H_2: driving the future

Julie Foley

the policy implications of developing hydrogen as a fuel for road vehicles

taking the lead on solutions
to climate change

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production & design by **EMPHASIS PUBLISHING LIMITED**

printed and bound in Great Britain by Biddles Ltd, Guildford and King's Lynn

ISBN 1 86030 XXX X

about IPPR

IPPR is Britain's leading centre-left think tank. Its purpose is to contribute to a greater public understanding of social, economic and political questions through research, discussion and publication. Established as an independent charity in 1988, the IPPR has developed a proud and influential record. Through its well researched and clearly argued policy analysis, its strong networks in government, academia, and the corporate and voluntary sector, and its high media profile, IPPR is playing a vital role maintaining the momentum of progressive thought.

IPPR's Low Carbon Initiative

H2: Driving the Future is a publication from the IPPR's Low Carbon Initiative that is addressing some of the key policy barriers to the development of a low carbon economy. International scientists are clear that all countries will have to cut greenhouse gas emissions by at least 60 per cent during the next century to prevent dangerous climate change. This will require major shifts in the way the economy and society operate, de-coupling economic progress and quality of life from the emission of greenhouse gases, in particular carbon dioxide. Significant carbon reductions are already technically feasible and, with appropriate business, social and political innovation, can be made economically feasible in the short and medium term. The Low Carbon Initiative will identify ways in which Government can stimulate this innovation to ensure the UK is taking the lead on solutions to climate change.

Apart from its hydrogen research, the Low Carbon Initiative will also involve a series of events, publications and focus groups throughout 2001 addressing the following themes:

- Micropower: moving towards decentralised energy technologies that provide more efficient and reliable services.
- Low carbon design: designing new infrastructure like buildings, transport and communications with energy efficiency in mind.
- Public perceptions: encouraging individual attitudes and behaviour that help reduce carbon emissions.

The Low Carbon Initiative is being supported by BG Group, BMW, the Carbon Trust, the Energy Savings Trust, Innogy, Shell and WWF. For more information about the IPPR's Low Carbon Initiative see: www.ippr.org/sustainability.

acknowledgements

I am particularly grateful to Chris Hewett of IPPR for all his support and advice throughout the research and writing of this report. A special mention should also be made to David Hart of Imperial College in London, John Hollis of BMW and Roger Cracknell of Shell for their detailed comments on earlier drafts.

I would also like to acknowledge the information and comments received from Stuart Jones of Advantica Technologies, Mike Jones of BP Amoco, Ausilio Bauen of Imperial College, Robert Mauro of the US National Hydrogen Association, Russell Marsh of WWF and Zoltan Zavody of the Energy Savings Trust. Comments by the IPPR Low Carbon Initiative advisory group have also been helpful. In March 2001, the IPPR ran a series of hydrogen seminars and much of the discussion from them influenced the writing of this report. I would therefore like to thank all the speakers and everybody who participated. However, the views expressed in this report are solely mine.

about the author

Julie Foley joined the IPPR in January 2000 and previously worked for the Institute for Social and Ethical AccountAbility. Her previous publications are *Plane Trading: Policies for Reducing the Climate Change Effects of International Aviation* (2000), with Chris Hewett and *Micro-entrepreneurs: Creating Enterprising Communities* with Andrea Westall and Peter Ramsden. Julie is currently working as a researcher on the IPPR's Low Carbon Initiative and is part of the IPPR's Sustainability Team.

Executive summary

Hydrogen—the zero emission transport fuel of the future

For the first time since the invention of the motor vehicle, a new transport fuel has the potential to sever the link between car use and air borne pollution. The fuel is hydrogen and it has the potential to change radically the way we power our transport system.

Hydrogen is a versatile fuel, which can be used in either adapted internal combustion engines or fuel cell vehicles. The emergence of fuel cell electric vehicles as a viable technology, which will be more efficient than conventional engines but require hydrogen fuel, has increased the prospects of hydrogen becoming a mainstream fuel.

Hydrogen powered vehicles have the potential to eliminate toxic emissions, greenhouse gases and noise pollution. The only emission from the tailpipe would be water vapour.

Like electricity, hydrogen is an energy carrier that has to be manufactured. It can be produced directly from fossil fuels or by electrolysis of water. If the latter uses renewable electricity then the hydrogen fuel could be genuinely zero emission. There is a growing consensus that hydrogen produced from renewable energy sources can deliver zero emission transport.

There are two potential pathways for the development of hydrogen as a transport fuel. Both will initially involve hydrogen being produced from fossil fuels. First, some fuel cell vehicles are being developed that produce hydrogen on board from either methanol or sulphur free petrol. The other pathway is based on the development of decentralised hydrogen production from natural gas, in combination with direct hydrogen fuelling of vehicles. It is too early to make a judgement over which pathway will predominate, but the evidence shows that decentralised production from natural gas is likely to produce fewer greenhouse gas emissions and be more cost effective.

The case for Government intervention

The introduction of hydrogen vehicles is bedevilled by a classic ‘chicken and egg’ problem. On one hand, vehicle manufacturers will not invest in hydrogen vehicle production plants until there are a sufficient number of places for refuelling. On the other, fuel suppliers will not invest in an entirely new hydrogen refuelling infrastructure until there are a sufficient number of vehicles on the road for using it.

What is missing is the initial catalyst to get the market going. Government is uniquely placed to provide this by co-ordinating policies to ensure stimulation of the zero emission vehicle market and development of hydrogen refuelling infrastructure goes hand in hand.

Hydrogen Task Force

Government should start this process immediately by establishing a high level Hydrogen Task Force. It should be charged with developing a 10-Year Hydrogen Strategy to identify ways in which policy can facilitate the development of a hydrogen transport economy.

The Task Force should involve government, industry, environmental and consumer groups but also senior members of the Conservative and Liberal Democrat parties as the transition to a hydrogen economy will cover a number of parliaments. It will be up to the Government to set the precise terms of reference but a number of key issues should be borne in mind:

- The short and medium term market should be steered towards options with the lowest levels of greenhouse gas emissions.
- The long term aim is to develop a refuelling infrastructure that supports hydrogen produced from renewable energy.
- Decisions on wider energy policy should incorporate the long term role for renewables in the production of hydrogen as well as electricity.
- Options for the use of hydrogen as a power source for stationary applications should also be considered.

Creating the market in hydrogen vehicles

The strategy will also need to identify ways in which Government can stimulate the market for hydrogen vehicles. The market is likely to develop in three segments: buses, fleet vehicles and private cars.

The combination of fixed routes, depot refuelling and space to store hydrogen easily on the vehicle means that the bus market will be the easiest starting point for hydrogen vehicles.

Pilot projects are already underway in North America and across Europe. London will be trialling three hydrogen buses between 2003 and 2005 as part of an EU funded project. Once the pilots have been completed then there will be a role for Government grants to support early developments of refuelling infrastructure and the purchase of hydrogen vehicles. We recommend a Hydrogen Infrastructure Fund and a 'Hydrogen Shift' Capital Grant be established under the remit of the Powershift Programme, currently run by the Energy Saving Trust, or similar organisation.

Local authorities should be given powers to set Zero Emission Bus (ZEBUS) Mandates for their areas, using strengthened regulation to specify a proportion of buses to be zero emission. Such legislation is already in place in California. The Mayor of London and the Greater London Authority also already have the powers to set such a mandate, and could do so at the end of their hydrogen bus pilots, if they are successful.

Fleet vehicles, such as delivery vans and public sector vehicles, would be the most likely place for the market to develop next. The grants mentioned above could also be made available to companies wishing to introduce hydrogen vehicles. Coupled with this, the Government could establish a voluntary Hydrogen Fleet Promotion Scheme for companies that agree to replace a proportion of their fleets with hydrogen vehicles. Public authorities should lead by example and procure hydrogen vehicles where possible. Local authorities could also use their discretion to exempt quieter hydrogen vehicles from night time delivery bans where appropriate.

The private car market will take longer to develop but Government should take early steps to use the tax system to encourage the uptake of hydrogen vehicles. Because hydrogen vehicles will be the cleanest on the market, they should be exempt from company car taxation and VED when introduced.

The tax on the fuel itself should also reflect its environmental impact. Hydrogen should have zero fuel duty for the lifetime of a Parliament. To reflect the emissions created in the production of hydrogen and encourage the use of renewable energy, hydrogen production should be subject to the Climate Change Levy.

Preparation for the hydrogen transition

The introduction of such a different fuel into the transport system requires careful preparation and work should start now on the development of standards, safety and raising public awareness.

The Government should send representatives to participate in the development of standards within Europe and internationally.

The Government should follow the US example and establish a national Hydrogen Outreach Programme for educating people about hydrogen safety and raising awareness of the environmental benefits of hydrogen vehicles. Elements could include:

- placing further vehicle pilots in areas where they get a lot of public use such as taxis, buses, airport transfer;
- provision of accessible public information on hydrogen as a fuel;
- integration of hydrogen energy into the national curriculum;
- working with higher education institutions to expand knowledge and experience of hydrogen power systems.

Finally, the UK is lagging behind countries like the US, Germany and Japan on government-led research and development into the hydrogen economy. The Carbon Trust could be a source of funding to set up a UK Hydrogen Research Programme.

Introduction

Imagine being able to walk around a busy city centre without having to breathe in dirty, filthy air…

Imagine a new pollution free vehicle on the road where the only emission from the tail pipe is water vapour…

This may sound like an environmentalist pipe dream, but for the first time since the invention of the motor vehicle, a radically different fuel has the potential to sever the link between car use and air borne pollution. The fuel is hydrogen and it has the potential to radically change the way we power our transport system. The introduction of hydrogen could be the most dramatic change to our energy system since electricity but its uptake will depend on Government's willingness to support its development.

More cost efficient transportation and significant cuts in carbon dioxide emissions are among the range of benefits that using hydrogen as a fuel can offer. All of us want, if possible, to quickly introduce hydrogen technologies and reap their benefits—environmental and financial.
Sir Mark Moody Stuart, Chairman of Shell International, at the Hyforum Conference in Munich, September 2000

I believe fuel cells will finally end the 100 year reign of the internal combustion engine. Fuel cells run on hydrogen could be a predominant automotive power source in 25 years time.
Bill Ford, Chairman of Ford Motor Company, at the Greenpeace Business Conference in London, October 2000

Hydrogen has the potential to deliver genuinely clean energy and bring the fossil fuel age to a close. We need to make the right choices today so that we produce hydrogen in an environmentally-friendly way.
Stephen Tindale, Director of Greenpeace UK

The recent petrol protests that brought parts of Europe to a standstill reinforce what we have known for some time—our modern economies are overly dependent on oil. Hydrogen is rapidly emerging as the most promising alternative transport fuel to offer a solution to some of the environmental and energy supply problems we are currently facing. Hydrogen vehicles that emit no pollution sound like the answer to both environmentalists' and politicians' prayers. The widespread use of hydrogen vehicles would help to tackle road pollution without having to sacrifice the mobility and convenience that people have come to expect from driving. However, it would not be the complete solution to sustainable mobility. Zero emission vehicles would not reduce traffic congestion or the number of deaths caused by road accidents. It is therefore important that policies for addressing the social impacts of road traffic are developed alongside policies for promoting zero emission, hydrogen vehicles. This report, however, focuses on eliminating emissions from vehicles.

What is interesting is that much of the momentum for hydrogen vehicles has come from companies reacting to public concern over environmental issues, rather than being led by Governments. The last year has seen a flood of announcements from vehicle manufacturers who want to position themselves as leaders in the hydrogen vehicle market. The race is on to develop the most marketable hydrogen vehicle. Energy companies have been keen not to be left behind. For example, Shell has established Shell Hydrogen which has a budget approaching US$500 million to investigate options for producing and supplying hydrogen. BP and Norsk Hydro are also involved in hydrogen development programmes.

There is no doubt that driving hydrogen vehicles would radically improve air quality in urban pollution hot spots and reduce emissions of greenhouse gases that worsen global warming. This is because there would be no harmful emissions from the tailpipe of a hydrogen vehicle. However, as with electricity, if the hydrogen is made from fossil fuel sources then significant amounts of pollution will still be released into the atmosphere at the point of production. Hydrogen vehicles could be a major environmental leap towards a zero emission transport system, but only if we choose the cleanest methods for producing the hydrogen. Hydrogen can be produced from renewable energy sources, like solar, wind or biomass. This should be the ultimate goal of policy makers.

In recent years, the Government has shown increasing interest in cleaner transport fuels. The Powershift Programme, managed by the Energy Savings Trust (EST), provides grants towards the cost of purchasing cleaner fuel vehicles. In 1998, the Cleaner Vehicles Task Force was established to identify ways in which the Government could encourage the public to switch to cleaner, less polluting vehicles. The Treasury has reduced fuel duty for some cleaner fuels, most recently cutting duty for ultra low sulphur petrol and diesel in the 2001 Budget. However, so far these initiatives have focused on the short term options and fossil fuels already on the market. There has been no Government strategy or support for the more radical changes required to get zero emission, hydrogen vehicles into the market. The UK is lagging well behind other countries, like Japan, Germany and the United States, who already have established national hydrogen research and development programmes.

The Government recently announced that it intends to produce a consultation document *Powering Future Vehicles—New and Emerging Fuels and Technologies.* The IPPR will feed into this process by identifying how Government can support hydrogen as the fuel of the future. This report seeks to highlight the key actions Government needs to take to aid the long term transition to a hydrogen transport economy based on renewable energy sources. It is divided into three main sections. The first outlines why society needs to reduce its dependency on oil powered vehicles and discuss the local air quality and climate change benefits that hydrogen vehicle technologies have to offer. The second examines how Government can help to get hydrogen vehicles onto the roads by supporting the development of refuelling infrastructure and creating a market for hydrogen vehicles. The final section discusses the importance of developing hydrogen standards and raising public awareness about hydrogen safety and the environmental benefits of hydrogen vehicles.

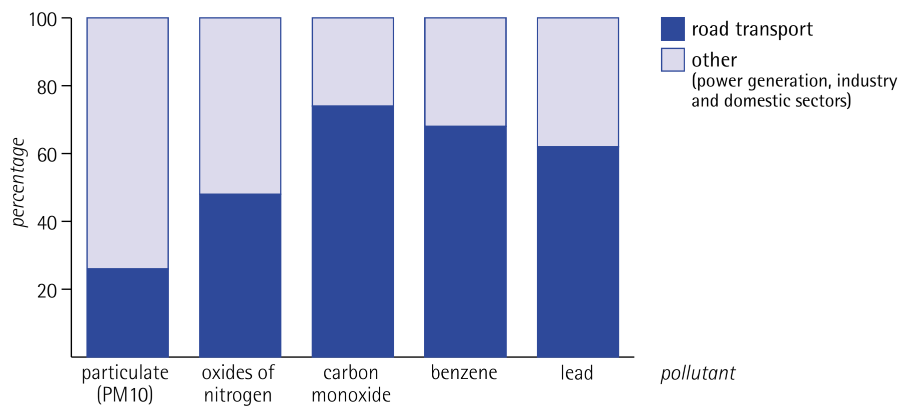
Why it's time to scrap the gas guzzlers

In the UK, 93 per cent of all journeys are made by road vehicle, the overwhelming majority made by cars (DETR, 2000a). Affordable road vehicles have brought people freedoms and opportunities they could have scarcely imagined 50 years ago. As a consequence, our roads are getting more and more crowded. New car sales in the UK have continued to rapidly rise from 1.59 million in 1992 to 2.06 million in 2000. 70 per cent of households now have regular use of a car (RMIF, 2001). We are indisputably living in a car culture. However, our dependence on oil powered vehicles is coming at a price that will not only affect us but also generations to come. Problems of urban air pollution, climate change, noise pollution and our continuing dependence on insecure foreign oil sources all provide a compelling case for cleaner alternatives to petrol and diesel guzzling vehicles.

Air pollution

Each year 24,000 people die prematurely in Britain from the effects of air pollution (DoH, 1998). The Government is only too aware that clean air is essential to a good quality of life and in January 2000 published its Air Quality Strategy for England, Wales and Northern Ireland. The Strategy sets out emissions targets for air pollutants to be achieved by 2005. If Government is to achieve its air quality targets, it will need to prioritise reducing air pollution from road transport. Despite improvements in fuel efficiency and tougher vehicle emission standards, road transport remains the largest source of air pollution in the UK. The main air pollutants from vehicles include carbon monoxide (CO), oxides of nitrogen (NO_X) and benzene, all of which contribute to respiratory problems and aggravate asthma. The Department of Environment, Transport and the Regions (DETR) estimates that road vehicles account for 74 per cent of CO emissions, 48 per cent of NO_X emissions and 68 per cent of benzene emissions (DETR, 2000b).

figure 1 contribution of road transport to air pollution



Data source: DETR, 2000b

These different air pollutants are thought to have different health effects and impact most severely on those with heart or lung conditions. Those susceptible to the negative effects of air pollution tend to be the most vulnerable in society—the very young, the old and the infirm, and often those who are on lower incomes.

Climate change

The threat of rising air temperatures, rising sea levels, floods and droughts in different parts of the world has made global climate change one of the most pressing issues facing today's society. In 1988, the Intergovernmental Panel on Climate Change (IPCC) was established to improve understanding of the risk of human induced climate change. The IPCC estimates that relative to 1990 levels, global mean temperatures may rise by 1.4 to 5.8^{o}C per by 2100, if no mitigating action is taken. This warming is expected to result in the thermal expansion of oceans and melting of glaciers and ice sheets leading to sea level rises. The IPCC predicts that global average sea levels could rise from 0.09 to 0.88 metres by 2010 (IPCC, 2001). In addition to sea level rise, studies have predicted increased frequency in extreme weather events like the kinds of storms, droughts and flooding we have experienced recently. In the UK, much of our best agricultural land could be at risk from flooding or salination of groundwater (DETR, 2000c).

As part of international climate change negotiations, the UK Government agreed to reduce greenhouse gas emissions by 12.5 per cent under the 1997 Kyoto Protocol. The Government's Climate Change Strategy has set a domestic goal of a 23 per cent cut in greenhouse gas emissions by 2010 (DETR, 2000c). CO_2 is the main greenhouse gas responsible for climate change worsened by human activities. Road transport makes up 25 per cent of all UK CO_2 emissions. Of greatest concern, however, is that greenhouse gas emissions from transport are increasing, and projected to rise by a further 25 per cent between 2000 and 2020 (DETR, 2000c). The Royal Commission on Environmental Pollution (RCEP) has called on the UK to cut

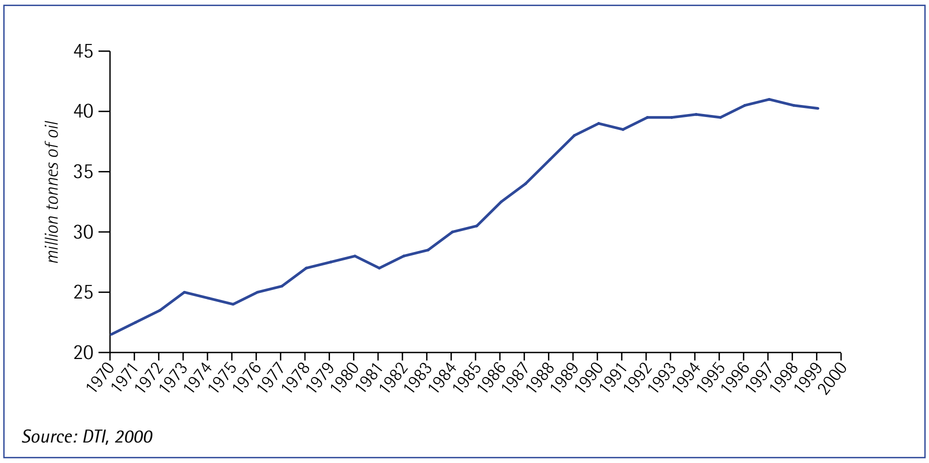


figure 2 oil consumption by road transport in the UK, 1970-1999

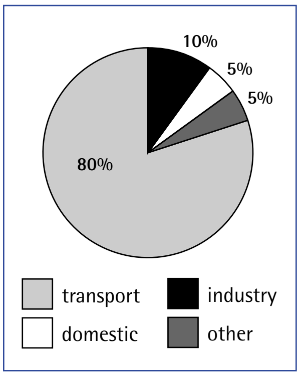


figure 3 oil consumption in 1999

emissions by 60 per cent by 2050 (RCEP, 2000). This will not be achieved unless the trend in transport emissions is reversed, and it seems unlikely that conventionally fuelled vehicles could deliver such reductions.

Energy security

Our reliance on oil powered vehicles has meant that the UK, as with much of the developed world, is becoming increasingly reliant on imported oil. In 1999, transport accounted for 80 per cent of total oil consumption. Almost 77 per cent of this is attributable to road vehicles. The amount of oil consumed up by road vehicles has almost doubled since the 1970s (DTI, 2000). In 1999, £305 million more was spent on imported oil products compared to 1997 – a huge increase over only two years (DTI, 2000). If we do not reduce our oil consumption we will become increasingly vulnerable to fluctuations in the global price of oil. The September 2000 fuel protests, precipitated by these price rises, demonstrated just how dependent we are on oil. By blockading oil supplies, the protesters were able to hold the Government to ransom. Public concern that oil supplies would run out led to panic buying of petrol, long queues at filling stations and stockpiling of food supplies. Governments would never allow such a dependency on one fuel to develop in the electricity market. Diversity and security of fuel is set to become a more important issue on transport.

Noise

There is no coherent policy to tackle noise in the UK. However, people are becoming increasingly intolerant of noise pollution and it has become one of the principal sources of complaint to Local Authorities (LAs). The noise pollution created by a busy road can be a major source of irritation. Most LAs now impose curfews on noisy delivery vehicles to prevent them from entering residential areas at antisocial times of the day, such as very early in the morning.

Why is hydrogen driving the future?

What is hydrogen?

Hydrogen is the lightest and most abundant element in the universe, constituting about 93 per cent of all atoms. Yet, on Earth its occurs as a free element only in trace amounts. Unlike oil or gas it cannot be mined or drilled out of the ground. Rather hydrogen must be produced from something else. Hydrogen can be made from hydrocarbon fuels, like natural gas or coal. It can also be made from biomass or renewable energy sources using electrolysis—the process of passing an electric current through water to split it into hydrogen and oxygen. As a result, hydrogen is often described as being an 'energy carrier' because, like electricity, hydrogen offers a means of delivering energy from a primary source. The fact that hydrogen can be produced from many sources means that it is unlikely there will be one global fuel choice for hydrogen vehicles as there is with petrol and diesel vehicles today. Rather, different geographical localities are likely to select the hydrogen feedstock that is most appropriate for that area.

A brief history of hydrogen as a fuel

The idea of using hydrogen as a power source has had a long history. In his 1766 Royal Society paper Henry Cavendish recognised hydrogen as an element and proved that it could be produced from a variety of reactions. In 1800, the British scientists William Nicholson and Anthony Carlisle were the first to demonstrate the process of electrolysis. Jules Verne recognised the opportunities for using hydrogen as a fuel long before any major research had begun. In his 1874 novel *The Mysterious Island* he foresaw a future where 'water will one day be employed as a fuel, that hydrogen and oxygen which constitute it, used singly or together, will furnish an inexhaustible source of heat and light.'

By the 1900s, interest in hydrogen had moved beyond the realms of science fiction. In 1923, the Scottish scientist JBS Haldane heralded hydrogen as the fuel of the future when he found that storing wind generated hydrogen gave about three times as much heat as a pound of petrol. In the 1930s, Franz Lawaczeck, a German turbine designer, investigated the possibility of using hydrogen engines in cars and trains and proposed transporting hydrogen by pipeline. Around the same time, the German engineer Rudolph Erren started to convert buses, lorries, trains, and cars to run on hydrogen. Over his lifetime he converted over 1000 internal combustion engine vehicles in both Germany and Britain. However, it was not until the early 1970s that the three major car companies—Ford, General Motors and Chrysler—began to take hydrogen as an alternative transport fuel seriously and started to develop prototype vehicles.

Source of information: Hoffman, 1981 and MacKenzie, 1994

Hydrogen vehicle technologies

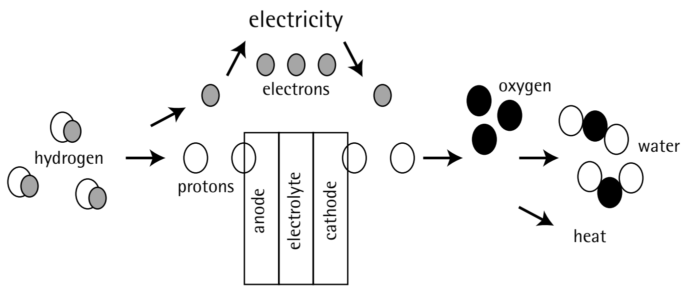
Approximately 45 million tonnes of hydrogen gas is produced globally each year (Hart, 2001). Very little of this is used as an energy source. Most of the hydrogen is used in oil refining processes or to produce ammonia for fertilisers. Beyond its use in the NASA space programme, hydrogen has had little use for transportation. Yet, hydrogen can be used in much the same way as conventional transport fuels. It can be burned in engines to provide power. For example, BMW have produced a hydrogen internal combustion engine vehicle. With conventional combustion of hydrogen, there are no CO_2 emissions that contribute to global warming. Small amounts of NO_X emissions that affect air quality are produced due to the high temperature reactions involving nitrogen in the air, although it can be far less than a standard petrol vehicle.

However, what has increased interest in the use of hydrogen as a fuel is the emergence of a completely new technology to power road vehicles, the fuel cell. The majority of vehicle manufacturers currently favour using hydrogen in a fuel cell vehicle rather than an internal combustion engine vehicle. Fuel cells function in a similar way to batteries in that they have no moving parts and convert chemical energy into electricity very efficiently and silently. Like a battery cell, multiple fuels cells are stacked together to increase the voltage. Although, unlike batteries, fuel cells never need to be recharged. They will produce electricity for as long as the fuel—usually hydrogen—is provided.

Fuel cells—their history and how they work

The fuel cell has its roots in British history. Sir William Grove set out the basic principles of a fuel cell in 1839. However, it was not until the 1930s that Francis T Bacon, a British scientist, actually made a fuel cell that could produce power. In the 1960s the US space program chose fuel cells to power the Gemini and Apollo spacecraft and provide water for the shuttles. Only recently have fuel cells become commercially available for road transport and stationary applications.

A basic fuel cell consists of an anode, a cathode and an electrolyte. At the anode, hydrogen molecules are split into positively charged protons and negatively charged electrons. The protons reach the cathode by passing through the electrolyte. The electrons have to pass through an external circuit to get to the cathode thus providing electrical energy. Oxygen supplied at the cathode then combines with the protons to form water.



The most widely used fuel cell technology for vehicles today is the Proton Exchange Membrane (PEM) fuel cell.

A hydrogen fuel cell vehicle would create no noise pollution and produce no local air pollution or greenhouse gases. In fact, the only emission from the tailpipe would be water vapour. In addition to this, the theoretical efficiency of hydrogen fuel cells in converting fuel to power is higher than internal combustion engines. An internal combustion engine vehicle can lose more than 80 per cent of the energy it generates, either as waste, heat or friction. A hydrogen fuel cell may lose only 40 per cent and will therefore be very fuel efficient.

The widespread use of both hydrogen fuel cell and hydrogen internal combustion engine vehicles would have considerable environmental benefits. This report will discuss both these hydrogen vehicle technologies. It is too early in their development to suggest that either will become dominant in the marketplace. The focus of this report, and the most important question for policy makers, is the use of hydrogen as a fuel rather than the type of vehicle. All policy recommendations will therefore be technology neutral and the term 'hydrogen vehicles' will refer to *both* hydrogen fuel cell and hydrogen internal combustion engine vehicles.

Hydrogen storage

Hydrogen storage on board the vehicle remains a problem area. A key difference from other fuels is that hydrogen has a much lower energy density. This means that to get the same amount of energy stored in a given space, the hydrogen would have to be compressed much more (Hart *et al*, 1999).

Hydrogen can be stored in both gaseous and liquid form. In liquefied form, hydrogen has the advantage that it would only weigh one quarter of its petrol equivalent, although it would occupy a much larger space (Geier *et al*, 2000). Also, for storage as a liquid, hydrogen's very low liquefaction temperature (-250 degrees Celsius) means that additional energy must be used. It must be stored in heavily insulated vessels to avoid boil off of liquid hydrogen. Technologies for storing and transporting liquid hydrogen are however well understood at an industrial level and BMW have developed a liquid hydrogen vehicle tank that would lose only one per cent of fuel per day through evaporation if the vehicle was not in use (Hollis, 2001).

Storing hydrogen as compressed gas may eventually be a simpler and less expensive method for storing hydrogen on board a vehicle. The refilling time of compressed hydrogen gas tanks is similar to petrol tanks and its storage uses similar technology to that of compressed natural gas, although a higher pressure is required. Currently the tank required for storing compressed hydrogen gas on board a vehicle is considered too bulky to acceptably fit into the average European size car. But, there are no barriers to storing hydrogen tanks on larger vehicles like delivery vans or buses.

Hydrogen storage technologies continue to advance at a rapid rate. It is widely thought that the metal hydrides and carbon absorption techniques currently being developed will be able to safely compress large quantities of hydrogen in order to give passenger cars an adequate range (Hart, 1997 and Lakeman and Browning, 2001). Shell Hydrogen recently announced that it was seeking to develop, manufacture and market hydrogen storage products based on metal hydride technologies (Shell, 2001).

The newest and cleanest fuel vehicle on the block

Since coming into power in 1997 the Labour Government has set aside money for supporting cleaner fuel vehicles. Much of this money has been channelled through the Energy Saving Trust's Powershift Programme. The Programme has been successful in bringing the supply and use of Liquid Petroleum Gas (LPG) vehicles into the mainstream marketplace. The Government has allocated a further £30 million to the Powershift Programme over the next three financial years. Much of the money is likely to be focused on developing the market in Compressed Natural Gas (CNG) vehicles that offer higher air quality benefits than LPG vehicles (DETR, 2001). (The future direction of the Powershift Programme will be discussed later in the report.)

Whilst LPG and CNG vehicles can help to reduce local air pollution, their performance in reducing greenhouse gas emissions is less impressive. For example, compared to petrol vehicles, LPG vehicles typically offer a 10-15 per cent reduction in lifecycle emission of CO_2 (DETR, 2001). CNG vehicles offer better greenhouse gas reductions, but neither LPG nor CNG vehicles compare with the air quality and climate change benefits promised by hydrogen vehicles. Hydrogen is in a league of its own because it has the potential to power vehicles that would have zero emissions.

However, have we not heard all this before with electric vehicles? Battery driven electric vehicles were designed to be zero emission vehicles before the latest interest in hydrogen vehicles. There will still be developments in electric vehicles but hydrogen vehicles have greater potential for two main reasons. Firstly, there have been considerable difficulties with the development of batteries that can store sufficient power to give the vehicles a good range. Secondly, refuelling is more inconvenient for battery vehicles, which generally have to be charged over a matter of hours. Hydrogen refuelling would take the same sort of time as petrol. Battery vehicles are therefore more likely to be confined to niche applications. Most vehicle manufacturers are now showing greater interest in developing hydrogen vehicles that overcome many of the problems with current electric vehicles.

Examples of how other countries are supporting hydrogen

Japan

Japan is credited with developing the World Energy Network Project, more commonly referred to as the WE-NET Project, which is the world's largest and most wide ranging national hydrogen programme. It is no coincidence that the Japanese, with few natural energy resources, are by far the biggest investors in hydrogen. One reason that the Japanese are happier about hydrogen than they are about oil is that it can be produced in many ways and will therefore not raise questions of security of supply.

The Japanese Government is determined to become the world leader in developing hydrogen technologies. This is reflected in the US$2 billion [£1.4 billion] that has been allocated to the WE-NET Project. The WE-NET Project is part of the Sunshine Programme which has a substantial budget of US$11 billion [£7.6 billion] over its 28 year life span. The WE-NET Project is divided into three stages. The first stage, which ended in 1999, was mainly concerned with analysing the possibilities for production, storage and usage of hydrogen. The second stage, running until 2005, will address the construction of facilities in Japan to demonstrate technologies which produce, store or use hydrogen. The final stage, which will run from 2006-2020, is when the technologies should actually be put to use.

Germany

The second largest national hydrogen programme is in Germany. Like Japan it is attracted to reducing its dependency on oil. The Bavaria region has shown a particular interest in hydrogen technologies. This is in part due to the presence of vehicle manufacturers such as BMW and Mercedes Benz. The Bavarian Ministry for Economics, Transport and Technology has given substantial subsidies to hydrogen projects totalling DM21 million [£7 million] between 1996 and 1999. The projects funded have included a hydrogen fuel cell bus project and the development of a hydrogen refuelling facility at Munich airport. Funding for hydrogen research by the German Federal Ministry for Education and Research (BMBF) has wavered over the years, although an impressive budget of DM17 million was announced for 2001.

United States

In January 2000, the US Department of Energy (DoE) launched a blueprint strategy for hydrogen fuel infrastructure development which draws largely on the experiences of the Californian Fuel Cell Partnership. The Partnership is a unique collaboration between auto manufacturers, energy companies, fuel cell companies and government agencies which formally began in April 1999. Partners include DaimlerChrysler, Ford, Honda, Nissan, BP, Shell, Ballard Power Systems, International Fuel Cells, the California Air Resources Board and the US Department of Energy and Transportation. The Partnership has largely been driven by strict environmental regulations in the state and public pressure for higher air quality standards. The Partnership will have up to 50 cars and 20 fuel cell buses in operation by 2003. In addition to testing the fuel cell vehicles, the Partnership will also identify fuel infrastructure issues and prepare the Californian market for this new technology.

The US DoE hydrogen programme as a whole had a budget of US$24.5 million [£17 million] in 2000 and has requested US$23 million [£16 million] for 2001. If all related projects, such as fuel cells for generation technologies and transport, are included it is estimated that funding on hydrogen and fuel cell research exceeded US$120 million [£83 million] in 2000. The 'positive role of hydrogen energy' was recently acknowledged in the National Energy Policy drawn up by the new Bush administration and Congress.

Source of information: Hart et al, 1999, Lakeman and Browning, 2001 and NHA, 2001.

In terms of emissions benefits, hybrid cars, powered by a battery and an internal combustion engine, actually perform better than LPG, CNG or electric vehicles. There is no reason why the market could not support both hybrid and hydrogen vehicles, but hydrogen vehicles would be better in the longer term. This is a view supported by Roger Cracknell of Shell who has said that 'hydrogen would be better because it can be generated from renewable energy sources which would have no effect on global warming' (in Hamer, 2001).

Driving hydrogen forward in the UK

The introduction of hydrogen vehicles is bedevilled by a classic 'chicken and egg' problem. On one hand, vehicle manufacturers will not invest millions of pounds to build hydrogen vehicle production plants until there are a sufficient number of places for hydrogen refuelling. On the other hand, fuel suppliers will not invest in an entirely new, national hydrogen infrastructure until there are a sufficient number of hydrogen vehicles on the road for using it. In such a situation there is a clear need for Government intervention to get the hydrogen economy started in the UK.

Getting hydrogen vehicles onto the roads

The UK, as with all other countries, is not set up to deliver hydrogen on demand to vehicles. The simple fact that hydrogen, unlike petrol or natural gas, is not widely available poses the most significant obstacle to the widespread use of hydrogen vehicles. This means that even though vehicle manufacturers are developing their own brands of hydrogen vehicle, to get them ready for the showrooms within the next five years, there will be no mass market demand for them. Obviously no one will choose to buy a hydrogen vehicle if they have their travelling severely restricted by the number of refuelling points. This has already proven to be the case with CNG vehicles, which have not taken off in the UK market because there is virtually no infrastructure. In contrast, Italy has 340,000 CNG vehicles, which is the largest number in the world, together with a network of 340 refuelling stations to support their use (ENGVA, 2001).

All this would suggest that without major investments in infrastructure, the hydrogen vehicle revolution would stall on the starting line. Not necessarily. There are ways of getting hydrogen vehicles onto the roads in the short term without the need for significant infrastructure investment. This discussion shall examine two possible broad pathways:

Pathway one: to produce hydrogen on board the vehicle from methanol or petrol
Producing hydrogen on board the vehicle bypasses the problem of finding a way of delivering hydrogen to it. The vehicle is not refuelled directly with hydrogen. Rather, an interim fuel, such as methanol or petrol, is used to fill the vehicle instead. The hydrogen for powering the vehicle is then produced on board from either methanol or petrol. On board hydrogen production is only technically feasible with fuel cell and not internal combustion engine vehicles.

The advantage of using petrol is that we already have an existing petrol infrastructure that is widely available. Using petrol to produce hydrogen would therefore reduce the problem of developing a new refuelling infrastructure. However, this is not the case with methanol. Choosing methanol to produce hydrogen involves making a decision about whether developing a new methanol refuelling infrastructure is worth the investment in the long term.

Pathway two: to produce hydrogen off board the vehicle from natural gas at local refuelling stations or depots
Producing hydrogen off board the vehicle means that it is refuelled directly with hydrogen. Hydrogen can be put directly into either fuel cell or internal combustion engine vehicles. Nearly all of the hydrogen currently in use is produced from natural gas in large plants. If production were to be scaled up to meet the demands of road users it would eventually require major investments in new production plants as well as hydrogen pipelines or fleets of hydrogen trucks for distributing the hydrogen to refuelling stations.

A far more feasible option would be to produce hydrogen on a much smaller scale by exploiting the fact that natural gas is currently delivered to the majority of towns and cities throughout the UK. There is no reason why hydrogen production could not occur on the same site as refuelling, thus avoiding the costs of hydrogen transportation. The costs of installing hydrogen production and storage technologies at refuelling sites would have to be accounted for. But, by in large, this kind of refuelling approach would help to get around the chicken and egg problem inherent in developing an expensive large scale, centralised hydrogen infrastructure.

What is the role of government?
The role of government is to support the pathway that benefits society most in terms of reducing road traffic pollution. Both pathways would help to get zero emission, hydrogen vehicles onto the roads that would be much cleaner than conventional petrol vehicles or clean fuel vehicles like LPG. However, neither of the pathways would be environmentally sustainable in the long term. This is because the process of producing the hydrogen fuel in the first place—from petrol, methanol or natural gas—would still release pollution into the atmosphere, notably greenhouse gas emissions. Becoming too reliant on fossil fuel derived sources of hydrogen would reduce the environmental benefits of developing new hydrogen vehicle technologies. The ultimate sustainable solution would be to produce hydrogen through electrolysis of water using electricity from renewable energy sources. The problem is that whilst electrolysis is a well established process, hydrogen made in this way is very expensive. This is principally because renewable energy sources are not yet commercially available at a large enough scale.

In the meantime, the above pathways offer a means of securing the air quality and climate change benefits that hydrogen vehicle technologies have to offer. But, it is important that Government keeps the vision of hydrogen from renewable energy sources in sight. The rest of this section will examine which of the two pathways serve as the best stepping stone to this longer term vision.

Should hydrogen be produced on board the vehicle?

Nearly all the leading vehicle manufacturers are hedging their bets by developing fuel cell vehicles that can produce hydrogen from either methanol or petrol.

Producing hydrogen from methanol
Hydrogen can be produced from methanol at relatively low temperatures of 260oC compared to 600-900oC for other common fuel choices such as petrol or natural gas (Ogden *et al*, 1999). Producing hydrogen from methanol is therefore a relatively easy process. This is probably why two of the five fuel cell vehicles that DaimlerChrysler has demonstrated use methanol to produce hydrogen. (The other three are direct hydrogen fuel cell vehicles).

The methanol industry has been keen to promote itself as a source of hydrogen on the grounds that large plants for producing methanol exist today; indeed more methanol is currently produced globally than is needed. However, methanol refuelling would require significant changes to the current transportation fuel distribution and dispensing system. Methanol is far more corrosive than petrol and so would require a virtually new refuelling infrastructure to be developed in terms of storage tanks, pipes and dispensing pumps.

If the aim is to move towards direct hydrogen refuelling, where in the longer term hydrogen could be made from renewable energy sources, it is questionable whether major investments in a methanol refuelling infrastructure would be worth it. As just an interim step it would not make sense as the existing refuelling infrastructure would have to be changed twice—once to support methanol refuelling and again to support direct hydrogen refuelling. The significant costs associated with developing a temporary methanol refuelling infrastructure mean that on board hydrogen production from methanol is unlikely to be a viable option.

In addition to this a number of vehicle and energy companies have expressed concern about the safety of methanol when handled by the public. Methanol is a poisonous toxin that can be absorbed through the skin. If it came into widespread use as a transportation fuel, there could be an increase in the number of deaths due to inhalation or even ingestion of the fuel. One energy company has gone as far as saying that it could become the centrepiece of yet another group of class action lawsuits akin to the recent litigation against tobacco companies.

Whilst some vehicle manufacturers continue to develop fuel cell vehicles with on board hydrogen production from methanol, it appears that interest in methanol is on the wane. In January 2001, General Motors publicly stated that it was no longer going consider producing hydrogen from methanol (General Motors, 2001).

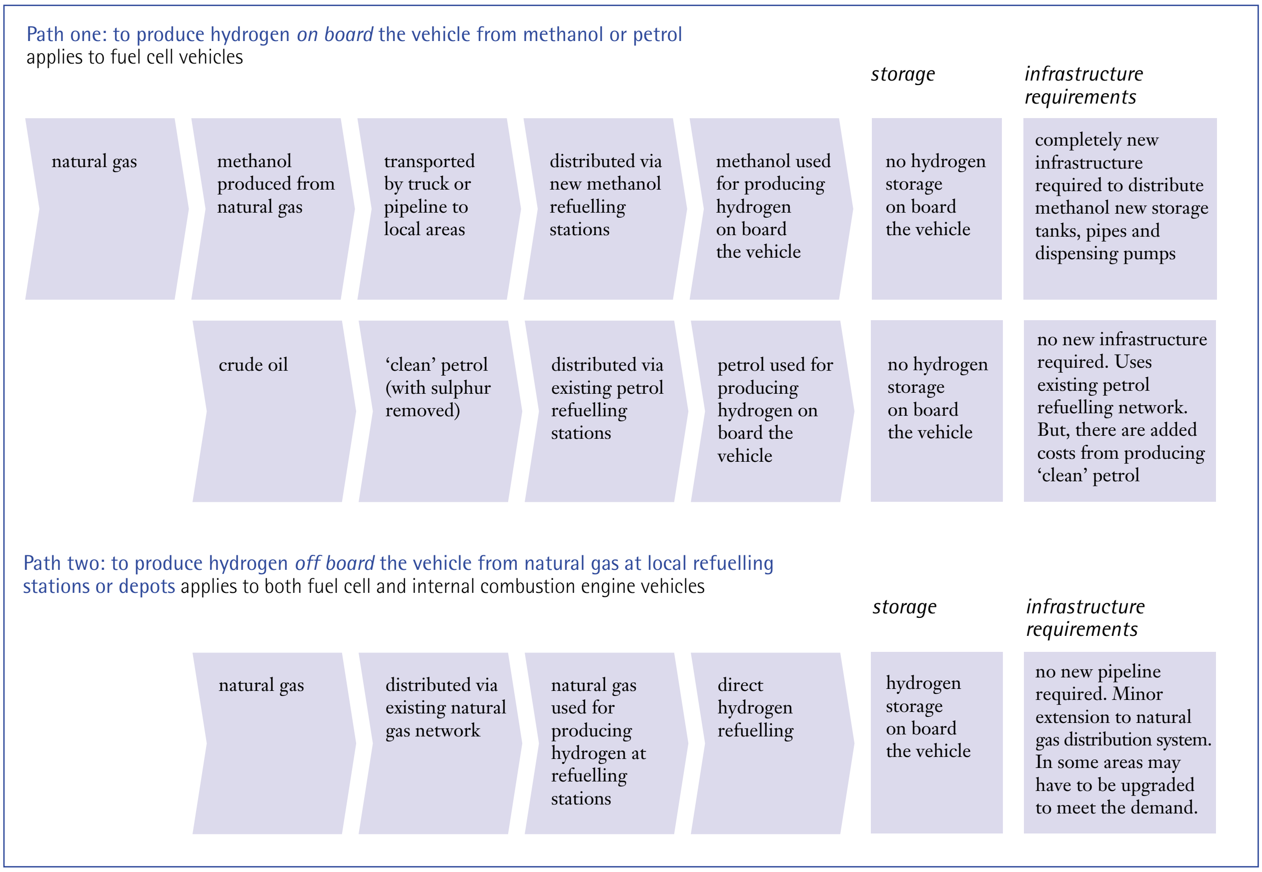


figure 4 getting hydrogen vehicles onto the roads

Producing hydrogen from petrol

Many of the energy companies are exploring the option of using petrol to produce hydrogen on board the vehicle. Given that there are already petrol refuelling stations up and down the country the rationale for using petrol to produce hydrogen at first seems sensible. It has the advantage of being widely available and also familiar to consumers. However, it should be noted that the petrol we currently put into our vehicles is not necessarily the same kind of petrol that would be required for fuel cell vehicles. Some of the technologies used to extract hydrogen from petrol are easily damaged by impurities such as sulphur. The sulphur content of ultra low sulphur petrol and diesel currently available are unlikely to be considered low enough for use in a fuel cell vehicle. Fuel suppliers would also have to meet the costs of producing 'clean' petrol with all the sulphur removed.

There are also technical question marks about whether hydrogen can be produced from petrol easily. Petrol is a far more complex and heterogeneous fuel than methanol with tightly bonded carbon molecules that would require very high temperatures to break. One fuel cell company has compared on board hydrogen production from petrol with putting a miniature oil refinery in a vehicle (M J Bradley and Associates, 2001).

Proponents of producing hydrogen from petrol are quick to point out that it would involve making one infrastructure change—from the existing petrol infrastructure to a new hydrogen one. Some argue that on board hydrogen production from petrol could accelerate the uptake of fuel cell technologies onto the market, therefore driving down their production costs. The danger is that there would be no incentive for vehicle manufacturers to develop fuel cell vehicles run on direct hydrogen and no incentive for fuel suppliers to move beyond petrol. Allowing the fuel cell vehicle market to develop only vehicles that produce hydrogen from petrol could actually serve to reinforce the status quo of a petroleum based transport system. Whilst it could get fuel cell technologies onto the market, it would fail to deliver the potential climate change benefits that hydrogen fuel cell vehicles have to offer. It would also delay action to reduce our dependence on oil.

On board hydrogen production—the right path?

The vast majority of analyses concur that the cleanest and most efficient way of running a fuel cell vehicle is simply to put hydrogen directly into it and to produce the hydrogen off board the vehicle. It is widely thought that the technical complexities of producing hydrogen on board vehicles from either methanol or petrol could cause vehicle companies liability and repair concerns (Hart, 1997, Ogden *et al*, 1999 and Thomas *et al*, 2000a). If the first fuel cell vehicles that are introduced prove to be unreliable they will not satisfy consumer demands and could tarnish the reputation of all types of hydrogen vehicle technologies. It is also an approach that places most of the burden of change onto vehicle manufacturers and purchasers, and very little on fuel producers and suppliers.

In contrast, direct hydrogen refuelling where hydrogen is produced off board the vehicle, would allow hydrogen vehicles to be developed that are simpler in design, less costly and more energy efficient (Ogden, 1999 and Thomas *et al*, 1998). In addition to this, it would allow the hydrogen to be made from many sources including in the long term renewable energy sources. This solution would ensure that vehicle manufacturers, fuel producers and suppliers take a shared responsibility in investing their time, expertise and resources in moving towards a zero emission road transport system.

If hydrogen is going to be put directly into vehicles there will need to be considerable advancements in hydrogen storage technologies. However, as mentioned earlier, concerns about hydrogen storage are not insurmountable. This is a view shared by Ford's TH!NK Group which was set up to develop cutting edge vehicles that are good for the environment. The

The 'well-to-wheels' greenhouse gas emissions for various fuel cell vehicles compared to the standard petrol vehicle

The rhetoric is that the only emissions created from driving a hydrogen fuel cell vehicle will be water. However, this only accounts for the emissions coming from the tailpipe of the vehicle. It is also important to conduct a 'well-to-wheels' analysis that accounts for the greenhouse gas emissions created throughout the life cycle of the fuel. This involves examining the environmental impacts not only of driving the fuel cell vehicle but also acquiring the raw material for the fuel and transporting and distributing it.

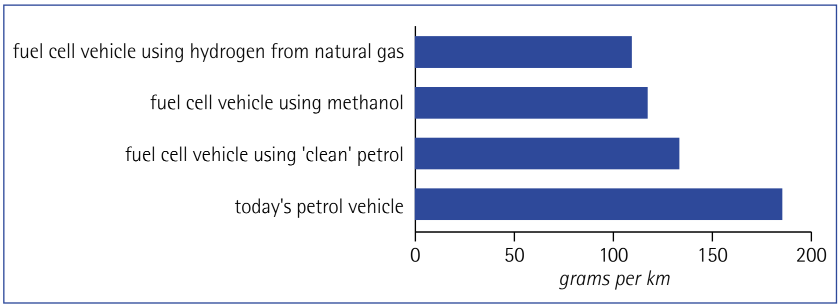


figure 5 greenhouse gas emissions from fuel cells

A recent well-to-wheels analysis conducted by Shell (Louis, 2001) found that all fuel cell vehicle options produce fewer greenhouse gas emissions* than the standard petrol car. Direct hydrogen refuelling, where the hydrogen is produced off board the vehicle from natural gas, showed the greatest reductions in greenhouse gas emissions. On board hydrogen production from methanol and petrol faired less well. Other studies come to similar conclusions (Hart and Bauen, 1998 and the Pembina Institute, 2000). Shell's study did not consider hydrogen produced from renewable energy sources. But it is worth noting that the well-to-wheel greenhouse gas emissions for renewable hydrogen would be close to zero.

** In Shell's analysis greenhouse gases include methane with a multiplication factor of 21 and carbon dioxide. Nitrous oxides were neglected because they only account for a small fraction of greenhouse gas emissions and because nitrous oxides from vehicles are largely unknown.*

TH!NK Group have already developed several prototype models of fuel cell vehicles run on direct hydrogen that have the same range as diesel engine vehicles (Ford, 2001).

If vehicles are able to store hydrogen on board, there is less justification for development of on board hydrogen production. Being too hasty in going down the pathway of on board hydrogen production could mean becoming stuck with hydrogen vehicle technologies that can only use fossil fuel based sources of hydrogen. There is only a limited amount of research and development that vehicle manufacturers will want to put into developing the hydrogen vehicle of the future. The more private sector investment that goes into developing hydrogen vehicles that produce hydrogen on board, the less that will probably be available for developing better hydrogen storage technologies. This could create larger barriers to direct hydrogen refuelling, which in the longer term could slow down or even block the transition to hydrogen produced from renewable energy sources.

Developing a hydrogen infrastructure—small is beautiful

An attractive stepping stone to renewable hydrogen production is to produce hydrogen off board the vehicle from natural gas. Natural gas is widely available in the UK. About 80 to 85 per cent of the population already has access to a natural gas connection. Also, natural gas generally offers the cheapest source of hydrogen and produces less CO_2 per unit of hydrogen compared to other fossil fuels like coal or oil. It is currently responsible for 48 per cent of the world's hydrogen production (Padro and Putsche, 1999) which is mostly produced in large, centralised plants. However, expanding large scale hydrogen production from natural gas would eventually require considerable infrastructure investments. Costs of tens to hundreds of millions of pounds have been quoted. Shell estimates that if hydrogen were to be sold at 25 per cent of UK retail sites it would cost US$1.5 billion [about £1 billion] (Huberts, 2001). From the point of view of energy and utility companies, some of whom are positioning themselves as future hydrogen fuel suppliers, investing in a totally new refuelling infrastructure would be high risk strategy. There is no guarantee that they would get a return on their investments if for some reason the hydrogen vehicle market did not take off.

This raises questions about what we mean by a hydrogen infrastructure and how we support it. If 'infrastructure' is perceived to mean massive investments in a hydrogen pipeline system then the costs of developing a hydrogen infrastructure will always be unacceptably high. As it turns out, a traditional refuelling infrastructure may not actually be the most appropriate way of supporting the widespread use of hydrogen vehicles.

Making hydrogen from natural gas without CO_2 emissions

Fuel suppliers are keen to explore the option of producing hydrogen from natural gas without CO_2 emissions through a process called 'CO_2 sequestration.' This involves storing CO_2 emissions in deep acquifers at depths of more than 800 metres under the ground. For example, in response to Norway's carbon tax on offshore activities, the Norwegian company Statoil separates CO_2 from natural gas coming from its Sleipner West field and injects it into an acquifer close to the site. The worldwide potential for CO_2 storage in such acquifers is thought to be thousands of gigatonnes. This sounds like a wonderful solution but there is still a question about who should take responsibility for monitoring acquifers in case there is leakage—fuel suppliers or governments? If there is a possibility that the CO_2 could leak out of acquifers in future years, we have to question whether it is socially just to impose our environmental costs on generations to come.

CO_2 sequestration is also likely to be expensive. Sequestering CO_2 emissions could add up to 25-30 per cent onto the costs of producing hydrogen from natural gas (Hart *et al*, 1999). The costs would still not be as much as producing hydrogen from electrolysis using renewable energy. However, without large scale investments in new pipelines there is simply no way of transporting the hydrogen from production facilities to local refuelling stations. The high costs of producing and transporting hydrogen from natural gas without the release of CO_2 emissions means that it is likely to have limited application in the short term.

Investments in small scale facilities for producing hydrogen from natural gas at local refuelling stations or depots could be the key to developing a hydrogen refuelling infrastructure. Some investment in technologies for producing and storing hydrogen from natural gas on site would have to be made by fuel suppliers. Nonetheless, allowing hydrogen to be produced at the same place as refuelling has the major advantage of avoiding any hydrogen transportation costs. In effect, it is using the existing natural gas pipeline as the backbone for hydrogen distribution. As long as there is access to a natural gas supply, hydrogen production and refuelling facilities could be sited virtually anywhere that is convenient—at existing petrol stations, car parks in shopping centres, near office buildings or even at the end of a residential street…the opportunities are endless. There would however be planning and safety issues to consider if such facilities were to become widespread.

There have been a several studies, mainly in the US, that have tried to assess the cost and feasibility of building a hydrogen infrastructure for vehicles. The most comprehensive of these was conducted by Directed Technologies Inc in 1997 and supported by Ford Motor Company and the US Department of Energy (US DoE). They all come to the same conclusion, that hydrogen can be delivered to vehicles cost effectively through the small scale production of hydrogen from natural gas at local refuelling stations or fleet operator depots. They show that the total capital infrastructure costs (on and off board the vehicle) are comparable and even less than those for producing hydrogen on board the vehicle from methanol or petrol. Directed Technologies Inc. cited long term infrastructure costs of US$230-380 [about £160-265] per vehicle for small scale hydrogen production from natural gas compared to US$630-1350 [about £440-945] per vehicle for on board hydrogen production from methanol (Thomas *et al*, 1997). This modelling has used assumptions that estimate supply and demand for hydrogen to follow each other fairly closely. Some argue that it may underestimate the lag between the investment in refuelling infrastructure and the uptake of hydrogen vehicles, or the chicken and egg problem. However, these results have been supported by the work of Joan Ogden and her colleagues at Princeton University which come to very similar cost estimations using different assumptions (Ogden *et al*, 1999).

For fuel suppliers, piggy backing the existing natural gas distribution system to produce hydrogen locally is likely to be an attractive option. This is because it would enable them to provide the facilities for producing and distributing hydrogen where and when it is needed, rather than having to provide a new infrastructure for the whole of the UK all in one go. Such an approach would allow a hydrogen refuelling infrastructure to be developed in a more incremental way reflecting the pace at which the hydrogen vehicle market grows. However, the experience of other cleaner fuelled vehicles shows that there would have to be significant coverage of refuelling facilities within a local or regional area before the public were inclined to buy hydrogen vehicles in large numbers.

The development of local hydrogen refuelling facilities that use natural gas fits in with the way in which the infrastructure for supporting CNG vehicles is likely to develop. As mentioned earlier the CNG vehicle market has not taken off in the UK partly because of the lack of an adequate refuelling infrastructure. Over the next 3 years, the DETR and the EST are proposing that the Powershift Programme be used to help remedy this through the development of a network of natural gas refuelling facilities (DETR, 2001). The Government's infrastructure investments to support CNG vehicles are likely to make the longer term transition to hydrogen vehicles easier. There is no reason why natural gas refuelling facilities could not be extended to allow hydrogen production from natural gas thus acting as a spring board for the introduction of hydrogen refuelling.

The longer term prospects for producing hydrogen from renewable energy sources

Natural gas currently fuels most of the UK's heating and cooking and requirements as well as being the fuel of choice for electricity generation. Natural gas is also likely to have greater usage as a vehicle fuel. If hydrogen is to be produced from natural gas at local refuelling facilities, this raises the obvious question of whether our economy would be relying too heavily on natural gas for its energy. There are enough natural gas reserves to meet all these demands, but it can only be a short to medium term fuel source. BP estimates that only 20 per cent of the world's natural gas supplies have been discovered (BP, 2000). Even though global natural gas reserves are abundant, they are not always located in the most convenient locations and much needs to be done to develop the products and transportation infrastructure to bring them to wider markets.

Whilst the UK currently has its own gas fields in the North Sea, eventually the majority of our supplies will come from Europe through the Interconnector pipeline to Belgium. However, this is likely to raise security of supply issues as much of the world's gas reserves are in the Middle East and former Soviet states with unstable regimes. It is also likely that the network would have to be extended to ensure nationwide coverage and in some areas systems might have to be upgraded to cope with the extra demand.

What is certain is that natural gas reserves will eventually run out. Also, as a fossil fuel its use will have climate change impacts. In the long term, only hydrogen from renewable sources of energy can offer a sustainable energy future. This is a view supported by Mark Moody-Stuart, Chair of Shell International, who describes hydrogen from renewables as 'clearly the best possible energy system—completely emission free and environmentally benign' (in ENDS, 2000a). Hydrogen can be produced by electrolysis using a diverse range of renewable energy sources including solar power, wind power, hydropower and geothermal power. It can also be produced directly from solar photoelectrolysis and biomass gasification. Sewage treatment gas and agricultural waste, for example, could be used for making hydrogen. Sewage produced in urban areas could provide a very suitable feedstock for hydrogen, given the majority of demand for transport fuel will also be urban.

Iceland—the world's first hydrogen transport economy based on renewable energy sources

In 1997, Iceland's Prime Minister announced that the Government was officially moving the country towards a hydrogen economy and that it would eliminate most of the nation's dependency on oil by 2030.

Compared to other nations, Iceland has been quite successful in transforming its economy into one based on renewable energy. Hydro and geothermal energy sources constitute about 68 per cent of the energy used in Iceland. No other country in the world uses as little fossil fuels for space heating and electricity generation. On the other hand, its car density is one of the highest in the world and investments in its fishing fleet have mainly been in energy intensive factory trawlers.

In February 1999, Icelandic New Energy Ltd was formed which is a coalition between Icelandic energy companies and major international companies like DaimlerChrysler, Shell International and Norsk Hydro. The coalition will test various applications for utilising hydrogen as an energy carrier. In January 2001, Iceland launched its draft sustainable development policy. It stated that by 2020, hydrogen would power 20 per cent of all vehicles and vessels in Iceland.

The abundance of hydro and geothermal energy in Iceland has given it a head start in moving towards a hydrogen economy based on renewable energy sources. For the UK, the transition will be slower. Natural gas offers a bridge, although the long term aim should be to maximise the use of wind and solar energy and biomass as sources of hydrogen. As Iceland faces the challenge of developing a hydrogen infrastructure based on renewable energy, the UK should watch and learn from its experiences.

Source: Dunn, 2000 and WWF, 2001

Hydrogen offers a good solution to the problem of intermittency of renewable energy. Renewable energy sources are subject to natural weather conditions, ie we have wind power when the wind blows. This can make it difficult to match electricity supply from wind, solar or wave power to demand. If there is no immediate need for the electricity produced from renewable sources then it goes to waste or has to be sold very cheaply to compete in the market. However, as an energy carrier, hydrogen offers a means of storing this energy and either converting it back to electricity when there is a high demand, or using it as a transport fuel.

The main barrier to renewable hydrogen production is simply the cost. The exception is hydrogen production from biomass. In most circumstances biomass can currently compete with small scale hydrogen production from natural gas on price. There therefore appears to be no reason why biomass could not lead the way for renewable hydrogen production.

Hydrogen production costs

Hydrogen source	*Cost in US$ per Gigajoule (GJ)*
Natural gas (small scale production)	11-12
Other fossil fuels such as coal and oil	10-12
Biomass (large scale production)	9-13
Hydroelectric power	10-20
Wind power	20-40
Solar power	50-100

Data source: Padro and Putsche, 1999. The hydrogen production costs are average costs based on a wide range of academic studies analysed by the US Department of Energy Laboratory.

The cost of renewable electricity has already fallen considerably over the last decade, so the costs of producing hydrogen from renewables is also likely to fall as the technologies mature. The Government has set a ten per cent target for renewable electricity by 2010 although there are doubts whether current policies will be able to deliver this target. Even if the UK does achieve its 10 per cent target, very little of this renewable electricity will be available for hydrogen production, but the costs will have been driven down in the process. Whilst achievement of this target would demonstrate the Government is taking renewable energy seriously, it would still leave the UK in third last position in the European renewable electricity league. This is because other European countries have set much higher targets. For example, France and Denmark plan to produce 21 per cent and 29 per cent of their electricity respectively from renewable energy by 2010 (ENDS, 2000b).

As discussed later in the report, it is not expected that significant demand for hydrogen in transport would start to occur until after 2010. The Government currently has no policy for renewable energy sources beyond 2010, although the Performance and Innovation Unit (PIU) in the Cabinet Office are currently developing a report to address this. If renewable hydrogen production is going to be an economically viable option, the Government should be setting more ambitious long term targets for renewable energy to address transport as well electricity needs. The potential growth of the hydrogen vehicle market should be considered as an important factor for post 2010 energy policy, adding even greater urgency to the acceleration of renewable energy into the market.

Sending the right signal to fuel suppliers

The Government should send a positive signal to fuel suppliers that its long term aim is to encourage the development of a hydrogen refuelling infrastructure supported by renewable energy sources. The Climate Change Levy, introduced in April 2001 as an energy tax on business consumers, provides a policy tool for doing this. The Climate Change Levy currently only taxes the users of energy and not the producers. Energy production industries therefore have no direct policy measures for addressing their CO_2 emissions.

In previous work, the IPPR has recommended that to rectify this, oil refinery and electricity generation industries should be obliged to pay the Climate Change Levy or take part in a compulsory emissions trading scheme (Hewett, 2000). Following the same argument, hydrogen production processes should also be subject to the Climate Change Levy. This would make fuel suppliers accountable for the energy they consume in making hydrogen from fossil fuels including natural gas. However, it would create an immediate incentive for renewably produced hydrogen as renewable energy sources have been exempted from the Climate Change Levy.

Joined up decentralised services

A distributed hydrogen refuelling infrastructure goes hand and hand with the way in which the energy sector as a whole appears to be evolving. There is increasing interest in decentralised electricity generation for providing services that are more efficient and reliable than the old system of large centralised power stations and long distance transmission of electricity to urban centres. This revolution, which is being driven by technological change, market liberalisation and environmental pressures, has seen the emergence of gas fired micro Combined Heat and Power (CHP) units, stationary fuel cells and renewable options like solar panels. The policy implications of decentralised energy services are the subject of another report in the IPPR's Low Carbon Initiative.

As stationary fuel cells come onto the marketplace, hydrogen could also be used as a fuel for powering homes and offices cleanly and efficiently. If this is the case, it seems sensible to look for links between the infrastructure for supporting the use of hydrogen in both mobile and stationary applications. Advantica Technologies are currently working with Alstom to develop a compact facility that uses natural gas for delivering hydrogen to fuel cells in both vehicles and buildings. A prototype is planned for 2005 with mass production in 2008 (Goulding *et al*, 2000). Other international companies, such as BP Amoco and Shell, and academic institutions, such as Warwick Manufacturing Group at Warwick University, have also developed similar prototype facilities. As technologies of this kind continue to develop, it will be important that policy makers recognise opportunities for tying together support for hydrogen fuel across the transport and energy markets.

What are the implications for policy makers?

The existence of the 'chicken and egg' situation is the core reason why Government intervention will be necessary to bring hydrogen vehicles into the mainstream. Whilst there are separate policies which Government could implement to stimulate the market for zero emission vehicles or facilitate the provision of hydrogen refuelling infrastructure, one could argue that given the right circumstances the private sector could deliver either of these without Government support. What is missing is the initial catalyst to get the market going in the first place. Government is uniquely placed to provide this by co-ordinating policies to ensure stimulation of the zero emission vehicle market and development of hydrogen refuelling infrastructure goes hand in hand.

The co-operation of fuel suppliers and vehicle manufacturers will also be essential to policy making. Moving from a petroleum to a hydrogen based road transport system will bring about fundamental change to the products, services and cultures of both these industries. Long term partnership working between government, business and the public will be the key to making this happen. Government should start this process by establishing a high level Hydrogen Task Force. It should be charged with developing a 10-Year Hydrogen Strategy to identify ways in which policy can support the development of a hydrogen refuelling infrastructure hand in hand with the creation of a market for zero emission vehicles. A 10-Year Hydrogen Strategy would signal the Government's long term commitment to securing the air quality and climate change benefits that hydrogen vehicles have the potential to achieve. At an international level it would put the UK on par with other developed nations who already have or are in the process of developing some kind of national hydrogen strategy. Raising awareness of the UK Government's interest in hydrogen would also give confidence to multinational vehicle manufacturers and energy companies seeking to develop the market in the UK.

If a genuine long term commitment to hydrogen is to be developed then membership of the Task Force will be crucial. As well as government and industry, representatives from academia, environmental pressure groups and motoring organisations should be invited to be full partners to avoid the Task Force being dominated by powerful vested interests. Their involvement would create greater transparency and ensure that consumers' interests are accounted for from the start. The Chair should be independent of government and any vested interest and the Task Force should report jointly to the Secretaries of State for Environment & Transport and Trade & Industry. As the 10-Year Strategy would have implications beyond one term of Parliament, the Task Force should also have cross party involvement. There is no reason why the development of a hydrogen transport economy should become an area of party political disagreement. Involvement of Conservative and Liberal Democrat representatives on the Task Force could help to embed its recommendations and give greater confidence to potential investors.

In the past, Governments have failed to reap the economic and environmental rewards of advancements in technology because they have failed to act early enough in developing policies to support them. The process of devising a 10-Year Hydrogen Strategy in partnership with industry experts would enable policy makers to develop policies that account for technological advancements.

Part of the reason why Government often seems so unresponsive to new technologies lies in the nature of traditional policy making which tends to occur in policy silos. As already mentioned, a number of multinational companies are close to commercialising a facility that will be able to meet the hydrogen refuelling requirements of both vehicles and buildings. This has implications for policy makers working on both energy and transport policy. Encouraging policy makers across Government departments to participate in the development of a 10-Year Hydrogen Strategy would help them to think outside their policy silos to devise joined up solutions.

The next section of this report highlights the key issues that this Strategy will have to address and suggests ideas for policies to stimulate the zero-emission vehicle market hand in hand with the development of a hydrogen refuelling infrastructure. Building on the arguments above, the IPPR believes that the ultimate goal is to develop a hydrogen based road transport system that maximises the environmental benefits for society in both the short and long term. In advising the Government on how it can support the development of a hydrogen refuelling infrastructure, the Task Force should take the following points into consideration:

- In the UK, natural gas offers the most cost and environmentally efficient means of producing hydrogen in the short to medium term. Natural gas is widely available and is the cleanest source of fossil fuel based hydrogen. However, Government will need to be careful not to stifle the market by making restrictions on hydrogen sources too onerous. In the earliest stages, hydrogen from any source may be necessary for helping to give confidence to consumers and investors.

- Government will need to make it clear to fuel suppliers that its long term aim is to move towards a hydrogen refuelling infrastructure supported by renewable energy sources. Incentives should be developed for encouraging fuel suppliers to investigate options for producing renewable hydrogen. Subjecting hydrogen production processes to the Climate Change Levy is an example of how Government could help to incentivise renewable hydrogen from the very start of the market's development.

- The capacity of renewable energy will need to be substantially improved if renewable hydrogen production is to become an economically viable option. Polices for promoting the growth of the hydrogen vehicle market should be linked directly to policies for promoting the growth of the renewable energy market, in the context of wider energy policy.

- Hydrogen will increasingly be used as a fuel for both mobile and stationary applications. Policies should seek to capitalise on the synergies between its use within the energy and transport markets.

Creating a market in hydrogen vehicles

In tandem with developing policies for supporting infrastructure, the 10-Year Hydrogen Strategy will also need to identify ways in which Government can help with the creation of a market for hydrogen vehicles. The market is likely to develop in three segments: buses, heavier duty fleet vehicles and private cars. The Government has a number of policy instruments at its disposal for stimulating the market, such as fuel duty, Vehicle Excise Duty (VED), the Company Car Taxation scheme, capital grants and infrastructure subsidies. The following discussion sets out how Government can use these tools most effectively.

Buses will come first

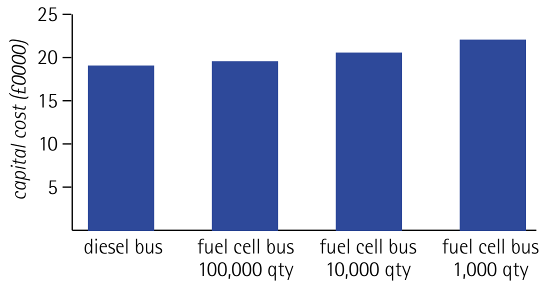
The first place in the transport system where hydrogen is likely to become a viable fuel will be the bus market. The necessity for zero emission vehicles and hydrogen infrastructure to be developed in tandem is perfectly illustrated by the bus market. For it is here that the refuelling infrastructure and vehicle owners are most closely linked. Ownership and control of buses and their depots is frequently down to one organisation, whether publicly or privately owned. Policy intervention for encouraging the development of hydrogen as a fuel is therefore easier and more direct for the bus market than the private car market.

Buses refuel at depots and have defined routes which therefore frees them from the requirement of an all encompassing, seamless refuelling network. Only a small number of refuelling stations at bus depots would be required to enable complete market coverage, far less than the number needed to meet the demands of the private car market. Small scale hydrogen production from natural gas would allow the development of hydrogen refuelling facilities at local bus depots to grow sporadically up and down the country. In this way, different localities would have greater flexibility in determining the pace at which they convert their local bus fleets to hydrogen.

From a technical point of view there are no 'show stoppers' to hydrogen buses. Buses have plenty of room for storing hydrogen tanks allowing them to be refuelled directly with hydrogen. Hydrogen buses are also likely to be popular with bus operators who may be forced to comply with more stringent local air quality and noise regulations in the future. The introduction of hydrogen buses would enable local bus operators to run both a quieter and pollution free service. The benefits to peoples' quality of life would be immediately noticeable particularly in busy urban areas. The main barrier will be the cost of a hydrogen bus. As with any new technology the costs will be initially high. The prototype hydrogen buses currently available are about five times the cost of a conventional equivalent. For example, DaimlerChrysler's prototype hydrogen fuel cell 'Citaro' bus costs £790,000 compared to £160,000 for the cost of its standard diesel Citaro bus (DaimlerChrysler, 2001). But as manufacturing volumes increase, the costs will come down. The best estimates predict that economies of scale could make hydrogen buses cost competitive with diesel buses by 2012 in developed countries allowing the market to take off (Hart *et al*, 2000, Mauro, 2001 and M J Bradley and Associates, 2001). However, they all assume that Governments will make some kind of provision for helping to initially kick start the hydrogen bus market to allow the economies of scale to take effect.

The take off of the hydrogen bus market

The predicted 2012 take off date for the hydrogen bus market is based on estimates for how the costs of hydrogen buses are likely to fall with manufacturing volume. Research conducted by Directed Technologies Inc. in the US found that once scales of production had reached 100,000 the cost of a hydrogen fuel cell bus would be comparable with that of a standard diesel bus (Thomas *et al*, 2000b). This kind of scale of production is likely to be relatively easy to achieve especially if one considers that Ballard, the world's leading fuel cell bus supplier, has a large scale production plant in San Diego coming on stream soon.



Data source: Thomas et al, 2001b. Capital costs are based on US diesel and hydrogen fuel cell bus prices which have been converted to pounds.

figure 6 hydrogen fuel cell bus costs

As costs converge the environmental advantages of hydrogen buses could ensure they become quickly established in the future UK bus market. This is a view shared by research undertaken by Imperial College in London which suggest that hydrogen fuel cell buses could make up two thirds of the total urban bus market in the UK by 2030 (Hart *et al*, 2000).

Hydrogen buses in North America and Europe

The suitability of hydrogen to the bus market has meant that interest in capturing their environmental benefits has accelerated in recent times particularly in North America. The California Fuel Cell Partnership was established to enable the authorities, energy companies and vehicle manufacturers to work together in testing and developing hydrogen vehicle technologies throughout the state (see box). As part of the California Fuel Cell Partnership, 20 hydrogen fuel cell buses will be placed in the Palm Springs and San Francisco Bay areas by 2003. The Californian authorities have also been keen to use regulatory drivers for spurring the development of the hydrogen bus market in the state. A Zero Emission Bus mandate, also known as the ZEBUS mandate, has been introduced. It requires that 15 per cent of all new bus purchases in California are for zero emission buses by 2008. This mandate does not specify hydrogen buses, but the hydrogen fuel cell bus is the most likely zero emission technology that will be available on the 2008 time scale.

In California it was recognised that it would be unreasonable to expect bus companies to buy hydrogen buses without offering them some kind of financial support. To help bus companies comply with the mandate the US DoE has agreed to meet 80 per cent of the capital cost of a new hydrogen bus. Given that the Californian bus market makes up a large proportion of the national bus market, it is thought that the mandate will have a significant impact on developing hydrogen buses across the US.

The ZEBUS mandate can be credited with driving much of the interest in hydrogen buses in North America. However, hydrogen bus manufacturers are also showing increasing interest in the potential European market. This was recently demonstrated by the launch of the European Union funded Clean Urban Transport in Europe (CUTE) project. The CUTE project is a collaboration between DaimlerChrysler and other companies that will see 30 hydrogen fuel cell buses trialled in cities throughout Europe including London. At the launch Wolfgang Diez of DaimlerChrysler said that

> *the sale of 30 fuel cell buses represents a successful market entry for this technology and proves the attractiveness of the fuel cell as an efficient and environmentally friendly power source for urban public transport.*

Each city will receive three DaimlerChrysler hydrogen fuel cell Citaro buses to be delivered at the end of 2002 and trialled until 2005. The total costs of the CUTE project (with bus and infrastructure costs included) will be in the region of £57 million.

The CUTE Hydrogen Fuel Cell Bus Project

Picture courtesy of DaimlerChrysler

The DaimlerChrysler 'Citaro' bus will have the fuel cell and the compressed hydrogen in gas bottles mounted on its roof giving it a range of 200-250 kilometres, the equivalent of any single deck diesel bus.

The cities participating in the CUTE project are: Amsterdam, Barcelona, Hamburg, London, Luxembourg, Porto, Stockholm, Stuttgart and Reykjavik. When the CUTE project had its London launch, Darren Johnson, Leader of the Green Group of the Greater London Authority (GLA) said:

> *If London is to be a clean and green city we need to improve air quality and reduce our CO_2 emissions in order to tackle climate change and provide a modern, state of the art public transport system. The introduction of hydrogen fuel cell buses would help us achieve all of these and I am confident the trial will prove a success* (TfL, 2001).

The various fuelling companies intend to try out different hydrogen sources in the different cities. 40 per cent will be produced from natural gas at local bus depots and a further 40 per cent will be produced through small scale electrolysis using renewable energy sources. For example, in Barcelona the fuel cell buses will be powered by hydrogen partly produced from solar power. Only 20 per cent of the hydrogen will be produced from crude oil.

What should Government do to support the hydrogen bus market?
It would be wrong to assume that the UK hydrogen bus market will simply take off and that Government just needs to sit back and watch. In California, the authorities have recognised the importance of using a mixture of carrots, such as capital grants for new hydrogen buses, and sticks, such as the ZEBUS mandate, for helping to kick start the market. Similarly, the UK will need to be proactive in developing policies for preparing the hydrogen bus market. Failing to do so could delay the predicted 2012 take off of the market which could result in the UK lagging behind other developed countries.

Grants and subsidies
To support the entry of the first hydrogen buses into the UK market, the Government should introduce a 'Hydrogen Shift' Capital Grant. The major barrier to purchasing a hydrogen bus in early years will be its high costs. A grant could help make up the difference in price of buying a hydrogen bus compared to a diesel bus. This would ensure that purchasing a hydrogen bus would not disadvantage the operators.

Government also has a role in helping to provide the infrastructure for the first hydrogen refuelling facilities at central bus depots. It could do this by establishing a national Hydrogen Infrastructure Fund that would offer a central pot of money that bus operators could bid for. A successful bid would be dependent on match funding from fuel suppliers who stand to also benefit from the subsidy, and who have the technical expertise for setting up hydrogen refuelling facilities. A further condition should be that some of the money is earmarked for training the staff responsible for refuelling and maintaining buses at depots in how to safely handle hydrogen. If there is more than one bus operator serving a local area, where possible they should be encouraged to prepare a joint bid for a central hydrogen refuelling depot that they would all have access to.

As argued earlier, the key is to provide co-ordinated Government support for purchase of the vehicles and provision of the refuelling infrastructure. Whilst we have described these two policy functions separately above, in the case of buses the two will almost certainly have to be fulfilled simultaneously. In practice, a local bus company is likely to form a partnership with a fuel provider so that they could then make a combined bid for Hydrogen Shift Capital Grants and Hydrogen Infrastructure Funds. It would therefore make sense for the two funding streams to be administered by the same body.

Over the next four to five years most of the hydrogen buses in use will be part of pilot schemes. As part of the CUTE Project three hydrogen buses will be trialled in London until 2005. In the Government's April 2001 budget it pledged to introduce further pilots (HM Treasury, 2001).

Mandates

In five years time, assuming the pilots prove to be successful, there is no technical reason why different local areas should not follow California's example and introduce ZEBUS mandates for helping to mainstream hydrogen buses. ZEBUS mandates would be best applied at the level of the LA rather than national Government. This is largely because bus operators tend to operate within a locally defined geographical boundary. LAs, perhaps in partnership with the Passenger Transport Authority (PTA), would therefore be best placed to negotiate a reasonable mandate with local bus operators and monitor their compliance.

LAs are under considerable pressure to meet the air quality objectives set out in the Government's Air Quality Strategy which requires them to continually review and assess their air quality. Yet, when it comes to reducing the air pollution from road traffic they are somewhat limited in how they can deliver central Government targets. LAs do not currently have the power to require that a specified proportion of all new buses operating in their area use zero emission, hydrogen fuel. Government would have to modify the Transport Act 2000 to give LAs in England and Wales this authority. The benefits of LAs introducing ZEBUS mandates would be twofold. It would not only help to meet local air quality targets but also national and international climate change targets.

London is in the unique position that the Mayor and the Greater London Authority (GLA) already have control over bus specifications. In contrast to the rest of the UK, the ability to specify cleaner fuels, such as hydrogen, for London's buses is in the power of the Mayor and the GLA and not the private bus companies. There is therefore nothing to stop the Mayor taking leadership in introducing a ZEBUS mandate in the capital. Later in 2001 the Mayor will be holding a Zero Emission Summit in which he is expected to reiterate his commitment to developing hydrogen as transport fuel.

The fleet market will follow

Policy makers should make developing the hydrogen bus market their top priority. However, the bus market is too small to help bring down the costs of hydrogen vehicle technologies on its own. Fleet vehicles present another market that policy makers should target, particularly heavier duty fleet vehicles like vans and coaches.

As with buses, heavier duty vehicles are more viable in the short to medium term as they have plenty space for storing large hydrogen tanks on board. For those heavier duty vehicles fleets that are *depot based*, policies for supporting the purchase of hydrogen vehicles and the provision of infrastructure could be designed in a similar way to buses. However, it is important that Government also seeks to support heavier duty vehicles that are *non-depot based*. This is because the refuelling infrastructure for supporting these vehicles could eventually be shared with hydrogen cars.

To help stimulate the fleet vehicle market, one option might be for the Government to establish a Hydrogen Fleet Promotion Scheme. Under this scheme the Government could seek to forge voluntary partnerships with companies owning large fleets of delivery vans or coaches. The Government could agree to provide infrastructure subsidies to companies that make a commitment to replace a proportion of their fleet with hydrogen vehicles. The partnerships could be developed as high profile commitments which companies could market as part of their Corporate Environmental Responsibility strategy. Companies could even have 'zero emission' painted on the sides of their vehicles. The involvement of several large companies in the scheme would help to raise public awareness about the environmental benefits of hydrogen vehicles.

Public authorities should lead by example and procure hydrogen vehicles where possible. For example, the Ministry of Defence has a large stock of vehicles used by the army would could benefit from high performance hydrogen trucks or vans. LAs also own a large vehicle fleet. It is estimated that LAs in England and Wales own approximately 100,000 vehicles, 40 per cent of which are heavier duty vehicles ranging from coaches, mini buses, ground maintenance trucks to refuse trucks (McMullan, 2001).

LAs also have a number of ways in which they can encourage private companies to replace some of their heavier duty fleet stock with hydrogen vehicles. For example, they could use their discretion to exempt hydrogen vehicles from night time delivery bans. According to Safeway, delivery curfews affect 51 per cent of their stores and reduces fuel economy by 10 per cent because deliveries have to be made during the busiest traffic times. Safeway estimates that its fleet could be 15 per cent smaller if it were not affected by delivery curfews (Timson, 2001). There is no reason why pollution free, quieter hydrogen vehicles should be subject to the same night time delivery bans as polluting, noisy diesel vehicles. Exemption from night time delivery bans would provide a clear business driver for large delivery companies to invest in hydrogen vehicles.

The private car market

Penetrating the private car market will require much longer term strategies. There is no consensus on when the hydrogen car market could take off. It could be up to 15 to 25 years away (Mauro, 2001 and MJ Bradley and Associates, 2001). When hydrogen vehicles come onto the market they will undoubtedly be more expensive to buy than their petrol and diesel counterparts. They are also likely to be less convenient to use because there will be fewer refuelling points available. Government will need to apply aggressive fiscal incentives to help develop the market. Company Car Tax and VED are the two policy levers currently available to help lower the costs of hydrogen vehicles.

The first way in which Government can help to bring forward the take off of the hydrogen car market is through the Company Car Tax regime. Company car fleets represent a large share of the private car market - 55 per cent of all new car sales are for company cars (HM Treasury, 2000). Under the recent reforms to Company Car Tax, rates are linked to the CO_2 emissions of the vehicle. Discounts are also given for the provision of CNG, LPG and hybrid vehicles. Introducing hydrogen vehicles will require bold incentives and the IPPR recommends exempting hydrogen cars from Company Car Tax to help encourage companies to develop long term strategies for purchasing hydrogen cars.

The Government has tried to encourage the use of cleaner vehicles through its reforms to VED. In Budget 2000, VED on new cars was altered so that the most polluting cars pay a higher rate. There will be four bands of VED for new cars based on CO_2 consumption, with the most CO_2 hungry cars paying £160 and the most efficient paying £90 (HM Treasury, 2000). Most other European countries have similar vehicle taxation but with a much wider differential between clean and polluting vehicles. The IPPR would recommend and hopes that by the time hydrogen vehicles enter the market, UK VED will have developed in this way. Having said that, hydrogen vehicles will not even be on this scale as they produce no CO_2 emissions from the tailpipe. It therefore seems reasonable to exempt hydrogen vehicles from paying VED.

Fuel Taxation

Fuel duty is often adjusted to help make cleaner fuels cheaper to buy at the pump. The classic example is unleaded petrol. Lowering fuel duty for unleaded petrol stimulated a rapid switch from leaded petrol by driver's whose cars could use it. Since coming into power the Labour Government has lowered rates of duty to help incentivise the latest cleaner fuels available on the market. In Budget 2001, the rate of duty on Ultra Low Sulphur Petrol (ULSP) was lowered to help give it an advantage over the price of conventional unleaded petrol. There will be a three pence per litre differential from mid June (2001?) (HM Treasury, 2001). Rates of duty on CNG and LPG have been cut in successive Budgets to create and maintain the differential between these cleaner gas fuels and petrol and diesel. In the 2001 Budget, the Government also pledged not to increase duty on LPG or CNG until 2004 at the earliest (HM Treasury, 2001).

When hydrogen becomes available it will be faced with stiff competition within an already crowded vehicle fuels market. To give an advantage to hydrogen vehicles, the Government should exempt hydrogen from fuel duty for a period sufficient to allow the market to develop. In the early stages of the market the loss of revenue to the Treasury would be negligible.

Zero fuel duty on hydrogen would help to:

- *Differentiate the price of hydrogen from unleaded petrol at the pump.*
  Table 1 presented earlier shows that the initial hydrogen production costs from natural gas range from 11 to 12 US$ per Gigajoule (GJ). This is about £8 per GJ. This of course would not be the retail price because some extra infrastructure costs would also have to be considered on the price of hydrogen when it was first introduced. Nonetheless, this compares well with price of petrol at the pump in the UK which is approximately £27 per GJ (Cracknell, 2001). Of this price about 76 per cent is fuel duty (EC, 2000). This suggests that zero fuel duty in the UK would have the potential to make the price of

hydrogen at the pump more competitive with the price of unleaded petrol and other conventional fuels.

- *Establish hydrogen as the 'cleanest' fuel on the market.*
  Hydrogen will be the only fuel that when used in a vehicle will create no polluting emissions whatsoever. Yet, when it comes onto the market, the average consumer may be confused about what is the difference between hydrogen and other cleaner fuels like CNG. Zero fuel duty on hydrogen would help to send a clear price signal to consumers that there is a link between hydrogen fuel and zero emission vehicles. In addition to public education about the air quality and climate change benefits of hydrogen fuel, zero fuel duty would help to make hydrogen the consumers' choice of fuel.

  This should be coupled with a simplification of fuel duty for other fuels, so that the level of duty is primarily linked to environmental impact. On that basis the IPPR would recommend that fuel duty on petrol and diesel should continue to increase gradually so that consumers are encouraged to buy only cleaner fuels.

The Government has already indicated that any pilots for hydrogen vehicles will be exempt from fuel duty (HM Treasury, 2001). To help give confidence to vehicle manufacturers and fuel suppliers that demand for hydrogen vehicles will be generated and sustained, the Government will need to make a longer term commitment to hydrogen. The Government should guarantee zero fuel duty on hydrogen over a 5-year term of parliament.

Governments can only be expected to stick to pledges that they make within their own term of parliament. In five years time, the hydrogen fuel market may still be dependent on whatever Government is in power to maintain a price differential between hydrogen and unleaded petrol and other cleaner fuels. This clearly indicates the importance of cross party commitment to mainstreaming hydrogen as a transport fuel. This kind of political commitment could be reached as part of the process of developing a 10-Year Hydrogen Strategy which has the involvement of the main political parties.

How would zero fuel duty benefit bus operators?

A bus purchaser, in contrast to a car purchaser, is more likely to take into account not only the capital cost of buying a bus but also the running costs over its lifetime. Hydrogen fuel cell buses will be much more fuel efficient than their diesel counterparts. If, in addition to this, hydrogen were exempted from fuel duty then bus operators would stand to make significant savings on the running costs of a hydrogen bus compared to a diesel bus. The average replacement age of a diesel bus is eight years. Under the IPPR's proposals, bus operators would be guaranteed zero fuel duty on hydrogen for a five year term of Parliament. It is unlikely that any following Government would radically alter fuel duty on hydrogen especially if some kind of cross party commitment to hydrogen is reached. A combination of both Hydrogen Shift Capital Grants and the expectation of zero fuel duty on hydrogen throughout the lifetime of the bus would make a strong business case for bus operators to switch to hydrogen.

A significant problem is that bus operators currently receive an 80 per cent rebate on diesel duty which last year was worth £330 million (DETR, 2000a). The rebate was introduced to help incentivise public transport over personal motoring and make it cheaper to run buses. However, without reform of this rebate, the fuel duty savings of converting to a hydrogen bus would be negated. In other research on buses the IPPR has advocated replacing the fuel duty rebate for buses with a mileage subsidy (Grayling, 2001). This would allow the Government to continue to subsidise bus services but in a way that equally benefits all types cleaner fuels including hydrogen.

What are the implications for the future of the Powershift Programme?

Since 1996, the Powershift Programme has developed considerable skills and networks for encouraging the take up of cleaner fuel vehicles. It has been so successful in mainstreaming LPG vehicles that the market can now virtually sustain itself. An increasing number of LPG vehicles are being purchased without any form of subsidy and it is expected that by the end of 2001 there will be over 1000 refuelling points available (DETR, 2001). The Powershift Programme therefore has all the necessary experience for helping to create a market in hydrogen vehicles and encourage it to eventually become self-sustaining. Through its support of LPG and CNG vehicles, the Powershift Programme has also developed strong networks with bus operators and fleet vehicle companies. This will be important given that most of Government funds for the purchase of hydrogen vehicles and the provision of hydrogen infrastructure will be targeted towards heavier duty vehicles in the early stages of the market's development.

The Powershift Programme is currently consulting on how best to use the £30 million it has been allocated over the next 3 financial years. It has been proposed that much of this money should go towards supporting the development of the CNG market, particularly in terms of developing a network of natural gas refuelling facilities (DETR, 2001). The IPPR would argue that the Powershift Programme should view its support of the CNG market as part of a longer term transition to the hydrogen vehicle market. As mentioned earlier in the report, there is no reason why natural gas refuelling facilities could not be later extended to allow hydrogen production from natural gas. However, the IPPR would argue that in the longer term Government money is best used to support hydrogen as the cleanest vehicle fuel on the market.

Once this round of funding ends in April 2004, the IPPR recommends that the Powershift Programme be given further funds for developing the hydrogen vehicle market. The provision of capital grants and infrastructure funds are likely to be critical around this time, particularly for kick starting the hydrogen bus market. They are also likely to be essential if LAs are given the power to impose ZEBUS mandates, which IPPR has recommended could be introduced post 2005.

In the mean time, some of the £30 million should be spent on pilot projects for testing and developing hydrogen vehicle technologies. The Powershift Programme is already supporting a hydrogen van pilot with Westminster City Council. Other ideas for pilot projects are discussed later. The Powershift Programme should also run hydrogen education workshops for bus operators, fleet managers and LAs officials as their willingness to support hydrogen vehicle technologies will underpin the market's preparation. For LAs there could be particular planning and safety issues to consider regarding the building of hydrogen refuelling facilities. The Powershift Programme could help to work through these issues with LAs at an early stage, to prevent any planning barriers blocking the take off the hydrogen vehicle market.

Hydrogen safety and standards

Every fuel has the potential to cause an accident—if it did not burn, it would not be much use as a fuel. What is important to realise is that hydrogen is no more dangerous than other fuels. Hydrogen was routinely used up until the 1970s as a key component of 'town gas' or coal gas that was prevalent before the introduction of natural gas networks. Up to 70 per cent of this fuel was made up of hydrogen and its widespread use was not considered to pose particular hazards (Hart *et al*, 2000).

Hydrogen has quite distinctive physical properties. In the event of a leak, hydrogen will quickly rise and disperse into the atmosphere rather than form a puddle on the ground. However, hydrogen also has its downsides. Its low ignition temperature and flammability means that leaks, particularly in enclosed spaces like a garage, could present serious fire hazards. It is also odourless and colourless which means that any leaks are more likely to go undetected than leaks of petrol or other fuels.

Comparison of hydrogen and other fuels

	Hydrogen gas	*Natural gas*	*Petrol*
Auto-ignition temperature (^{0}C)	585	540	228-501
Flame temperature (^{0}C)	2045	1875	2200
Limits of flammability in the air (vol %)	4-75	5.3-15	1.0-7.6
Minimum ignition energy (mJ)	20	290	240
Theoretical explosive energy (TNT/m3 gas)	2.02	7.03	44.22

Data source: Hart et al, 1999

Hydrogen is simply different from other fuels, and so will require new safety standards and handling procedures. Standards for storing hydrogen safely on board vehicles are already being developed internationally within the International Standards Organisation (ISO) through its hydrogen standards working group ISO TC197.

It is also important to standardise the design and safety requirements of hydrogen refuelling facilities to ensure both near term needs and to facilitate and sustain the long term development of infrastructure. The EU is currently conducting the European Integrated Hydrogen Project (EIHP) for harmonising standards, codes of practice and filling procedures for refuelling stations. The project has a budget of 4.9 Million Euros and has 20 industrial partners (EIHP, 2000). It has been co-ordinating its activities with the ISO TC197 working group in attempt to harmonise refuelling standards not only within Europe but also internationally.

So far the Government has had limited involvement in both the ISO TC197 working group and the EIHP Project. The Government should send representatives to participate in the development of standards within Europe and internationally. This would help to ensure that the UK adopts standards that are either the same or complimentary to those being developed at the European and international level. The officials participating in the ISO TC191 working group and the EIHP Project could provide regular feedback to the Hydrogen Task Force so that the proceedings are incorporated into the development of the 10 Year Hydrogen Strategy.

Public acceptance of hydrogen

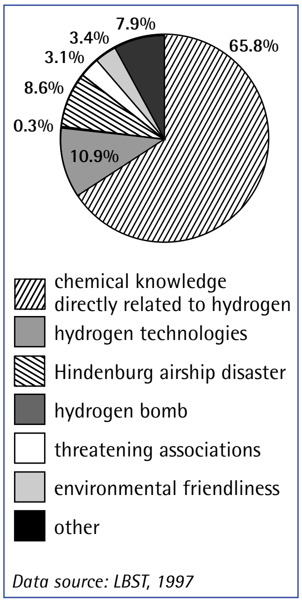


figure 8 associations with hydrogen

Even today the media mentions the 1937 Hindenburg airship disaster when reporting about hydrogen technologies. There have been very few surveys of the public acceptance of hydrogen technologies and none have been conducted in the UK. However, they all refute the idea that people only associate hydrogen with the Hindenburg airship disaster.

For example, in 1997 Ludwig-Bolkow-Systemtechnik (LBST) carried out a study to determine the level of acceptance for hydrogen technologies amongst students in Munich. It revealed that only 0.3 per cent explicitly mentioned the Hindenburg disaster when asked what they associated with the term 'hydrogen.' However, it also found that the students generally linked hydrogen to negative, threatening situations. Nearly 8 per cent associated hydrogen with bombs and nearly 11 per cent thought that hydrogen technologies were dangerous. Positive references to the air quality and climate change benefits of using hydrogen technologies were barely mentioned. For example, very few students were aware that driving a hydrogen vehicle would create no polluting emissions.

What this survey and others suggest is that Government needs to be proactive in dispelling any myths about hydrogen safety and raising awareness about the environmental benefits of using hydrogen vehicles. This is because if people perceive hydrogen to be dangerous with no positive attributes then they will not buy hydrogen vehicles and could oppose the development of hydrogen refuelling facilities near populated areas. Public education will therefore be essential to mainstreaming hydrogen vehicles.

Hydrogen education and awareness raising

In the US, the DoE has established a programme of outreach activities to 'promote and educate the public, decision makers and business leaders about the opportunities and progress towards the establishment of an energy infrastructure with hydrogen as a clean, safe fuel' (US DoE, 1998). The UK Government should follow the US example and establish a national Hydrogen Outreach Programme for educating people about hydrogen safety and raising awareness of its environmental benefits.

Highlighting the environmental benefits of hydrogen vehicles will be critical to building public support for any policies that are developed. Too often Governments devise policies for protecting the environment but do not explain to the voting public the reason why they were introduced in the first place. The recent fuel tax protests exemplify this. Many people did not make the link between higher fuel prices and reduced traffic pollution because the Government failed to explain the environmental rationale behind its policy. An important aspect of the Programme should be to raise awareness of the environmental benefits of hydrogen vehicles so that people understand the value of pursuing policies that support their use.

The Programme should be integral to the 10 Year Hydrogen Strategy. This would help to ensure that as local refuelling infrastructure starts to be developed, any concerns that local people might have about hydrogen safety are dealt with at the same time. The Programme's remit should not just focus on the use of hydrogen fuel in vehicles since, as already mentioned, it is likely to be also used as a fuel for powering homes and offices. Where possible the Programme's activities should be delivered in conjunction with other Government led education initiatives for promoting, for example, renewable energy. This would help to raise public awareness that hydrogen is part of a wider agenda for moving towards a sustainable, renewable energy based society. Some of the Programme's activities could also be delivered through the Government's new Carbon Trust, which has a substantial annual budget of £150 million for promoting and accelerating the take up of low carbon technologies.

Within society, environmental organisations have become important as awareness raisers and acted as 'environmental educators.' The direct action of such organisations has proven in the past to be influential in shaping the public and media perception of an issue, particularly when there is a low level of knowledge about it.

Whilst there is a situation of little public understanding and awareness about hydrogen, Government, environmental and business organisations will all be seeking to achieve the same end—to reassure the public about its safety as a fuel and to highlight the environmental benefits of its use. The 10-Year Strategy provides a framework for taking the unusual step of co-ordinating some of the hydrogen outreach activities of Government, environmental and business organisations. To see such uncommon bedfellows working in partnership to deliver a Hydrogen Outreach Programme would provide a great deal of both market and public confidence in mainstreaming hydrogen as a fuel.

The Hydrogen Outreach Programme might include:

- *Hydrogen vehicle pilots*
  Pilots provide people with first hand experience of what it is like to ride in a hydrogen vehicle. In Germany, Canada and the USA hydrogen bus pilots have proved to be an effective way of gaining public acceptance of the use of hydrogen as a vehicle fuel. There have been very few pilots in the UK so far, although there are plenty of opportunities for more. Hydrogen buses could be piloted as part of airport or school bus services. Taxis are also ideal vehicles for demonstrating hydrogen technologies because they are used by a wide cross section of the public. Imperial College in London is currently examining the feasibility of using London's taxis to pilot hydrogen vehicle technologies.

  In addition, hydrogen vehicles could be piloted within specific areas. An obvious place to pilot hydrogen vehicles would be within Clear Zone areas. This is because the Government established the Clear Zones Initiative to specifically encourage the innovative use of technology to reduce pollution in urban centres (Clear Zones, 2001). Also, LAs are showing increasing interest in introducing Low Emission Zones (LEZs) that admit or exclude vehicles on the basis of their emissions characteristics (NSCA, 2001). If LAs choose to adopt LEZs, hydrogen vehicles could be piloted within these zones.

- *Hydrogen information initiatives*
  The internet provides an interactive way of learning that virtually everyone now has access to. There are already a number of international hydrogen websites. The UK Hydrogen Energy Network (H2NET) was recently established as a joint collaboration between industry and academia for providing a forum for the discussion of research and information about hydrogen events. However, the HYNET website is mainly aimed at professionals. The Government could co-ordinate a website aimed at the general public that could provide an introduction to hydrogen technologies and signpost other useful sites. Another way of raising awareness about hydrogen technologies is through high profile exhibitions at museums or city centres where vehicle manufacturers, energy companies and hydrogen associations could sponsor displays.

- *Hydrogen education classes*
  Lessons about the use of hydrogen as a zero emission fuel should be incorporated into the national curriculum. Schools are already encouraged to teach their students about sustainable development, climate change, renewable energy and environmental responsibility as part of their geography or citizenship classes. Students could also be taught about hydrogen energy and how it could power future vehicles, homes and offices in an environmentally sustainable way.

- Hydrogen competition for graduates
  Most engineering graduate courses do not teach about non petroleum based power systems. Mark Meltser of General Motors (2001) has warned that there is 'a black hole in knowledge about fuel cell propulsion systems and that engineering students will need to learn new skills in electrochemicals and computer science.' To help tackle this skills shortage the US DoE, Ford Motor Company, General Motors and DaimlerChrysler has teamed up with 15 universities in the US and Canada to run the Future Truck competition. The competition challenges students to build green and efficient trucks using parts that the vehicle manufacturers have donated. The sponsor companies also provide training and support for the students involved in the project. Last year, all the finalists were offered graduate training placements with at least one of the vehicle manufacturers. There is no

reason why the Future Truck project could not also be run in the UK in association with leading engineering colleges and universities. Such a competition could help to inspire engineering students to develop the kinds of cutting edge skills required in a future hydrogen transport economy.

Hydrogen research

Many developed countries have Government led hydrogen research funds, such as Japan, Canada, Germany and the US. The UK does not currently have any dedicated research on the potential role for hydrogen technologies. The Department of Trade and Industry (DTI) is currently running a Renewable Energy Programme for improving the competitiveness of new renewable energy. Amongst other things it is looking to support research projects on fuel cells, although it is not specifically looking at hydrogen. There is therefore a strong case for arguing that a separate programme should be created for hydrogen research.

A forthcoming report by the Defence Evaluation Research Agency (DERA) argues that a co-ordinated, long term, strategic research effort is required to realise the significant potential of hydrogen energy (Lakeman and Browning, 2001). The IPPR would reiterate the need for a Government led Hydrogen Research Programme. The programme could be run alongside the development of a 10 Year Hydrogen Strategy so that the findings from the programme are fed directly into policy making. The programme should support projects for designing and testing new hydrogen technologies. But, it should also set aside money for blue skies research by academia for helping to develop the UK into a hub for new and innovative hydrogen research. Some money for supporting hydrogen research and development projects could be sought from the Carbon Trust.

It is also important that the Government participates in international research projects. For example, the International Environment Agency (IEA) is responsible for administering the Hydrogen Implementing Agreement. The Agreement is intended to promote technical exchanges between member countries and encourage joint research projects (IEA, 2001). Collaborating in international projects, such as those administered by the IEA, would enable the UK to tap into the learning of other countries and avoid any duplication in research.

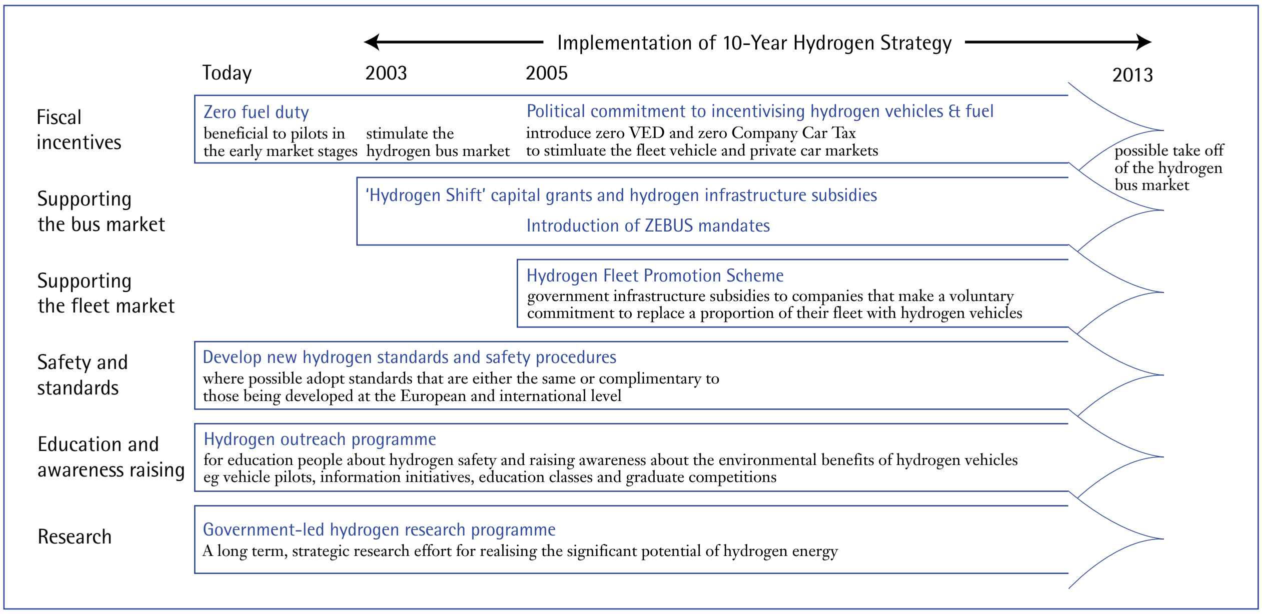


figure 9 what a 10-year Hydrogen Strategy could achieve

Some final comments

Hydrogen has emerged as the most credible transport fuel that can simultaneously improve local air quality, tackle climate change, lower noise pollution and reduce our dependency on oil, wins hands down. Yet the policy community in the UK has been slow so far to latch onto the benefits of hydrogen vehicles. Meanwhile, other developed countries are already piloting hydrogen vehicles and have developed national strategies to support their widespread use.

Government intervention will be pivotal to the introduction of hydrogen vehicle technologies in terms of helping to both develop a hydrogen infrastructure and create a market in hydrogen vehicles. Developing a 10-Year Hydrogen Strategy would signal the Government's long term commitment to developing hydrogen as a transport fuel and give confidence to investors. However, the development of a zero emission transport economy cannot occur without the co-operation of fuel suppliers and vehicle manufacturers as it will require fundamental change to their products, services and cultures. The transition to hydrogen vehicles therefore cannot occur overnight but is likely to occur in stages. The bus market is most likely to develop first, and it is here that Government provision of capital grants and infrastructure subsidies will be most useful in helping to kick start the market and drive down the costs of new hydrogen technologies. Government support for fleet vehicles would also help develop the hydrogen vehicle market as a whole.

However, if hydrogen is to eventually penetrate the mass private car market then public acceptance of hydrogen vehicle technologies is needed. As is often said in California, 'you cannot mandate people to buy hydrogen vehicles.' Outreach activities for educating people about hydrogen safety and the environmental benefits of hydrogen vehicles will therefore be critical to the success of hydrogen vehicles.

Government also has an important role to play in ensuring that fuel suppliers opt for the cleanest methods of producing hydrogen. In the long term, only hydrogen from renewable energy sources can maximise the air quality and climate change benefits that hydrogen vehicle technologies have to offer. If renewable hydrogen is to be an economically viable option then considerable more Government investment and planning will need to go into accelerating the take up of renewable energy.

Radical changes in transport and energy consumption will be required to prevent dangerous climate change. The development of a hydrogen transport economy will be one of those changes. It will not happen overnight. It is unlikely to happen without Government intervention. But the quicker policy makers start to plan for the transition, the sooner the emissions reductions can be delivered.

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