

M A T I S S E

WORKING
PAPERS

2

9/2006

SUSTAINABLE TRANSPORT VISIONS:
What role for hydrogen and fuel cell vehicles technologies?

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MATISSE (Methods and Tools for Integrated Sustainability Assessment) aims to achieve a step-wise advance in the science and application of Integrated Sustainability Assessment (ISA) of EU policies. In order to reach this objective the core activity of the MATISSE project is to improve the tools available for conducting Integrated Sustainability Assessments.

Project duration: April 1st, 2005 - March 31st, 2008

MATISSE is supported by the 6th Framework Programme of the European Union.
Contract number: 004059 (GOCE) - MATISSE

MATISSE Working Papers are the outcome of ongoing research activities in the integrated research project MATISSE, funded by EU 6FP. They present preliminary results, which are open for debate and improvement for publication in scientific journals. All comments and suggestions are welcome.

The MATISSE Working Papers can be downloaded at <http://www.matisse-project.net/>.

Preface

About the MATISSE project

The MATISSE (Methods and Tools for Integrated Sustainability Assessment) project is funded by the European Commission, DG Research, within the 6th Framework Programme. The project is interested in the role that Integrated Sustainability Assessment (ISA) could play in the process of developing and implementing policies capable of addressing persistent problems of unsustainable development and supporting transitions to a more sustainable future in Europe. The core activity of MATISSE is to develop, test and demonstrate new and improved methods and tools for conducting ISA.

This work is carried out through developing and applying a conceptual framework for ISA, looking at the linkages to other sustainability assessment processes, linking existing tools to make them more useable for ISA, developing new tools to address transitions to sustainable development and applying the new and improved tools within an ISA process through a series of case studies.

The extent to which the case studies are carrying out a complete ISA for their area of focus varies between attempts to cover all phases of an ISA process to partial implementation of the process. Equally, different case studies are oriented to developing and testing tools and approaches to some, but not all, of the methodological challenges of ISA. The case studies are complementary, however, and the set of cases offers the opportunity to address a wide range of methodological challenges and to explore linkages between cases. An evaluation of practical experiences with ISA implementation in the case studies will provide guidance on the further improvement of methods and tools. Results will also contribute to more informed policy advice.

What is ISA?

Within the MATISSE project, Integrated Sustainability Assessment (ISA) has been defined as a cyclical, participatory process of scoping, envisioning, experimenting, and learning through which a shared interpretation of sustainability for a specific context is developed and applied in an integrated manner, in order to explore solutions to persistent problems of unsustainable development. ISA is conceptualised as a complement to other forms of sustainability assessment, such as Sustainability Impact Assessment, Integrated Assessment and Regulatory Impact Assessment. Whereas these other forms of assessment fulfil the pragmatic need for *ex ante* screening of incremental sectoral policies that are developed within the prevailing policy regime, ISA is conceptualised as a support to longer-term and more strategic policy processes, where the objective is to explore persistent problems of unsustainable development that have a systemic pathology and possible solutions to these. ISA is therefore oriented toward supporting the development of cross-sectoral policies that specifically address sustainable development and at exploring enabling policy regimes and institutional arrangements.

MATISSE Working Papers

Matisse Working Papers are interim reports of project activities that are published in order to illustrate ongoing work and some provisional conclusions, as well as providing the opportunity for discussion of the approaches taken by the project and interim results. This discussion should be both within the project and between project members and the broader scientific and policy communities. Readers are encouraged to contact the authors to discuss the content of MATISSE Working Papers.

Jill Jäger and Paul Weaver
Editors of the MATISSE Working Paper Series

Abstract

Transport systems perform vital societal functions, but in their present state cannot be considered 'sustainable'. Particular concerns in this respect include emissions, accidents, land use, noise, obesity and social exclusion. Increasing attention is being focussed on hydrogen transport technologies as a means to achieving more sustainable transport. In this paper, we draw on expert stakeholder evidence and the wider literature to elucidate criteria for sustainable transport and determine the extent to which hydrogen transport technologies can meet these criteria. Our findings indicate that hydrogen could alleviate some of the problems in the transport sector associated with emissions and energy supply security. However, other transport problems are not mitigated - and some may even be exacerbated - by hydrogen use. Thus, we highlight the need for integrated transport policies and argue for more reflexive and inclusive societal debate about the impacts and beneficiaries of hydrogen transport technologies.

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Sustainable transport visions: what role for hydrogen and fuel cell vehicle technologies?

1 INTRODUCTION

In this paper, we integrate two debates - one on the transition to a ‘hydrogen economy’ and one on sustainable transport - which currently are often conducted in isolation. To this end, we present findings from recent stakeholder consultation conducted within the EU Framework Six MATISSE project¹, to elucidate criteria for sustainable transport and assess the potential for hydrogen transport technologies to meet these criteria. In section 2, evidence for the unsustainability of the transport system and policy initiatives for sustainable transport are reviewed; particular attention is given to the recent focus within policy and industry on hydrogen and fuel cell vehicles to offer a means of achieving sustainable transport. Section 3 outlines the methodology and results of recent work conducted within the MATISSE project to elicit stakeholders’ visions of sustainable transport and sustainable hydrogen futures. In section 4, we link these two areas of discussion to reveal where hydrogen technologies can play a role in achieving sustainable transport, and where they cannot. We conclude by outlining the implications for policy-making with regard to hydrogen technologies, as well as wider transport and energy systems; and reconsider the value that stakeholder perspectives hold in assessing these issues.

2 UNSUSTAINABLE TRANSPORT AND OPTIONS FOR ACHIEVING SUSTAINABILITY

2.1 The unsustainability of today's transport system

Transport is crucial for our economic competitiveness and commercial, economic and cultural exchanges. This sector of the economy accounts for some 1,000 billion Euro, or over 10% of the EU’s gross domestic product, and employs 10 million people. Transport also helps to bring Europe’s citizens closer together, and the Common Transport Policy is one of the cornerstones of European development and integration [1].

However the current transport system does not correspond to the requirements of sustainability in many respects. Recent studies on external costs of transport systems (e.g., [2-6]) indicate a wide range of uncertainties, and vary in respect of basic assumptions and methodology (e.g., [7-9]). Nevertheless, they are more or less in agreement with respect to the major unsustainable areas in relation to environment and health, which include climate change, local air pollution, noise and accidents. With regard to climate change, transport is the sector with the highest increase of greenhouse gas emissions in recent decades, rising by 24% between 1990 and 2003 [10]. In turn, this threatens human health and ecosystem integrity. Local air pollution and noise associated with transport are problems for the increasing proportion (80%) of the European population living in urban areas. With regard to health², particulate emissions and ozone are the main problems, contributing to around 370,000 premature deaths in Europe

¹ Methods and Tools for Integrated Sustainability Assessment (MATISSE). See: www.matisse-project.net

² Although not included in these external cost studies, increasing dependence on car use has been linked to rises in obesity in western societies.

each year [12]. Up to 80 million Europeans suffer from unacceptable levels of noise, much of which is caused by traffic-related sound. This can lead to hypertension, myocardial infarction or sleep disturbance [13]. Road transport also presents other risks to human health and safety. Although fatality rates have decreased, road accidents still claim 41,000 lives per year in the EU [5].

Congestion and land use associated with transport infrastructure are also problems for most European countries. INFRAS [6] estimate the deadweight losses, which reflect the economic costs in relation to an optimal traffic situation, at 63 billion Euro for EU17 in 2000, and the additional time costs at 268 billion Euro (3% of GDP). Furthermore, transport infrastructure is both costly to maintain and takes up increasing amounts of rural and urban land, leaving less space for other human needs such as housing, services and recreation, and threatening biodiversity [10,14]. Other impacts associated with transport infrastructure include soil sealing and fragmentation of natural, semi-natural and agricultural areas [14].

There are also several notable social problems associated with transport, which have not been included in the external cost studies above. One major element for a sustainable transport system is access to basic services such as shopping, work and education (e.g., [15]). In some countries, people have to travel increasing distances to gain this access due to changing spatial patterns (e.g., urban sprawl and development of out-of-town centres). Furthermore, due to increasing fuel prices, limited reserves of oil and gas, as well as increased spread of incomes in EU countries, the issue of wide access to affordable transport in the EU could become an increasingly relevant issue in the future. The issue of access and social inclusion particularly affects rural communities and groups with impaired mobility, such as the elderly and disabled [16]. As European populations age, this problem is likely to be exacerbated.

Additionally, transport is a major driver of energy use. It accounts for more than one quarter of the world's and 32% of the EU's commercial energy use, and these proportions are increasing. The transport market is today almost entirely dependent upon oil-based fuels and is responsible for about 67% of final oil demand in the EU [10]. Therefore energy supply security and resource use are two critical topics for today's transport system.

2.2 Policy initiatives for sustainable transport, and the role of hydrogen technologies

Because of the importance of transport to economies, EU policy has historically focussed on liberalisation and harmonisation of transport to form a single trans-European transport network. More recently it has incorporated sustainability considerations into transport policies. Mobility is one of the six priority areas of the EU's Sustainable Development Strategy [14]. Furthermore, the European Commission's [1] *White Paper on the future Common Transport Policy* highlights a range of initiatives necessary for tackling problems of sustainability in the transport sector, including fostering modal shift towards environmentally friendly modes (rail, inland waterways, short sea shipping); promoting alternative vehicle and fuel technologies; improving efficiency; and internalising environmental costs in transport prices.

However, measures taken so far to influence individual travel decisions have had little effect relative to the underlying growth in demand. Indeed, in some cases, interventions to reduce demand or foster modal shift have had the reverse effect [17]. Similarly, the benefit of technical measures to reduce vehicle emissions and noise has often been outstripped by the increase in vehicle numbers, engine size, travel frequency and trip length [14]. The rising demand for transport, particularly road transport, suggests a need for radical rather than incremental technological improvements as well as integrated approaches to reducing demand and encouraging modal shift.

With regard to transport technologies, hydrogen and fuel cell vehicles have become a focus of considerable investment by public and private sector organisations in Europe (see, e.g., [18]). The

European Commission has been investing in a range of hydrogen technology research, development and demonstration projects in recent years (e.g., HyWays, HySociety, Zero-Regio, ECTOS, Renewable-H2, CUTE). Furthermore, the Commission has made the hydrogen economy one of its long-term priorities for Europe's energy system. To this end, it has created a private-public collaboration (known as a 'technology platform') to share expertise on hydrogen and to devise an action plan for creating an integrated hydrogen economy based on renewable energy sources and nuclear power by the middle of this century [19]. The Commission has also set a target of substituting 20% of traditional fuels by alternative fuels by 2020, with a total hydrogen penetration of 5%. Hydrogen and fuel cell technologies also contribute to the Commission's vision of *Environmental Technology for Sustainable Development* [20] which posits that use of clean technologies can create 'win-win' situations, where economic benefits can be reaped without resulting in environmental degradation.

This interest in developing and diffusing hydrogen and fuel cell vehicle technologies is based on the assumption that hydrogen offers effective solutions to both emission problems and concerns about security of energy supply, since hydrogen is an energy carrier that:

- is emission-free at final use³; and
- can be obtained from a variety of different primary sources.

Furthermore, fuel cell vehicles contribute to reduced noise pollution since:

- the drive system is virtually noiseless.

It is revealing that the social impacts of these technologies have been given much less attention than their economic and environmental benefits. As will be discussed in the following sections, there is a potentially significant, but limited, role for hydrogen and fuel cell technologies within a transition to sustainable transport.

3 STAKEHOLDERS' VIEWS ON SUSTAINABLE USE OF HYDROGEN IN TRANSPORT

3.1 Rationale and background

Stakeholder engagement is relevant to this issue given the complexity, ambiguity and subjectivity that surround persistent problems of unsustainability, such as transport. The MATISSE project, in which this transport case study is situated, is developing and testing approaches to Integrated Sustainability Assessment (ISA), which has been defined as a fundamentally participatory approach to sustainability assessment [21]; cf. [22]. This is consistent with the notion of 'Mode 2' science, which is more interdisciplinary, socially-accountable and applied than traditional scientific models of knowledge production [23].

Three main arguments may be posited for the value of stakeholder participation in sustainability research and assessment: normative, substantive and instrumental [24]. Firstly, sustainability involves subjective judgements about what future we should have and would like to have. While scientific research plays an important role in defining environmental, social and economic impacts of transport options, decisions about the acceptability of these impacts, and any trade-offs between different sustainability criteria, are based on social values and personal preferences. Secondly, sustainability issues are interdisciplinary and complex, and their assessment demands the expertise and unique experiences of a range of stakeholders [25]. Drawing on this diverse knowledge improves the quality of

³ When hydrogen is burnt as a fuel or used in a fuel cell to produce electricity, water is the only by-product.

decision-making and produces socially robust science. Thirdly, participatory assessment can foster trust and learning. By involving stakeholders in policy-relevant research, they will be more likely to feel ownership of the knowledge-making process and to be prepared to cooperate. Furthermore, stakeholder engagement processes can reduce conflict and build trust between stakeholders, by providing an opportunity to learn about other perspectives, values and knowledge [26]. In this sense, the process itself - as well as the substantive outcomes - can be beneficial. Involving stakeholders will not necessarily result in a more sustainable solution; consequently, participation should not be seen as a panacea. However, considering diverse perspectives is likely to improve the validity and applicability of assessment [22].

Stakeholder perspectives are reflected in the European Commission's vision and strategy for hydrogen and fuel cell technologies by their *High Level Group for Hydrogen and Fuel Cell Technologies*. This group was set up by the Commission in 2002 and represents the research community, industry, public authorities and end-users. They have defined four principal criteria for a sustainable hydrogen and fuel cell future [27]:

- Clean, safe, reliable and secure energy supply;
- Economic competitiveness (affordability and efficiency of supply; business opportunities);
- Air quality and health improvements; and
- Greenhouse gas reduction (energy supply from a growing proportion of carbon-free sources).

Other stakeholder processes have similarly highlighted these concerns as key drivers of a hydrogen economy (for a review see [28]). Recent work with European (principally expert) stakeholders has focussed on developing a 'roadmap', and identifying potential barriers, to a hydrogen transition [28-30]. In this work, stakeholders have highlighted a need for European commitment to clean energies and political support for hydrogen over the long term to ensure a successful transition to a hydrogen economy. Barriers to a transition, identified by stakeholders, include financial risks of innovation, technological immaturity (e.g., on-board storage and fuel cell lifetimes), lack of hydrogen refuelling infrastructure, lack of public acceptance, and competing technological alternatives. While these studies provide useful assessments of the potential for a hydrogen transition, these are typically uncritical about whether hydrogen and fuel cell technologies are the most *appropriate* solutions to effectively address sustainability challenges in the energy and transport sectors. Furthermore, the review of this literature by McDowall and Eames [28] shows that 'few studies seek to systematically assess the broader sustainability impacts of a large-scale transition to a hydrogen economy'; rather, most 'tend to treat prospective developments in hydrogen in relative isolation, rather than as embedded features of overarching energy and transport systems' (p.1247).

In contrast, research on energy and transport futures has located hydrogen and fuel cell technologies within a broader context. The EU Fifth Framework Programme project, *EurEnDel*, elicited expert perspectives on energy futures for Europe, including the role of hydrogen and fuel cell technologies [31]. Participants felt fuel cells and hydrogen technologies offered only moderate economic, social and environmental benefits, compared to alternative energy options. Renewable-based hydrogen production, although more challenging, was considered to offer more benefits than hydrogen from diverse sources.

Stakeholder perspectives on the role of hydrogen transport technologies within the wider sustainability transport context have to some extent been addressed within transport research and policy processes (e.g., [32-35]). This research points to a potential role (in the medium- to long- term) for hydrogen transport technologies in reducing emissions associated with motorised transport, alongside other technological and non-technological measures to tackle rising transport demand.

The research described here builds on and extends this previous work on stakeholder perspectives of sustainable transport and hydrogen futures. However, in contrast to this earlier work, the aim of the MATISSE research is to elicit stakeholder perspectives about the particular role hydrogen transport technologies might play in the broader context of sustainable transport. In this sense, our study employs a more integrative and reflexive focus than in previous studies on hydrogen futures, by assessing the

potential for hydrogen and fuel cell technologies to meet society's needs and preferences for transportation.

3.2 Methodology

As part of a cluster workshop on sustainability of hydrogen transport technologies held in Frankfurt during February 2006, MATISSE researchers conducted break-out discussion groups with, and distributed self-completion questionnaires to, stakeholders in hydrogen transport technology. The aims of the break-out groups and questionnaires were to elicit stakeholders' *visions of sustainability* in relation to both hydrogen transport technology and transport; and their views on *viable pathways*, and any *barriers*, to sustainable hydrogen-based transport.

Participants at the cluster workshop included researchers and consultants, an NGO representative, policy-makers, and members of the automotive and energy industries from across Europe, with interests and expertise in hydrogen and transport technologies (see Figure 1). While this does not represent a comprehensive range of stakeholders in a transition to hydrogen transport, it includes key decision-makers for the issue (see Table 3, below). Many of the participants can be considered experts in hydrogen technologies and sustainable transport, with researchers constituting the largest proportion of participants. The rationale for focussing on a more elite sample in assessing hydrogen and fuel cell transport is that perspectives on novel technologies tend to be more coherent and discriminating as knowledge about the technology increases [36]. Indeed, the little research that has been conducted to elicit the views of the non-expert public on hydrogen and fuel cell vehicles suggests only a small minority know anything about these technologies [37]. Further research will be conducted to elicit the views of stakeholder groups not represented at the workshop.

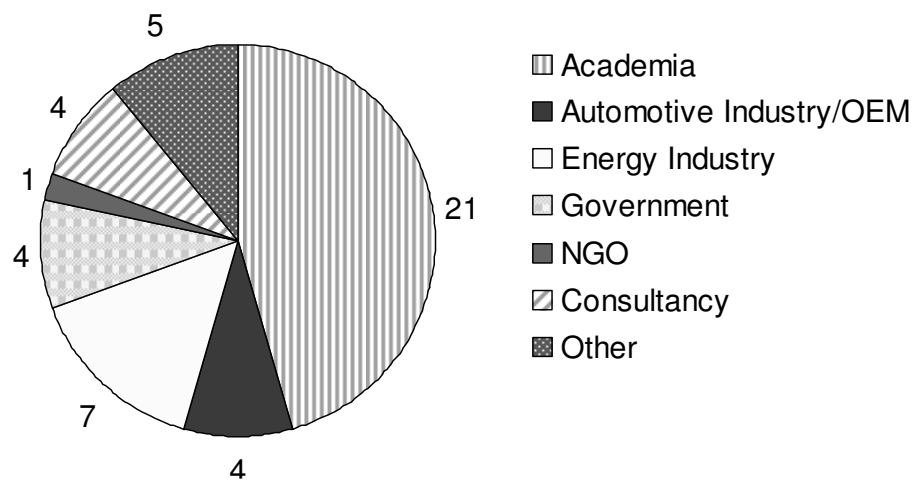


Figure 1: Background of participants

All workshop participants were assigned to one of five break-out groups according to the stakeholder 'category' they represented (i.e. Automotive Industry, Energy Industry, Research/ Academia, Consultancy, NGO, and Policy/ Government). The composition of the break-out groups was designated in advance of the workshop. The break-out groups comprised both heterogeneous and homogeneous categories of stakeholders:

- Group 1 was a homogeneous group of 10 Research stakeholders only (4 women, 6 men)
- Group 2 was a heterogeneous group comprising 3 Research, 1 Consultancy, 1 Policy, 1 NGO, 3 Energy Industry, and 1 Automotive Industry stakeholders (2 women, 10 men)
- Group 3 was a heterogeneous group comprising 2 Research, 4 Consultancy, 2 Policy-Makers, 1 Automotive Industry, and 1 Energy Industry stakeholders (1 woman, 9 men)

- Group 4 was a heterogeneous group comprising 2 Automotive Industry, 1 Energy Industry, and 3 Research stakeholders (6 men)
- Group 5 was a homogeneous group of Energy Industry stakeholders only (2 women, 4 men)

The rationale for using both homogeneous and heterogeneous groups was to enable a comparison of group dynamics and social learning amongst similar and diverse stakeholder groups. Each group lasted around one hour and was facilitated by one or two facilitators from the MATISSE project team. At the end of the break-out group discussion, participants were asked to fill in a self-completion questionnaire with more focussed questions that allowed respondents to express their opinions anonymously. All 44 questionnaires were returned completed. Excel and SPSS were used to produce descriptive statistics and graphs, and to perform chi-square tests to compare variation in responses between break-out groups.

3.3 Advantages and limitations of the approach

The rationale for using both group discussion and individual self-completion questionnaires is that there are advantages and limitations to each method. Qualitative discussion is appropriate for exploring the range of beliefs, ideas and behaviours that exist in relation to a particular issue, and the way in which the issue is framed in relation to more salient concerns or broader debates. However, in a group setting, social influences (e.g., different personality types, professional credibility and status), can determine and constrain participants' contributions, while also providing an insight into the dynamic construction of attitudes [38]. Furthermore, qualitative methods are not able to indicate the prevalence of particular beliefs or actions, or allow for statistical comparison between groups. On the other hand, quantitative questionnaires allow researchers to ask more focussed questions about the issue, and determine the prevalence of particular views or concerns amongst the sample. Furthermore, there may be issues that respondents would prefer not to discuss in a group that can be expressed in an anonymous questionnaire. Combining these methods thus provides a complementary strategy for knowledge elicitation and social learning.

A limitation of the current study relates to the representativeness of the stakeholder sample. As mentioned, the aim of the research was to elicit the views of elite stakeholders in hydrogen transport technology in particular, rather than of a more diverse sample of transport stakeholders (who may have had less expertise in hydrogen technologies). Nevertheless, the sample is not evenly weighted between stakeholder groups in hydrogen transport technology, with academic participants accounting for almost half the sample. The quantitative findings discussed below should therefore be considered in light of this academic bias. To mitigate this limitation the view of stakeholders elicited in other hydrogen studies (mentioned in section 3.1), are also included in the following discussion where they deal with the same topics addressed in this study.

The following three sub-sections discuss the key findings relating to stakeholders' views about sustainable hydrogen technologies and transport. Detailed findings from the break-out group discussions and questionnaires are reported elsewhere [39].

3.4 Key themes in stakeholders' visions of sustainable hydrogen

3.4.1 Discussion group findings

Overall, stakeholders in the discussion groups pointed to the attractiveness of hydrogen in offering environmental and economic benefits. In particular, they highlighted the potential for hydrogen technologies to offer emissions reduction, energy supply security and economic growth. In these

respects, the views expressed by these stakeholders reflect those of previous projects that used stakeholder perspectives to define a sustainable hydrogen economy (see section 3.1, above).

On the other hand, there was no consensus on whether hydrogen and fuel cells would be the only vehicle technologies in a sustainable transport system. While some participants saw a future in which *all* vehicles were powered by hydrogen, many saw alternative technologies playing a role. For example, several participants felt that the technological advantages of hybrid and plug-in hybrid vehicles may match or outweigh those of hydrogen vehicles; while participants in Group 3 felt that biofuels are more attractive than hydrogen as a fuel for trucks. Furthermore, there was disagreement about the role that fuel cells would play in a sustainable transport future; some participants in Groups 2 and 3 felt internal combustion engines (ICEs) with hydrogen as fuel offer more advantages.

In terms of the characteristics of sustainable hydrogen, stakeholders felt feedstocks are the key determinant. Consistent with previous stakeholder processes (e.g., [28,31]), there was widespread support amongst all groups for the ultimate goal of having renewable sources for hydrogen production. As several participants noted, renewable sources are needed to address air pollution, climate change and dwindling oil and gas supplies. However renewables are seen as challenging. Several groups talked about the practical and economic difficulties in moving towards a renewables-based transport system and referred to trade-offs, such as demand from other sectors (electricity, heat, industry, etc.) and other land use needs (e.g., for food production).

While renewable energy was a widely favoured, if challenging, end-vision for sustainable hydrogen, there also seemed to be some agreement that diversification of supply was an important feature of future energy systems. This was raised by participants in nearly all groups. Furthermore, participants pointed to the risks associated with focussing on, and becoming locked in to, one technological solution to the exclusion of possible alternatives. Participants proposed that future energy supply security will depend upon diversification of both energy sources (different primary energies and different geographic sources of supply) and modes of delivery of final energy services.

There was disagreement between the stakeholders over whether nuclear or coal with carbon capture and storage (CCS) are 'sustainable'. For a number of participants, sustainability was equated with zero emissions or 'CO₂ free'. These feedstocks fulfil this criteria and, additionally, many stakeholders felt these are necessary to achieve energy security and diversified, flexible supply. However other participants pointed out the problems with these technologies. For example, for nuclear feedstocks, the problem of nuclear waste, concern about the vulnerability of nuclear power to terrorism, and misuse of technology were mentioned. For CCS, the storage problem was raised.

The discussion about appropriate feedstocks, or bundles of feedstocks, for hydrogen production also dominated the discussion in other hydrogen research projects and policy processes with stakeholder involvement [27,30,40]. The identified discrepancies between the stakeholders' visions involved in the break-out group discussions and the questionnaire could be found in other projects, too. The major results of the HyWays project, which aims to develop hydrogen visions at EU Member State level, were that most of the EU-Member States' end visions of a hydrogen economy focus on renewable and other CO₂-free hydrogen production options. However, the end visions vary depending on domestic feedstocks, differences in the design of the national power systems, and country characteristics such as population density or populated islands with special supply requirements [40].

In three groups (1, 3 and 4) at the cluster workshop, the economic dimensions of a hydrogen transition were discussed. Participants pointed to the need for a timely response to international competition in developing hydrogen technologies, and to provide good value in relation to alternative technologies in order to attract consumers. A number of participants argued that consumers' transport choices are motivated above all by cost. One participant from the automotive group explained that since the success for Japanese manufacturers of hybrid cars, which impacted negatively on European manufacturers, EU car manufacturers are cautious about falling behind in development of other new technologies like

hydrogen. On the other hand, one Energy Industry participant suggested the priorities for a sustainable future should not be dominated by economic concerns. However, the important role of the competitiveness of the European industry and new market opportunities is stressed in other stakeholder work (e.g., [27,40]).

3.4.2 Questionnaire findings

Consistent with the break-out group discussion, renewable hydrogen production was identified in questionnaire responses (Table 1) by the largest proportion of stakeholders (14 out of 45) as ensuring widespread use of hydrogen in road transport is ‘sustainable’.

Responses given by participants *	N
Production of H2 by Renewables	14
Rising Oil Prices	6
Policy, Tax Incentives	6
Technology Development	5
Public Education	4
CO2 Reduction	4
Other Mobility Scenarios	3
Public Acceptance	2
Security of Supply	1

* This was an open-ended question: respondents were not given any options or answers to select

Table 1. What, if anything, do you think will ensure widespread use of hydrogen in road transport is 'sustainable'?

When presented with a check-list of sustainability considerations (Table 2), ‘greenhouse gas emissions’ were identified as the most important consideration for a hydrogen transition in road transport. ‘Cost of infrastructure development’ was the next most popular consideration, followed by ‘local air pollution’, and ‘energy security’.

Response options *	N
Greenhouse gas emissions within EU	38
Investment and infrastructure costs to develop new system	33
Local air pollution within EU	33
Energy, resource and technology security/ self-sufficiency within EU	29
Cost of mobility	24
Demand for or diversion of renewable resources from other uses within and outside of EU and indirect consequences	21
General level of economic activity (impact of any change in mobility level on jobs, taxes, production, etc. counterbalanced by impact of stimulation of new sectors/services)	18
Level of mobility	17
Impact on innovativeness, competitiveness and technological 'image' of EU	15
Water and land pollution within EU	14
Air, water and land pollution outside EU	14
Costs of RD&D associated with development of hydrogen transport technologies	13
Level of congestion	9
Nuclear implications (number of reactors, quantities of waste, etc.) within and outside EU	9
Premature capital write-down of existing investments and infrastructures associated with change to new system (as defined by a mobility level and a technology configuration)	8
Recurrent costs of maintaining new infrastructure (overall and per unit of mobility)	7
Impact on exchange value of €	4
Other	8

* Respondents were asked to tick as many of the items as they felt applied

Table 2. Questionnaire responses: 'Which of the following do you consider to be important 'sustainability' considerations for the widespread use of hydrogen in road transport applications?'

3.5 Stakeholders' perspectives on key players in hydrogen transport

Stakeholders identified the automotive industry and European Commission as well as national government as the key influencers in a transition to hydrogen transport within Europe (see Table 3). This emphasis on the role of government shows that a successful introduction of hydrogen in the transport sectors needs policy support (e.g., public R&D, subsidies and taxes). Additionally, stakeholders see the oil companies and the broader energy industry as relevant key players. This points to the role of the build-up of a hydrogen infrastructure (hydrogen production, distribution and filling stations) in a hydrogen transition. Previous stakeholder studies similarly highlight the importance of policy support and infrastructure development in a hydrogen transition [29,30].

It is interesting to note that the public and society are seen as playing a major role by very few (5) stakeholders. This perhaps indicates the 'technology push', rather than 'market demand', nature of hydrogen transport technologies. Furthermore, it appears to reinforce the findings, discussed above, that stakeholders conceptualise hydrogen technologies in terms of economic and environmental benefits, rather than wider societal benefits.

Responses given by participants *	N
Automotive Industry	35
European Commission / EU	20
Government / Policy / Public authorities	16
Oil Industry / Fuel Providers	11
Energy Industry / Companies	10
Public / Society	5
Research / Academia	4
Industry	3
EU H2 Platform	2
Technology Producing Companies	1
Chemical Industry	1
Fuel Cell Industry	1
Hydrogen Producers	1
Other	5

* This was an open-ended question: respondents were not given any options or answers to select

Table 3. Which 3 individuals/organisations/groups are the key players (i.e. influencers) in relation to hydrogen transport technology in Europe?

3.6 Key themes in stakeholders' visions of sustainable transport and the role of hydrogen

Stakeholders' requirements for sustainable transport systems go beyond simple considerations of hydrogen production and supply to include sustainable levels of mobility and societal values that impact on travel choices (see Table 4).

Sustainability criteria	Group(s) which mentioned criterion
Renewable (inexhaustible supply)	All groups
Low/zero emissions - particulates and GHGs	Groups 2, 3
No toxic waste	Group 5
Energy supply security	Groups 2, 3, 4
Diversity of supply	Groups 1, 2, 4, 5
Flexibility/ synergy between sectors	Groups 1, 2, 3
Competitiveness	Groups 1, 2, 3, 4
Prices reflect real value/ externalities	Groups 1, 2, 4, 5
Efficiency	Groups 1, 2, 4, 5
Low/no congestion	Groups 2, 4
Available infrastructure	Groups 2, 3, 4, 5
Political and industrial support	Groups 1, 2, 4
Public support	Groups 1, 2, 3, 4
Safety	Group 4
Social inclusion	Group 1
Personal freedom	Groups 5, 3

Table 4. Sustainability criteria for transport/energy systems identified by discussion group participants

There appeared to be widespread acknowledgement amongst break-out group participants that hydrogen is not the sole solution for a sustainable road transport system. Rather, hydrogen is seen as providing a possible technological solution to problems of emissions and energy security, as well as offering economic opportunities; but could not address wider mobility problems of, for example, congestion or social exclusion. The questionnaire findings (see, e.g., Table 2) also indicate that concerns about cost and level of mobility are relevant to many of these stakeholders.

Furthermore, it was widely acknowledged by stakeholders that current assessments and predictions for hydrogen transport technology do not consider whether forms or levels of mobility are sustainable. Rather, this suggests that research has focussed on methods of hydrogen production and supply in determining assessments of 'sustainability'. However, recognising the limits to car ownership and use in respect of infrastructure capacity and environmental and social impacts is important for investment and policy decisions in relation to supporting or commercialising hydrogen technologies. In this sense, trends in mobility may constitute a *barrier* to a successful hydrogen transition.

Stakeholders felt that sustainable transport requires modal shift and reduced demand - through more public transport use, congestion charging, teleworking, internalising costs, and societal value change - as well as new transport technologies. In contrast, then, to their conceptualisations of sustainable hydrogen, stakeholders raised social, as well as economic and environmental, criteria for sustainable transport. Indeed, stakeholders raised many of the aspects of sustainable transport considered in the Commission's *White Paper on the future Common Transport Policy* [1].

The degree to which stakeholders - many of whom would likely be 'winners' in a transition to a hydrogen economy - had such balanced and broad perspectives about hydrogen transport technologies is perhaps surprising. The reason for participants' reflexivity may be that, while these individuals are experts and stakeholders working for organisations with a stake in hydrogen, they also express personal opinions and experiences about transport. Many may also be aware of wider policy approaches to sustainable transport beyond simply hydrogen technologies. Consequently, the views expressed in these groups were often not 'the party line' (that is, their employer's policy) but a more balanced and nuanced perspective of sustainable transport and energy systems based on both personal values and professional expertise.

4 CONCLUSION

The break-out group discussions revealed that stakeholders do not hold naïve views about the potential for hydrogen by itself to meet requirements for sustainability within the transport system. That is to say, most stakeholders do not equate hydrogen transport technology with sustainable mobility. A common view was that hydrogen itself is not the aim; rather greenhouse gas reduction, energy supply security and economic growth are the objectives. Nevertheless, stakeholders were broadly positive about hydrogen technologies. They felt that hydrogen has the potential to lead to a more sustainable transport system through:

- Reducing local air pollution;
- Lowering greenhouse gas emissions that cause climate change;
- Greater energy security; and
- Economic opportunities.

Comparing the focus of academic and policy discussions on transport (section 2) and the stakeholder findings discussed here (section 3), the following issues emerge. In section 2, noise was seen as one of the problematic areas of today's transport system. Especially in urban areas, hydrogen use in fuel cell vehicles can lead to a relevant reduction of noise (see, among others, [28]). However this issue was not

discussed in the stakeholders' workshop. It is unclear whether the noise problem is not recognised as an unsustainability problem by stakeholders because current discussions are dominated by concern about greenhouse gases, local air pollution (especially particulates) and energy supply security; or whether the noise advantages of hydrogen cars are not recognised by stakeholders (perhaps because some advocated hydrogen ICE cars rather than fuel cell vehicles).

When we compare the above list of benefits from hydrogen technologies with the areas of unsustainability in transport detailed in section 2, we can see that several of these areas are not addressed by adoption of hydrogen transport technologies. These include:

- Land use;
- Congestion;
- Social inequality and exclusion; and
- Accidents and obesity.

Furthermore, our findings and those of previous studies point to a number of areas in which hydrogen use in transport may lead to an *increase* of unsustainability in the transport sector. This may include aggravation of existing problems, but also creation of new problems:

- Accidents (due to vehicle noise reduction);
- Travel cost may increase (due to large investments in infrastructure and production technologies);
- Nuclear waste (if hydrogen is produced from uranium feedstocks);
- Storage of carbon dioxide by CCS solutions: this is often not seen as a long term solution and does not address energy security concerns. Furthermore, exploratory studies indicate carbon sequestration may not be acceptable to the public [41];
- Increased demands on land use (if hydrogen uses biomass or other renewables as feedstocks).

There has been little discussion or analysis, however, of these possible negative impacts of hydrogen and fuel cell diffusion within transport [28]. The little research that has been done on societal impacts of a hydrogen transition, for example within the HySociety [42] project, has focussed on positive impacts (health benefits, economic opportunities, greater consumer choice). The only negative impacts identified relate to possible public anxieties about the safety of hydrogen technologies, which are viewed as a barrier to be overcome through improved public communication [42]. The focus in the hydrogen economy literature on overcoming barriers to a hydrogen transition suggests support for a 'technology push' model of technological development. This linear, determinist perspective typically focuses on the technological potential of innovation while ignoring its social relevance [43]. Furthermore, it reduces the complexity and ignores possible feedbacks and 'rebound effects' associated with innovation [44].

Looking at the last three problems listed above, it becomes clear that the introduction of hydrogen in transport applications is fundamentally linked to wider energy systems. Discussion of sustainable hydrogen in transport is therefore not limited to the context of sustainable transport but also includes discussion of sustainable energy systems. This increases the complexity of the issue, and expands the range of interests and perspectives to be considered in decision-making about hydrogen transport technologies. Together, the possible negative societal impacts of hydrogen use in transport and the implications for energy systems suggest a need for more reflexive and inclusive debate about the range of impacts and beneficiaries of hydrogen and fuel cell technologies.

Furthermore, our research indicates a need for integrated policy approaches to tackle unsustainable transport by addressing the socio-cultural and structural determinants of transport demand, as well as by offering technological solutions. Pathways to sustainable transport with both technological and behavioural elements are necessary. We can also identify synergies between these pathways. Firstly, there are implications for hydrogen and other vehicle technologies in relation to modal shift. With a shift towards increased use of public transport, vehicle technologies used in buses will need to be clean,

affordable, reliable and safe. Here, the CUTE project has already indicated that hydrogen and fuel cell technologies may provide a viable option [45]. Secondly, there are important and largely unrecognised links between mobility demand and a hydrogen transition. The implications of increasing mobility demand and variation in modal preferences across regions have so far not been considered in assessments and predictions for hydrogen transport technology, (e.g., [30]). However, trends in mobility may constitute a barrier to a successful hydrogen transition. Given these synergies between technological and behavioural pathways in transport, we conclude that debates about sustainable transport and a hydrogen economy should no longer be conducted separately; rather there is a need for the wider implications of changes in patterns of transport demand and a hydrogen transition to be considered in decision-making about both environmental technologies and transport futures.

Thus we conclude that sustainable transport demands long-term planning and systemic, rather than end-of-pipe, policy solutions. Indeed, as proposed at the European Council's summit in Cardiff in 1998, and reinforced in the EU Sustainable Development Strategy [14], there is a need for more integrated policy-making in consideration of transport demand implications from all sectors [12]. We have here presented research that informs such an integrated policy approach, by drawing on stakeholder perspectives to develop long-term sustainable transport visions. The role of stakeholders in this process fulfilled the three functions (normative, substantive and instrumental) outlined in section 3.1. Participants drew on their professional expertise, personal values and diverse experiences in defining a sustainable transport future and exploring practical challenges in achieving it. Furthermore, there was evidence of learning as a result of stakeholders' participation in the discussions⁴. Future work will draw on the unique experiences of other transport users and the values of other societal groups not represented in this current study in defining sustainable transport visions.

Acknowledgements

The research reported here was conducted as part of the MATISSE project, which is funded under the Sixth Framework Programme of the European Union (contract no. 004059). Grateful thanks go to the MATISSE stakeholder workshop participants and to Michael Ball, Jill Jäger, Björn Nykvist, Wolfgang Schade, Philipp Seydel, Sophie Strasser, and Paul Weaver, who helped facilitate and record the break-out group discussions. The authors are also grateful for the comments on an earlier version of this paper from David Whitmarsh, and from participants at the *Workshop on Socioeconomic Research in Hydrogen and Fuel Cell Introduction in the Transport Sector*, on 25-26 May 2006, in Roskilde, Denmark.

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⁴ In the questionnaire section on social learning, most stakeholders identified things they had learnt from the group discussions (e.g., new insights, information about other countries, technological information, or sustainability considerations); and a third of stakeholders felt they had changed their views about the topics discussed in the groups. Observational evidence also indicates that some participants revised their opinions during the course of discussion. A comparison of heterogeneous versus homogenous groups indicates a higher proportion of participants in the homogeneous groups (Groups 1 and 5) felt they had not learnt anything (68.8%, compared to 48.1%); however, a chi-square test indicates this difference is not statistically significant ($p=0.154$).

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