

**Towards a sustainable hydrogen economy:
A multi-criteria mapping of the UKSHEC hydrogen
futures**

SUMMARY REPORT

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1.Introduction

Hydrogen has the potential to provide a sustainable and secure energy system. However, there is no consensus on what a hydrogen future should look like, and deep disagreements are emerging over the energy sources and types of infrastructure that should be included or rejected.

This report presents the results of an exercise in developing a set of visions of possible hydrogen futures for the UK, and subjecting those visions to a participatory multi-criteria sustainability appraisal, with a view to exploring the broader dimensions of sustainability around hydrogen systems. The work is part of a backcasting scenario project, which aims to develop visions of a sustainable hydrogen future, and then explore the pathways by which those visions might be achieved.

This summary report aims to:

- Present the six UKSHEC Hydrogen Visions, representing possible hydrogen futures for the UK
- Report the findings of a multi-criteria sustainability appraisal of those six visions
- Draw conclusions about the uncertainties, different perspectives, and key issues that are important in considering how hydrogen energy might contribute to sustainability
- Highlight lessons for research and policy

The full report is available from the PSI website, at www.psi.org.uk/ukshec

1.2 What does vision appraisal tell us?

Visions of the future are important in technological change, helping to create a shared sense of purpose about priorities and policies. However, visions are often contested, and hydrogen is no exception: there is no single agreed sustainable hydrogen economy. This work is based on an understanding that where uncertainties are large, and where there are different social priorities involved, it is not possible to identify a single best or 'optimal' solution. The six future visions in this study are not intended as predictions. The technologies they comprise could be configured into a wide range of possible future hydrogen systems, and hybrid systems, involving some components of a number of visions, may be much more likely. Instead, the visions are intended to cover the broad range of possibilities in a manageable number of visions. This means that the results cannot be seen as advocating or endorsing any one of the visions alone, but they are rather to be thought of as tools for learning about the important perspectives, issues, and uncertainties that surround the hydrogen debate.

1.3 How were the visions developed?

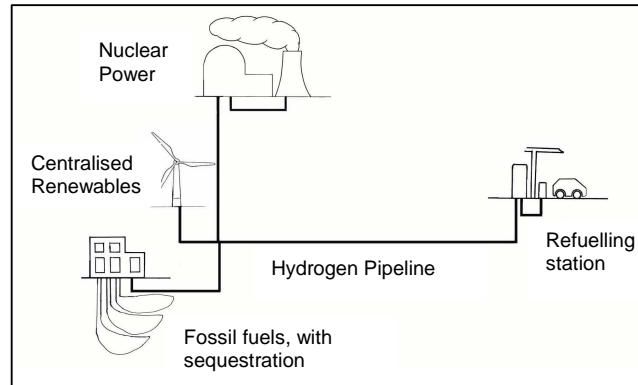
The visions were developed through a review of the hydrogen futures literature, and on the basis of a workshop bringing together 40 UK hydrogen stakeholders. Each vision consists of a description and diagram of a technological system, including the production, distribution and end-use of hydrogen.

2. Summaries of the Six UKSHEC Hydrogen Visions

Full vision descriptions can be found in the full report.

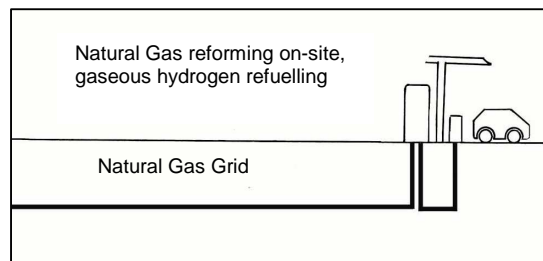
CENTRAL PIPELINE

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.



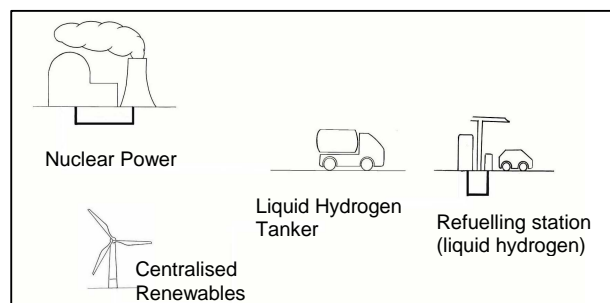
FORECOURT REFORMING

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.



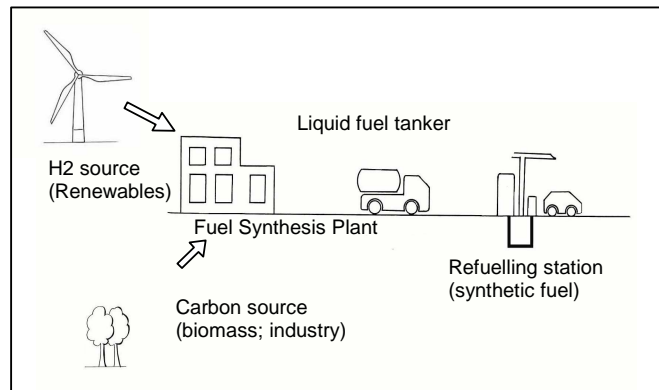
LIQUID HYDROGEN

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.



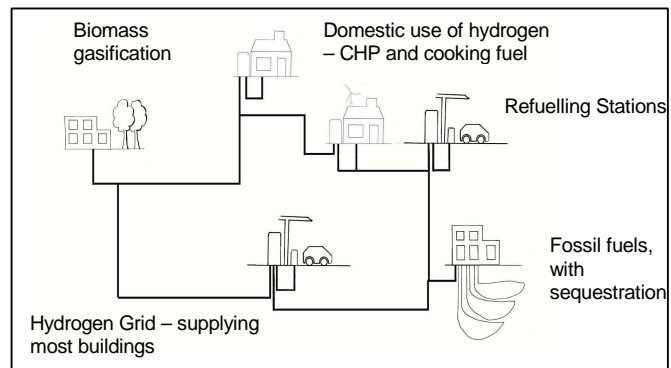
SYNTHETIC LIQUID FUEL

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.



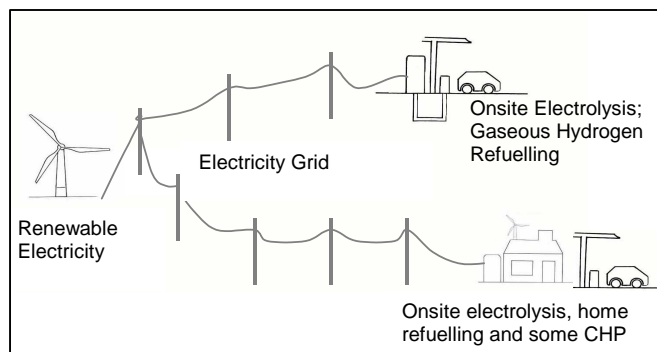
UBIQUITOUS HYDROGEN

Renewably produced hydrogen is a major energy carrier for heat and power as well as the dominant transport fuel. A hydrogen pipeline grid serves most buildings. Many homes and businesses use fuel cell CHP systems running on hydrogen, and it is common to refuel your vehicle at home. Hydrogen is produced from a mix of larger centralised and smaller-scale distributed renewables and biomass.



ELECTRICITY STORE

Hydrogen, produced through onsite electrolysis, is the dominant road transport fuel, and also plays a vital role overcoming the intermittency problems of a renewables-based electricity system. Hydrogen production is flexible, and can respond to variable electricity supply conditions, easing load-balancing. Since hydrogen is produced onsite it requires no distribution infrastructure. Locally-stored hydrogen provides back-up power for domestic and commercial CHP units at times of peak electricity demand/limited supply.



3. Appraising the UKSHEC Visions: Multi-criteria mapping

The six visions were appraised by a panel of 15 expert stakeholders, with backgrounds in government, research, industry, and environmental campaigning, using a Multi-Criteria Mapping method. The appraisal process involved a series of in-depth, 2-3 hour interviews with each of the expert stakeholders¹, who develop a set of criteria on which they then score the visions' performance, and provide a weighting scheme to assess the importance of each criterion. Each performance score is given as a range, to capture how performance changes under optimistic or pessimistic assumptions about key uncertainties.

Expert Panel	
<ul style="list-style-type: none">• Nuclear Industry Expert• Carbon Trust Analyst• DTI Policy Maker (Department for Trade and Industry)• Fuel Cell Industry Participant• Sustainable Energy Policy Consultant• Industrial Gases Industry Participant• Energy Technology Researcher• Environmental Campaigner	<ul style="list-style-type: none">• Health & Safety Regulator• Energy Policy Researcher• Senior Oil Industry Participant• DfT Policy Maker (Department for Transport)• Automotive Industry Participant• Regional Government Policy Maker• Climate Scientist

4. Headline Results from the Appraisal

The results from the multi-criteria mapping indicate that, overall, *Electricity Store* was seen as the most sustainable vision, subject to concerns about feasibility. *Forecourt Reforming* was judged to be least sustainable, largely because of carbon emissions, but also concerns about the energy security and economic implications of natural gas dependence.

Central Pipeline was the most contentious vision, with the widest range of rankings, reflecting divergent opinions on nuclear power, carbon sequestration, and the economic viability of a large, centralised pipeline infrastructure. *Synthetic Liquid Fuels* performed unexpectedly well, reflecting the benefits of a low carbon fuel that is straightforward to store and transport, and that offers fewer technological barriers than the use of pure hydrogen. It was also the vision around which there was greatest uncertainty. *Liquid Hydrogen* did poorly, partly because of some participants' concerns about nuclear power, but more importantly because liquid hydrogen was seen as impractical and inefficient for use as a mainstream transport fuel (although many participants felt that liquefied hydrogen would have a role in some applications). Finally, *Ubiquitous Hydrogen* performed relatively well, but as with *Electricity Store*, there were some concerns about its feasibility.

The primary energy sources were important in the final performance of the visions, and clearly other combinations are possible (a system like *Ubiquitous Hydrogen* or even *Electricity Store* could include some nuclear, for example). Since there are many possible configurations of the technologies that compose each vision, the final rankings of the visions tell us only a small part of the story. The important issues, uncertainties, and participants' perspectives on particular technological components are more useful. Analysis of the appraisal outputs leads to the following key conclusions:

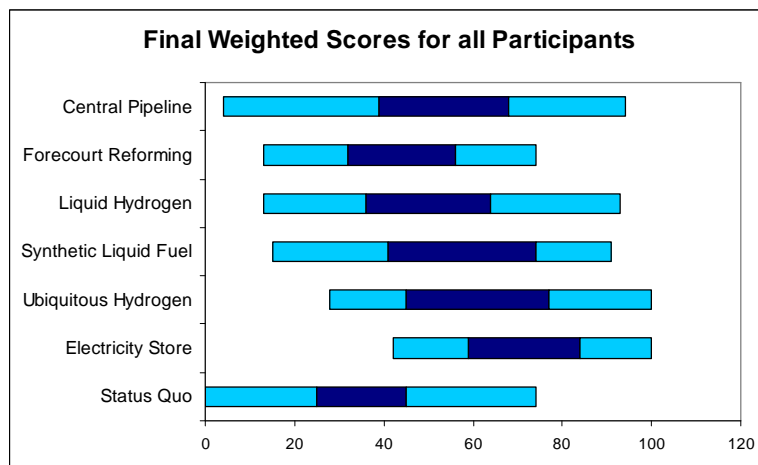
¹ Participants took part as individuals with an informed background, rather than as representatives of their institutions. The small number of participants clearly mean that the results cannot be taken to be representative in a quantitative way of views in the population as a whole, or among hydrogen experts. However, we do expect that a similar range of issues would have been raised with a different panel, and that the panel was sufficiently representative to explore and open up a diversity of issues and perspectives.

- ❑ 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.
- ❑ 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.
- ❑ Assumptions about technological change are important – do some routes mean that we close off others? This is an area that further research might cast some light on.
- ❑ 'Business as usual' or the market alone are thought to be unlikely to deliver any of the visions, at least in the short term.

5. Summary of Detailed Results

This section provides an overview of the results from the MCM process.

The aggregated final weighted scores show the overall picture of participants' appraisals, showing which visions were thought to be most or least sustainable.



Final weighted scores aggregated across all participants. Bars indicate extreme (light blue) and average (dark blue) 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.

Central Pipeline

All participants recognised this future as playing a well established role in hydrogen debates, but it was the vision with the widest range of rankings. *Central Pipeline* was ruled out by the *Environmental Campaigner* because of its inclusion of nuclear. In the view of two other participants, who penalised centralised systems and pipelines, and nuclear and carbon sequestration, *Central Pipeline* was the worst performing vision. In contrast, the *Sustainable Energy Policy Consultant* ranked this vision as the best performing, arguing that it provided the most cost effective way to reduce carbon emissions and enhance energy security.

Forecourt Reforming

Eight participants saw this as having little role as a viable 'end-point' vision, but spoke of it as having a valuable role to play as a transitional step in terms of infrastructure development. An interesting feature of this vision was the debate over its practicality, with the panel showing sharply opposing views on the feasibility of widespread distributed natural gas reforming. While most participants tended to see this as a more straightforward vision, the *Oil Industry Participant* commented that, as a vision for the UK as a whole "as someone who actually runs one thousand three hundred petrol stations, I could tell you this is nigh impossible", due to space restrictions at refuelling stations.

This vision was seen as the worst performing by six participants. This was because of poor performance on carbon criteria, and for some participants, poor performance on energy security criteria. In no case was this seen as the best performing vision. The overall poor performance of this vision is confirmed at the aggregate level, where it performs worst under both optimistic and pessimistic assumptions

Liquid Hydrogen

Several participants felt that this was one of the least likely visions presented in the set. However, the technologies within the vision were all felt to be relevant and worth exploring. The *Industrial Gases Industry Participant* felt it was not likely, but broadly plausible: “the technology’s known, it’s a current way of distributing hydrogen, ... if you can justify the investment and you know there’s a market there, then it doesn’t seem unreasonable.” The feeling overall seemed to be that while liquid hydrogen is likely to play an important role in the distribution and storage of hydrogen in some circumstances, the sole use of liquid is unlikely.

The *Health and Safety Regulator*, the *Senior Oil Industry Participant*, and the *DfT Policy Maker* ranked *Liquid Hydrogen* worst under both pessimistic and optimistic assumptions. A further participant (the *Environmental Campaigner*) ruled it out entirely, on the basis of its inclusion of nuclear power. In no case was the *Liquid Hydrogen* vision the best performing. However, the *Automotive Industry Participant* created an additional vision, a hybrid of liquid hydrogen and ubiquitous hydrogen, and this performed very highly in their appraisal.

Synthetic Liquid Fuel

Unlike the other visions, this was new to many of the participants, but in general it was thought to be an interesting addition to the overall set. The *Sustainable Energy Policy Consultant* and *Industrial Gases Industry Participant* saw scope for this being the worst performing vision, but both of these participants gave this ranking a high degree of uncertainty. Only in the view of the *Industrial Gases Industry Participant* did it remain the worst performing even under most positive assumptions. Both of these participants were sceptical of the carbon balance of this vision, and of its likely feasibility and costs. No participant saw this as the best performing vision, but in the views of six participants it performed well under positive assumptions.

Ubiquitous Hydrogen

Opinion on this vision was sharply divided. The *Sustainable Energy Policy Consultant* felt it to be implausible, because of the efficiency issues around distributing energy for stationary applications as hydrogen. For others, it is the most sensible and desirable system. A common attitude to this vision summed up by the *DTI Policy Maker*, who commented that “it’s credible when there aren’t really any alternatives left”, and particularly when natural gas is no longer economically available.

Only the *Sustainable Energy Policy Consultant* saw this as potentially the worst performing vision. This was largely on the basis of cost and feasibility, and the feeling that hydrogen should not compete with electricity to distribute energy for stationary power. Two participants (the *Carbon Trust Analyst* and *Senior Oil Industry Participant*) saw this as potentially the best performing vision, and a further two participants saw it as joint best with *Electricity Store*. However, no participant ranked it best under least favourable assumptions, suggesting that it would not be seen as a fall-back option.

Electricity Store

All participants recognised this as a major part of the hydrogen debate. Most saw it as only viable in the very long term, given its reliance on renewables, and the *Industrial Gases Industry Participant* and *DfT Policy Maker* were concerned that pursuit of this vision would lead to less efficient use of limited renewable electricity supplies. The *Nuclear Industry Expert* felt that the inclusion of nuclear power in this vision would make it more robust and more feasible.

No participant saw this as the worst possible vision. Where this vision performed relatively poorly, this was on the basis of concerns about feasibility and cost, and scepticism about the availability of sufficient renewables capacity. Several participants saw it as only viable in the very long term. This vision was seen as performing best under five participants views, and as joint best along with *Ubiquitous Hydrogen* under a further two. This vision did best among participants that strongly

supported renewables, rejected nuclear and carbon sequestration, and preferred decentralised systems. *Electricity Store* also performed best overall at the aggregate level.

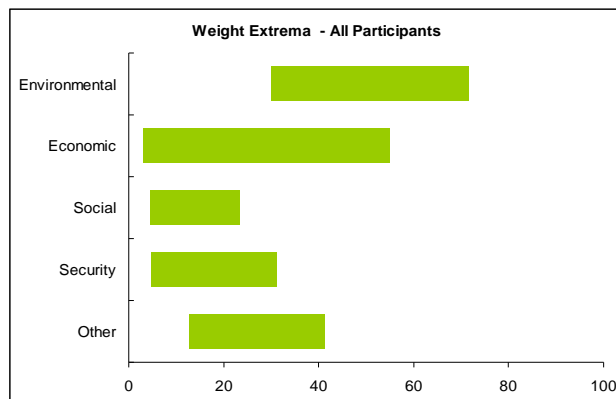
Comparisons with the Status Quo

In addition to the six hydrogen visions, participants were also asked to appraise the performance of a ‘status quo’ or business as usual vision. In the appraisals of many participants, there were conditions under which the status quo was not the worst performing option, implying that some hydrogen futures could be less sustainable than current, or business as usual, activities. However, status quo was frequently the worst performing option. In no case was status quo seen as the best performing option, suggesting broad agreement that many hydrogen systems bring sustainability gains.

5.2 Criteria and Weighting: dimensions of sustainability for hydrogen

Between them, the 15 members of the expert panel defined a total of 98 sustainability criteria, of which many were very similar across different participants (e.g. various criteria exploring carbon emissions, social acceptability, energy security etc).

The weightings chart provides an overview of the groups of issues that participants judged to be most important. Participants were invited to identify criteria under the classic three elements of sustainability: environmental, economic, and social, as well as an energy policy category of energy security, and an ‘other’ category for criteria that participants felt did not fall within the other groups. There is a clear tendency for environmental issues to receive high weightings, with social issues in general receiving much less attention, and with a substantial spread of views around the importance of economic criteria.



Shows the spread of weightings from all participants. Each participant distributed 100 weighting ‘points’ among their criteria, to indicate relative criteria importance.

Environmental Issues

The six visions were clearly differentiated on the basis of their environmental performance. This was dominated by carbon emissions, but included a range of other criteria. In terms of weightings across the participants overall, carbon emissions were clearly considered to be the most important single determinant of sustainability. Environmental issues other than carbon emissions favoured *Electricity Store* and *Forecourt Reforming*.

Issues considered under environmental criteria included:

- Greenhouse Gas Emissions
- Local Air Quality
- Toxicity and non-carbon pollution
- Visual Impact
- Nuclear Waste
- Impacts on water
- Impacts on wilderness
- Impacts on biodiversity
- Catastrophic Risk
- Resource Depletion

Economic Issues

The economic scores are interesting, with none of the visions coming out as obviously better or worse when the appraisals of all participants are examined at an aggregated level, although many individual participants did see significant variation among the visions in terms of economic performance. All participants scored some form of economic criterion (although for the *Heath and Safety Regulator* this was through a 'feasibility' criterion in the 'other' category of issues).

The most highly weighted economic criteria concerned feasibility, and the economic attractiveness of the vision to investors. Nine participants scored some kind of 'cost' criterion. However, these were varied. Some of these criteria concerned costs to society overall, while others were intended to represent what consumers might pay at the pump. Variations in the assessments of likely economic performance of the visions were in part dependent on different assumptions about policy frameworks around carbon; fossil fuel prices; the costs of nuclear power; and the relative affordability of more decentralised, modular systems or capital-intensive centralised systems.

Issues considered under economic criteria included:

- Cost or affordability of hydrogen
- Impact on the UK economy
- Degree of consumer choice
- Business case/economic feasibility
- Upfront capital costs

Social Issues

Seven participants scored only a 'social acceptability' criterion under this heading, and the way in which it was scored suggested that participants felt that this was a potential barrier to feasibility, rather than an ongoing dimension of a desirable or sustainable future. Most participants also gave social acceptability relatively low weightings. The performance of the visions varied amongst participants, with some feeling that 'out of sight' centralised systems such as *Central Pipeline* would be most acceptable, and others feeling that publics would be most willing to accept the least polluting visions, such as *Electricity Store*.

Some participants scored visions on a wide range of social and political concerns. These other social issues tended to be given higher weightings than the more homogenous 'acceptability' concerns. In general, visions involving greater decentralisation tended to do well under these criteria. Issues considered under social criteria included:

- Social or public acceptability
- Access to energy services
- Social Justice
- Degree of physical intrusion
- Usability
- Control of energy
- Degree of state intervention required

Energy security Issues

All but three participants scored criteria under 'energy security'. Unsurprisingly, *Forecourt Reforming* did badly under energy security criteria, given its dependence on natural gas. Issues considered under energy security criteria included:

- Security of primary sources
- Diversity of primary sources
- Resources scarcity
- Infrastructure and downstream supply
- Compatibility with decentralised systems

Other Issues included:

- Quality of supply
- Technical feasibility
- Public safety
- Flexibility
- Radioactive Waste (seen as both environmental and social/political)
- Complementarity with renewables
- Geo-political concerns

5.3 Uncertainties Affecting Vision Performance

The appraisal as a whole clearly demonstrates the huge uncertainties involved. In some participants' views, the scale of uncertainties within the visions is as important as the differences between them, a conclusion that should not be surprising given the long time horizons involved. The task of the analysis is to explore the basis of those uncertainties.

Uncertainty about technologies

There are uncertainties surrounding technologies, not only in terms of their physical performance, but in terms of what impacts the technologies might have in broader socio-economic terms. The following uncertainties were each identified by more than three participants, and were reflected in variations between pessimistic and optimistic scores:

- Potential leakages of CO₂ from carbon capture and storage
- Fuel cell performance
- Performance of small scale natural gas reformers – in terms of both cost and pollution
- Likely carbon balance and toxic emissions from synthetic liquid fuel synthesis and use
- Costs for all technologies were subject to uncertainty, but in particular uncertainties relating to the costs of synthetic liquid fuels, nuclear power, and pipeline infrastructures were raised.
- Significant uncertainties around public acceptability of technologies in general
- Performance, integrity and vulnerability of pipelines
- Very large uncertainties around the possible impacts on the UK economy as a whole

Other areas of uncertainty, raised by fewer participants, included: hydrogen storage, safety of handling hydrogen in a domestic environment, safety of liquid hydrogen, likely developments of fast-breeder reactors (seen as necessary if uranium resource constraints are to be avoided), efficiency of liquefaction, performance of electrolysers, likely pollution from biomass gasification, necessary purity levels of hydrogen for PEM fuel cells, whether the natural gas network can be upgraded to take hydrogen, and whether decentralisation constrains or enhances access to energy.

Sensitivity of vision performance to different possible future contexts

Variation between optimistic and pessimistic scores also occurs where there is uncertainty about the broader context in which the visions exist, such as:

- Future natural gas availability and price – particularly important for the feasibility of *Ubiquitous Hydrogen*, and the feasibility and costs of *Forecourt Reforming*.
- Future national and international climate change policy frameworks, such as carbon taxes, clearly have an important effect on the feasibility of the visions, and on their relative costs.
- Social attitudes towards technology and the environment.

5.4 Perspectives and issues in appraising the sustainability of hydrogen

Overall, carbon emissions was clearly felt to be the most important factor on which to judge the sustainability of the different visions. However, participants differed strongly over three key issues, and it is participants' attitudes towards nuclear power, decentralisation, and feasibility that most clearly define different perspectives on how to judge the future sustainability of hydrogen systems.

Nuclear Power

"Nuclear... is fundamentally opposed to the notion of sustainable development. The idea that you have to bury waste in a hole for a hundred years before you can even deal with it, to me flies in the face of the leaving the world in the state that you found it. However, I see it as a lesser of evils debate, because leaving the world closer to the risk of catastrophic climate change is probably a worse thing to do"

Some participants saw nuclear power as a necessary and desirable part of a future hydrogen mix. Many others saw nuclear as a 'necessary evil' – a technology that is problematic, but worth the potential difficulties given the challenges of climate change and energy security. Three participants were strongly opposed to nuclear power, one of them ruling out any vision that included nuclear. Their reasons for opposition went beyond concerns about environmental impacts to encompass more social and political concerns. One reason for opposition was a belief that nuclear power is 'anti-democratic', and likely to lead to militarisation of the state. In the context of a future world that will be to some extent destabilised by climate change, expansion of a potentially dangerous technology was viewed as fundamentally undesirable. A second reason was a belief that the development of new nuclear power would in practice mean that renewables and energy efficiency would not be pursued. There were also debates about its cost.

Decentralised Systems

"I think that hydrogen has the potential to revolutionise...the way we use energy, by enabling us to produce and manage the supply and distribution and use of energy locally...we can emphasise local control of environment so to some extent we can empower local people in their control over energy services."

There are claims in the hydrogen futures literature and popular press about the potential for hydrogen to enable decentralisation and consumer awareness of energy or even greater democratisation and empowerment. The members of the expert panel took a range of views about such claims, and their approach to decentralisation was an important factor distinguishing their appraisals. Some felt that more decentralised systems would encourage renewables, energy efficiency, and changing consumer behaviour. Others disagreed, and did not see this as likely or plausible, feeling that the way in which the technological system was organised did not imply decentralised structures of ownership, management and control. There were also disagreements about the relative costs of centralised and decentralised systems.

Feasibility, Practicality, and Speed.

"What's important is how quickly will this particular route get to the end game [of low carbon emissions]. And I would say that's probably THE most important issue. Because we might not have very long."

Some participants felt that the most important issue was not to compare the likely sustainability impacts of the various hydrogen systems, since with the partial exception of *Forecourt Reforming*, all the visions tackle the basic problem of climate change. The question, for these participants, was more to do with the feasibility and practicality of arriving at the visions. The most important dimension of feasibility was in terms of the economic case for investing in the technology, or the presence of a consumer logic. This raised important questions about the degree to which radical change in the face of environmental pressures is possible in a democratic consumer society.

"Why should the customer want to do this rather than maintain the status quo? In a democratic situation the customer is going to have to want to do one of these rather than be told to do one of these."

5.4 Mapping different perspectives in the appraisal

The way in which participants approached these three key issues had a major impact on their overall ranking of the visions. Three participants (the *Energy Policy Researcher*, *Environmental Campaigner*, and *Regional Government Policy Maker*) were strongly opposed to nuclear power, and strongly favoured renewables and decentralised systems. Their appraisals and weightings are shown below.

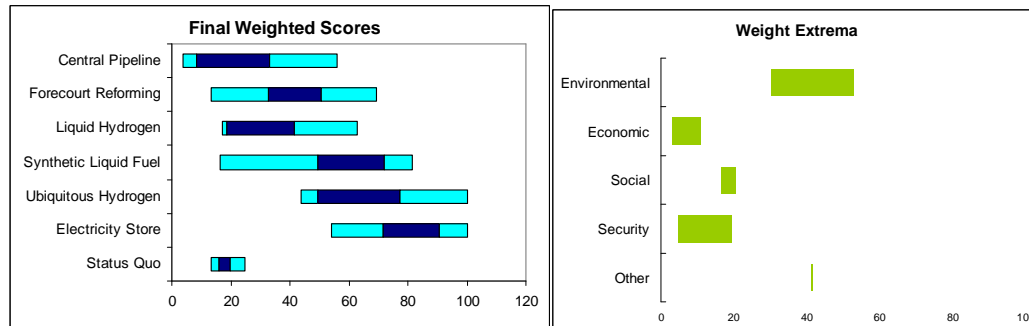


Figure showing weighted scores and weightings for the *Energy Policy Researcher*, *Environmental Campaigner* and *Regional Government Policy Maker*

A second group of participants took a view much more clearly defined by economic feasibility. This group comprised the *Sustainable Energy Policy Consultant*, *Industrial Gases Industry Participant*, *DfT Policy Maker*, *Health and Safety Regulator*, *Automotive Industry Participant* and *Nuclear Industry Expert*. Some of these participants felt that there would be little difference between the environmental performance of the six visions, with the exception of *Forecourt Reforming*. Instead, the important aspect of appraisal was the relative feasibility and economic attractiveness of the visions.

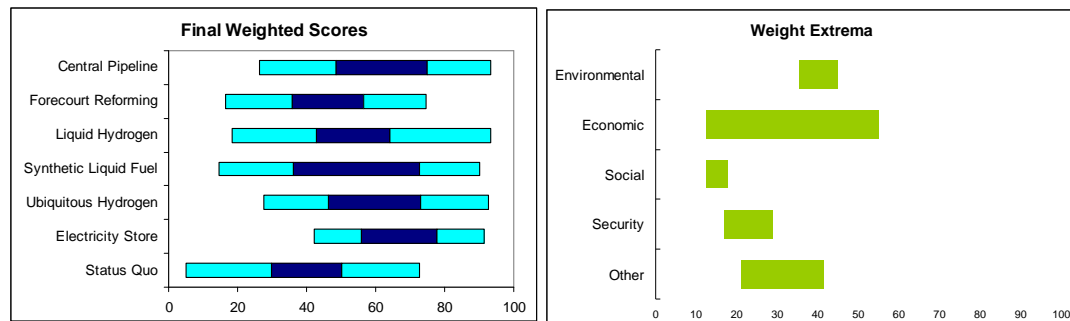


Figure showing the rankings and weightings for the *Sustainable Energy Policy Consultant*, *Industrial Gases Industry Participant*, *DfT Policy Maker*, *Health and Safety Regulator*, *Automotive Industry Participant* and *Nuclear Industry Expert*

Striking differences between the patterns of appraisal are clear, based on very different perceptions of what is important in determining sustainability.

6. Conclusions: Recommendations for Research and Policy

Recommendations for Policy

- ❑ While carbon emissions were recognised to be the most important single determinant of the sustainability of a hydrogen energy system, there are a wide range of other criteria that are seen as important. Issues other than carbon and cost need to be considered if the introduction of hydrogen is truly to deliver greater sustainability.
- ❑ Hydrogen policy must also be robust in the face of uncertainties about future context conditions, such as future availability and price of natural gas, and public attitudes to technology. The future of political frameworks around carbon and climate change is a key uncertainty affecting the perceived feasibility of the visions.
- ❑ The broad interest coalition promoting hydrogen is fragile. If hydrogen systems develop, there is significant potential for future social conflict over the shape and direction that those systems take.
- ❑ Robust research policy should address ‘backstop’ technologies – for example, that explore the possibility that hydrogen storage technologies fail to improve significantly.

Recommendations for Research

- ❑ Public acceptability research needs to take a whole systems approach, including primary energy as well as just the use of hydrogen as a fuel. Studies that only examine the public’s attitudes to the safety or end-use of hydrogen in isolation are likely to be of little use in understanding future conflicts.
- ❑ Research into social issues must move beyond narrow questions of safety and public acceptance: control, state intervention, access, and consumer choice may all be important. While public acceptability is important, there appear to be broader concerns about the potential social impacts of hydrogen systems.
- ❑ Combining scenario approaches with multi-criteria appraisal provides a valuable tool for exploring and mapping the perspectives, issues and uncertainties involved in long-term strategic technology choice. The approach could be fruitfully explored in other contexts. In particular, many of the issues raised as important for hydrogen would not have been discussed and explored with reliance on a more narrowly framed approach.

Transition Pathways to the UKSHEC Hydrogen Visions

A UKSHEC working paper published in Summer 2006, *Transitions to a UK Hydrogen Economy*, explores possible transition paths to the visions outlined in this summary report. The transition paths are theoretically-informed qualitative scenarios, drawing on historical patterns of large scale technological change. The working paper will be available from www.psi.org.uk/ukshec

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