THE FUTURE´S WHITE:

Exploring the Hydrogen Spectrum

By Michael Hart. Beam Earth Board Advisor

> *"Yes, my friends, I believe 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"*
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> *- Jules Verne*

In 1865, Jules Verne's *The Mysterious Island* was published. In it, Verne, one of the fathers of science fiction, wrote, "Someday the coal rooms of steamers and the tenders of locomotives will, instead of coal, be stored with these two condensed gases, which will burn in the furnaces with enormous calorific power".

Thirty years later in 1895, the Compagnie Belge Maritime du Congo (now CMB) launched its first steam-powered ship on its maiden trip from Antwerp to Congo and a month ago in 2021, a CMB joint venture launched HydroBingo[1], the first 80 passenger ferry for commercial use with two hydrogen diesel combustion engines.

Meanwhile, the world's first hydrogen cargo vessel went on its maiden voyage in September. Right now, shipping produces some 3% of the global greenhouse gas emissions, equivalent to one billion tonnes per annum, and according to the International Maritime Organization's Fourth IMO Greenhouse Gas Study[3], this is projected to rise to 50% by 2050.

And while global transport emissions made up 24% of direct CO_2 emissions[4] in 2019, it was cars, trucks, buses and two- and three-wheelers that accounted for nearly three-quarters of the transport CO_2 emissions. Now, planes, trains and automobiles are all part of the great hydrogen fuel experiment. On 6 September, Alstom's Coradia iLint hydrogen train ran in France for the first time[5], having presented its zero-emission train designed to run on hydrogen technology at InnoTrans, the railway industry's largest trade fair, in September 2016.

To date, 41 hydrogen-fuelled Alstrom trainsets have been ordered by two German states and in addition to France, successful trials have taken place in Austria, the Netherlands and Sweden. In Italy, the operator FNM confirmed an order for 14 hydrogen-powered trains at the end of 2020. And Siemens[6] has joined the hydrogen train movement too.

Hydrogen fuelled planes for zero carbon aviation are also on their way with the successful flight of ZeroAvia's six-seater Piper M-Class and Airbus' plans for ZeroE's hydrogen-fuelled propulsion systems[7].

And with the global hydrogen fuel cell market valued at $12.80 billion in 2020[8], and expected to grow at a CAGR of 21.4% to reach $59.81 billion value by 2028, some believe the electric car industry could be given a run for its money, at least in terms of driving range, refuelling time and the problem of recycling lithium-ion batteries.

Hydrogen production is already a $150 billion market globally and according to the International Energy Agency (IEA), global hydrogen use is predicted to expand to 122% by 2030[9].

This goes to explain why, according to Hydrogen Insights[10], McKinsey and the Hydrogen Council estimate that $300 billion will have been invested in hydrogen projects by 2030. With this back drop, it is easy to see why hydrogen is seen by many as the (clean) fuel of the future.

But for it to be a viable net zero alternative, accessing hydrogen in its pure form is the main challenge, as all hydrogen is not 'born' equal. In IEA's 2019 report *The Future of Hydrogen*[11] the demand for the gas, which has grown more than threefold since 1975, was almost entirely supplied from fossil fuels. Some 6% of global natural gas and 2% of global coal go to produce grey hydrogen and brown hydrogen, respectively.

Out of the 75% of the hydrogen produced from natural gas, most of it is produced by methane reforming (at a low cost of 1.7$/Kg/$H_2$); a process that emits some 10Kg of carbon dioxide for each kilo of hydrogen produced.

The production of the majority of hydrogen was responsible for CO_2 emissions of around 830 million tonnes of carbon dioxide per year, equivalent to the CO_2 emissions of the United Kingdom and Indonesia combined in 2019, according to IEA, effectively taking most of the current hydrogen production off the clean energy table.

Blue and green hydrogen have been handed the hydrogen baton as solutions to clean energy sources, but how green are they really?

blue hydrogen is obtained from converting methane—a greenhouse gas that is 100 times stronger as an atmospheric warmer than carbon dioxide when first emitted—into hydrogen and carbon dioxide.

Earlier in the year, BP announced plans to develop the UK's largest blue hydrogen facility. But removing carbon dioxide and other impurities using Carbon Capture Technologies, which not only increases the price of hydrogen but also has a significant carbon footprint.

In fact, according to a new report *How green is blue hydrogen?*[12] written by Cornell and Stanford university researchers, the carbon foot print of blue hydrogen is more than 20% greater than using either natural gas or coal directly for heat and 60% greater than using diesel oil.

Meanwhile green hydrogen, which is produced by electrolyzing water molecules into hydrogen and oxygen, is currently the only 'clean' industrial solution. This is why Germany, which is making hydrogen the centrepiece of its decarbonization strategy, has signed green hydrogen deals with Canada and Namibia, while Chile, Mexico and Uruguay are all exploring green hydrogen projects.

The problems with green hydrogen, currently only 2% of the hydrogen produced, are the amounts of energy used in the electrolysis, which would need to come from renewable sources to keep the carbon footprint low; and that at a cost of $4-$5 per kilo of hydrogen produced, it is not cost competitive at the moment.

The other hydrogen production processes include: pink hydrogen, derived by using nuclear energy to electrolyze water; yellow hydrogen that uses solar power for electrolysis; turquoise hydrogen generated from methane pyrolysis through molten metal and solid carbon is a by-product; and hydrogen extracted from waste and biomass gasification, which solves the problem of mounting waste stocks and at $2.7 per kilo of hydrogen[13] is also more economically viable.

There is now a new contender, which is naturally occurring and renewable, that is seen as the net zero clean fuel's white knight; white geological hydrogen extracted from the ground through natural hydrogen reservoirs. These flows of natural hydrogen have been documented throughout the world, primarily above deep continental cratons, for example in Central Africa, Russia, Brazil and the US.

Right now, there are close to 100 de-carbonization technologies that reduce greenhouse gas emissions currently available at commercial large scale. But, according to Goldman Sachs' October 2020 Carbonomics[14] report, it is estimated that 25% of current global anthropogenic GHG emissions are not stoppable under current commercially available large-scale technologies, which means innovation is essential.

Hydrogen has the estimated potential to aid the de-carbonization of 45% of current global GHG emissions across: transportation, power generation, buildings, industry and waste and it has a very high energy content per unit mass, more than two times higher than gasoline or natural gas, and does not emit CO_2 when burnt. Hydrogen can be used and stored without any direct GHG emissions, or as an energy carrier, with ammonia as the best solution for storing and distributing hydrogen, because it can be used as feedstock for fertilizer, and benefits from lower transport cost and higher energy density than hydrogen in its pure form.

Around 180 million tons of ammonia are produced globally, with 80% used as feedstock for fertilizer, and according IEA´s *Net Zero Emissions Scenario for 2050*[9], ammonia will account for around 45% of global energy demand for shipping in 2050.

According to Pierre Levin, chief technology officer at Beam Earth, if renewable white hydrogen only has a 20% market share of the decarbonised hydrogen market by 2030, this would already be a $75 billion industry. Particularly, as unlike green hydrogen, white hydrogen production does not require electrolysis and can be produced at a much lower cost of $0.5 to $1 per kilo.

While the genesis of this hydrogen is still debated, economic hydrogen production has been ongoing in Africa for 10 years, with no sign of loss of pressure or volume decline. Development of production in large reservoirs is planned in Ukraine, Brazil, Europe, Africa, Australia and the USA.

One of the key challenges for developing what seems to be the ultimate clean hydrogen resource will be overcoming transportation issues as liquifying is expensive, but adapting clean oil and gas technologies will be one of the ways to harness what could become the hydrogen equivalent of the oil rush 150 years ago.

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