Some rules of thumb of the hydrogen economy

1, A kilogramme of hydrogen - the unit most often used – has an energy value of about 33.3 kWh.[1] So a tonne of hydrogen delivers about 33 MWh and a million tonnes about 33 terawatt hours (TWh). To provide a sense of scale, the UK uses about 300 TWh of electricity a year.

2, Estimates vary, but about 70 million tonnes of pure hydrogen is made today, mostly for the fertiliser and oil refinery industries. This has an energy value of about 2,300 TWh, or roughly the same amount as the EU's electricity consumption (excluding the UK, of course).

3, Many estimates of the eventual demand for hydrogen centre around a figure of about 500 million tonnes.[2] This will have an energy value of about 16,500 TWh, or about 40% of the world's current consumption of natural gas.

4, How much electrical energy does it take to make a kilogramme of hydrogen in an electrolyser? A survey of the major manufacturers suggests a figure of about 50 kWh at present for both Alkaline and PEM electrolysers. Put an energy value of 50 kWh of electricity in and get hydrogen out with an energy value of 33.3 kWh, or 67% efficiency. Alkaline and PEM electrolysers offer performance of this level but Solid Oxide electrolysers already offer 80% conversion of electricity to hydrogen. But they need substantial sources of external heat.

5, Will the efficiency of electrolysers rise? Yes. The assumption in the industry is that Alkaline and PEM electrolysers will rise to an efficiency of about 75% (44 kWh in, 33.3 kWh out) within five years.

6, Many observers say that green hydrogen made from the electrolysis of water will be fully cost competitive with fossil hydrogen when it costs less than $1.50 per kilogramme.[3] This is equivalent to 4.5 US cents per kWh of energy value, or $45 per MWh. As at today's date (June 11th 2021), unrefined crude oil costs about the same amount per kWh.

7, What will it take to get H2 to $1.50 per kilogramme. Low electricity prices are, of course, utterly critical, followed by falling electrolyser prices. Hydrogen is little more than transformed electricity. NEL, the world's largest electrolyser manufacturer, says that it believes $1.50 is achievable in 2025, based on $20 per megawatt hour electricity. It is coy about the prices it expects for its own products, but I guess that it projects about $500 per kilowatt of capacity by mid-decade.[4]

8, How much renewable electricity will need to be generated to satisfy the demand for hydrogen? At the current efficiency level of about 67%, the world will need about 50 terawatt hours for each million tonnes of green hydrogen.

9, At the prospective efficiency level of about 75%, this number falls to about 44 TWh. A world that requires 500 million tonnes of hydrogen will therefore need to produce 22,000 TWh of green electricity a year just for this purpose. Today's global production from all wind and solar farms is a little more than

10% of this figure. To meet the need for hydrogen we need a sharp acceleration in renewable installations to several terawatts a year.

10, 22,000 TWh is roughly equivalent to 15% of total world primary energy demand.

11, How large a wind farm is needed to make a million tonnes of hydrogen? If we assume a capacity factor of 50% for a well-sited North Sea wind farm, each gigawatt of capacity will provide about 4,400 GWh a year, or 4.4 TWh. At the future efficiency level of about 75%, this will produce about 100,000 tonnes of hydrogen. Therefore most of the UK's current North Sea wind output from 13 GW of wind would be needed to make one million tonnes of H2.

12, The amount of electrolysis capacity required to make 500 million tonnes of hydrogen a year depends on how many hours a year that the electrolysers work. If we assume the average is 5,000 hours a year, or about 60% of the time, then the world will need around 4,500 gigawatts of electrolysis capacity - about five hundred times what is currently in place - at the prospective 75% efficiency level. This is an important conclusion because it points to the necessity of creating a massive new industry. My figures suggest the investment in electrolysers may exceed the cost of building the renewables necessary to provide the electricity for making hydrogen. Those of us who look at the stock market valuations of the existing electrolyser manufacturers and recoil in disbelief may not being sufficiently imaginative.

The size of the hydrogen opportunity

The sectors which will drive the growth of hydrogen.

1, Shipping. These reports envisage ammonia, a derivative of hydrogen, becoming the main fuel for long-distance shipping. Ships, such as island ferries, that cover shorter distances will typically use batteries. The ETC sees ammonia for shipping as being the single most important use of hydrogen by 2050 using about 145 million tonnes, twice today's global production for all purposes.

2, Steel manufacture will also be an important market. I project that this will be the largest use of hydrogen. Other industries that need high temperature heat, including cement manufacture, glass-making and some chemicals, will provide large opportunities for the gas.

3, Aviation will decarbonise using synthetic fuels, made from hydrogen combined with CO2 probably derived from direct air capture. Aircraft, according to these three reports, will not use hydrogen directly in any significant quantities.

4, Personal cars will not move to hydrogen as the predominant energy source. Batteries will dominate. But some long-distance commercial vehicles that do not return to the same point each night may move to hydrogen fuel cells. Surface transport will therefore not be a major user of hydrogen, although I say that railways may move to the use of fuel cells.

5, Although much low temperature space heating will move to electricity, and away from natural gas, there is a significant role for hydrogen in this market.

6, Lastly, but probably most importantly, hydrogen will perform a vital role balancing the electricity market. When power supplies are abundant, hydrogen will be made and then converted back to electricity in conventional combined cycle gas turbines when there is an energy shortage. All three reports see this as a large-scale use of hydrogen. The IEA sees this function as demanding almost 100 million tonnes, almost 20% of its total projection of the global need for the gas. My figure is similar.

Other conclusions shared between the reports.

7, Hydrogen will be transported across regions largely by pipeline. Repurposed natural gas pipelines will play an important role.

8, Storage will be concentrated in newly constructed salt caverns, where this is possible. Large parts of the world, including much of Africa and Asia may not have adequate capacity but Europe, the Middle East and North America are well supplied with geological salt.

9, Transport from energy-surplus areas, such as NW Australia and Chile, will use ammonia as the carrier for the hydrogen.

10, The cost of green hydrogen will be dominated by the price of renewable energy. At prices of $20 per megawatt hour or below, hydrogen made from electrolysis would already be competitive with the 'grey' product in higher cost natural gas markets.

11, The relatively low figure for hydrogen production from the IEA arise because the Agency assumes that a large amount of decarbonisation will take place through the use of biomass. This, for example, explains the limited use of hydrogen for aviation. Instead, aviation fuel will be made from biological materials. Many will question whether the emphasis on sustainable biomass is remotely plausible. The ETC and I assume that almost all energy use will employ electricity or hydrogen made from electricity.

The central numbers

The table below gives some of the forecasts for hydrogen from the three reports. I should stress that some of these numbers may not be directly comparable because the authors use different definitions. In addition, the IEA report includes figures that vary between different sections of the document. This report also omits some critical estimates, such as the amount of hydrogen needed for methanol - an important precursor for many important chemicals - and fertiliser manufacturing.

How much 2050 H2 is from electrolysis?

ETC - About 680 million tonnes. (about 85% of total hydrogen production)

IEA - About 320 million tonnes (about 60% of total hydrogen production).

CLSA,Goodall - About 562 million tonnes (all prepared by electrolysis)

These differences are driven by the assumption about how much of the hydrogen is made from electrolysis of water and how much from steam reforming of natural gas with CCS.

Electrolysis capacity

ETC - 7800 gigawatts

IEA - 3600 gigawatts

CLSA, Goodall - 4800 gigawatts

These figures are approximately consistent with the forecast hydrogen production.

Share of final energy demand

ETC - 15-20%

IEA - 13%

CLSA, Goodall - 20%

The key differences derive from the assumption about how much remaining fossil fuel is used. A forecast with high gas use (with CCS) requires more primary energy production because of the inefficiencies of conversion into useful energy.

Eventual electricity generation 2050 excluding for the production of hydrogen

ETC - 93,000 TWh

IEA - 60,000 TWh

CLSA, Goodall - 120,000 TWh

I project that almost all energy-using activities are switched to hydrogen or electricity by 2050. The other forecasts are for a slower transition.

Cost of electrolysers, 2050

ETC - $100/ kW

IEA - $200-390/ kW