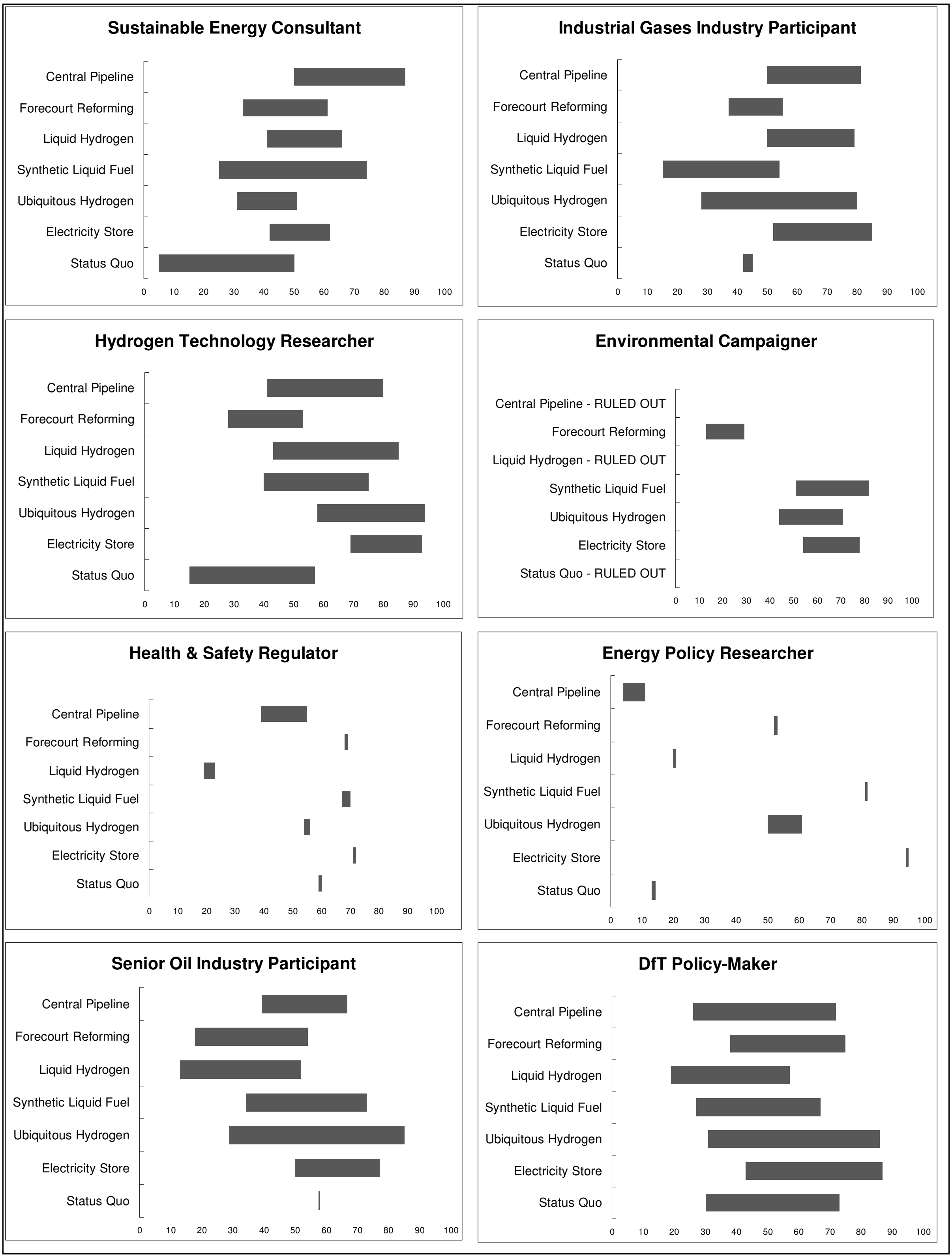


Fig 6: Final weighted scores aggregated across all participants. Bars indicate extreme (grey) and average (black) pessimistic and optimistic scores, capturing the degree of uncertainty about future performance. The x-axis is a relative scale indicating low (0) to high (100) performance. Source: McDowall & Eames, 2006

Individual Weighted Scores for all Participants




Sustainable Energy Consultant
Industrial Gases Industry Participant
Hydrogen Technology Researcher
Environmental Campaigner
Health & Safety Regulator
Energy Policy Researcher
Senior Oil Industry Participant
DfT Policy-Maker
Central Pipeline
Forecourt Reforming
Liquid Hydrogen
Synthetic Liquid Fuel
Ubiquitous Hydrogen
Electricity Store
Status Quo
Central Pipeline - RULED OUT
Liquid Hydrogen - RULED OUT
Status Quo - RULED OUT
0
10
20
30
40
50
60
70
80
90
100

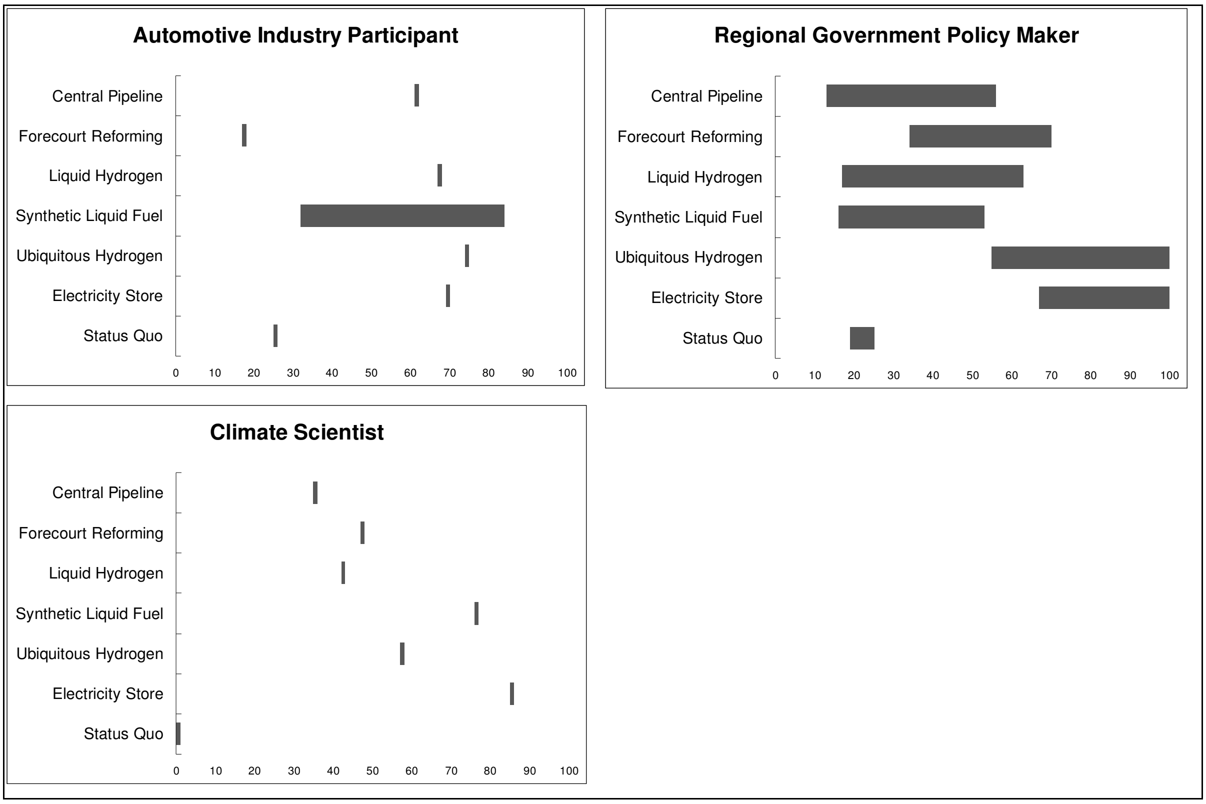


Fig 7: Individual weighted score ranges. The x-axis is a relative 1-100 scale showing performance, with better performing visions further to the right. Bar length is a result of the degree of difference between pessimistic and optimistic scores, and is thus a function of the degree of uncertainty. Source: McDowall & Eames, 2006

The results from the MCM appraisal have been reported in detail elsewhere (McDowall & Eames, 2006). These confirm the highly contested nature of the debate, with no absolute winners or losers, and with a wide range of weighted scores for all visions. This does not mean no patterns are clear, but rather that there are no uncontested winners. Indeed, examination of the relative performance of each vision, under both optimistic and pessimistic assumptions, does provide some clear messages about the likely sustainability of the different futures. It is not out intention to re-examine these here. Rather, we summarise some of the broader underlying expectations revealed through the MCM appraisal below. In terms of these broader messages, it was clear that:

Hydrogen is not automatically a sustainable option. Participants recognised a range of circumstances in which hydrogen energy might be less sustainable than the current system or some non-hydrogen business as usual futures. However, hydrogen was perceived as having the potential to deliver substantial sustainability benefits over a wide range of issues.

The panel identified carbon emissions as the single most important dimension of sustainability with respect to the hydrogen futures. However, a very wide range of other environmental, social, economic, political and technical issues were also seen to be important in judging the sustainability of hydrogen systems.

Even for issues with relatively well characterised data sources (such as wells-to-wheels carbon studies) there were debates about how well technological systems could be expected to perform in real world applications.

There is significant uncertainty over the future costs and performance of the technologies, and these uncertainties have important impacts on the likely sustainability of the different futures. In particular, there are uncertainties concerning: the performance and costs of carbon capture and storage, nuclear power, pipelines, small scale steam methane reformers, fuel cells and hydrogen storage technologies.

There is a wide range of rationales for ranking different futures (e.g. political implications vs. technical appraisals of likely system performance). Some of these issues are amenable to further research, others are based on normative value judgements about the way in which society should operate, and are therefore likely to be a continuing source of disagreement and dissent. Nuclear power, the degree of decentralisation, and feasibility were key areas dividing participants' appraisals.

For those concerned about nuclear power, opposition was as much to do with social and political aspects as environmental concerns.

These contested priorities and perspectives suggest that the broad advocacy coalition currently promoting hydrogen may be fragile, and that there is significant potential for future social conflict over the shape and direction of any transition towards a hydrogen economy.

In discussing the sideswipes at the end of the MCM interviews, it was noteworthy that many participants felt these were plausible, and not radically different from the futures they expected despite their somewhat extreme character. However, while many participants recognised the importance of the threats embodied in the sideswipes during the appraisal, they did not take into account the radically changed conditions that such sideswipes would imply. Rather, participants explored future states in terms of current society's assessment of the importance of climate change and energy security.

Key Insights from the UKSHEC Transition Scenarios

Structural Shift → *Electricity Store:* much of the literature and policy discussions around the future of hydrogen in the UK emphasise the role of hydrogen as a transport fuel and assumes that breakthroughs will come about as a result of developments with respect to fuel cell vehicles. By contrast this scenario illustrates a transition driven by moves towards a low-carbon energy system. Here the emergence of hydrogen is not driven by a particular guiding vision, but rather is an emergent response to a restructuring of energy markets and the broader technological changes this creates. This scenario therefore focuses attention on the importance of market structure and regulation as a driver of innovation. It challenges the assumption that a major programme of investment in infrastructure will be required for the development of a hydrogen transport system.

Corporate Race → *Ubiquitous Hydrogen:* Often it is assumed that government holds the key to the development of a hydrogen economy. This scenario emphasis the role and power of global companies, and the potentially positive outcomes of strategic competition as a driver for radical innovation. It draws attention to the relationship between global companies, niche experimentation and regional systems of innovation with respect to hydrogen, and the importance of environmental regulation in fostering new markets for clean technologies.

Government Mission → *Central Hydrogen for Transport:* Despite the scale of the challenge posed the climate and energy security drivers of a hydrogen economy, much of the policy discussion about hydrogen is constrained by current assumptions about the dominance of the market, the limits of government and antipathy to 'picking winners'. In contrast to the *Corporate Race* scenario, this storyline explores the idea that stronger government intervention may be required for a rapid transition to hydrogen, and challenges us to critically reconsider the ability of liberalised markets to deliver the purposive, large-scale socio-technological and infrastructural developments that may be required in an increasingly unstable and hostile world.

Disruptive Innovation → *Synthetic Liquid Fuel* is an alternative or 'wild card' scenario. Conventional wisdom suggests that the market alone will not deliver a transition to a hydrogen economy, and that the automotive industry in particular has moved away from research into the use of synthetic liquid fuels such as methanol as a possible source of power for future fuel cell vehicles. The Disruptive Innovation → *Synthetic Liquid Fuel* transition scenario challenges us to rethink these assumptions and re-examine the sorts of technological developments, firms and industrial sectors which might drive the transition to hydrogen, and indeed what a hydrogen economy might actually look like.

Despite very different governance structures and policies across the four scenarios, all contain at least some attempts by policy-makers to reduce carbon emissions and enhance energy security. This together with the results from the earlier MCM appraisal this suggests that, in the short term at least, 'business as usual' or the market alone are unlikely to deliver a transition to hydrogen without these efforts from government.

There is a portfolio hydrogen production, storage, purification and handling, and fuel cell technologies common across all the scenarios. However, some of the technologies envisaged do not fit all the scenarios. The development and widespread use of stationary hydrogen 'energy stations', nuclear power, gasification, methanol fuel cells, carbon capture and storage, and pipeline technologies would fit into some pathways but lead others elsewhere. Decisions to support some but not others of these would clearly influence the direction of technological change, and create a different set of choices in the future.

Picking a 'winning' set of technologies is impossible given the uncertainties inherent in their development, and the market alone or 'business as usual' may not deliver the technologies that make a transition possible. Instead, support for portfolios of promising technologies may be the most robust approach.

The scenarios also highlight a number of broader strategic decision points, for government, business and wider society, which are likely to prove influential in shaping the direction of future technological developments with respect to hydrogen. These include decisions over: i) the construction of new nuclear capacity, carbon capture and storage, and large scale renewables; ii) the viability of distributing hydrogen through natural gas pipelines; and iii) the commercialisation of FCVs by major automotive firms.

6. Reflections on the UKSHEC hydrogen futures methodology

This final section briefly reflects on the utility of the UKSHEC foresight methodology and scenarios framework.

Overall the participatory backcasting approach developed for this study illustrates one approach to working more systematically and transparently with the challenges of uncertainty, and diverse and contested expectations of the future, in studies of long term prospective systems innovation. Participatory backcasting incorporates a wide range of stakeholder views and expertise, whilst combining the scenario and MCM tools allowed us to 'open up' the appraisal of the sustainability of different hydrogen futures. Systematically mapping the different social perspectives and exploring uncertainties.

The findings should be seen as complementing more conventional modelling and technical appraisals such as wells-to-wheels carbon analysis. Indeed, in a recent report to the European Parliament on the environment and innovation, for example, these results were presented alongside wells-to-wheels data to provide a broader insight into the issues at stake (Giljum et al 2006).

The findings suggest that even with perfect foresight and no uncertainties it would not necessarily be possible to obtain a single consensus view on which futures are most sustainable. This is because participants have different ideas about what sustainability means, what elements are more or less important, and about what sort of society is desirable. In short, there is an inescapably political element to long term technological choice.

Finally, drawing upon the systems innovation and socio-technical transitions literature encouraged us to explore novel pathways, and a broader range of drivers, decision points and policies shaping the future. Moreover, the framework and structure of the scenarios, linking the SPRU transition contexts and IVM governance paradigms with the MLP, enabled exploration of different transition dynamics and encouraged attention to the role of governance, agency and power in transitions.

The experience of the UKSHEC scenarios project suggests significant value in the combination of multi-criteria appraisal and participatory backcasting. The critical thinking stimulated by the exercise provides policy-makers with deeper insights into the issues at stake.

References

Anderson et al 2005. Decarbonising the UK: Energy for a climate conscious future. Report of the Tyndall for Climate Change Research, UK.

Berkhout, F., Smith, A, & Stirling, A. (2004) Sociotechnical regimes and transition contexts, In Elzen, Geels & Green (eds), *System Innovation and the Transition to Sustainability: Theory, Evidence and Policy.* Camberley, Edward Elgar.

Dierkes, M. Hoffmann, U. & Marz, L. (1996), Visions of technology: social and institutional factors shaping the development of new technologies. New York, Campus Verlag St. Martin's Press.

DTI, 2003. Our common future: creating a low carbon economy. The Stationery Office, London.

Geels, F.W., 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. Research Policy, 31(8-9): p. 1257-1274.

Giljum S, Hinterberger F, Jäger J, Karlsson S, Lorek S, Kaivo-oja J, Kemp R, Kinnunen V, Luukkanen J, Schnepf D, Schreuer A. (2006), Environment and innovation: new environmental concepts and technologies and their implications for shaping future EU environmental policies. Study for the European Parliament's Committee on the Environment, Public Health and Food Safety. Report number IP/A/ENVI/ST/2005-84, Brussels.

Hisschemoller, Bode, Van der Kerkhof (2006). What governs the transition to a sustainable hydrogen economy? Articulating the relationship between technologies and political institutions. *Energy Policy* 34 (11): 1227-1235.

Eames, M. & McDowall, W. (2005), UKSHEC Hydrogen Visions. UKSHEC Social Science Working Paper No. 10. Policy Studies Institute, London.

Eames, M. & McDowall, W. (2006) Transitions to a UK Hydrogen Economy. UKSHEC Social Science Working Paper No. 19, Policy Studies Institute, London.

Eames, M. & McDowall, W. (2006), *Systems innovation and the transition to a sustainable hydrogen economy: a multi-level perspective*, Paper for the SPRU 40th Anniversary Conference, Brighton, September 2006

Eames, M., McDowall, W., Marvin, S., & Hodson, M.,(2006), Negotiating Generic and Place-Specific Expectations of the Hydrogen Economy, *Technology Analysis and Strategic Management*, Vol. 18, Number 3-4/July-September 2006, pp 361 – 374.

Eames, M. & McDowall, W. (2007) Towards a sustainable energy future: participatory foresight and appraisal as a response to managing uncertainty and contested social values, Chapter in Flynn, R. and Bellaby, P. Risk and the Public Acceptance of New Technologies, Palgrave Macmillian.

Elzen, B. Geels, F. Hofman, P.S. Green, K. (2004), Socio-Technical Scenarios as a tool for Transition Policy - An example from the traffic and transport domain, in *System Innovation and the Transition to Sustainability: Theory, Evidence and Policy.* Eds Elzen, B. Geels, F. Green, K., Camberley, Edward Elgar, pp 251-281.

Kemp. R, & Loorbach, D. (2006), "Transition management: a reflexive governance approach", in *Reflexive Governance for Sustainable Development* Eds J-P Voss, D Bauknecht, R Kemp (Edward Elgar, Cheltenham, Glos) pp 103 – 130.

Mattias Weber, K. (2006) Foresight and adaptive planning as complementary elements in anticipatory policymaking: A conceptual and methodological approach, in *Reflexive Governance for Sustainable Development* Eds J-P Voss, D Bauknecht, R Kemp (Edward Elgar, Cheltenham, Glos) pp 189-224

McDowall, W. & Eames, M. (2004), Report of the September 2004 UKSHEC Hydrogen Visions Workshop. UKSHEC Social Science Working Paper No. 9, Policy Studies Institute, London.

McDowall, W. & Eames, M. (2005), *Report of the September 2005 UKSHEC Hydrogen Transitions Workshop.* UKSHEC Social Science Working Paper No. 11. Policy Studies Institute, London.

McDowall, W. & Eames, M. (2006a), Forecasts, Scenarios, Visions, Backcasts and Roadmaps to the Hydrogen Economy: A Review of the Hydrogen Futures Literature, Energy Policy, 34 (11) 1236-1250.

McDowall, W. & Eames, M. (2006), Towards a Sustainable Hydrogen Economy: A multi-criteria mapping of the UKSHEC hydrogen futures, Full report, Policy Studies Institute, London

Shove, E. & Walker, G (2007), "CAUTION! Transitions ahead: politics, practice, and sustainable transition management" *Environment and Planning A* **39**(4) 763 – 770.

Spath, P. Rohracher, H. Matthias Weber, K. Oehme, I. (2006), The transition towards sustainable production systems in Austria: a reflexive exercise? in Reflexive Governance for Sustainable Development Eds J-P Voss, D Bauknecht, R Kemp (Edward Elgar, Cheltenham, Glos) pp 355-382

Stirling, A. (2006), Precaution, foresight and sustainability: reflection and reflexivity in the governance of science and technology, in *Reflexive Governance for Sustainable Development* Eds J-P Voss, D Bauknecht, R Kemp (Edward Elgar, Cheltenham, Glos) pp 225-272

Stirling, A. (2005), Multi-criteria mapping: a detailed analysis manual, Version 2.0. Mimeo. Brighton: SPRU, University of Sussex.

Stirling, A. (2004), Detailed multi-criteria mapping interview protocol. Mimeo. Brighton: SPRU, University of Sussex.

Stirling, A. (1999), The Appraisal of Sustainability: some problems and possible responses, Local Environment: 4 (2): 111-135.

Stirling, A. and Mayer, S. (1999), Rethinking risk: a pilot multi-criteria mapping of a genetically modified crop in agricultural systems in the UK. Brighton: SPRU/Genewatch.

Van Lente. H. (1993), *Promising Technology: the dynamics of expectations in technological development*. (Enschede, Department of Philosophy of Science & Technology, University of Twente.

Van Notten, P. W. F., A. M. Sleegers and M. B. A. van Asselt (2005). The future shocks: On discontinuity and scenario development. *Technological Forecasting and Social Change* 72(2): 175-194.

Voss, J.P. Truffer, B. Konrad, K (2006),Sustainability foresight: reflexive governance in the transformation of utility systems in *Reflexive Governance for Sustainable Development* Eds J-P Voss, D Bauknecht, R Kemp (Edward Elgar, Cheltenham, Glos) pp 162-188.