Hydrogen – the fuel of the future?

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Abstracts: ***To a certain extent, there are some common solutions to the where and when of deploying renewable energy: stronger electricity grids, better demand management, the use of embedded generation, and in the longer term, the developments of the hydrogen economy.***

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Hydrogen has been widely advocated as an energy carrier for the future. Its use as a fuel has many advantages:

- It can act as a store of renewable energy from season to season,
- It can provide a transport fuel not dependent on the world`s declining reserves of oil,
- The only by-products of its combustion are water and a very small amount of nitrogen oxides, and even the emissions of these can be reduced to zero if fuel cells are used.

Hydogen is already used in large quantities as a feedstock for the chemical industry, mainly in the manufacture of fertilizers. Currently, it is mainly produced by steam re-forming of natural gas (methane) which necessarily also produces carbon dioxide:

$$2H_2O + CH_4 \rightarrow CO_2 + 4H_2$$

Steam + methane → carbon dioxide + hydrogen

One possibility is a hydrogen economy using such fossil-fuel sources together with carbon capture and sequestration. However, renewable or solar hydrogen can be produced without CO_2 by-products, in a number of ways:

- By the electrolysis of water using electricity from non-fossil sources. If direct current electricity is passed between two electrodes immersed in water, hydrogen and oxygen can be collected at the electrodes. This process could be used to produce hydrogen from renewable electricity virtually anywhere: solar plants in the desert of Africa, wind power in the north of Scotland, or geothermal energy or hydropower in Iceland.
- By the gasification of biomass. Large amounts of hydrogen can be produced leaving a residue of high-grade carbon for chemical purposes. This carbon, is of course likely to end up as CO_2, but will be reabsorbed as long as the biomass is sustainably grown.
- By the thermal dissociation of water into hydrogen and oxygen using concentrating solar collectors (probably in desert areas). To do this directly would require very high temperatures, over 2000^0C, but with more complex process using extra chemical compounds the same result may be achievable at temperatures of under 700^0C. These processes have not yet been developed on a commercial scale.

Other techniqoues are under investigation, including the use of photoelectrochemical cells that produce hydrogen directly from water via artificial chemical photosynthesis.\

Using hydrogen as a fuel is well understood. Town gas produced from coal before the arrival of natural gas consisted mainly of a mixture of hydrogen and carbon monoxide. Space rocket motors run on a mixture of liquid hydrogen and liquid oxygen.

When burned, 1 kilogram of hydrogen will produce 120 MJ of heat, assuming that the resulting water is released as vapour. Although this is nearly three times the energy per unit mass of petrol or disel fuel, hydrogen has the disadvantage of being a gas, with a low energy per unit volume at atmospheric pressure. It can be stored in a number of forms:

- As a gas in pressurized containers, typically at around 300 atmospheres. These containers obviously have a weight penalty
- By absorbing it into various metals, where it reacts to form a metal hydride : the hydrogen can be released by heating,
- As a liquid, although this requires its temperature to -253^0C and the use of highly insulated storage. Natural gas (methane) is already widely shipped in liquid form, but this only requires temperatures of -162^0C

Hydrogen can also be pumped through pipelines. Here is has a disadvantage: at atmospheric pressure, its energy density is only 10 Mj/m^3, about quarter of that of natural gas. Although this would limit its use as a direct substitute in the existing heating network, a simple answer to its initial deployment might be to add a modest proportion to the existing natural gas flows, effectively reducing their overall carbon content.

This would have to be limited to 15-20% hydrogen by volume before the modification of existing burners or other end-use technologies would be required.

It has been suggested that countries with plentiful supplies of renewable energy, such as Iceland, which has large untapped reserves of hydroelectricity and geothermal energy, could give up the use of fossil fuels entirely. It might be possible to convert all its road vehicles to run on hydrogen. As a step in this direction, three hydrogen buses using fuel cells are being deployed on the Reykajvik bus system and a high pressure hydrogen filling station was opened in april 2003. A variety of hydrogen-powered vehicles are now under test in a number of other countries world-wide.

Any practical scheme for the large-scale use of hydrogen would require many steps, such as those illustrated in Figure 1, each of which would require large capital investments.

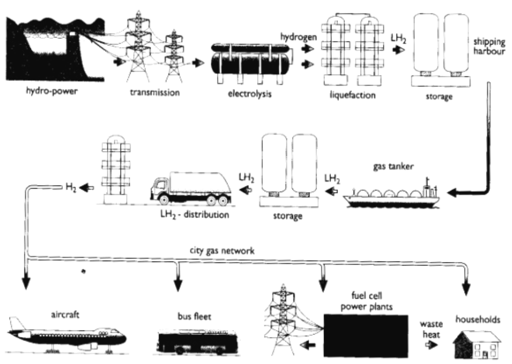

Figure 1. A possible future hydrogen economy. Many possible sources of renewable energy could be tappet to manufacture hydrogen. This could be shipped to the consumers and used in a vriety of ways

For example, surpuls hydropower could be electrolysed to produce hydrogen, which would then be stored, either as high pressure gas or as a low temperature liquid, before being shipped to its destination in special tankers. At the receiving end there would need to be further storage facilities and provision to distribute the hydrogen by road tanker or pipeline. Finally, there are the individual end uses:

- In homes for cooking and heating – possibly as a mixture with natural gas,
- In fuel cell power stations (off all sizes) to generate electricity and useful heat,
- In road vehicles using fuel cells or hydrogen-fuelled internal combustion engines,
- And even ultimately in jet aeroplanes.

Bringing such a vision to the current energy marketplace will require a high premium for hydrogen`carbon-free and pollution-free qualities, since it will initially be in competition with natural gas and its well-developed technologies. Even taking low prices for surplus renewable enrgy and long-term prospective prices for processing and distibuting the hydrogen, its cost to the end user is likely to be several times higher than current gas prices. Table 1 gives an illustrative breakdown of the cost of supplying natural gas under the current conventional supply system and a possible future renewable hydrogen alternative.

Table1. Comparisons of costs of supply of natural gas and renewably generated hydrogen

Component of costs	Current natural gas supply cost p kWh^{-1}	Prospective hydrogen alternative cost in p kWh^{-1}
Intermitent renewable energy source		2.2
Electrolysis		0.5
Compression and Storage		0.5
Distribution to industrial consumers		0.3
Total costs to industrial consumers	**0.7**	**3.3**
Extra distribution costs to residential consumers	1.0	1.5
Total costs to residential consumers	**1.7**	**4.8**

Taking this further, the ICCEPT report from Imperial college, London, cited in Table 1 suggests that with prospective future fuell cell prices of £500/kW, hydrogen-produced electricty might cost about 5.8p/kWh to industrial consumers. This would represent an increase of 60% on conventionally industrial genereted electricity prices in 2006. Yet this potential supply would have to co-exist in competition with other sources of electricity, renewable and nuclear. It way well prove cheape to invest in stronger power grids to transport renewable electricity directly, and in other forms of storage, than to invest in hydrogen technology. Only time will tell.

In the short-to-medium term, it seems likely that transport will be the major developing user of hydrogen, because of the dificulty of finding other viable alternatives to petrol and diesel fuel and the fact that these fuels are highly taxed already.

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