National Environmental Research Institute
Aarhus University · Denmark

Research notes from NERI No. 248, 2009

Socio-cultural barriers to the development of a sustainable energy system – the case of hydrogen

[Blank page]

National Environmental Research Institute
Aarhus University · Denmark

Research notes from NERI No. 248, 2009

Socio-cultural barriers to the development of a sustainable energy system – the case of hydrogen

Lars Kjerulf Petersen
Anne Holst Andersen

Data sheet

Series title and no.: Research Notes from NERI No. 248

Title: Socio-cultural barriers to the development of a sustainable energy system – the case of hydrogen

Authors: Lars Kjerulf Petersen, Anne Holst Andersen
Department: Department of Policy Analysis

Publisher: National Environmental Research Institute ©
Aarhus University - Denmark
URL: http://www.neri.dk

Year of publication: February 2009
Editing completed: January 2009
Referee: Ulf Hjelmar, AKF (Danish Institute of Governmental Research)

Financial support: Partly financed by the Danish Strategic Research Council

Please cite as: Petersen, L.K. & Andersen, A.H. 2009: Socio-cultural barriers to the development of a sustainable energy system – the case of hydrogen. National Environmental Research Institute, Aarhus University. 34 pp. –Research Notes from NERI No. 248. http://www.dmu.dk/Pub/AR248.pdf

Abstract: Any transition to a more sustainable energy system, radically reducing greenhouse gas emissions, is bound to run in to a host of different barriers – technological and economic, but also socio-cultural. This will also be the case for any large-scale application of hydrogen as energy carrier, especially if the system is going to be based on renewable energy sources. The aim of these research notes is to review and discuss major *socio-cultural* barriers to new forms of energy supply in general and to hydrogen specifically. Reaching sufficient reductions in greenhouse gas emissions may require more than large-scale dissemination of renewable energy sources. Also reductions or moderations in energy demand may be necessary. Hence, a central point in the research notes is to consider not only socio-cultural obstacles for changing technologies in energy production, distribution and consumption but also obstacles for changing the scale of energy consumption, i.e. moderating the growth in how much energy is consumed or even reducing consumption volumes.

Keywords: Energy, transport, hydrogen, scenario, socio-cultural barriers, socio-technical systems, lock-in, lifestyle, consumption, mobility.

Layout: Ann-Katrine Holme Christoffersen

ISSN: 1399-9346

Number of pages: 34

Internet version: The report is available in electronic format (pdf) at NERI's website
http://www.dmu.dk/Pub/AR248.pdf

Contents

Preface

These research notes emerge from the HYSCENE–project, a multidisciplinary Danish research project about environmental and health impacts and societal aspects of advancing an energy system based on hydrogen and renewable energy sources. The project was partly supported by the Danish Strategic Research Council. The project team counted researchers from Risø National Laboratory for Sustainable Energy at the Technical University of Denmark and the departments of Atmospheric Environment and Policy Analysis at the National Environmental Research Institute, Aarhus University in Denmark. Project leader was Steen Solvang Jensen and Lise Marie Frohn. Thanks to all who have contributed to the work.

Summary

The aim of these research notes is to review and discuss major socio-cultural barriers to new and more sustainable forms of energy supply, particularly to those that are based on hydrogen as energy carrier. Any transition to a more sustainable energy system, radically reducing greenhouse gas emissions, is bound to run into a host of different barriers – technological and economic, but also social and cultural. This will also be the case for a large-scale application of hydrogen as energy carrier, especially if the system is going to be based on renewable energy sources. Reaching sufficient reductions in greenhouse gas emissions may require more than dissemination of new energy technologies. Also reductions or moderations in energy demand may be necessary. Hence, a central point in the research notes is to consider not only socio-cultural obstacles for changing technologies in energy production, distribution and consumption but also obstacles for changing the scale of energy consumption, i.e. moderating the growth in how much energy is consumed or even reducing consumption volumes.

The concept of *socio-technical systems* is central in understanding the significance of socio-cultural factors in technological transition. Everyday routines and habits, aesthetic preferences and locked-in logics of consumption and mobility are important features of and may constitute significant barriers to changes in technological systems such as our predominantly fossil fuel based energy system. These issues are further discussed in relation to transport and mobility as well as household and equipment.

The conclusion is that barriers to change may be comparatively small as long as transition to a more sustainable energy system seeks to emulate existing practices and properties of current technologies, for instance in terms of speed and range of vehicles, but reductions in CO_2-emissions will also be insufficient. More radical changes that address the level of consumption will meet more substantial obstacles that touch upon basic elements in the dynamics of consumption, household and economic development. Overcoming these more serious obstacles is not unfeasible, but it will require more ambitious technological development combined with changes in the architecture of the energy system and changes in social practices – which will require political-administrative funding, investment and regulation.

Sammenfatning

Denne rapport handler om de samfundsmæssige betingelser for overgang til et mere bæredygtigt energisystem med særlig interesse for udbredelsen af brintteknologier. Rapporten fokuserer på forholdet mellem livsstil og energiforbrug og på studier af teknologiske forandringsprocesser for derigennem at identificere sociale og kulturelle barrierer for udvikling af et mere bæredygtigt energisystem.

Scenarier peger på, at med udviklingen af et brintbaseret energisystem, vil forbruget af olie og benzin falde over en 30-50 års periode, men forbruget af kul vil stige fra 2015, simpelthen for at kunne dække energibehovet. Scenarierne bygger på antagelser om fortsat økonomisk vækst, en fortsættelse af den nuværende centraliserede energiforsyningsstruktur, en årlig 1,3 %-effektivisering af elektriske apparater og en fortsat vækst i transporten. Hvis energisystemet på lang sigt skal være uafhængigt af fossile brændsler og helt udfase udledningen af drivhusgasser, kræver det således ændringer i energiforbrugets omfang og større energieffektiviseringer end forudsat i scenariet. Sådanne ændringer vil støde på anselige samfundsmæssige barrierer.

Især transportsystemerne og transportkulturen udgør en væsentlig barriere, men også i husholdningernes praksisser – som disse er bestemt af samspillet mellem rutiner og teknologier – ligger der væsentlige barrierer for overgang til et bæredygtigt energiforbrug. Et andet væsentligt samfundsmæssigt aspekt ved omstilling til et bæredygtigt energisystem vedrører graden af centralisering eller decentralisering i energiproduktion og distribution. Endvidere kan man forestille sig, at der vil være praktiske, følelsesmæssige og kulturelle forhindringer for at forlade olie/benzin og overgå til brint, forhindringer der knytter sig til, at apparater og maskiner får nye egenskaber og til at æstetiske præferencer ikke kan realiseres med de nye teknologier. Disse forhindringer vil dog være af mindre omfang, og egenskaber ved brintdrevne apparater og maskiner vil også kunne fungere som en positiv drivkraft i omstillingen. Derudover kan man forudse lokal modstand mod brintrelaterede energianlæg, såvel anlæg til vedvarende energiproduktion som opbevaringsfaciliteter for brinten.

Overgang til nye teknologiske regimer, i en størrelsesorden som afvikling af fossile brændstoffer fordrer, er en vanskelig proces, som ikke alene støder på økonomiske og tekniske barrierer og politisk-administrativ træghed, men også på barrierer der vedrører hverdagens rutiner, sociale normer og æstetiske præferencer. Så længe man i teknologiudviklingen søger at efterligne de eksisterende egenskaber i energisystemet og i de energiforbrugende apparater, bl.a. hvad angår transportinfrastrukturen og bilers hastighed og rækkevidde, så vil de sociokulturelle barrierer for denne teknologiudvikling være relativt overkommelige, men reduktionen i udledning af drivhusgasser vil også være utilstrækkelig. Mere omfattende ændringer, der ikke blot berører energiforbrugets teknologier, men også dets omfang, vil støde på alvorligere barrierer, der angår de grundlæggende dynamikker i forbrug, mobilitet, husholdning og økonomisk udvikling. Det er dog ikke umuligt at overkomme disse mere alvorlige barrierer, men det fordrer en mere ambitiøs teknologiudvikling kombineret med ændringer i indretningen af energiforsyningssystemet – såsom dets grad af centralisering – og ændringer i sociale praksisser, hvilket alt sammen er noget der kan fremmes af en politisk-administrativ indsats.

1 Introduction

These research notes emerge from the HYSCENE –project, a multidisciplinary Danish research project about environmental and health impacts and societal aspects of advancing an energy system based on hydrogen and renewable energy sources.

Hydrogen has for some time been depicted as one element in solving energy problems on a global level, and a large number of scenarios, forecasts and visions for hydrogen futures have been developed. In a review of hydrogen futures literature, McDowall & Eames ask how different visions and scenarios establish the need and understand the drivers for a hydrogen society. Four overarching problems or policy objectives are consistently understood as providing the basic reasons and underlying drivers for a hydrogen future: (1) climate change and the need to reduce CO_2-emissions; (2) energy security, regarding the finite nature of fossil fuel reserves as well as their geopolitical sensitivity and highly unstable pricing; (3) local air quality that is presumed to improve considerably with a shift from fossil fuels to hydrogen; and (4) competitiveness, i.e. gaining competitive advantage by leading the development of a global hydrogen economy (McDowall & Eames, 2006, pp. 1242f).

In addition, some associate hydrogen technologies with a shift towards greener social values and a more egalitarian society and envision hydrogen technologies as instrumental in a democratisation of energy, allowing people to gain control over energy rather than being dependent on monopolised energy distribution systems (McDowall & Eames, 2006; Rifkin, 2002).

The basic consideration in the HYSCENE-project, and hence in these research notes, is environmental. Mitigation of global warming and local air pollution, i.e. considerable reduction of CO_2-emissions and other pollutants are understood as the main incentive and driver for large-scale application of hydrogen as energy carrier. Whatever the incentive, a change in energy technology and energy supply structure towards large-scale application of renewable energy sources with hydrogen as energy carrier is bound to run into a host of different barriers. Whereas technical, economic and environmental aspects of changing energy technologies are frequently discussed it is important to consider also the socio-cultural aspects – which are an integral part of changes in socio-technical systems such as the energy system (understood as the total system of energy supply for transport, electricity and heating).

Socio-cultural aspects of technological developments and transitions are of course intertwined with the technological and economic aspects, and socio-cultural barriers may well be overcome through economic means, and through the design of artefacts – or through other strategies such as prohibitions and campaigns – all of which can be part of policies to promote a certain technological development (such as the spread of hydrogen as energy carrier). But to be considered the kind of barriers that are embedded in everyday practices and routines, in social norms and values, and in aesthetic preferences etc. have to be recognised and understood. The aim of this paper is to outline and discuss these social and cultural aspects of technological development in general and development of hydrogen technologies in particular.

Projections of future developments in energy demand, including demand for transport fuels, indicate that it will be difficult to produce enough power and hydrogen from CO_2 neutral energy sources alone. If the goal is an energy system based entirely on sustainable energy sources then it is not only the technology of energy supply that will need to be addressed but also the scale. Development in energy consumption and transport loads will have to be decoupled from economic development – through radical improvements in energy efficiency, through radical changes in energy supply structure, or through changes in energy consuming practices.

In the following we will discuss possible socio-cultural barriers to a more sustainable energy system – based on hydrogen or other technologies – including barriers to reduced levels of consumption. In the first section we will outline a scenario for the introduction of hydrogen as energy carrier in Denmark, thus providing a reference point for discussions. The second section introduces the concept of *socio-technical systems* as a key to understanding the significance of socio-cultural factors, and the barriers they may represent when attempting to change technological systems such as our predominantly fossil fuel based energy system. Against this background, the remaining sections review and discuss potential socio-cultural barriers to the introduction of hydrogen as energy carrier as well as to reducing levels of energy consumption, both in the transport sector and in the overall energy system.

2 The scenario

As part of the HYSCENE project a scenario has been set up, a scenario that investigates the workings of an energy system based on renewable energy sources while at the same time considering the feasibility of such a system and the societal context in which it has to be realised. The scenario is based on the following general assumptions:

- Hydrogen covers an increasing part of energy demand in the transport sector: 1 % in 2015, 22 % in 2030, and 75 % in 2050.
- Hydrogen is almost entirely used in the transport sector.
- All hydrogen is assumed produced by electrolysis.
- Denmark is understood as a closed energy system, i.e. no net import/export.
- The existing centralised energy supply structure dominated by combined power plants producing both electricity and district heating – and hydrogen – is preserved.
- Continued economic growth; in private consumption: around 2.5 % p.a. until 2010, 2.2 % in the period 2010-2020, and 1.7 % 2020-2030; in BNP around 2 % p.a. until 2010, 1.5 % in the period 2010-2020, and 1.1 % 2020-2030. With this economic development follows growth in energy consuming practices in the form of more machinery for household, leisure and communication, more and larger houses to heat and cool, higher demand for material goods, etc.
- Continued growth in transport loads; approximately 1.4 % p.a. for passenger and 0.7 % p.a. for freight transport until 2030; energy consumption in the transport sector is expected to grow with 0.9 % p.a. until 2030.
- A yearly 1.3 % increase in energy efficiency of electrical devices, which is the current rate.

Assumptions about development in economy and transportation are derived from official Danish forecasts and prognoses from governmental bodies, primarily from the Danish Energy Authority (Energistyrelsen, 2005). The scenario assumes a relative – but not an absolute – decoupling of developments in energy consumption and transportation from economic development.

Calculations based on these assumptions show that it will take a lot of power to produce the needed hydrogen; in 2050 power production is increased by 190 PJ/year compared to reference, for a population of 5-5½ million people. Consequently a 100 % renewable power production cannot be reached in this scenario. After a decrease from 2003 to 2015 it will be necessary to increase the use of coal for power production from 2015 and onwards, returning to 2010 levels in 2050. A development as outlined in the HYSCENE-scenario does lead to a decrease in CO_2-emissions. In Denmark CO_2 emissions were in 2005 reduced by 4.3 % compared to the base year 1990 where emissions were at a level of 52.7 million tons. The Kyoto target for Denmark for 2008-2012 is 21 %; the HYSCENE scenario forecasts a 16 % reduction by 2015 compared with the base year 1990, a 48 % reduction in 2030, and a 62 % reduction in 2050 (Winther et al., 2008). In this calculation it is assumed that fossil fuel power plants by 2050 will capture and store CO_2, but still the Danish Kyoto targets aren't met within or close to the time frame. Nor is a more ambitious target of 80 % reduction by 2050 met; a goal that for instance is set by the State of California (Office of the Governor, 2007).

The scenario's prospect of increased use of coal, insufficient reduction of CO_2-emissions and costly as well as highly energy-demanding storage of CO_2 compromises environmental concerns and provokes reconsideration of the scenario's basic assumptions. A higher percentage of renewable energy production and a larger reduction in CO_2-production might be reached if the scale of consumption is addressed both through further efficiency increases in energy consuming devices and through changes in social practices and socio-technical systems.

The forecasted development in the HYSCENE-scenario – with its arguably insufficient reductions of CO_2 emissions – requires major changes, even though the basic energy supply structure is preserved. Among these is the development of an infrastructure of filling stations as well as the problems with technological immaturity regarding fuel cells and hydrogen storage (McDowall & Eames, 2006, p. 1243). But as these research notes argue, significant obstacles of a more socio-cultural nature may also be encountered.

3 Changing socio-technical systems

According to Frank W. Geels it is important to perceive technologies as more than just artefacts or specific technical solutions, such as a car or a fuel cell engine, but as elements in a realisation of societal functions such as transport of goods or maintenance of social relations across distances etc. (Geels, 2004, p. 898). Artefacts are elements in wider socio-technical systems consisting also of knowledge, capital, labour, social practice, and cultural meaning (Geels, 2004, p. 900) and socio-cultural dynamics play an important role in determining the workings of specific technical devices and wider socio-technical systems.

Washing machines and tumble dryers may serve as an example. As applications in a larger socio-technical system – involving fashion, hygiene, home building, chemical industry, energy consumption etc. – these 'laundry machines' are involved in a number of social functions that go beyond just washing and drying, e.g. keeping the home tidy and unblemished by loose pieces of clothing and maintaining social standards for changing clothes and appearance (Shove, 2004; Gram-Hanssen, 2006, p. 86).

Artefacts and users in socio-technical systems are dialectically shaping each other. On the one hand users don't adopt new technologies passively, but integrate them into their own practices, organisations and routines. 'New technologies have to be 'tamed' to fit in concrete routines and application contexts (including existing artefacts)' (Geels, 2004, p. 902); a taming that feeds back into the functionality and design of new technologies. On the other hand templates and conditions for social interaction are embedded in and emanate from artefacts and technical contexts (Geels, 204, p. 903). For instance, when verandas no longer are incorporated in standard building designs while air conditioning is systematically incorporated as the sole facility for ventilation and temperature regulation then the social functions made possible by verandas – such as informal interaction with neighbours – are also affected. Thus large-scale introduction of air conditioning isn't only increasing household energy consumption but is also shaping conditions for social interaction (Cooper, 1998; Shove, 2003, p. 399).

With a large-scale application of hydrogen, it is the entire socio-technical system of fossil fuel based energy supply and the associated system of fossil fuel driven mobility that will be affected. With the long established knowledge that these fossil fuel based systems are harmful to the environment the question is why such changes aren't well on their way already. Or as Gregory C. Unruh puts it: 'why don't carbon-saving technologies and practices diffuse faster if they exist, save money and reduce climate impacts?' (Unruh, 2000, p. 819).

His answer revolves around the concept of *lock-in*. Techno-social systems 'become established through a co-evolutionary process among technological infrastructures, organizations, society and governing institutions' making it difficult to effect or even initiate change (Unruh, 2002, p. 317; see also Walker, 2000). Forces of lock-in exist at a technical and industry level as well as in a larger societal context. Firstly, when a technological design, such as the internal combustion engine or alternating current electricity, becomes dominant it isn't necessarily because of its technical superiority. Designs can become locked-in, regardless of technical inferiorities at various counts, through a process in which timing, strategy and historic circumstances determine the winner (Unruh, 2000, p. 820; Bijker, 1995). The VHS standard for videotapes and recorders has often been mentioned as inferior to other videotape technologies, but it won nonetheless because the manufacturer and patent holder bought they obtained the rights to market a large catalogue of movies on videotape.

Secondly, domination of a design implies massive capital investment, specialisation of labour and knowledge, and emergence of standard operating procedures that all support the same design, just like investments and product development will be focused on optimising the existing design while alternatives are neglected. Thirdly, supply industries – e.g. rubber and petrol for cars – settle around the dominant design thereby further contributing to its lock-in (Unruh, 2000, pp. 820ff).

Moreover, social norms and customs constitute powerful non-market forces of lock-in – for specific technologies as well as for the scale of consumption. For instance, a study of Norwegian habits for energy consumption shows how cultural norms favour a homely and cosy atmosphere ('hygge') in the home and a stark contrast between the coldness and darkness of the outdoors and the warmth and light indoors. So plenty of lights have been kept on at all times and all rooms in a house have been kept constantly warm at a high temperature. Such customs have co-evolved with the development of plentiful hydraulic power and the discovery and extraction of off-shore oil resulting in low energy prices, but have continued even when energy prices were rising (Wilhite et al., 1996). Such customs can be expected to constitute a serious socio-cultural barrier when environmental concerns put restraints on energy consumption.

Public administration can further enforce and stabilise a socio-technical system through industrial support, infrastructure investment, educational programs etc. And together all these factors may constitute a *techno-institutional complex* composed of large technological systems and the public and private institutions that govern their diffusion. A techno-institutional complex may facilitate the expansion of useful technological systems like sewage or collective transport networks – or a network of hydrogen fuel stations – but can also 'become the locus of a powerful lock-in that slows the emergence of alternative technological solutions.' (Unruh, 2000, p. 826).

To such processes of technological lock-in should be added the locked-in logic of expanding consumption. In an environmental perspective, growth in consumption may undermine efforts to promote a sustainable development (Laessoe, 2003, p. 109), for instance when improvements in energy efficiency are surpassed by growth in the number of appliances. Thus, while consumption of energy for household heating has fallen by 25 % in Denmark since 1985 the total energy consumption in households have risen by 7 % which is due to an increase in the amount of electronic equipment (Bach et al., 2005). The dynamics of growing consumption will be further discussed below.

In short, socio-cultural dynamics play an important role in the workings of socio-technical systems and the forces of lock-in. This will presumably also be the case in a any future changes towards an energy system based on renewable energy sources and hydrogen. Socio-cultural barriers specific to diffusion of hydrogen technologies and changes in energy demand will be discussed in the following.

4 Transport and mobility

In the EU, transport is one of the main contributors to energy consumption and currently the fastest growing source of greenhouse gas (GHG) emissions. According to the European Commission, transport is responsible for an estimated 21 % of all GHG emissions contributing to climate change – a proprotion which continues to rise as does the energy demand for transport (European Communities, 2006, p. 5). This has placed transport and mobility among the top issues on the last few years' mounting energy and sustainability agenda. Hydrogen technologies, using hydrogen as carrier of sustainably produced renewable energy, have been presented as promising solutions to rising levels of GHG emissions from transport, and at the same time hydrogen fuel cell technologies promise very low levels of noise and particle pollution from cars (Jørgensen, 2007, p. 4; Teknologisk Institut, 2007). There may, however, be a range of socio-cultural barriers to the implementation of hydrogen technologies in the transport sector – and even more so to reductions in transport loads.

The growing European transport load comprises both freight and passenger transport (European Commission Directorate-General for Energy and Transport, 2006). The steady increase in transport of goods is closely related to the social and economic dynamics behind growing levels of consumption in general, which will be discussed later. This section focuses instead on potential socio-cultural barriers to the introduction of hydrogen vehicles for passenger transport and to reductions in passenger transport.

4.1 Barriers to the acceptance of hydrogen vehicles

Any large scale application of hydrogen technologies in the transport sector will require that individuals and households actually embrace these new technologies and that substantial numbers of them will purchase and drive hydrogen cars. But that cannot necessarily be taken for granted. Changes in technologies in general and in technologies for transport specifically may affect the practices and attitudes of users and do not come uncontested.

Mobility practices of individuals and households are not reducible to isolated choices of technically or environmentally efficient solutions and products. Routines and habits rooted in everyday life can be difficult to alter, even if individuals are conscious, at a reflexive level, of negative impacts of daily routines and habits – and aware of possible alternatives (Ilmonen, 2001, p. 17).

This is due, among other things, to the fact that even the more or less routinised and habitual everyday life practices are often established through negotiations of diverse and potentially contradictory considerations (Halkier, 2001, pp. 32ff). As Daniel Miller has argued in his analysis of 'driven societies', when it comes to transport there is often 'a conflict between an ethics which is concerned with aggregate effects of personal action on the world at large and a morality that sees caring in terms of more immediate concerns such as one's partner and children' (Miller, 2001, p. 28). Regarding choice of transport means, environmental considerations must be balanced against other concerns, such as the financial situation of the household and the convenience, efficiency and flexibility of any chosen means of transport in an increasingly time-compressed everyday life (see Jensen, 2001). Thus, fuel and vehicle prices as well as the placing of hydrogen filling stations in relation to daily patterns of travel between home, work, children's institutions, spare time activities, shopping etc. may be decisive for whether or not individuals or households choose to shift to hydrogen cars. In other words, changing practices in relation to everyday (auto)mobility in favour of environmental considerations will almost inevitably interfere with other everyday life considerations, and the larger the interference, the larger the potential barriers to the shift.

At the same time, routines in themselves represent a lock-in of everyday life practices. Routines and habits, as opposed to reflexive actions, have always formed a significant part of human everyday life practices. Routines conveniently reduce the number and complexity of the choices we make in everyday life; they put everyday life activities into order and thus help create a safe, inhabitable world and a sense of normality; and they make our actions predictable and thus reliable to others (Ilmonen, 2001, p. 17). A change of routines, on the other hand – for instance a change to new vehicle technology which may have different properties regarding cruising range and speed or other factors – requires renewed reflexivity and uncertainty about the outcome (Halkier, 2001, p. 26).

Furthermore, although awareness of risks associated with a modern transport system based on the use of fossil fuels has been one of the driving forces behind the development of hydrogen technologies for transport, the hydrogen alternative may also become associated with risks. For example, some concern has been expressed about the danger of explosion related to on-board storing of hydrogen for cars in high-pressure fuel tanks (FuelCellStore, 2007; Hydrogen Now!, 2007). Thus, if a more or less routinised choice of the usual and preferred type, brand and/or model of car is questioned at all, a conventional carbon fuelled car may seem like a safer choice than some new technology, the exact functionality and long-term consequences of which are yet to be discovered.

Perhaps related to such perceptions of risk or uncertainty associated with new technologies car culture, along with so many other aspects of modern western cultural life, is rich in examples of more or less nostalgic trends and subcultures. Vintage automobile clubs are abundant, and classical cars continue to attract the attention of enthusiasts idolizing the charm of those noisy, smoking and uncomfortable vehicles, regardless of the obvious environmental and functional disadvantages compared to modern cars (O'Dell, 2001). As pointed out by Mimi Sheller in her sociological analysis of 'automotive emotions', some drivers and passengers feel content with a smooth and silent ride, whereas others prefer a drive that 'shakes the bones and fills the nostrils with diesel and engine oil (historically aligned with ideas of adventure, masculinity and challenge)' (Sheller, 2004, p. 228).

Thus, powerful cultural images of cars and driving may represent emotional barriers to a swift and complete shift to hydrogen technologies for transport. At least it is certainly true that the predominantly petrol fuelled automobility has played a crucial role for modern culture and social life. Petroleum-based cars have had high visibility in the social landscape and cultural imaginary over the last century. They have reconfigured ways of dwelling, travelling and socialising; they have provided potent cinematographic and literary images and symbols; they have dominated discourses of what constitutes the good life and what is necessary for appropriate citizenship and mobility (Dant & Martin, 2001; Featherstone, 2004; Miller, 2001; Urry, 2004).

An illustrative example of the cultural dominance of the image of smoking, polluting petrol fuelled cars is the amount of concern expressed about the phasing out of leaded petrol, a process initiated in the 1980's due to the highly negative impact of lead on health and environment. Some motor magazines and chat forums for motor enthusiasts still cover debates about whether or not older cars and motorcycles can use unleaded petrol, even though fuel injection experts claim that there are no problems using unleaded petrol even for older vehicles (in Denmark e.g. Audiclub.dk, 2007; Moto Guzzi Klub Danmark, 2007; Smalnet, 2007).

Another aspect of the appeal of known technologies and the corresponding aversion against new technologies is the fact that hydrogen cars are virtually impenetrable for do-it-yourself mechanists. Lay people will have no chance to fix their own car if something is wrong. This is, however, already preceded by recent developments in car technology where more and more functions are computerised.

Despite 'pockets' of nostalgia, however, novelty holds a strong attraction for modern consumers, and theories of modern consumerism generally stress its dependence on consumers' continuing desire for the new (Campbell, 2001). This also extends to the consumption of cars. According to Dant & Martin, the technological development of the car has revolved around its ability to 'seduce': Incremental improvements of the car's features have been designed to make each new model slightly more attractive than previous ones. And whereas initial improvements were largely mechanical, in recent years the 'functional features' of the car have become more important with regard to seducing consumers. Functional features include passenger safety, recycleability of components, engine efficiency and power, etc. (Dant & Martin, 2001).

To a large extent, the introduction of hydrogen technologies for transport seems to be in line with, or at least not in itself an obstacle to, further improvements of such functional features of cars. Or in other words, hydrogen cars are developed to resemble – and extend – the existing socio-technical system of mobility as much as possible when it comes to central socio-cultural features like the individualised character of passenger transport and its speed and range.

Regarding speed, the car industry has presented prototypes, which besides the projected environmental advantages promise highly competitive engine power compared to conventional petroleum fuelled cars. One example is the fuel cell driven Mercedes-Benz A-Class 'F-Cell' car, which the manufacturer, DaimlerChrysler, is currently testing. It has a top speed of 140 km/h and accelerates from 0-100 km/h in 16 seconds (DaimlerChrysler, 2007). Another example is the World's first serial built hydrogen car, the luxurious BMW Hydrogen 7. The car's hydrogen fuelled ignition engine enables acceleration from 0-100 km/h in 9.5 seconds and a top speed of 230 km/h (BMW, 2007). With such engine power the hydrogen car ride, although smooth and silent rather than rough and noisy, is likely to still invoke feelings and images of power and, possibly, masculinity.

The cruising range, i.e. the number of km a car can drive on a single filling, is another important parameter of functionality and convenience for cars - as indicated by the efforts made to maximise the range and filling speed associated with alternative fuel systems in order to match the freedom of movement provided by conventional fossil fuelled cars. At this point some technical obstacles remain for fuel cell driven cars. The Mercedes Benz F-Cell car, for instance, has a cruising range of only about 150 km. As expressed by DaimlerChrysler: 'there is still a great deal of developing work to do until the 'F-Cell' becomes the vehicle for everyman' (DaimlerChrysler, 2007). Nonetheless, hydrogen cars are projected to be able to drive up to 6-700 km on a single filling, which can be done within just a few minutes at a hydrogen filling station. This poses a serious challenge to competing 'green' transport technologies, such as battery-driven electric cars, which at present have a maximum range of about 100 km, and even assuming further technological advances are projected to reach a maximum range of no more than 3-400 km (Hovald Petersen, 2006; Jørgensen, 2007; Hydrogen Link, 2007).

However, such levels of functionality and convenience of hydrogen cars come at a price that may cause consumers to hesitate. Apart from concerns about safety in relation to high-pressure storing of hydrogen, questions may be raised about the environmental viability of hydrogen cars: The luxurious BMW Hydrogen 7 uses the least energy efficient of known hydrogen fuel technologies, and even using the most efficient technology, hydrogen cars still use much more energy per driven km than do battery driven electric cars, thus somewhat undermining the environmental argument for choosing hydrogen technologies over other fuel technologies (Jørgensen, 2007).

To sum up, hydrogen technologies do seem in many ways to provide a promising alternative to fossil fuel technologies in the transport sector in that they enable a compromise between environmental considerations and the demand for powerful, flexible, and convenient transportation. A shift to hydrogen technologies may help reduce greenhouse gas emissions as well as noise and particle pollution from transport while to a large extent concurring with existing household routines and preferences in relation to transport.

However, since the projected hydrogen transport system is at a very early stage of development there is still considerable uncertainty about its environmental and functional features as compared to the existing transport system or other possible alternatives. This calls for caution in making any straight-forward assumptions about the extent to which households will embrace the new hydrogen technologies.

Moreover, although socio-cultural barriers to a shift from petrol fuelled cars to hydrogen fuelled cars may turn out to be limited and manageable, serious socio-cultural barriers are likely to face any efforts to address the more general problem of ever increasing transport loads and accelerating mobility.

4.2 Barriers to reductions in transport loads

In the transport sector, reduced energy consumption levels may be achieved partly by further enhancing car energy efficiency. Nevertheless, even if cars become significantly more energy efficient, the energy reductions achieved are likely to be, at least partly, eaten up by an increase in the number of cars as well as the distances travelled in them. Today, increasing numbers of people drive ever-larger distances (European Commission Directorate-General for Energy and Transport, 2006; Jensen, 2006, p. 329). By all indications, to halt this development is a task that is bound to run into a host of socio-cultural barriers. As pointed out by Mette Jensen in relation to her sociological studies of accelerating mobility in modern life: 'No one seems to be able to control these increasing flows of mobility, nor reduce the social and environmental consequences of our collective choices' (Jensen, 2006, p. 329).

Mobility seems to represent to modern individuals both freedom and constraint: On the one hand, mobility – especially automobility – literally as well as in popular imaginary represents a source of freedom: the freedom of travel, the 'freedom of the road', the freedom to extend the physical boundaries of everyday life and thus the range of work, family, and leisure activities and the social circles available to the individual (Jensen, 2006, p. 329; Urry, 2004, pp. 28f). On the other hand, modern individuals are constrained by their need to be mobile in order to participate in society and coordinate everyday life activities across time and space. E.g., as automobility increases and urban infrastructure develops, more people are enabled to combine ideals of spacious suburban or even rural living (see e.g. Bhatti & Church, 2004) with the pursuit of urban diversions and career opportunities. Concurrently, however, property prices on the outskirts of cities rise, pushing the limits of affordable settlement and thus the drive for ever longer commuting distances and the demand for infrastructural expansion even further (Graham & Marvin, 2001). In John Urry's words, automobility is a system that coerces people into an intense flexibility: 'It forces people to juggle fragments of time so as to deal with the temporal and spatial constraints that it itself generates […] extending the individual into realms of freedom and flexibility whereby inhabiting the car can be positively viewed and energetically campaigned and fought for, but also constraining car 'users' to live their lives in spatially stretched and time-compressed ways' (Urry, 2004, p. 28).

Accelerating mobility, then, is not only about covering ever longer distances in space, but also about doing it in increasingly time-compressed ways: the acceleration of mobility is related to an acceleration of time in modern everyday life (Jensen, 2006). Time pressure in everyday life seems to be increasing, and increasingly spreading from working life to leisure and family life (Hochschild, 1997; Jensen, 2006, pp. 331ff). In the words of Hartmut Rosa we are witnessing an acceleration of the pace of life which can be seen as part of a more general trend towards social acceleration leading to an increasingly desynchronized high-speed society (Rosa, 2003). This is important to our understanding of the dynamics of mobility: On the one hand, increasing time pressure and an accelerating pace of life create needs for increased mobility and flexibility in order to coordinate activities in time and space. In many families, the car is a necessity to 'hold it all together' (Shove, 2003, p. 412). On the other hand, mobility in itself opens up new and tempting opportunities for activities dispersed in space, and very often the result is further time pressure and further needs for efficient and flexible forms of mobility in order to coordinate activities to fit into a tight time schedule (Jensen, 2006, pp. 335ff; Urry, 2004, pp. 28f).

Thus, (auto)mobility opens opportunities for engaging in activities across time and space and makes modern everyday life possible. At the same time, daily transport routines often provide opportunities to unwind and take a break from the pressures and demands of work and family life, or to mentally prepare for or digest impressions from either (Jensen, 2006, pp. 339ff). The car in particular seems to create a space for relatively undisturbed solitude – In Dant & Martins words 'an outer clothing or mini-environment for 'downtime' from the flow of sociality in peopled contexts' (Dant & Martin, 2001, p. 151) – but also for intimate and unusually undisturbed sociality, as '[l]overs, couples, friends, families, parents and children can talk in close proximity while the car is in motion', with nothing much else to do or to distract the attention of speakers and listeners (Dant & Martin, 2001, p. 151). With these social meanings and functions of (auto)mobility, added to the strong cultural meanings attributed to cars and driving pointed out above, there are no doubt significant socio-cultural barriers to reducing the transport load in modern society as we know it today.

However, the acceleration of time and mobility may also help create potentials for halting the rise in motorized transport. Built into the dynamics of increasing mobility and time-compression are also opposing trends and potentially restraining mechanisms; the increasing time pressure is beginning to make people yearn for slowness (Jensen, 2006, p. 347). And increased automobility makes rush hour traffic in the cities reach a near standstill, thus increasing the incentive to search for alternative means of transport or less mobility intensive everyday lives. A certain degree of disenchantment with the car is emerging (Sachs, 1992, p. 175).

Whether the increasing public attention on environmental consequences of motorized transport may help break the upward trend in mobility as well is as yet an open question. Some studies have found that concerns about health and environmental risks are replacing earlier fears about the volume of road accidents in keeping the public ambivalent about the car (Dant & Martin, 2001, p. 145). So far the dynamics of acceleration have been stronger than any built-in counter-mechanisms, however. With transport loads raising steeply it is apparent that, regardless of environmental and other concerns, modern individuals are still allured by – or coerced into – a pattern of increasing mobility, with all the freedom and opportunities it promises us. From an immediate point of view then, the dynamics of accelerating mobility seem to a larger extent to represent barriers than potentials for reductions in transport loads and thereby for an energy system where demand isn’t higher than can be provided by renewable energy sources.

5 Household and equipment

Using hydrogen as an energy carrier is mainly relevant in the transport sector, at least as the technology is currently known and developed, but producing hydrogen is and will be an integral part of the total energy system, and use of hydrogen in buildings and for mobile devices such as laptop computers can come to play a more significant role. Addressing the scale of energy consumption in order to ensure sufficient CO_2-reduction in a future hydrogen based energy system will consequently need to focus not only on the transport sector but also on other forms of energy consumption. Socio-cultural barriers to hydrogen – as part of a sustainable energy system – are therefore also to be found in individual and household consumption (as well as in business and industry).

5.1 Barriers to reduced energy consumption

There are a number of social dynamics that play a role in increasing volumes of household and individual energy consumption, including processes of individualisation, growing consumption (including proliferation of domestic power tools and electronic appliances), and changes in housing patterns.

There is in modern societies a long term development towards *individualisation*. This does not imply that individuals are unconditioned by the larger societal contexts in which they exist, nor does it imply an abandonment of social coherence or social obligations (or a 'me-first' society). Rather, individualisation is a structural characteristic of highly differentiated societies and can be defined as the desire, the right and the obligation of each individual to lead a life of one's own (Beck & Beck-Gernsheim, 2002, p. xxii). This individualism is institutionalised in legal norms which make individuals rather than groups or couples the recipients of social benefits and holder of legal rights (Beck & Beck-Gernsheim, 2002, pp. xxi, 23). But individualisation also means that technologies and institutions for societal interaction, i.e. mobility and communication, increasingly, are geared to the individual – individual telephones, individual computers, individual transport vehicles etc. And it means that within social groups, such as households and families, all kinds of resources, not only material objects and money, but also space and time and social networks, are defined as one's own (and from that outset engaged in the social group).

Individualisation therefore implies that a range of practices that have been located in communal use of technologies – for household chores, communication, entertainment etc. – are increasingly located in individual use. This in turn has a tendency to lead to increased energy consumption, as when each member of a household strives to have his or her own television, computer, telephone and I-pod, and all are turned on. (Christensen et al., 2007).

This development is also mirrored in *changing housing patterns*. The number of households has increased across Europe by 11 % between

1990 and 2000, thereby exceeding the increase in population (Liu et al., 2003). As a socio-cultural dynamic this development is part of greater changes in family structures. More couples are getting divorced, the number of single parent and single person households is growing, and social networks are to a lesser extent embedded in shared dwellings and living conditions and to a higher extent maintained through interaction outside the household. At the same time demand for more living space, i.e. larger houses and apartments, is also growing. In Denmark, for instance, the average dwelling space per person has grown from 48.8 m^2 to 58.8 m^2 between 1986 and 2005 (Christensen et al., 2007, p. 102).

In addition to the process of individualisation there are other significant cultural dynamics that promote *growth in consumption*. It is propelled by inherent logics and dynamics of the economic system, but these interact with dynamics at household level regarding normative social pressure, maintenance of social identity, aesthetic demands etc. (Laessoe, 2003, pp. 109f). Without attempting to make a complete list, some of the social mechanisms that support escalating consumption shall be mentioned here: Domain and time conflict is one such mechanism. Everyday life consists of different spheres or domains of activities: work, household chores, family time, leisure, association activities etc. The individual will often experience conflicts between these different domains, and resolution of such conflicts may be established through consumption and employment of new technologies. Thus, 'condensation technologies' allow people to do more things at once, as when exercise machinery allows a person to watch television while exercising – with both types of machines using electricity. In other words, growing consumption helps to deal with an increasingly stressful daily life (Laessoe, 2003, pp. 121ff).

Other mechanisms for escalating consumption are discussed by Shove & Warde (2002, pp. 233ff) and comprise: *Social comparison*, where accumulation and display of possessions is important for social and cultural status, also in the sense that the variety of consumption experiences must be as wide as possible. Distinctions between social groups are established through consumption, and the process is endless, when the more privileged seek to distinguish themselves through more consumption of resources, energy and space, and the less privileged seek to keep up. Creation of self-identity which is not finally set but constantly maintained through consumption. Novelty, i.e. the mental stimulation of experiencing new things and the social obligation to do so.

These socio-cultural dynamics and developments, including the processes of individualisation and changing housing patterns, contribute to a disposition for increasing energy consumption and therefore constitute a significant barrier to an energy system based entirely on renewable energy sources.

It is beyond the scope of these research notes to discuss a possible diversion or termination of the processes of individualisation etc., but the obstacles for a sustainable energy system that the scale of energy consumption constitute can be addressed in other ways: through changes in the architecture of energy supply going beyond an approximated maintenance of current architectures, and also through more radical efficiency increases in energy consuming devices and intensification of energy efficiency in buildings (e.g. more radical than what is envisioned in official forecasts from the Danish energy authority). Such efficiency increases may come about both as a result of technological development and through changes in social practice.

5.2 Barriers to changes in supply architecture

In the Hyscene-scenario energy supply structure remains centralised, as it is in Denmark at present with combined power plants and large distribution nets for central heating and natural gas. Even when maintaining the general structure of the system, changing energy technologies can run into significant socio-cultural barriers. Thus, an important obstacle can be found in the social conflict that facilities for renewable energy production and for hydrogen storage can cause. Plans for the development of windmill farms are regularly met with local protest (Gamboa & Munda, 2007; Szarka, 2004), and the same is the case for other kinds of renewable energy production like biomass energy. Public distrust and so-called 'siting conflicts' are major barriers to the promotion of renewable energy (Upreti, 2004). In situations where (1) the development of a renewable energy facility is involuntarily imposed , (2) the technology is not familiar, (3) local people have no decision making power, and (4) the development is for corporate profit rather than local benefit, conflict between the public and the developers is likely to escalate (Upreti, 2004, p. 787).

However, in other visions for a sustainable energy system – based on hydrogen or otherwise – the supply structure may be of a different character with a considerable element of decentralised energy production (McDowall & Eames, 2006), to the extent where apartment blocks, blocks of terrace houses or even individual households produce their own energy through micro-generation of renewable energy. They may produce their own – or at least some of their own – heat, electricity and hydrogen from solar panels, small windmills, geothermal energy units, and small installations for electrolysis.

It may be that a partial decentralisation in the energy supply structure – or a combination of decentralised and centralised elements – is necessary for the entire energy system to become sustainable and at the same time meet energy demands. But such changes can also run into socio-cultural barriers (not just economic, administrative and political barriers).

The central issue in this respect is the issue of self-determination, autonomy and individualisation. As discussed above there is a long term societal development towards individualisation, implying that the lives of individuals are increasingly understood, defined and practised as their own lives, but this development coexists with another strong social development where maintenance of livelihood, practice of everyday life and pursuit of life goals increasingly depend on expert systems that are beyond the individual's control or even understanding (Giddens, 1990). Thus, in socio-technical systems of heating – which are crucial, not just for the well-being of residents but for the very subsistence of households, at least in temperate climates – competences to provide warmth, comfort and good living conditions aren't necessarily located at household level. They are to a large extent bound in expert systems, for instance in the form of networks for district heating, natural gas distribution and power supply (Klintman et al., 2003, p. 44).

Choice of heating source can be motivated by a desire for self-determination, as for instance a recent study of domestic wood combustion in Denmark has shown (Petersen, 2008; see also Klintman et al., 2003). On the other hand, when relying on an expert system like district heating much less work and much less inconvenience is required to keep warm during the cold season, and this – it could be hypothesised – can also be perceived as facilitating a sense of self-determination or freedom. Being relieved of the struggle for subsistence and trusting expert systems to provide basic needs enables people to devote more time and attention to realising personal development. In other words, sense of self-determination can be located differently: as liberation from the constraints of subsistence or as self-determination in ordering one's basic living conditions.

Precisely that schism is likely to be evoked in a large scale transition to more decentralised and even household based energy production. Installing facilities for micro-generation of renewable energy can cause a range of practical and economical problems: finding economic means for the necessary investment, administrative constraints regarding building standards and urban planning, problems with fitting installations into existing buildings and problems with proper maintenance of the installations. But beyond these problems, micro-generation of renewable energy may appeal to a desire for self-determination but may also be shunned for the constraints on other aspects of self-realisation it can impose. Especially when it comes to hydrogen technologies, i.e. fuel cells, electrolysis, hydrogen storage, hydrogen fuelling, the schism of micro-facilities becomes more complex. Even though facilities can be located at a decentralised level, the technology is so advanced that no maintenance can be carried out without the aid of specialists, i.e. without the involvement of and reliance upon expert systems. Self-determination and dependence on socio-technical systems will go hand in hand.

6 Conclusion

Above we have discussed potential socio-cultural barriers for changes towards a more sustainable energy system in general and to an increased use of hydrogen as energy carrier in particular.

The discussion has been based on the assumption that while the energy system must be viewed as a whole, including energy for transport as well as electricity and heating in buildings and households, there will still be different kinds of socio-cultural barriers in the different sectors. Another important distinction is that between socio-cultural obstacles for a shift to a specific new technology such as hydrogen on the one hand and obstacles for changing the scale of energy consumption on the other hand, i.e. moderating the growth in how much energy is consumed or even reducing consumption volumes.

Regarding the introduction of hydrogen technologies in the transport sector two issues were discussed.

- The infrastructure of filling stations. Filling stations have to be situated so that they match daily patterns of travel between work, home, leisure and all other activities of everyday life; especially if the range of hydrogen vehicles remains smaller than that of petrol cars.
- The properties of hydrogen vehicles.
    - Acceleration and speed in hydrogen cars promise to exceed that of petrol cars. This is a continuation of the appeal of automobility and constitutes no barrier for hydrogen technology. But as long as such high rates of acceleration and speed are achieved only with the least energy efficient hydrogen technologies, it may constitute a barrier for the development of a sustainable transport system.
    - The range of hydrogen vehicles is in most current models still limited. This constitutes a significant barrier if the problem is not solved. For some transport purposes, however, it should not be a problem.
    - Nostalgia vs. novelty. There may be some nostalgic sentiments towards petrol cars but this is likely to be countered by the attraction of the new and the silence and smoothness of the ride that hydrogen cars can offer.

Hydrogen technologies seem in many ways to provide a promising alternative to fossil fuel technologies in the transport sector in that they enable a compromise between the demand for powerful, flexible, and convenient transportation and environmental concerns.

This is of course only feasible if production of hydrogen is based on renewable energy sources but, as the HYSCENE scenario indicates, if transport loads continue to grow as they do currently it will not be possible to produce enough hydrogen from renewable energy sources, at least not with the existing energy supply architecture and with current rates of energy efficiency increases in other sectors of society. Seeking to limit the growth in transport loads and maybe even decrease energy consumption for transport and in buildings and households will, however, run in to more serious socio-cultural barriers.

- Time pressure and accelerating pace of life create needs for increased mobility and flexibility in order to coordinate activities in time and space
- High mobility is aligned with a sense of freedom and also a sense of wider social space.
- Everyday practices are intertwined with and locked in to a system of automobility.

Regarding levels of individual and household energy consumption there are also some persistent socio-cultural dynamics at work that tend to cause increased consumption and therefore constitute considerable barriers for a more sustainable energy system.

- Long term development towards individualisation – in the sense that technologies and institutions for societal interaction increasingly are geared to the individual resulting in more energy consuming devices.
- Changing housing patterns and family structures – in the sense that more people live in single or two person households resulting in more energy consuming devices.

Or to summarize: As long as transition to a more sustainable energy system seeks to emulate existing practices and properties of current technologies, e.g. in terms of speed and range of vehicles, barriers to change are comparatively small, but reductions in CO_2-emissions will also be insufficient. More radical changes that address the level of consumption will meet more substantial obstacles that touch upon basic elements in the dynamics of consumption, household and economic development. Overcoming these more serious obstacles is not unfeasible, but it will require more ambitious technological development combined with changes in the architecture of the energy system and changes in social practices – all of which, we might add, may in turn require political-administrative funding, investment and regulation.

References

Audiclub.dk, 2007: http://www.audiclub.dk/forum/viewtopic.php?f=23&t=850 accessed July 13, 2007.

Bach, H., Christensen, N., Gudmundsson, H., Jensen, T.S., Normander, B. (Eds.), 2005: State of the Environment in Denmark 2005. National Environmental research Institute, Denmark. http://www2.dmu.dk/1_viden/2_Publikationer/3_Ovrige/rapporter/MTR2005_folder_UK.pdf

Beck, U. & Beck-Gernsheim, E. 2002: Individualization. Institutionalized individualism and its social and political consequences. Sage, London & Thousand Oaks.

Bhatti, M. & Church, A. 2004: Home, the culture of nature and the meanings of gardens in late modernity. Housing Studies, 19 (1), 37-51.

Bijker, W.E. 1995: Of Bicycles, Bakelites, and Bulbs. Towards a Theory of Sociotechnical Change. The MIT Press, Cambridge, Ma & London.

BMW, 2007: http://www.bmw.com/com/en/insights/technology/cleanenergy/phase_2/cleanenergy.html accessed October 1, 2007.

Campbell, C. 2001: The desire for the new: its nature and social location as presented in theories of fashion and modern consumerism, in: Miller, D. (Ed.), Consumption. Critical concepts in the social sciences. Routledge, London & New York.

Christensen, T.H.; Godskesen, M., Gram-Hanssen, K., Quitzau, M.-B. & Røpke, I. 2007: Greening the Danes? Experience with consumption and environment policies. Journal of Consumer Policy, 30 (2), 91-116.

Cooper, G. 1998: Air conditioning America: Engineers and the controlled environment, 1900-1960. Johns Hopkins University Press, Baltimore, MD.

DaimlerChrysler, 2007: http://www.daimlerchrysler.com/dccom/0-5-7154-1-73792-1-0-0-73812-0-0-135-7145-0-0-0-0-0-0-0.html accessed November 28, 2007.

Dant, T. & Martin, P.J. 2001: By Car: Carrying Modern Society, in: Gronow, J., Warde, A. (Eds.), Ordinary Consumption. Routledge, New York.

Energistyrelsen, 2005: Fremskrivning af energiforbruget i erhverv, husholdninger og transport. Teknisk baggrundsrapport til Energistrategi 2025. http://www.ens.dk/graphics/Publikationer/Energipolitik/Fremskrivning_energiforbruget_erhverv_husholdninger.pdf

European Commission Directorate-General for Energy and Transport, 2006: European Union Energy & Transport in Figures 2006. Part 3: Transport. European Commission/Eurostat.

European Communities, 2006: Biofuels in the European Union: An Agricultural Perspective. Office for Official Publications of the European Communities, Luxembourg.

Featherstone, M. 2004: Introduction. Theory, Culture & Society, 21 (4/5), 1-24.

FuelCellStore, 2007: http://www.fuelcellstore.com/information/hydrogen_safety.html accessed October 1, 2007.

Gamboa, G. & Munda, G. 2007: The problem of windfarm location: A social multi-criteria evaluation framework. Energy Policy, 35 (3), 1564-1583.

Geels, F.W. 2004: From sectoral systems of innovation to socio-technical systems. Insights about dynamics and change from sociology and institutional theory. Research Policy, 33 (6-7), 897-920.

Giddens, A. 1990: The Consequences of Modernity. Polity Press, Cambridge.

Graham, S., Marvin, S. 2001: Splintering urbanism: networked infrastructures, technological mobilities and the urban condition. Routledge, New York.

Gram-Hanssen, K. 2006: Consuming technologies – developing routines, in: Andersen, M.M., Tukker, A. (Eds.), Proceedings: Perspectives on Radical Changes to Sustainable Consumption and Production (SCP). Workshop of the Sustainable Consumption Research Exchange (SCORE!) Network, April 2006, Copenhagen, Denmark. Pre-workshop version, http://www.risoe.dk/rispubl/art/2006_117_proceedings.pdf accessed November 28, 2007.

Halkier, B. 2001: Routinisation or Reflexivity? Consumers and Normative Claims for Environmental Consideration, in: Gronow, J., Warde, A., (Eds.), Ordinary Consumption. Routledge, New York.

Hochschild, A.R. 1997: The Time Bind – When Work Becomes Home and Home Becomes Work. Metropolitan Books, New York.

Hovald Petersen, J. 2006: Teknologiudredning – Fuel Cell Shaft Power Pack-projektet. Hydrogen Innovation & Research Centre, Herning, Denmark.

Hydrogen Link, 2007: http://www.hydrogenlink.net/dk/mps accessed June 25, 2007.

Hydrogen Now!, 2007: http://www.hydrogennow.org/Facts/Safety-1.htm accessed October 1, 2007.

Ilmonen, K. 2001: Sociology, Consumption and Routine, in: Gronow, J., Warde, A. (Eds.), Ordinary Consumption. Routledge, New York.

Jensen, M. 2001: Tendenser i tiden – en sociologisk analyse af mobilitet, miljø og moderne mennesker. Samfundslitteratur, Frederiksberg, Denmark.

Jensen, M. 2006: Environment, Mobility, and the Acceleration of Time: A Sociological Analysis of Transport Flows in Modern Life, in Spaargaren, G., Mol, A.P.J, Buttel, F.H. (Eds.), Governing Environmental Flows. Global Challenges to Social Theory. The MIT Press, Cambridge, MA.

Jørgensen, K. 2007: Køretøjer på el fra vedvarende energi. Paper presented at Trafikdage på Aalborg Universitet 2007, Aalborg, Denmark. http://www.trafikdage.dk/td/papers/papers07/tdpaper111.pdf accessed January 2009.

Klintman, M., Mårtensson, K. & Johansson, M. 2003: Bioenergi för uppvärmning – hushållens perspektiv. Research Report 2002: 1, Department of Sociology, Lund University.

Laessoe, J. 2003: Acquisition and domestication of new household technologies – some dynamics behind growth in material consumption, in: Gökşen, F., Seippel, Ø., O'Brien, M., Ünal Zenginobuz, E., Adaman, F., Grolin, J. (Eds.), Integrating and Articulating Environments. A Challenge for Northern and Southern Europe. Taylor & Francis (Swets & Zeitlinger), London, 109-142.

Liu, J., Daily, G.C., Ehrlich, P.R. & Luck, G.W. 2003: Effect of household dynamics on resource consumption and biodiversity. Nature, 421, 530-533.

McDowall, W. & Eames, M. 2006: Forecasts, scenarios, visions, backcasts and roadmaps to the hydrogen economy: A review of the hydrogen futures literature. Energy Policy, 34 (11), 1236-1250.

Miller, D. 2001: Driven Societies, in: Miller, D. (Ed.), Car Cultures. Berg, Oxford & New York.

Moto Guzzi Klub Danmark, 2007: http://www.motoguzzi.dk/dokumenter/blyfri2.htm accessed July 13, 2007.

O'Dell, T. 2001: Raggare and the Panic of Mobility: Modernity and Hybridity in Sweden, in: Miller, D. (Ed.), Car Cultures. Berg, Oxford & New York.

Office of the Governor, 2007: http://gov.ca.gov/index.php?/press-release/4111/ accessed November 27, 2007.

Petersen, L.K. 2008: Autonomy and Proximity in Household Heating Practices: the Case of Wood Burning Stoves. Journal of Environmental Policy &Planning, 10 (4), 423-438

Rifkin, J. 2002: The Hydrogen Economy: The Creation of the Worldwide Energy Web and the Redistribution of Power on Earth. Polity Press, Cambridge.

Rosa, H. 2003: Social Acceleration: Ethical and Political Consequences of a Desynchronized High-Speed Society. Constellations. An International Journal of Critical and Democratic Theory, 10 (1), 3-33.

Sachs, W. 1992: For love of the automobile: looking back into the history of our desires. University of California Press, Berkeley.

Sheller, M. 2004: Automotive Emotions: Feeling the Car. Theory, Culture & Society, 21 (4/5), 221-242.

Shove, E. 2003: Converging Conventions of Comfort, Cleanliness and Convenience. Journal of Consumer Policy, 26 (4), 395-418.

Shove, E. 2004: Sustainability, system innovation and the laundry, in: Elzen, B., Geels, F. W., Green, K. (Eds.), System Innovation and the Transition to Sustainability: Theory, Evidence and Policy. Edward Elgar, Cheltenham, UK & Northampton, USA, 76-94.

Shove, E. & Warde, A. 2002: Inconspicuous consumption: The sociology of consumption, lifestyles, and the environment, in: Dunlap, R.E., Buttel, F.H., Dickens, P., Gijswijt, A. (Eds.), Sociological Theory and the Environment. Classical Foundations, Contemporary Insights. Rowman and Littlefield Publishers, New York & Oxford.

Smalnet, 2007: http://www.smalnet.dk/v21/images/stories/volvo1800klub/klubbladet/Valvemaster_1800.pdf accessed July 13, 2007.

Szarka, J. 2004: Wind power, discourse coalitions and climate change: Breaking the stalemate? European Environment, 14 (6), 317-330.

Teknologisk Institut, 2007: http://www.teknologisk.dk/energi/13185?print=yes accessed June 22, 2007.

Unruh, G.C. 2000: Understanding carbon lock-in. Energy Policy, 28 (12), 817-830.

Unruh, G.C. 2002: Escaping carbon lock-in. Energy Policy, 30 (4), 317-325.

Upreti, B.R. 2004: Conflict over biomass energy development in the United Kingdom: some observations and lessons from England and Wales. Energy Policy, 32 (6), 785-800.

Urry, J. 2004: The 'System' of Automobility. Theory, Culture & Society, 21 (4/5), 25-40.

Walker, W. 2000: Entrapment in large technology systems: institutional commitment and power relations. Research Policy, 29 (7-8), 833-846.

Wilhite, H., Nakagami, H., Masuda, T., Yamaga, Y. & Haneda, H. 1996: A cross-cultural analysis of household energy use behaviour in Japan and Norway, Energy Policy, 24 (9), 795-803.

Winther, M., Nielsen, O.K., Jensen, M.T., Plejdrup, M.S., Illerup, J.B., Jørgensen, K. & Karlsson, K. 2008: forthcoming. Assessing the Emission Impacts from the Introduction of Hydrogen in the Road Transport Sector - Results from the HYSCENE Project. Proceedings, 17th International Symposium, Transport and Air Pollution, Grazer Congress, 16.-17. June 2008, Graz, Austria.

NERI **National Environmental Research Institute**

DMU Danmarks Miljøundersøgelser

National Environmental Research Institute, NERI, is a part of University of Aarhus.

NERI's tasks are primarily to conduct research, collect data, and give advice on problems related to the environment and nature.

At NERI's website www.neri.dk you'll find information regarding ongoing research and development projects.

Furthermore the website contains a database of publications including scientific articles, reports, conference contributions etc. produced by NERI staff members.

Further information: www.neri.dk

National Environmental Research Institute
Frederiksborgvej 399
PO Box 358
DK-4000 Roskilde
Denmark
Tel: +45 4630 1200
Fax: +45 4630 1114

Management
Personnel and Economy Secretariat
Monitoring, Advice and Research Secretariat
Department of Policy Analysis
Department of Atmospheric Environment
Department of Marine Ecology
Department of Environmental Chemistry and Microbiology
Department of Arctic Environment

National Environmental Research Institute
Vejlsøvej 25
PO Box 314
DK-8600 Silkeborg
Denmark
Tel: +45 8920 1400
Fax: +45 8920 1414

Monitoring, Advice and Research Secretariat
Department of Marine Ecology
Department of Terrestrial Ecology
Department of Freshwater Ecology

National Environmental Research Institute
Grenåvej 14, Kalø
DK-8410 Rønde
Denmark
Tel: +45 8920 1700
Fax: +45 8920 1514

Department of Wildlife Ecology and Biodiversity

248 Socio-cultural barriers to the development of a sustainable energy system – the case of hydrogen

Any transition to a more sustainable energy system, radically reducing greenhouse gas emissions, is bound to run in to a host of different barriers – technological and economic, but also socio-cultural. This will also be the case for any large-scale application of hydrogen as energy carrier, especially if the system is going to be based on renewable energy sources. The aim of these research notes is to review and discuss major socio-cultural barriers to new energy forms of energy supply in general and to hydrogen specifically. Reaching sufficient reductions in greenhouse gas emissions may require more than large-scale dissemination of renewable energy sources. Also reductions or moderations in energy demand may be necessary. Hence, a central point in the research notes is to consider not only socio-cultural obstacles for changing technologies in energy production, distribution and consumption but also obstacles for changing the scale of energy consumption, i.e. moderating the growth in how much energy is consumed or even reducing consumption volumes.

National Environmental Researh Institute
University of Aarhus · Denmark

ISSN 1399-9346