In the Dutch National Environmental Policy Plan 4 it has been recognised that persistent environmental problems (such as global warming caused by greenhouse gases) cannot be solved by traditional policy instruments or by technological innovation alone. Transitions are necessary and have been defined as long-term, continuous processes in which a society or a subsystem changes fundamentally—interconnected changes that reinforce each other in technology, the economy, institutions, ecology, culture, behaviour and belief systems. One of the examples where transitions are necessary is in the realm of mobility. Although there is currently no accepted single strategy, promising new options are increased multimodal chain mobility (in order to reduce car mobility), and a transition towards a sustainable fuel infrastructure.

In the last few years leading car companies have been investing in fuel cell technologies, possibly requiring new infrastructures based on hydrogen. Innovation in the direction of hydrogen fuel cells requires a future vision that is shared by many stakeholders, collaboration between many public and private stakeholders, and experimentation in Bounded Socio-Technical Experiments, in which second-order learning processes take place about the nature of the technology, about collaboration between stakeholders with various interests, and about sustainable solutions for the future.

As a case study, consumer acceptance of fuel cell buses in Amsterdam has been analysed. In this case, special emphasis has been given to social learning among stakeholders.
This paper addresses one of the most persistent environmental and social problems in our society—the ecological effects of personal mobility. The dominant form of personal transportation is the car. As well as the obvious benefits of door-to-door transportation, freedom to move, satisfaction in driving and perceived social status, there are many disadvantages—local air pollution, mainly in cities; greenhouse gas emissions; road congestion; noise; accidents; use of space; and urban sprawl. On a personal level, many people are aware of the disadvantages but feel unable to act differently, especially as there are also many disadvantages to alternative forms of transportation (see, for example, Hardin 1968). Many people, however, also feel that the social effects of the car system are becoming unbearable. In the US the discussion of urban sprawl is often on the agenda (Gillham 2002). High levels of vehicle-related air pollution urged the state of California to develop its mandate for zero-emission vehicles (ZEV). Both in the US and in Europe local emissions are increasingly regulated (although until recently sports utility vehicles (SUVs) in the US escaped such regulatory control). Greenhouse gas emissions are high on the agenda, not only in Europe but also in many US states, municipalities and civil institutions.

Increasingly, attention is being directed at urban mobility problems, not just in developed countries but in developing ones too. For example, a recent Indian court order has ensured that many buses and taxis operating in New Delhi are now fuelled by liquefied natural gas (LNG), a cleaner alternative to petrol (Beella, Diehl and Vergragt 2002). In some cities, such as Curitiba and Bogota in Colombia, daring experiments with alternative mobility systems are being tried,1 while Brazil has had its ‘gasohol’ (alcohol from biomass for car propulsion) programme for many years now. If the world population eventually reaches nine to ten billion, and if the current direction of personal mobility continues to develop without some form of action to reduce its adverse effects, there will be a global ecological disaster, with countries such as India and China in the frontline.

In the 1990s, the Dutch sustainable technological development (STD) programme argued that increasing population growth and increasing production and consumption could only be met in a sustainable way by developing so-called factor 20 solutions (Vergragt and van Grootveld 1994; Weaver et al. 2000). These solutions are not about redesigning the car, but about rethinking the system of personal mobility over the long term. Factor 20 is derived from a 50-year perspective in which the global population will have doubled and the standard of living will, on average, have increased five-fold, while the environmental burden should be at least halved. For greenhouse gas emissions, especially carbon dioxide, reductions of factor 20 per unit of need fulfilment are now generally accepted as global aims for the long term and as a necessary condition for increasing wealth in developing countries without unacceptable consequences for the climate.

Redesigning the car, or even just its propulsion system, will not be enough to achieve 95% reduction of emissions over the entire life-cycle. In the long term, personal mobility needs must be fulfilled in other ways than by the car. The most radical solution is to reduce transportation needs. There are two ways of achieving this. One is by increasing use of communications technologies (ICT) for teleworking, teleshopping, e-conferencing, e-tourism and e-leisure. The other is by radically rethinking and re-envisioning nations’ infrastructure in order to locate the main functions (i.e. living, working, recreation) within close (e.g. cycling) proximity. Projects and experiments are underway to pilot these solutions, but they are not covered in this chapter.

A somewhat less radical approach is to shift personal mobility to other modes—walking, cycling and public transport. This approach has received a lot of attention in recent

---

1 See www.transmilenio.gov.co/Transmilenio.htm.
years. For instance, the Mitka project developed a three-wheeled bicycle that affords better protection from wind and rain, with an electric motor providing additional power (Brown et al. 2003; see Chapter 10). Public transport can be, and is being, transformed and upgraded; however, some fundamental issues need to be addressed, notably personal comfort, time consumption and privacy.

A third potential approach lies in the realm of sustainable mobility services. One of these is car sharing, which results in a slight reduction of the environmental burden (Meijkamp 2000; Truffer 2003). Another is chain mobility solutions, in which the consumer is presented by door-to-door mobility solutions that use both personal and mass transportation. A further dimension is sustainable mobility solutions offered by employers to employees, or by service providers to employers. These solutions may use an appropriate mix of sustainable vehicles ranging from personal to mass, and from two to four wheels, including forms of sharing.

So far, each of these solutions has captured only a very small fraction of the market, with the car (including SUVs and vans) continuing to be the preferred solution for personal mobility. This is no surprise if we take into account the entrenchment of the car system, and with it the petrol system, in Western industrialised societies (Knot et al. 2001). The inertia in such a system is enormous, not just for economic, scientific and technological infrastructure reasons, but also because of the vested interests of powerful key actors such as vehicle manufacturers and oil companies, mining companies, petrol stations, dealers and repair shops. Moreover, many authors have noted the powerful position of the car as a modern cultural icon (Grin, Van der Graaf and Vergragt 2003).

Governments do not escape societal preferences; on the contrary, government policies are expressions of such preferences. Furthermore, governments can do what societal interest groups cannot, for instance regulate emissions to air. However, governments in democratic industrialised societies do not regulate personal car use or choice of car. Hence, government regulation has, until recently, concentrated on controlling the negative impacts of car use (such as exhaust emissions), through technologies such as the catalytic converter, and by providing fiscal incentives to change consumers’ behaviour, for example by reducing fuel duty on unleaded petrol. Further, governments can increase tax on unleaded petrol (as has been done in Europe but much less so in the US) and they can regulate access to inner cities by permits, parking fees and congestion charges.

Recently, an interesting change in US state government rhetoric has been observed. First, the state of California adopted the ZEV regulation which mandates that a certain percentage of cars should be zero-emission. With the present technologies this means either electric cars or fuel cell cars. Although over the years the ZEV regulation has been watered down, it has certainly given an incentive to R&D into alternatives such as fuel cell propulsion systems. The other interesting shift is that the Dutch government has adopted transition management as part of its policy repertoire (Dutch Ministry of Housing 2001). The Dutch National Environmental Policy Plan 4 recognises that persistent environmental problems (such as climate change caused by greenhouse gases) cannot be solved by traditional policy instruments or by technological innovation alone. Transitions are necessary and have been defined as long-term, continuous processes in which a society or a subsystem changes fundamentally: these are interconnected changes which reinforce each other through technology, the economy, institutions, ecology, culture, behaviour and belief systems. One of the examples where transitions are necessary is in the realm of mobility.

2 California Air Resources Board (CARB), www.arb.ca.gov/msprog/zevprog/factsheets/factsheets.htm.
Grin, Van der Graaf and Vergragt (2003) call this third-generation environmental policy, in which the government facilitates transition processes by setting long-term goals and bringing stakeholders together. Transition management has been derived from system dynamics in combination with evolutionary economics (Rotmans, Kemp and van Asselt 2001). It presupposes that there will be a transition from an initial state towards a final state, which may take as long as 50 years. Examples of these types of transition are the transition from coal to gas heating in the Netherlands and the transition from sailing ships to steam ships (Geels 2002).

Another aspect of transitions is that they are multi-level. They encompass regime shifts at the meso-level which can be reinforced by changes at the macro- (the ‘landscape’) and micro-levels (‘experimentation in niches’). They are multi-phased in the sense that in each of the four phases different mechanisms are at work and different government policies should be applied. They are multi-stakeholder in the sense that many stakeholders (business, non-governmental organisations (NGOs), civil society, consumers and governments) can be part of a transition process.

One of the problems with transition management is that it is not at all clear whether there will be a stable final state or, if there is, what it will look like. In part, this can be handled by constructing scenarios describing possible final states or different pathways (Vergragt and Green 2001; Green et al. 2001; Ashford et al. 2001, 2002). Sociotechnical scenarios have been proposed in order to describe possible paths to a possible future state (Elzen et al. 2004; Suurs et al. 2003). In the case of car transportation and personal mobility it is clear that there is no consensus at all about a possible final state. We simply do not know whether the car will continue its dominant position in the long term or whether one of the other solutions—other modes, new services, e-solutions, infrastructural changes—will become dominant. We also do not know whether future solutions for individual personal mobility will be in the form of oversized cars, as at present, or small electric vehicles.

In this context, it is interesting to note that the Tellus Institute has developed a number of scenarios including the so-called great transition scenario (Raskin 2002). The interesting difference between the Tellus approach and that taken by Rotmans, Kemp and van Asselt (2001) is that it does not assume a final state; rather, the transition takes place in a timeframe of 50–100 years.

Transition management thus amounts to a lot of experimentation and learning about solutions and their acceptability before any move towards a macro-scale solution can take place. The problem with the government as transition manager is that it often has a dual role: it sets the rules for emissions and taxes (and subsidies) while also managing a multi-stakeholder, multi-level transition process in which social learning is central. The paradox is that the government is supposed to learn about its own role as transition manager, but bureaucratic divisions between agencies often act as barriers for experimentation and higher-order learning. The same applies to divisions between local, national and federal governments (including EU member states). Despite this paradox, transition management is an interesting new idea that should be endorsed and monitored carefully. However, it remains to be seen how successful it can be in the context of sustainable mobility.

In this chapter we focus on one aspect of a possible transition to sustainable personal mobility—that of hydrogen fuel cells as the propulsion system for cars and buses. Hydrogen fuel cells have been in the limelight over the past few years. There are basically two aspects to this—the introduction of fuel cells as a source of electrical energy, mainly for propulsion, and the use of hydrogen as a fuel. As we shall see, although these
are connected they are also quite different as fuel cells are possible without hydrogen and hydrogen for propulsion can be used without fuel cells. The question is: ‘What are the possible and optimal solutions for car and bus propulsion, taking into consideration the possibilities and restrictions of both fuel cells and hydrogen?’

The hydrogen fuel cell and its potentialities

Hydrogen fuel cells are electrochemical devices that convert hydrogen with oxygen into water, creating an electrical current in the process. This is the reversal of the electrolysis of water, in which an electric current splits water into hydrogen and oxygen. The fuel cell reaction requires a catalyst (often platinum) in order to function at low temperatures with enough speed and yield. Fuel cells have been known for a long time; they obtained practical application in the Apollo space programme in the 1960s.

There are many different types of fuel cells, using different electrolytes and fuels, operating at different temperatures. Presently, the most widespread fuel cell for transportation is the proton exchange membrane (PEM) which uses a special plastic membrane separating the cathode and the anode (Vergragt and van Noort 1996). The most common fuel is hydrogen, although mixtures of hydrogen and methane are also used, and a methanol fuel cell is under development. Fuel cells are used in stacks in order to obtain the required voltage and current density; in addition, provisions have to be made to add hydrogen and oxygen, to remove water and heat, and to handle the electrical current.

In the past few years, fuel cells have undergone a tremendous decrease in weight and volume, in conjunction with an increase in efficiency and reliability. This has enabled vehicle manufacturers to mount them in prototype vehicles and even in experimental city buses. Also, fuel cell costs have gone down, although they remain much more expensive than the internal combustion engine (ICE).

The advantages of fuel cells for car transportation lies in their high efficiency and their potential for zero emissions in use, which makes them especially suited for city traffic (like other electric cars). Furthermore, the absence of moving parts removes the need for lubrication and reduces maintenance costs. Their primary disadvantages are high investment costs, high costs of infrastructure changes and, more generally, the costs associated with a large system shift.

It is feasible that fuel cells will break through in other sectors earlier than in the transport sector. One sector where there is considerable progress is in the stationary generation of electricity, where large-scale fuel cell systems are used. Another promising area is the market for portable electrical appliances, such as mobile phones and laptop computers, where conventional batteries have too-limited a lifespan. It is quite feasible that these sectors will eventually lead the break-through to the mass market that is necessary to achieve the economies of scale needed for drastic price reductions.

One of the potential bottlenecks in the transition to fuel cell vehicles (FCVs) is the provision of the fuel. For a long time, hydrogen was considered unsuitable for storage in a car. Its energy density is too low, making it impossible to transport enough hydrogen to travel an acceptable distance. Now it appears that, by storing hydrogen under high pressure, sufficient density can be achieved.

Neither hydrogen nor methanol are currently available at commercial fuelling stations, except in Reykjavik. The building of a fuelling infrastructure is extremely expensive (US$5,000/car, according to Keith and Ferrell 2003) and the problem is that hardly

---

4 Since April 2003, see www.newenergy.is.
any FCVs will be sold until a fuel delivery infrastructure is in place. This problem is partially being tackled by experimenting with bus and taxi fleets which have a limited range and need only one central fuelling station.

A complication is that there does not seem to be a consensus about what should be the preferred fuel of the future (van den Hoed and Vergragt 2004). From the outset, Mercedes (post-merger, DaimlerChrysler) has lobbied for the use of methanol which can be converted ‘under the hood’ into hydrogen, although this still produces emissions. However, DaimlerChrysler has also built prototypes of cars and buses with hydrogen storage, especially for fleet use. On the other hand, General Motors and Toyota, followed by PSA, Renaul and Nissan, have switched their position on petrol-reforming under the hood. Petrol-reforming means the production of hydrogen from petrol by a chemical reaction (a so-called reformer) in the car. However, such a reaction generates emissions and reduces the overall efficiency of this method of propulsion. General Motors also uses hydrogen for testing fleet vehicles. BMW uses hydrogen in an ICE: the reaction does not produce hydrocarbon emissions but, because the temperature is high, it generates nitrous oxides. BMW also uses hydrogen in fuel cells, not for propulsion but mainly for enhancing the provision of electricity for other functions in the car (such as air-conditioning).

Because there is no consensus about the long-term commercial future of fuel cells in vehicles, governments are unwilling to make the infrastructure changes needed to support fuel cell transportation technology. As a complicating factor, there are a number of other solutions for propulsion, for example hybrid vehicles and bio-diesel (see Chapter 4), that may be equally sustainable from an environmental point of view. To complicate matters further, there is no consensus about the overall environmental gains (the so-called well-to-wheel efficiency) of the hydrogen fuel cell as compared to other solutions. Before we look into that, let us first take a closer look at hydrogen.

Hydrogen and its problems

For many years hydrogen has been lauded as the fuel of the future, with talk of the hydrogen economy (Hoffman 2000). Although hydrogen is abundantly available, turning it into transportation fuel costs energy and generates pollution. There are generally two routes available to generate hydrogen—electrolysis and steam-reforming. To produce hydrogen by electrolysis sustainably requires green electricity produced from renewable sources. In most places, renewable energy sources are not widely available: moreover, electrolytic production of hydrogen must compete with other consumers of green electricity, such as households. One report, looking at the situation in England (Eyre, Ferguson and Mills 2002), argues that, for at least the next 30 years, there will not be enough renewable energy available to produce hydrogen sustainably. Except for Iceland, with its abundance of geothermal and hydroelectric power, this is also likely to be the situation in most other countries.

To produce hydrogen by steam-reforming, natural gas is needed as a feedstock. Although natural gas reserves are large, they are by no means infinite. Moreover, steam-reforming generates carbon dioxide, a greenhouse gas. While it is possible for carbon to be stored (known as sequestration), the technology involved is not yet proven and itself requires energy, so reducing the life-cycle efficiency of steam-reformed hydrogen.

Instead of talking about the hydrogen economy and looking at hydrogen as ‘the fuel of the future’ it may be more realistic to view hydrogen as a medium to transport and store energy that has been generated elsewhere (preferably by renewable resources) and that might be used for fuelling mobility. The question then is: ‘What is the most sus-
tainable and cost-effective way to store and transport energy, and to make it available for cars and buses? It may be that, in the end, hydrogen is not the solution, for instance because electrical solutions or bio-fuels are more cost-effective and sustainable.

Thus, it appears to be better to be agnostic about the use of hydrogen as a solution in the final state after the transition to sustainable mobility. As we have seen before, we do not even know whether personal vehicles will be part of such a final state (or, indeed, whether a stable final state will ever emerge). On the one hand, there will be no hydrogen option if there is no R&D to develop and test the associated technology. On the other, opting for hydrogen now seems somewhat premature (Keith and Ferrell 2003).

Moreover, we need to be careful about the hype surrounding hydrogen. In his 2003 state of the Union address, President Bush allocated US$1.2 billion for research on hydrogen as a transportation fuel. There are doubts, however, about how the hydrogen is to be produced: for example, there are fears that nuclear energy may be used to generate hydrogen on a large scale.

Future scenarios and their assessments

Recently, many papers have appeared with scenarios and expectations about the potentialities of hydrogen fuel cells for personal vehicle propulsion. Ogden, Williams and Larson (2001) have developed what they call an optimistic scenario under a number of assumptions, including aggressive ZEV mandates (50%), a quickly-developing infrastructure and the continuation of falling prices with cumulative FCV production (see Table 1).

<table>
<thead>
<tr>
<th>Year</th>
<th>Production of FCVs per year</th>
<th>As a percentage of total cars on the road</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000–2004</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>2005–2008</td>
<td>10 000</td>
<td>Pilot manufacturing facility</td>
</tr>
<tr>
<td>2010</td>
<td>300 000</td>
<td>First commercial factory</td>
</tr>
<tr>
<td>2015–2019</td>
<td>900 000 extra each year</td>
<td>0.7% &lt;of how many?&gt;</td>
</tr>
<tr>
<td>2020</td>
<td>Cost-competitive</td>
<td>3.3% of 1.160 million</td>
</tr>
<tr>
<td>2020–2025</td>
<td>10 new factories/year</td>
<td>9.7% &lt;of how many?&gt;</td>
</tr>
</tbody>
</table>

Table 1 Production of fuel cell vehicles

Source: Ogden, Williams and Larson 2001

Ogden, Williams and Larson conclude that, even under the most favourable conditions, FCVs will not contribute to the solution of environmental problems much before 2025 at the earliest.

A UK report Fuelling Road Transport (Eyre, Fergusson and Mills 2002) details three demand-side scenarios: baseline, world markets (high demand scenario) and global sustainability (low demand scenario). In addition, five technical vehicle scenarios are outlined, among them rapid progress (hybrids and fuel cells), biomass (methanol) and a combination of the two. In the energy system, four scenarios are sketched, business as usual (BAU), high renewables, electrolytic hydrogen and high bio-fuels. Some of the most salient combinations of these scenarios are elaborated. Vehicle innovations (hybrid and hydrogen fuel cells) could lead to significant reductions in greenhouse gases in 2050, with greater reductions achieved through a combination of renewables and bio-
mass hydrogen. The most promising in terms of greenhouse gas reductions in 2050 are in the high biomass scenarios. Moreover, the report argues that in the UK there are no carbon benefits in producing hydrogen for use in transport from renewable energy, at least not before 2030. Instead, using it for power generation yields a larger reduction in carbon dioxide emissions. Only in cases where there is excess capacity of renewable energy (such as in Iceland) or an additional effective market demand for renewable energy or potential for the production of renewable hydrogen off-grid, could there be a net carbon benefit.

In 2000, a team at the Massachusetts Institute of Technology (MIT) published an influential report which concluded that hybrid–ICE vehicles have advantages over hybrid (and non-hybrid) FCVs with respect to life-cycle greenhouse gas emissions, energy efficiency and vehicle cost (Weiss et al. 2000:<page no. for quote?>):

vehicles with hybrid propulsion systems using either ICE or fuel cell power plants are the most efficient and lowest emitting technologies assessed. In general, ICE hybrids appear to have advantages over fuel cell hybrids with respect to life cycle GHG emissions, energy efficiency, and vehicles costs, but the differences are within the uncertainties of our results and depend on the source of fuel energy . . . if automobile systems with drastically lower GHG emissions are required in the very long run future (perhaps 30–50 years or more) hydrogen and electrical energy are the only identified option for ‘fuels’, but only if both are produced from non-fossil fuels of primary energy (such as nuclear or solar) or from fossil primary energy with carbon sequestration.

In 2003, a further report appeared in which these conclusions were refined (Weiss et al. 2003:<page no. for quote?>):

there is no current basis for preferring either fuel cell or ICE hybrid power plants for mid-sized automobiles over the next 20 years or so. Hybrid vehicles are superior to their non-hybrid counterparts and their advantages are greater for ICE than for FC designs. Hybrids can reduce both life-cycle energy use and greenhouse gas emissions to about 37% to 47% of current comparable vehicles and to about 52% to 65% of what might be expected in 2020 as a result of normal evolution of conventional technology.

On the other hand, a General Motors study (General Motors 2001) reports that hybrid hydrogen–FCVs give a 47% reduction in greenhouse gas emissions, as compared to the present benchmark vehicle. This is consistent with General Motors’ current interest in developing hydrogen–FCVs for the market, albeit with a petrol infrastructure and with petrol-reforming under the hood.

An Feng et al. (2003) have made a comparative analysis between these two conflicting forecasts and two other studies in order to identify the reasons for the difference in outcomes. They clearly show that these can be largely explained by differences in methodology, timeframes, vehicles sizes and assumptions about the baseline. Taking all these into account, they calculate that in all studies the hybrid hydrogen fuel cell car has the greatest fuel efficiency (and lowest greenhouse gas emissions), ranging from 92% miles per gallon equivalent gains in the MIT study, 138% in the General Motors study to 173% in one of the other studies. It needs to be taken into account that, according to An Feng et al. (2003:<page no. for quote>): ‘MIT results imply greater gains from 2010 to 2020 for conventional drivetrain technology than for FCV’. However, the analysis does not discuss how much of the fuel efficiency increase comes from hybridisation and how much from the fuel cell component.

Ogden, Williams and Larson (2001) take the life-cycle costing (LCC) of fuels as their yardstick. They calculate that for hybrid vehicles the LCC is about 50% that of conventional ICE vehicles and for compressed natural gas (CNG) vehicles it is 33%. The hydrogen–FCV would give one-eighth of the LCC if the hydrogen was derived from natural gas without carbon sequestration and one-fifteenth with carbon sequestration. If the hydrogen was derived from on-board fuel processors the LCC reductions would be much lower.
These figures would mean that greenhouse gas emissions over the entire life-cycle of a hydrogen–FCV would be much lower than other studies have shown.

Erdmann and Grahl (2000) calculate that, in Germany by 2010, the hydrogen–FCV may be cost-competitive for the user in the long-run because the higher price of the vehicle will be offset by the lower price of fuel. In a situation in 2010 where 2.5% of all cars are driving on compressed hydrogen and 10% of all fuel stations provide compressed hydrogen, a higher price of US$4,000 (1997) may be acceptable to German consumers.

Concluding thus far, we can state that the environmental gains from hydrogen–FCVs are widely disputed. One dispute is about the relative environmental gains of hydrogen fuel cells relative to hybrid vehicles. One gets the impression that the environmental gains of hybrid vehicles as compared to ICE vehicles is much larger than the environmental gain of hybrid–FCVs as compared to hybrid–ICE vehicles. Of course, a lot depends on how the hydrogen is produced (known as well-to-tank). The actual differences between vehicles show up in tank-to-wheel comparisons.

Transition towards hydrogen fuel cell mobility?

A future transition to a car system fuelled by hydrogen fuel cells requires that hydrogen is available on a large scale and at highly dispersed fuelling stations. Moreover, the hydrogen will need to be produced in a sustainable manner. There are two possible options, both of which can be carried out centrally or decentrally: steam-reforming with carbon sequestration; and electrolysis of water. Both have disadvantages. Central steam-reforming makes carbon sequestration viable but the technology is not yet proven and its risks are largely unknown; moreover, it requires natural gas as a feedstock. Sustainable electrolysis of water requires large amounts of green electricity which will not be available for at least another 30 years in the UK, according to Eyre, Fergusson and Mills (2002). Thus, in the shorter term, the electrolysis approach may actually increase rather than decrease carbon dioxide emissions.

Acceptance by users is crucial for a successful transition. Adamson (2003) suggests that a hydrogen–FCV will have to address three different adopter groups each with different requirements. The first, the primary niche market, will require that the FCV provides a new function with a high economic value to the customer. The secondary niche market will require that the subjective usefulness of the FCV is greater than of the current vehicle. And, finally, in order to enter the mass market, a market pull will have to be developed and costs brought down.

It is wise to try out the elements of a future system transformation before attempting to change the entire system. In evolutionary economics this is called strategic niche management (SNM) (see Hoogma et al. 2002) and in the social learning literature it is called bounded sociotechnical experiments (BSTE) (see Brown et al. 2003). In SNM the government creates a technological niche, a protected space in which stakeholders can experiment with a new technology. We can see many of these niches arising. For
instance, in the EU Clean Urban Transport for Europe (CUTE) project, stakeholders collaborated in setting up an experimental trial for hydrogen fuel cell buses in 11 European cities. The niche consists mainly of government funding; the buses have to comply with all safety standards and need to fulfil all other regulations for passenger transportation. However, the project does not aim to change urban public transport to a hydrogen fuel cell system.

It is probably more appropriate in this case to use the conceptual analytic scheme of BSTE. This approach is:

- Bounded in space and time
- Undertaken by heterogeneous stakeholders
- Driven by a shared long-term vision
- Aimed at higher-order learning about the technology, stakeholders' needs and interests, conditions for success and failure, and consumer acceptance

Iceland, with its abundance of renewable energy resources, is an interesting case as lack of green electricity is not an obstacle, at least not in the short term. Furthermore, the Icelandic experiment is driven by a shared common vision of a hydrogen economy, with private vehicles, public transport and even fishing vessels powered by green hydrogen. Moreover, this vision embraces independence from oil and gas imports, and thus appeals to the traditional Icelandic value of self-reliance. It also creates potential export markets of sustainable hydrogen to Europe.

In other European cities, such as Amsterdam, the CUTE project is driven by a heterogeneous group of stakeholders seeking to learn more about the application of hydrogen in specific applications, such as passenger buses. Research by Suzanne van den Bosch (2003) revealed that although the various participants in the project shared a common vision, they had quite different short-term objectives and interests. Thus, for DaimlerChrysler the CUTE experiment provided an opportunity to test the reliability of fuel cell systems in buses under real-life conditions. For Shell Hydrogen it helped explore the market for hydrogen and the potentialities for investment in hydrogen fuelling stations. For the Amsterdam transit authority CUTE chimed with the authority’s aim to be the front-runner in environmentally-friendly mass transit. For NUON, the energy company, the main issue was how to generate hydrogen from renewable sources.

The CUTE project is in its infancy and should not be seen as a sign of any fundamental shift towards hydrogen fuel cell bus transportation. However, it is helping to raise interest in the provision of green electricity for generating sustainable hydrogen. Thus, Hoek Loos, a producer of hydrogen for industry, sees the generation of sustainable hydrogen for the transportation market as a promising new business opportunity. NOVEM (a government funding agency) is co-funding the project because it fits with its policy of supporting pre-market pilots aimed at overcoming barriers and communicating new sustainable technology options.

It is interesting that this kind of radical innovation has been introduced by a coalition of heterogeneous stakeholders who share a common vision but have quite different short-term interests, as reflected in their success criteria. For instance, DaimlerChrysler sees the project as successful when there are 30 buses in operation in 11 European cities generating a lot of data on performance in real-life situations. For the transit authority and the municipality of Amsterdam the most important success criterion is lack of com-

---

plaints from transit passengers. For Shell Hydrogen the project is important as a world-
wide communication tool and for developing new markets, while Hoek Loos hopes to
be a partner in future hydrogen fuel cell projects. Most stakeholders see the develop-
ment of reliable and efficient technology as the clearest measure of success. NOVEM,
however, also counts the project as successful when learning takes place from failure.
Some partners, especially Shell Hydrogen and the transit authority, are very inter-
ested in consumer acceptance of hydrogen fuel cell buses, as they realise that adverse
publicity could kill the project in an early stage. The provision of high-quality consumer
information is therefore considered crucial for the success of the project.

Case study: consumer acceptance of hydrogen fuel cell buses in
Amsterdam

Consumer acceptance can be defined as ‘a positive attitude of individuals towards an
innovation and the intention to consume the product or service’<source for this quote?>. Note
that we are talking of an intention because the innovation may not yet be com-
mercially available and the actual behaviour of consumers may not yet have been tested.
This situation is similar to that of the SusHouse project where a methodology for con-
sumer assessment of long-term scenarios has been developed (Bode 2000; Vergragt and
Green 2001).

Behavioural intention is derived from consumer attitudes and social norms (Raaij et
al. 1999). From earlier consumer acceptance research on hydrogen fuel cells carried out
by the California Fuel Cell Partnership,8 J.D. Power and Associates9 and others (Pem-
bina Institute 2002; Altmann and Gräsel 1997<1998?>; Gruber and Wurster 2002), it
appears that consumer acceptance is determined by the following key issues:

- **Basic requirements**: affordability, comfort, range, storage capacity, acceleration, reli-
ability, safety
- **Extra benefits**: faster acceleration, reduced noise level, more electric power available
  for other functions
- **External benefits**: fuel prices, supply security, tax incentives, environment
- **Barriers**: shorter driving range, lack of performance, lack of information
- **Price**: consumers are willing to pay slightly more for the benefits
- **Perception of safety**: consumers expect the technology to be safe; however, com-
munication about safety aspects may raise concerns
- **Awareness/knowledge**: level of knowledge is very low; demonstration projects may
  help, but additional measures may be needed
- **Positive attitude**: although consumers have a positive attitude, this is not based on
  level of knowledge or perception of safety
- **High level of acceptance**: environmental aspects play hardly any role

---

7 This section is mainly based on the work of Suzanne van den Bosch (2003).
8 See www.fuelcellpartnership.org/releases/2000-10-1_media_update.htm and ‘Survey confirms pub-
lic support for fuel cells’ FutureDrive Newsletter, summer 2002, www.cafcp.org <can’t find survey on
website>.
Direct experience: significant positive effect on acceptance (and attitude)

In order to test these assumptions, and to obtain a measure of consumer acceptance of hydrogen fuel cell buses before their introduction (zero measurement), qualitative research was carried out among bus passengers in the Amsterdam region. The aim of the research was to investigate the knowledge, attitude and behavioural intentions of Amsterdam bus passengers.

In order to assess knowledge, passengers were asked about associations with the words 'fuel cells' and 'hydrogen', and were also asked what they knew about the planned introduction of the hydrogen fuel cell buses. In order to assess attitudes, questions were asked about advantages and disadvantages, about environmental aspects, safety, noise and smell, as well as about general attitude. In order to assess behavioural intention, passengers were asked if they intended to make use of a hydrogen fuel cell bus. The research was carried out on 22 bus passengers on a working day.

Knowledge of both fuel cells and hydrogen on the basis of associations was found to be low; most of the associations were either absent or incorrect. After a short explanation, most passengers were able to make a correct assessment of advantages and disadvantages. Attitudes towards fuel cells and hydrogen were predominantly positive, with only a very small number negative towards hydrogen. The overall attitude towards the introduction of hydrogen fuel cell buses ranged from neutral to positive. Attitudes towards the environment were predominantly positive, but mixed for other aspects such as sound, smell and safety. The importance given to the (positive) environmental aspects of hydrogen fuel cell buses was high. The behavioural intention to use the hydrogen fuel cell bus was 100%.

The overall results of this investigation suggest that general attitudes and behavioural intentions tend to be positive, but level of knowledge is generally low. It is expected that the level of knowledge will rise either as a result of the communications strategy or from direct experience with the hydrogen fuel cell bus. It is remarkable that the safety of the bus is regarded as obvious; the passengers had confidence that the buses comply with current safety standards.

The results of this qualitative research are in accordance with the published literature. However, because they are not firmly rooted in knowledge, the stability over time of the attitudes reported here is likely to be low. Negative incidents and press reports tend to influence attitudes and thus behavioural intentions. On the other hand, greater knowledge may reinforce existing attitudes which are a good starting point for general consumer acceptance of the new technology.

However, it was surprising that the stakeholders (and in particular the transit authority) were quite satisfied with the findings of this study and were not interested in carrying out any follow-up research. Indeed, the transit authority plans to use the findings to inform its public communications strategy on hydrogen fuel cell buses.

Conclusions

In this paper we first argued that a transition towards a future sustainable personal mobility system is hard to envisage because there are so many options available and so many uncertainties about their potential for implementation. We then argued that hydrogen–FCVs offer a promising option for a future sustainable personal mobility system. However, due to the large number of uncertainties identified in this chapter, it is highly improbable that a fundamental shift to a hydrogen–FCV system will take place in the foreseeable future.

First, hydrogen–FCVs are, at present, very expensive. In order to obtain economies of
scale large quantities need to be produced and sold. However, due to uncertainties about
the necessary infrastructure, and the high costs involved, it will take a long time before
commercial production is considered possible. In the meantime, there are other options
such as biomass fuels or hybrid vehicles (see Chapter 4) that may be more environ-
mentally friendly and that may better fit the present infrastructure.

Second, even if these barriers are overcome, there are uncertainties over whether suf-
ficient sustainable hydrogen can be produced and distributed. Ideally, hydrogen should
be produced by electrolysis using green electricity generated from renewable energy
sources. However, it is highly unlikely that there will be enough renewable energy
sources available in the long term to achieve this. Another option, steam-reforming of
natural gas, is not sustainable because gas is a fossil fuel; moreover, it presupposes that
carbon can be sequestered safely in the long term. Nevertheless, if carbon sequestration
is possible and there are enough natural gas reserves, this option could be an attractive
intermediate stage on the route towards sustainable hydrogen.

For the short and medium term, it is more probable that hydrogen fuel cells will be
applied in niches such as city buses with central fuelling depots, thus making an exten-
sive hydrogen delivery infrastructure system unnecessary. Reduction of local air pollu-
tion and noise may be important drivers for local authorities to promote these systems
for in-city use. An additional advantage of this strategy is that learning can take place
both about the technology and the motivations and desired outcomes of the heteroge-
neous stakeholders (businesses, governments, transit authorities, civil society, passen-
gers and others). Monitoring of these (possibly higher-order) learning processes is
highly advisable using conceptual frameworks such as the BSTE approach.

It is possible that hydrogen fuel cells will take off earlier in other sectors, for instance
on board ships or in portable laptops and mobile phones. With regard to ships, for exam-
ple, there are significant environmental problems associated with the use of crude oil
for transportation. By contrast, there are likely to be far fewer environmental problems
associated with storing and transporting large amounts of cooled or pressurised hydro-
gen. In mobile phones and laptops there is another driver—the demand for long-use
batteries that are easy to replace. Fuel cells could fill this gap, provided that hydrogen
storage problems can be solved.

Another possible route for transition is via stationary fuel cells. It is possible that in
the future the provision of electricity to households comes from fuel cells, either in the
form of large or micro units. Either way, electricity may be used at home to either gen-
erate hydrogen for transportation or fuel directly electrical propulsion of vehicles at
home<meaning of sentence not clear, please rephrase>.

Thus, the role for governments in transition management should be to foster learning
experiments with alternative fuels, vehicles and infrastructures, without opting pre-
maturely for a solution that may or may not be sustainable and cost-effective. These
experiments should be carried out in conjunction with heterogeneous stakeholders
(from business, local government and transport agencies, civil society and users/con-
sumers). Monitoring these experiments in order to analyse learning processes is
extremely important and is often neglected; moreover, making the results available to
other projects is essential in order to create a broader understanding of the sociocultural
aspects of the new technology. Governments can play an important role in connecting
dispersed sociotechnical experiments and in monitoring learning processes and follow-
up activities. Many experiments end when the project is terminated, with no clear fol-
low-up stage.

It will be a long time before we are able to reach a consensus on what the final sys-
tem will look like. Visioning exercises can help create a common understanding among
stakeholders about possible future scenarios and to exchange what has been learned
from experiments (Vergragt and Green <correct> 2001; Brown et al. 2003). Ongoing
learning about different aspects, including consumer acceptance, cost-effectiveness and long-term sustainability, will remain necessary for a long time. Furthermore, because the options are rapidly changing, investments in new infrastructure will remain low. Nevertheless, limited investment in experimental schemes is worthwhile as without this there can be no alternative to the present ICE trajectory (which is quite probably a sub-optimal solution, even if it is developed to its extreme). It is intriguing that the ICE trajectory is being spurred by the recent strong developments in fuel cell propulsion systems.

References


