
The Practicalities of Developing Renewable Energy

The Society's submission to the Lords S&T Select Committee was based upon the following Society view of some of the issues involved

The Royal Society of Chemistry (RSC) welcomes the opportunity to comment on the practical steps that are needed to achieve a move towards renewable energy sources at the rate proposed in the recent White Paper. In response, we submit a report entitled *Hydrogen – the fuel of the future* which was produced by the RSC based on one of the *Fuelling the Future* workshops held in January 2002. These workshops were part-sponsored by the Foresight programme of the Office of Science and Technology, within the Department of Trade and Industry to explore the future of energy supply in the UK.

Hydrogen is increasingly promoted as one of the solutions of the world's energy problems. Key drivers for a hydrogen economy are its potential

- to ensure a security of energy supply
- to reduce CO₂ emissions and improve local air quality

The report focuses on the potential benefits of a hydrogen economy and goes on to detail the problems and solutions with regard to generating hydrogen and overcoming storage and transport issues. Finally, it addresses some key considerations for moving the UK towards a hydrogen economy.

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Foresight Fuelling the Future Workshops

Hydrogen – the fuel of the future

This document is based on a meeting that took place at the DTI conference centre in London on 9 January 2002, where attendees discussed some of the key issues surrounding the widespread adoption of hydrogen as an energy source. The meeting was the second in a series of three workshops organised by the Royal Society of Chemistry, the Institute of Physics and the Institute of Biology, looking at the future of energy supply in the UK.

Introduction

Access to a regularly available supply of energy is taken for granted in the developed world. Indeed, it is the central foundation on which the developed world was built. We rely on a continuous supply of energy to heat our homes, cook our food, power our cars and deliver our entertainment. Unfortunately, this foundation is not as stable as we would like to think.

For throughout the developed world, including the UK, the vast majority of our energy is derived from fossil fuels, in the form of oil, coal and gas. And, for a number of reasons, we cannot rely on fossil fuels to provide our energy for very much longer.

Perhaps the most fundamental problem with fossil fuels is that their supply is finite. Although the timing varies for different types of fossil fuel, eventually all of them will run out – or, more precisely, the remaining reserves will become increasingly expensive to extract. The most pressing concern is oil, with many commentators now predicting that the global supply of oil will peak within this decade, and then go into inexorable decline. However, demand for oil looks set to carry on increasing, which will lead to a growing short fall in oil supply. The UK fuel protests in September 2000 showed how quickly a developed country can be brought to a standstill without regular supplies of oil. That could be just a taster for what is to come.

The burning of fossil fuels to provide power is also the prime contributor to global warming, through the production of carbon dioxide. The UK, along with many other developed countries, has committed to reducing its carbon dioxide emissions under the Kyoto Protocol. It now looks as though the UK will meet its initial commitment of reducing its greenhouse gas emissions (including carbon dioxide) by 12.5 per cent below 1990 levels by 2012, but the present government has also set itself the domestic goal of a 20 per cent reduction in carbon dioxide emissions below 1990 levels by 2010. In addition, the Royal Commission on Environmental Pollution has suggested that the UK should reduce its carbon dioxide

emissions by 60 per cent by 2050. If all this is to be achieved, it will require a drastic lessening in the UK's reliance on fossil fuels.

Lastly, there is growing concern about the security of the UK's future energy supply. For the past 20 years, largely thanks to North Sea oil and gas, the UK has been fairly self-sufficient in terms of energy. However, the government predicts that by 2007 the UK will have become a net importer of oil and that it will have increased its net imports of gas from a current level of 2 per cent to around 15 per cent. Unfortunately, these imports of oil and gas will increasingly have to come from unstable areas, such as Russia and the Middle East.

For these reasons we need to consider alternative sources of energy, and one of the most attractive options is hydrogen.

The hydrogen economy

Although hydrogen can be burnt to produce energy, its candidacy as the basis for a new energy source is based upon its use in fuel cells. These devices, the original idea for which was developed by the nineteenth century Welsh physicist William Grove, produce electricity via the reaction of hydrogen and oxygen (usually derived from the air), producing water as the only by-product. Fuel cells consist of two electrodes separated by a liquid or solid electrolyte. At the anode hydrogen is split into protons and electrons; the electrons travel to an external circuit, providing the power, and the protons travel to the cathode, combining with the oxygen to produce water.

The theory is deceptively simple, but it has taken years to develop fuel cells that are commercially viable. There are currently five different types of fuel cell – alkaline cells, phosphoric acid cells, molten carbonate cells, solid oxide cells and polymer electrolyte membrane (PEM) cells. They all work in the same basic manner, and mostly differ in the type of electrolyte that is used. PEM cells have received the most attention over the past few years, because they work at fairly low temperatures and have a high power density. Much of this attention has been paid by car manufacturers.

It is in transport that fuel cells seem set to make the most impact, having the potential to overturn our century-long reliance on oil as the main transport fuel. Most vehicle manufacturers are already developing fuel-cell powered vehicles and recently a number of manufacturers, such as General Motors, unveiled the first prototype models. The most advanced fuel cells are now more energy efficient than diesel engines: a fuel cell can convert 60 per cent of its fuel supply to useable energy, while a diesel engine can only manage around 40 per cent.

However, the long-term potential of fuel cells goes beyond transport, for electricity is already the main energy carrier in the developed world and anything that is currently powered by electricity could theoretically have that electricity provided by a hydrogen-based fuel cell. For instance, many homes in the UK already have a supply of natural gas for cooking and heating. Natural gas can also act as a source of hydrogen, which could be used in home-based fuel cells to generate both electricity and heat. This kind of hydrogen-based energy infrastructure has been termed the hydrogen economy and it could be part of the long-term answer to humanity's energy supply problems (see Fig 1 for a diagram of a fully-integrated hydrogen economy).

Problems and solutions

'It is only kinetics that stops us achieving higher efficiencies in fuel cells, not thermodynamics'.

There are a great many challenging problems to be overcome before such a hydrogen economy can become a reality. Now that fuel cells are close to becoming commercially-viable, the most pressing scientific challenges revolve around where the hydrogen is going to come from and how it can be stored and transported (although there are still problems to be solved in developing a cost-effective manufacturing technology for fuel cells).

Unlike fossil fuels, there are no huge reserves of naturally occurring hydrogen, it needs to be generated from some other compound or material. Hydrogen is an energy carrier (like electricity), rather than a primary energy source (like oil), and generating it represents one of the most fundamental scientific problems facing the hydrogen economy. Hydrogen can be produced in a number of different ways, but all of them require the input of energy, such as electricity or heat.

One option is to generate hydrogen from fossil fuels. The hydrogen can either be produced at a central refinery, via processes such as steam or autothermal reforming, or at the point of use, in fuel cells with on-board reformers that can run on petrol, methanol or natural gas. The problem with this option is that it still relies on fossil fuels and the processes involved would still generate carbon dioxide.

Hydrogen is already produced as a by-product in some industrial process, such as the manufacture of chloralkali, and this hydrogen would be available for no extra outlay of energy. But this route could only ever supply a small fraction of the total amount of hydrogen required.

The most straightforward way to generate hydrogen is via the electrolysis of water. This basically works in the opposite way to a fuel cell, whereby electricity is used to split water into oxygen and hydrogen. But if hydrogen generated in this way is used to power a fuel cell, then

this creates the seemingly nonsensical system of electricity being used to produce hydrogen to generate electricity. Nevertheless, this could still be attractive if transporting energy in the form of hydrogen can be made more efficient than transporting it as electricity through pylons (where a lot of the energy can be lost). Improving the energy efficiency of both water electrolysis and fuel cells would go a long way towards increasing the attractiveness of this proposition. In addition, generating hydrogen in this way would be desirable if it is used to power a vehicle and if the electricity comes from a non-fossil fuel source, such as nuclear power or renewables (wind, wave, solar etc).

Such a system would not be the most energy-efficient in absolute terms, but, if powered by renewables, it would be based on an energy source that is not going to run out, is non-polluting and is fairly secure. Generating hydrogen from renewable energy via water electrolysis is therefore the long-term aim. Indeed, hydrogen could help to solve the problem of intermittency in renewables by acting as a storage medium. On windless or cloudy days, or just when electricity demand outstrips supply, excess demand could be met by hydrogen-powered fuel cells. At the moment, however, there is not enough renewable energy capacity in the UK to make producing hydrogen in this way a realistic proposition (in 2000, renewable energy accounted for only 2.8 per cent of the UK's electricity generation).

'If one could crack the problem of the storage of hydrogen in solids then there would be an overnight revolution.'

Once the hydrogen has been produced, the next problem is how to store and transport it. There are a number of ways that hydrogen can be stored, for instance as a liquid, a compressed gas, as a hydride, in glass microspheres or adsorbed onto a material such as carbon black. But there are problems with all of these methods, and these problems are compounded when considering hydrogen transportation.

The most fundamental problem is that of energy density, getting enough molecules of hydrogen in a small enough space – current petrol cars can travel around 600km on a 50 litre tank of petrol, to travel as far using a fuel cell-powered vehicle running on compressed hydrogen gas would require a pressurised tank able to hold 180 litres of hydrogen. What's more, hydrogen gas is potentially explosive; but then so is petrol. Despite its reputation, hydrogen is at least as safe as other fuels.

Hydrogen would take up less space as a liquid, but this requires extremely low temperatures. Research into the use of hydrides and other compounds as storage mediums is at a fairly early stage and there are a number of major problems that need to be overcome in terms of storage capacity and reversability of the adsorption process. The many difficulties inherent in this area are demonstrated by the fact that one much-trumpeted possibility, the trapping of

hydrogen within carbon nanotubes, has failed to live up to its early promise. These problems suggest that the first versions of the hydrogen economy may need to store and transport hydrogen as part of another chemical compound such as methane or methanol.

The issue of storage and transportation is also at the heart of a more prosaic problem with the development of a hydrogen economy: how to set up the necessary supply infrastructure. For fuel cell-powered vehicles to become a regular sight on our roads, there will need to be places where they can re-fuel. But without fuel cell-powered cars on the roads, fuel companies are reluctant to invest in developing the necessary re-fuelling infrastructure. It's a chicken and egg problem. And it's only going to be overcome with the right commercial incentives.

'Hydrogen and fuel cells are a disruptive development ... the previous [fossil fuel] infrastructure is long established. Developing a hydrogen economy will require society to overcome the barriers and mobilise private investment.'

Towards a hydrogen economy

A great deal more scientific research is needed to understand the best way to implement a hydrogen economy. In particular, research needs to be done into developing new and more efficient ways to generate, store and transport hydrogen. To this end, the UK government needs to encourage a massive increase in investment, both public and private, in developing the hydrogen economy (the UK government currently spends around £18 million a year on renewable energy research). Along with this increased funding, the UK research councils will need to co-ordinate and focus their research activities in this area; this co-ordination should be between each of the councils, as well as with the private sector and other countries. There is no point in UK researchers simply duplicating work being performed elsewhere.

This type of hydrogen programme has already been successfully introduced in other countries. For instance, the Canadian government has spent C\$160m over the past 10 years developing a hydrogen and fuel cell programme, and in doing so has mobilised several billion dollars worth of private investment into Canadian fuel cell companies.

A coherent policy framework for renewables, which includes a firm provision for developing 'hydrogen technologies', needs to be established by the UK government. An aggressive policy on emission regulations, such as the zero emissions mandate recently introduced in California, should form the central tenet of any framework. Such a policy would help to guarantee a future market for hydrogen and fuel cells, and would encourage private companies to invest the huge amounts of money that will be needed to set up the necessary refuelling infrastructure. This would then have a beneficial knock-on effect on the

development of a full-scale hydrogen economy, encompassing stationary and transport energy.

Although installing the necessary supply infrastructure will be expensive, the long term cost to the UK of developing a hydrogen economy should be far less than the cost of the current reliance on fossil fuels (if all costs, such as the environmental and health costs of using fossil fuels, are taken into account). On long enough timescales the hydrogen economy should become economically competitive.

Nevertheless, there is still a great deal of debate about exactly how to go about establishing a hydrogen economy. Whether it should involve a number of intermediate steps, such as initially producing the hydrogen from natural gas or methanol, which would be easier to store and transport, or whether to bite the bullet and look at switching directly from fossil fuels to hydrogen. The rate at which new hydrogen technologies are developed over the next few years should help to resolve this issue.

So far, the UK has lagged behind other developed countries, such as Canada, the US and Japan, in developing a hydrogen economy, but there is no reason why that should continue to be the case. Indeed, there are many reasons why the UK should lead the way. It is an island state with access to a variety of renewable energy sources, and it has an active science base that is well placed to develop the necessary technologies.

'In the 18th and 19th centuries, the UK led the way in the use of fossil fuels, it would be only right if in the 21st century the UK could take the lead in moving away from the use of fossil fuels.'