Hydrogen Energy

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This entry explains why the 'hydrogen economy' has been so slow in coming, despite the abundance of hydrogen (H2) on Earth. H2 is either bound up with oxygen in water, or with carbon in fossil fuels, which release CO2 on combustion. For several decades, hydrogen-powered vehicles using fuel cells were seen as the major opportunity for H2. But if H2 is produced from fossil fuels, its use makes little contribution to climate change mitigation, and in any case, electric vehicles are now the main challengers to oil for powering transport. H2 will only come into its own when intermittent renewable energy, mainly wind and solar energy, dominate energy supply, as it makes sense to convert surplus power to H2 for storage or immediate use.

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1. Introduction

The French novelist and visionary, Jules Verne, in his book, *The Mysterious Island*, first published in 1874, wrote that 'water will one day be employed as fuel, that hydrogen and oxygen which constitute it, used singly or together, will furnish an inexhaustible source of heat and light, of an intensity of which coal is not capable. '[1] True, our planet has vast amounts of hydrogen locked up in water. The global ocean contains 1.4 *billion* cubic km of water. Each cubic km has a mass of around one billion tonnes, and hydrogen (H2) forms one part in nine of this mass. (Water has the chemical composition H_2O. Hydrogen, the lightest element, has an atomic mass of one, oxygen, 16. So, H_2O has a total molecular weight of 18, giving 1/9 or about 11% by mass as H2.)

Another source of H2 is all living matter, whether plants or animals. This H2 is again ultimately derived from water, in this case combined with carbon dioxide (CO_2) through photosynthesis in plants. Earth's fossil fuels—coal, oil and natural gas—formed from buried plant matter, and likewise contain H2 in varying proportions. For coal, the hydrogen to carbon ratio (H/C) is roughly 1:1, for oil a little more than 2:1 and for natural gas, which is mainly methane (chemical composition CH_4), 4:1. Whenever we burn fossil fuels, the main waste products are CO_2 and water. (Because fossil fuels contain various impurities, such as sulphur, pollutants such as sulphur dioxide are also released upon combustion.) Both H2 and carbon contribute to the energy produced. In a sense, we are already using H2 as a fuel, alongside carbon.

2. Production of H2

Use of H2 as a fuel is not new. Earlier in the century, in many countries H2 was a constituent of 'town gas', made from the partial combustion of coal. Town gas was piped to homes and businesses, but has now been entirely superseded by natural gas. Still, large quantities of H2 are produced from H2-rich natural gas and used in the petrochemical industry, where it is used to raise the proportion of lower molecular weight (lighter fraction) hydrocarbons in crude oil. These lighter molecules, such as *octane*, are used as transport fuels in road vehicles and airplanes.

How do hydrogen promoters envisage H2 being produced in future as a major energy source? We could continue to make it from coal or natural gas, but producing it this way releases CO_2. (Natural gas not only has a greater H2 content, but, as a gas, can be combusted more efficiently than the other fossil fuels in electric power stations. The result is that natural gas produces much more kWh of electricity for each kilogram of CO_2 produced and emitted to the atmosphere, and at lower cost. Natural gas generated electricity has accordingly risen as a share of global electricity generation.) One downside of using gaseous methane as a fuel is that it is prone to leak from old pipe networks as well as from gas wells themselves. Further, many gas fields contain appreciable quantities of CO_2, which is usually released directly into the atmosphere. Methane, although relatively short-lived in the atmosphere, molecule for molecule is a far more effective greenhouse gas than CO_2. So natural gas, while cleaner than coal, is not a good bridge to a low-carbon society.

What's more, barring effective action on climate change, we will eventually run short of easily accessed fossil fuels. We could electrolyse water into its constituents, oxygen and hydrogen, but if the electricity comes from fossil fuels, as most does today, H2 production still produces CO_2. (One question: 'Why not use, for example, Norway's hydropower, which doesn't produce CO_2 emissions?' The answer is that Norway, exports its surplus hydroelectricity to the European grid. If it exports less to neighbouring countries, they will need to burn more coal for electricity generation. The global technical potential for hydropower is severely limited, even ignoring its many environmental and social problems.[2] It is important to view the energy system as a whole.)

Japan would like to import H2 from Australia. The initial plan was to use the brown coal reserves of the Latrobe valley in Victoria. Brown coal is composed mainly of carbon and hydrogen. When it is combusted with limited air in the presence of steam, it is possible to finally finish up with H2 and CO_2 through the *water gas shift reaction*[3]. The H2 could then be liquified and exported in tankers to Japan. (Japan would get a clean, non-polluting fuel, but under present accounting rules, the CO2 released in the Latrobe valley would contribute to Australia's total emissions.) More recently, though, the plan is to produce the hydrogen by electrolysis of water, using Australian wind energy farms.

A more promising route to H2 is to use surplus electricity from *intermittent* electricity sources—wind and solar—to provide the electric power for water electrolysis. These two sources are the only ones which together can hope to supplant the present dominant fossil fuel economy. Because they are intermittent, as their share of the electricity market rises, they will often produce far more electricity than the grid can use at that time [4]. The alternatives are to either dump the electricity or convert it to another form and store it—as chemical energy in batteries, or compressed in underground caverns, or use it to produce H2 in an electrolyser. Because the electric grid is so widespread, it would make more sense to produce the H2 at its point of use (at a freight vehicle depot for instance) than to produce it at the solar or wind farms, then transport it. The existing H2 pipe network is very limited, and liquefying H2 for truck or rail transport to points of use is very energy intensive.

The H2 produced can then either be stored for use in fuel cells, or fed directly into the natural gas grid (see below). Fuel cells are devices which convert H2 into electricity, either on-board vehicles, or in stationary power plants. (As with battery electric vehicles, in fuel cell vehicles, electric motors provide the power to the wheels.) The only waste product of fuel cells is water. Stationary fuel cells are also being promoted, especially in Japan and South Korea, for combined heat and power to buildings. McDowall and Eames[5] have earlier identified 'four major policy drivers' important in the hydrogen futures literature: 'climate change, energy security, air pollution, and perceived competitive advantage in developing hydrogen technologies.' In the important transport sector, if all the world's road vehicles were replaced by hydrogen fuel cell vehicles (HFCVs), 'hydrogen demand would be as high as 300 Mt of H2/year, more than four times current global demand for pure hydrogen' .

However, a key challenge is that electric vehicles (EVs) offer a similar set of advantages over conventional road vehicles. For both light duty vehicles (LDVs) and buses, EVs appear to have a dominant market lead, with a 2018 global fleet of 5.1 million, compared with only around 11,200 vehicles for HFCVs. Bloomberg New Energy Finance, for example, in their 2019 report[6], give a figure of 56 million new EV sales by 2040, or 57% of estimated total new LDV sales. Staffell et al[7] have reported that HFCVs have over twice the capital and operating costs of EVs, so this EV dominance will not be eliminated any time soon.

3. The 2019 IEA report on hydrogen

The IEA 2019 report 'The future of hydrogen'[8] stressed that hydrogen has seen three 'waves of enthusiasm' in recent decades—in the 1970s, in the 1990s and in the early 2000s. Interestingly, these past 'false starts'—largely for H2 vehicles—are not reflected in global H2 production statistics, which show a steady linear growth since 1975, reaching about 74 Mt in 2018. (Paradoxically, as already mentioned, the main use for H2 is still for crude oil refining, where it helps bolster the continued consumption of oil-based transport fuels!) Nevertheless, the IEA report felt that this time the enthusiasm will not fade away as in the past, stressing that 'What is new today is both the breadth of possibilities for hydrogen use being discussed and the depth of political enthusiasm for those possibilities around the world.' The report argued that H2 is versatile, that it can 'help tackle various critical energy challenges' and 'enable renewables to provide an even greater contribution.'

The IEA report further listed four near-term opportunities to enable H2 to be used far more widely. These points are expanded on, as follows:

1. Develop existing industrial ports as centres for increasing the use of H2, such as fuelling ships. Piccard [2019] has highlighted the concern over emissions from the polluting residual fuel oil used to power ships. A switch to H2 would

reduce air pollution in port areas.

2. Use the vast existing gas pipe network by adding H2 to NG. The addition of even 5% by volume of H2 into global NG supplies would require expansion of 2018 H2 production manyfold.
3. Increase use of H2 in transport especially for fleet vehicles for freight, concentrating on particular corridors. EVs are unlikely to be able to compete with HFCVs for long-distance road or rail freight.
4. Start soon a global trade in hydrogen, using the existing LNG system as a template. For example, Japan is looking to import liquid H2 in tankers from Australia. In a zero FF future, H2 (or possibly ammonia) will be the only way of exporting energy overseas.

While these areas are the likely points of entry for H2 into the global energy system, they do not answer the important question: will their introduction help mitigate climate change, compared with alternatives? At present, promoting H2 applications is a separate question from reducing energy-related GHG emissions. One area with minor but immediate climate benefits would be the second of the four IEA points: feed H2 from electrolysis of surplus intermittent IRE into the NG grid. This introduction would remove the need for a H2 distribution system, necessary for major growth of the HFCV fleet.

4. Conclusion

Despite all the talk and international meetings, we are getting nowhere with climate change mitigation. In 2018, CO_2 emissions from fossil fuels rose 2% over the 2017 figure. Hydrogen is best thought of as an *energy carrier* like electricity, rather than a primary energy source. Today, there is little climate change relief to be gained from shifting to hydrogen or battery electric vehicles, given that fossil fuels will be the main basic energy source for both. Electric drive vehicles are somewhat more efficient than internal combustion engine vehicles, but there is little point in substituting electricity derived from coal or gas for oil-derived fuels. But when intermittent wind and solar electricity finally dominate our energy supply, hydrogen will then make sense.

References

1. Verne, Jules. The Mysterious Island; Wesleyan Univ Press: CT, 2001; pp. 777.
2. Moriarty, Patrick; Honery, Damon; Can renewable energy power the future?. *Energy Policy* **2016**, *93*, 3-7, .
3. Hydrogen production . Wikipedia. Retrieved 2020-4-30
4. Moriarty, Patrick; Honnery, Damon; Prospects for hydrogen as a transport fuel. *International Journal of Hydrogen Energy* **2019**, *44*, 16029-16037, .
5. McDowall, W; Eames,M; Forecasts, scenarios, visions, backcasts and roadmaps to the hydrogen economy: a review of the hydrogen futures literature. *Energy Policy* **2006**, *34*, 1236-1250, .
6. Electric vehicle outlook 2019 . Bloomberg New Energy Finance. Retrieved 2020-4-30
7. Staffell, I; et al; The role of hydrogen and fuel cells in the global energy system. *Energy and Environmental Science* **2019**, *12*, 463, .
8. International Energy Agency (IEA). The future of hydrogen; IEA: Paris, 2019; pp. 203.