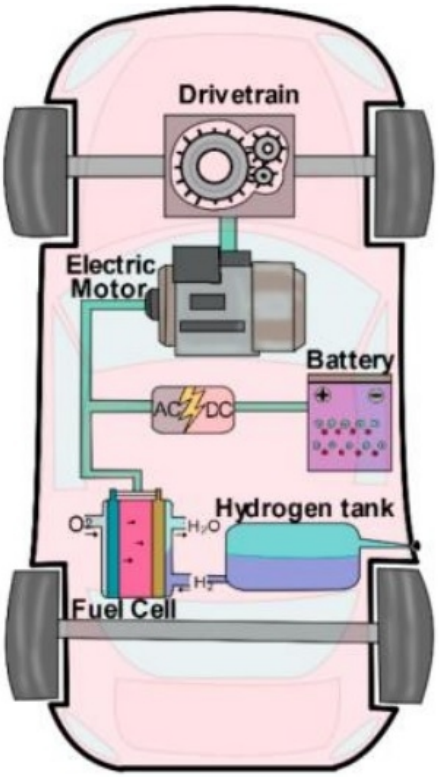
The Hydrogen Economy by **Paul Dodds** on 19th March 2021

Dr Paul Dodds is professor of Energy Systems, at University College, London, and is mainly concerned with the 'clean' growth of Hydrogen and Biological energy systems.

Hydrogen has been a fuel since the early 19th century - as a main constituent of Town Gas. Frederick Winser (a Swiss) was its first promoter, though it was others who went on to develop gas supplies. Lighting by gas was much cheaper than using Whale Oil, and the first outdoor lighting to enable ordinary people to go out at night. By 1875 gas cooking in the home had come in. Central heating had to wait for natural gas (methane), when between 1967-77 demand rose from 10 to 67-70 giga joules per customer.

Hydrogen in Transport – Dr Dodds mentioned airships – particularly the Hindenburg which famously burst into flames when mooring at Lakehurst New Jersey in 1937. It has also been used for space mission launches.

He next considered cars with PEM (polymer electrolyte membrane) fuel cells to produce electricity from hydrogen. The fuel cell would take in atmospheric oxygen and emit only water. A fuel tank would be needed – either a high pressure tank, the vehicle recharged by tank replacement; or perhaps a tank in which the hydrogen is stored as a hydride. Also a battery for moments of high power demand.



- A battery electric car is highly efficient, but restricted in range unless more (heavy) batteries are fitted.
- A fuel cell car would be less efficient but go longer distances.
- An internal combustion engine car is much less efficient.

Power Train efficiency

What one gets from 100kWh of renewable AC electricity:

- Battery electric vehicle (with regenerative braking) – 69kWh
- Compressed hydrogen for a Fuel cell vehicle – 23kWh

Have battery cars already cornered the market? People aim for lowest cost rather than the most efficient option. The cars are getting longer ranges, and more charging points are coming. Nevertheless hydrogen cars are better suited to long distance travel, and some are already in manufacture. Dr Dodds thought battery and fuel cell cars would be of comparable weight. He said it was difficult to predict whether battery electric vehicles or fuel cell vehicles will dominate: their cost projections are similar, and battery breakthroughs are on the horizon (eg Li-air) - super-fast charging?

Other markets for fuel cells

Fuel cells are scalable from watts to gigawatts – a mobile phone powered by one would work for weeks.

Large long distance lorries, busses and trains are good candidates; in-house hydrogen facilities in the depot would make for efficiencies. If an existing electric train had a fuel cell driven generator, it could continue a journey from an electrified line along an unmodified branch line (saving the cost of electrifying it).

At the other end of the scale fork lift trucks working inside warehouses are also good candidates, particularly where in-house hydrogen facilities are provided for the delivery lorries.

Hydrogen production and delivery infrastructure

Electrolysers can quite efficiently produce hydrogen from water. There could be many small ones sited where needed. Surplus wind turbine energy, or waste heat from, eg, nuclear reactors, could be used to drive them. Fossil fuels could be reformed, the resulting CO_2 removed by CCS (Carbon

Capture & Storage, yet to be developed). This could repurpose existing North Sea gas facilities and expertise.

Existing gas mains can be partially decarbonised by adding hydrogen to the methane – up to 20% by volume without having to modify gas appliances, or more with new kit (though there are many more appliances now than when the switch from town gas was made). A long standing limit is 1%, but there are already trials at 6%. Existing gas mains could be used to supply hydrogen – except in the highest pressure (90 bar) stainless steel pipework which would suffer embrittlement; low pressure mains are in polythene.

Hydrogen could be delivered round the country by gas pipelines between nodes from which it could go to local networks, or be compressed for delivery by 'tube' lorry – a lorry carrying the gas in a number of high pressure tubes.

Another option is to liquify hydrogen by cooling it to a temperature of ~20^{O}K, for bulk transport in suitably equipped lorries. This would further reduce the power train efficiency (see above) to19kWh.

Hydrogen for heating

Heating is by far the largest global market for fuel cells at the moment – supplied with natural gas. Hydrogen is the least cost option for heating in all scenarios but the cheapest option depends on assumptions about the cost of heating technologies and whether steam-methane reforming is viable in a net-zero energy system.

Gas to Power

Limitations of pump-and-store hydro and batteries at current technology levels suggests that Open or Combined Cycle Gas Turbines, utilising green hydrogen, could be a more immediately viable source of backup capacity for demand peaks or windless days in the UK. Such turbines are relatively cheap to build, can operate on methane or hydrogen, and can be brought online relatively quickly.

Hydrogen in industry

Can high-temperature process heat be decarbonised? Hydrogen is a potential alternative (eg for reducing iron ore for steel production). Industry could also provide a high demand at a single location that could enable high-volume, lower-cost hydrogen production. The UK is already looking at using hydrogen in seven large industrial clusters.

Synthetic fuels are starting to be investigated…

Long distance aircraft will continue to need jet fuel – this is refined from oil, but could be made from other fossil fuels with CCS, biomass, bio-oil, even CO_2 & Hydrogen.

Ammonia could also have a role - it can be used as a fuel, or be a more easily stored source of hydrogen.

Is the UK at the forefront of hydrogen and fuel cell innovation? Consider patents

Dr Dodds, said that Japan and the USA, now with South Korea, are world leaders in the numbers of relevant patents.

He cited David Cebon, professor of mechanical engineering at Cambridge University who said:

"Energy conversion processes required by the green hydrogen economy (electrolysis, compression, storage and fuel cells) are very inefficient: wasting energy as low grade heat. A huge amount of new renewable electricity capacity would be needed to compensate for the wasted energy." "The proposed green hydrogen economy is unlikely to be realisable in the UK because of sheer amount of renewable electricity required, the low Technology Readiness Level (TRL) of large scale electrolysis and the undeveloped technology for storing hydrogen in salt caverns."

Dr Dodds said Hydrogen is cheaper to store than Electricity, and closed with a brief summary of:

Challenges for hydrogen and fuel cells for cars

1. Funding innovation through learning-by-doing to reduce fuel cell vehicle and other technology costs.
2. Chicken-and-egg infrastructure.

3. Hydrogen purity and compression requirements for different applications - and how these will affect the development of the infrastructure.
4. Expense compared to high-carbon alternatives, and also compared to battery electric vehicles in the short-to-medium term.
5. New demand patterns (eg driverless vehicles).

and **Conclusions:**

1. Hydrogen cars are belatedly being commercialised. A range of other hydrogen technologies are also being pursued. There is a lot more realism now than in the past.
2. Economics, user experience and air pollution will all be key drivers.
3. The future for hydrogen is difficult to predict, not least because hydrogen and fuel cells could contribute in many diverse ways across many sectors, spanning the energy system.

RJB