

## FOCUS: ECONOMICS

H<sub>2</sub>, H<sub>2</sub>O or CO<sub>2</sub>?



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## H<sub>2</sub>, CO<sub>2</sub> or H<sub>2</sub>O?

### The Hydrogen economy

With recent shocks in oil prices, a fear of security of supply regarding both oil and gas and the acceptance that continually pumping Carbon Dioxide and other greenhouse gases into the atmosphere is bad news, the world is searching for energy's "magic bullet".

The search is for a relatively cheap source of energy that is plentiful and does the minimum of atmospheric or environmental damage. Clean Coal technology might be one, but Coal is a fossil fuel and will run out. Nuclear fission has minimal atmospheric emissions, but provokes strong emotions, has long lasting waste and can be disastrous as Chernobyl demonstrated. We can look to the natural elements: Wind – good, but the turbines are ugly and relatively inefficient (generates electricity only for 30% of the time according to the BWEA [British Wind Energy Association]). We could go for solar power, but this is the UK – sunshine is at a premium. Tidal power may be a good method, but we can only have so many tidal barriers before we isolate our islands – but wait! We are an island nation, surrounded by water that contains a lot of Hydrogen – a flammable gas that burns in Oxygen to produce....water. Isn't this a virtuous circle? Use water as a raw material, produce Hydrogen and Oxygen, burn them to produce energy and end up with the raw material again. [The alternative to nuclear fission (nuclear fusion) also employs Hydrogen and gives off Helium as its waste material – great, but very difficult to achieve.]

Well, if only it were that simple. However, there is a compelling case for looking very closely at the idea. Without being patronising, let's firstly look at Hydrogen the element:

### What is Hydrogen?

The basics about Hydrogen, the element:

Atomic number: 1

Symbol: H

Atomic weight: 1.0079

Melting point: -259.34°C

Boiling Point: -252.87 °C

Hydrogen is the most abundant element in the Universe – 90% of all the atoms and 75% of the mass of the Universe. It has been reported that metallic Hydrogen has been created, but only at a pressure of about 2-3Mbar. Hydrogen combines with itself and exists in normal conditions as the H<sub>2</sub> molecule (25% Para Hydrogen and 75% Ortho Hydrogen, forms defined by the different spins of their electrons and nuclei).

This sounds great, but a little esoteric. In a nutshell, what are the practical advantages of Hydrogen as a source of energy and as a replacement for Oil and Natural Gas?

### The advantages of Hydrogen

There is a plentiful supply of Hydrogen, according to 'Basic Research Needs for the Hydrogen Economy' published by the Argonne National Laboratory, U.S. Department of Energy in May 2003, hydrogen is the third most abundant element on Earth. The report goes on to say that Hydrogen burns cleanly, producing only pure water and heat as a by-product, thus greatly reducing harmful emissions; in addition, any emissions from using hydrogen as an energy source will be confined to areas where hydrogen is being produced, this will greatly help clean up towns and cities where emissions from vehicles can cause high levels of air born pollutants.

The production of Hydrogen using electrolysis of water, with the electricity supplied by renewable energy sources such as wind or solar power would reduce any potential emissions even further. With respect to motorised vehicles, the hydrogen internal combustion engine is said to be about 38% efficient, 8% higher than the gasoline internal combustion engine, while the fuel cell is 2-3 times more efficient than an internal combustion engine. Hydrogen carries high energy per unit mass (one kg of hydrogen has approximately the energy content of one gallon of gasoline – about 2.7 kg). A distinct advantage of the hydrogen economy would be that it may lead to reduced emissions of NO<sub>x</sub> (Nitrogen Oxides) and, in turn, reduced concentrations of tropospheric ozone. Therefore, kilo for kilo, Hydrogen has the potential to deliver more energy than fossil fuels; but there are disadvantages too:

#### *The disadvantages of Hydrogen*

Nearly all of the present worldwide production of hydrogen gas (H<sub>2</sub>) is from reforming natural gas. The most efficient method currently used to reform natural gas is Steam Methane Reforming (SMR) in a large industrial plant. However, this reforming process (as well as the other current processes in less widespread use) releases Carbon Dioxide (CO<sub>2</sub>) to the atmosphere as a by-product (11.8 kg CO<sub>2</sub> per kg H<sub>2</sub>). In order to reduce the environmental impact of this method of hydrogen production, the Carbon Dioxide would have to be captured and sequestered. However, this would increase the cost of production - and disposal of the captured CO<sub>2</sub> could be a problem.

Electrolysis of water currently only has an efficiency of 75%; this would not be a problem if the electricity was sourced from renewable sources. Currently this is not the case, and electricity costs are too high for a viable hydrogen energy economy. A major drawback to using hydrogen as an energy source is this inefficiency of hydrogen production: To obtain H<sub>2</sub> it is necessary to extract

it from other compounds such as water or hydrocarbons, to do this requires energy – so there is always going to be a net loss of energy.

Another challenge is the storage of hydrogen. It presents a real challenge because of its chemical structure: To store the same amount of energy compared to gasoline you need a much larger volume of hydrogen. Even at pressures of 10,000 PSI. Liquid hydrogen stored at temperatures of 20K (-253°C) has a higher energy density, but one third of the energy stored is required in maintaining the correct storage temperature. This means that for a vehicle or aircraft to get the same range, it would need to carry a much larger volume of fuel.

There are challenges even with the widely publicised Fuel Cell technology: Hydrogen fuel cells currently rely on a very expensive platinum catalyst, and require the hydrogen gas to be 99.9% pure in order to work. Also, hydrogen has a wide concentration range of flammability (4-75% volume when compared to gasoline, 1.0-7.6% volume) and it also has a wide detonation range (18.3-59% volume vs. 1.1-3.3% for gasoline). Therefore, a hydrogen leak from a high-pressure container could be self-igniting due to the heat caused by the friction of the liquid escaping through a tiny fracture. As with the airships of old, this could lead to a major disaster.

Due to the very small size of the hydrogen molecule ( $H_2$ ), it can easily escape through imperfections in a container that would stop other gasses escaping. Liquid hydrogen storage systems lose some hydrogen gas by boil-off, due to unavoidable heat leakage which must be permitted for safety reasons. The rate at which hydrogen is lost depends on the amount being stored, but would be significant for use in vehicles (3-4% a day).

Its diffusivity allows it to incorporate into the material of its containers, especially at the surface, and cause embrittlement – an issue that did for the Lockheed Constellation airliner many decades ago.

Hydrogen has no odour and can burn with an invisible flame – this could make detection of a leak very difficult. If the hydrogen input to the fuel cell is not sufficiently pure, the fuel cell may emit secondary pollutants that could have negative environmental effects.

Furthermore, the impact of significantly increased releases of hydrogen on the atmosphere is not currently well understood. Current estimates suggest increased water vapour in the atmosphere will cool the lower stratosphere and enhance destruction of ozone at the poles. Hydrogen is itself an indirect greenhouse gas: adding Hydrogen to the atmosphere reduces the concentration of the hydroxyl (OH) radical, which is the primary methane sink. Increased hydrogen thereby leads to more methane, a greenhouse gas being present in the atmosphere. OH also plays a role in cleansing the atmosphere.

A study of the well-to-wheels efficiency of hydrogen vehicles compared to other vehicles in the Norwegian energy system indicates that hydrogen fuel-cell vehicles tend to be about a third as efficient as electric vehicles when electrolysis is used, with hydrogen Internal Combustion Engines (ICE) being barely a sixth as efficient.

Transport of pressurized or liquid hydrogen using trucks is extremely inefficient. It takes about 22 hydrogen tube trailers to deliver the same amount of energy as a single gasoline tanker. For a pipeline length of 3000 km (e.g., for gas from Russian fields to Germany), the mass fraction consumed for transporting natural gas is about 20%, while transporting hydrogen gas over the same distance would require about 35% of the original mass flow. This result was obtained for pipes of equal diameter. Delivery of both compressed and liquefied hydrogen would be troublesome. If by road, it would require 13% more tankers so about 1 in 7 lorry accidents would, on average, involve a

tanker. If using pipelines, it would take 1.5 times more energy to transfer hydrogen 3,000 km than is contained in the gas itself.

Electricity has one of the most efficient methods of energy transfer known – up to 90% efficiency. Whatever method you use to transfer power through hydrogen, the efficiency is likely to drop to about 30%. Figure 1 below illustrates this:

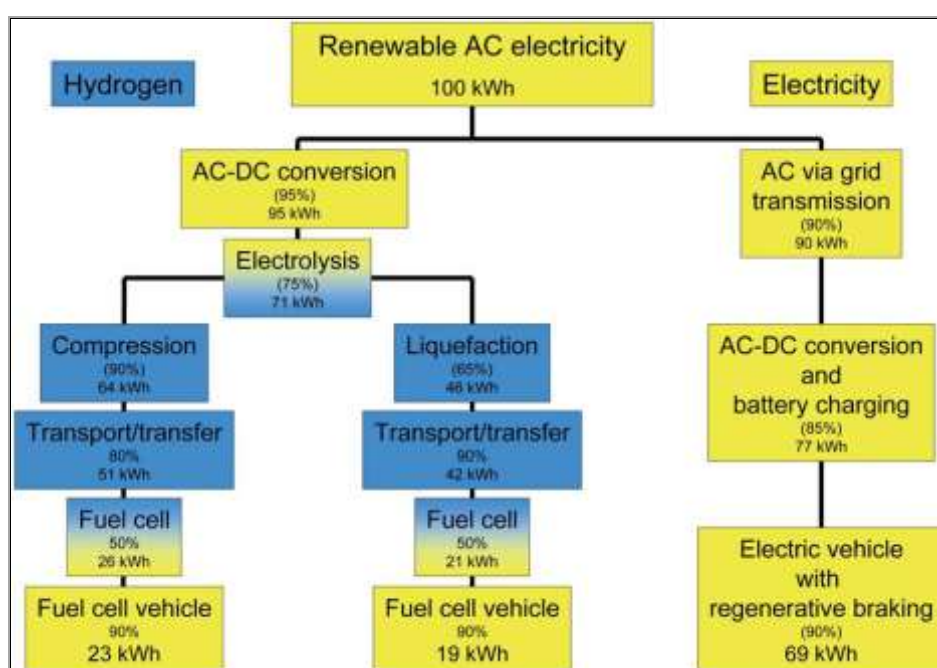


Figure 1

And the economics?

NREL (the National Renewable Energy Laboratory) in Colorado wrote a report some ten years ago examining the economics of a Hydrogen economy in the USA. They looked at methods of production, Carbon Dioxide removal (from processing), storage, transportation and delivery. More recently, 2004, the National Research Council (U.S.). Committee on Alternatives and Strategies for Future Hydrogen Production and Use revisited the economics. Table 1 below illustrates the estimated costs relating to use of Hydrogen in vehicle fuel cells:

Case	Production Costs (\$/kg)	Distribution Costs (\$/kg)	Dispensing Costs (\$/kg)	Total Dispensing and Distribution Costs (\$/kg)	Total Costs (\$/kg)	Total Energy Efficiency (%)
<b>Centralized Production, Pipeline Distribution</b>						
Natural gas reformer						
Today	1.03	0.42	0.54	0.96	1.99	72
Future	0.92	0.31	0.39	0.70	1.62	78
Natural gas + CO <sub>2</sub> capture						
Today	1.22	0.42	0.54	0.96	2.17	61
Future	1.02	0.31	0.39	0.70	1.72	68
Coal						
Today	0.96	0.42	0.54	0.96	1.91	57
Future	0.71	0.31	0.39	0.70	1.41	66
Coal + CO <sub>2</sub> capture						
Today	1.03	0.42	0.54	0.96	1.99	54
Future	0.77	0.31	0.39	0.70	1.45	61
<b>Distributed Onsite Production</b>						
Natural gas reformer						
Today					3.51	56
Future					2.33	65
Electrolysis						
Today					6.58	30
Future					3.93	35
Liquid H <sub>2</sub> Shipment						
Today		1.80	0.62	2.42		
Future		1.10	0.30	1.40		
Gasoline (for reference)	\$0.93/gal refined			\$0.19/gal	\$1.12/gal	Well to tank: 79.5%

Table 1

Again in 2004, the National Academy of Engineering (NAE) and the Board on Energy and Environmental Systems (BEES) wrote a book on the Hydrogen economy as it relates to the USA. They gave a positive review of the idea and recommended a number of actions that the US should take to bring the cost of production, distribution and use for energy generation to viable levels.

### What about the UK?

In 2006, a paper written by the UK Sustainable Hydrogen Energy Consortium, funded by the UK Research Councils, concluded that:

*“The paper shows that current niches show few signs of the characteristics that are necessary for niche expansion to the extent required, and concludes that at present hydrogen technologies still need substantial R&D support*

*resulting in a number of scientific breakthroughs before they will become viable in competitive markets.”*

In 2002 the Parliamentary Office of Science and Technology published a paper titled “Prospects for a Hydrogen economy”. It concluded:

*“Hydrogen is widely considered to have a strong potential for use in future energy systems, meeting climate change, air quality, noise and resource use goals. Hydrogen technology is well established in industry and further commercialisation for vehicles and stationary uses is expected in the next few years. However, the need for cost reduction, demonstration, and infrastructure development mean that mass markets are unlikely before 2015. Nevertheless, many have called for coordinated research and demonstration now and a clear strategy to enable future infrastructure and market development.”*

In December 2004, the UK government published “A strategy framework for Hydrogen energy in the UK”. The report identified 33 measures that would be needed to develop the UK’s hydrogen economy and listed five recommendations:

- “Co-ordination of UK hydrogen activities;
- support for research and development;
- support for demonstration of hydrogen systems;
- support for product commercialisation;
- policy changes to help create demand for hydrogen.”

Since this, there does not appear to be much by way of tangible policy development or high profile support other than the occasional initiative such as the GLA’s fuel cell bus scheme and a recent visit to Scandinavia to look at how they are developing a hydrogen infrastructure.

*Conclusion:*

In spite of the difficulties, it would seem sensible to look towards hydrogen for the supply of at least some of our future energy needs. If we could generate hydrogen using clean electricity and overcome the storage and transportation challenges, it must play a part in a future oil-free UK economic model.

However, we should not underestimate the challenges that need to be overcome. The state of California in the USA is taking on the challenge in a serious manner – promoting the development of a hydrogen infrastructure and laying down rules for the cleanliness of hydrogen production ready for the introduction of vehicles powered by fuel cell technology. There will be a number of lessons to learn from their experience and it would be useful if the UK or the EU were there working with California hand in hand to bring those lessons back so that we can make an early start.

Another benefit of such an approach would be to stimulate research and create meaningful jobs at a time of economic depression. Additionally, it would leave a useful legacy to the next generation, who will be saddled with the UK's huge debt.

Sources:

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*Note: The views expressed in this paper are solely those of the authors and do not necessarily represent the policies of SVP (UK) or any of its associated companies.*

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