Aswan high dam, Egypt

Will green ammonia overtake hydrogen?

An international perspective

By Stephen B. Harrison

Here's a curious fact. The largest green hydrogen projects in operation today are small in comparison to the green hydrogen and green ammonia projects of the 50-year period from 1928 to the 1970s. From this point on, however, cheap natural gas meant that ammonia production on electrolysers was no longer economic.

A brief recap of those pioneering projects. In Norway, two mega-projects used green hydropower to make hydrogen on electrolysers. Rjukan started up in 1928 with 165 MW of power flowing to 150 electrolyser modules generating 27,900 Nm3/hr of green hydrogen.

At a similar scale, also using Norwegian hydropower, Glomfjord commenced in 1949. Both schemes used atmospheric pressure, alkaline electrolysis. The hydrogen was converted to ammonium nitrate, a fertiliser.

And in Egypt, in a similar set-up to the two Norwegian projects, hydropower from the Aswan dam was used to generate green hydrogen. One facility was built using Demag electrolysers in 1959. It had a total of 203MW capacity of atmospheric pressure alkaline electrolysers across 288 modules generating 36,000 Nm3/hr of hydrogen. A slightly smaller system was implemented using equipment from BBC Electrolyser System Oerlikon in 1973. As was the case in Norway, the goal was to make ammonia for fertilisers to increase the yield of local food production.

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The revival of green ammonia

For several years, attention has focused on green hydrogen as a clean energy vector. Produced on electrolysers from renewable electrical power generated by wind, solar or hydro schemes, green hydrogen is regarded as a fuel with a very low-carbon footprint. And, as the historical cases above demonstrate, the conversion of green hydrogen to green ammonia has been an established concept for many decades.

The motivation to produce green ammonia in the future will in part be to generate nitrogen fertilisers. The motivation will also stretch as green ammonia is increasingly recognised as being one of the most cost-effective ways of transporting green hydrogen over long distances as an energy vector. Conversion of hydrogen to ammonia adds cost at the production location, sure, but it means that ammonia, rather than hydrogen, can be shipped to the end-use location.

Ammonia is readily liquefied and as a liquid it has a high volumetric energy density – about 50% higher than liquid hydrogen. The savings in shipping costs of liquid ammonia, compared to liquid hydrogen, mean that CAPEX and OPEX savings from the shipping operation can be routed to the ammonia conversion facility. For long distances, such as the Australia to Europe route, liquid ammonia is the most cost-effective mode of green hydrogen transportation.

One of the attractions of using ammonia as a tradeable energy vector is that it is already a globally produced and traded commodity. Worldwide gray ammonia production capacity is around 225 million metric tonnes per year (tpy), of which typically 185 million tpy is utilised.

The global merchant market for traded gray ammonia, at circa 20 million tpy, represents only 10% of total worldwide production capacity. As many as 170 ammonia tankers sail the world's oceans, shipping these merchant ammonia volumes across 120 portside ammonia terminals.

A typical ammonia tanker can transport 60,000 metric tonnes of liquid ammonia and a terminal would typically be built to store twice this capacity. The maturity of this ammonia transportation infrastructure is an attractive reason for considering green ammonia as a traded energy vector.

Merchant grey ammonia pricing has been influenced by natural gas costs and supply versus demand balance. Significant under-utilised ammonia production capacity exists in China, but this is land-locked inland production and is not available to international markets, so utilisation of internationally tradeable ammonia capacity has been high.

Solar panels for green hydrogen and green ammonia

Rjukan hydropower plant turbines, Norway

© RAG & Karin Lohberger Photography, McPhy

Aswan dam hydro power plant, Egypt

The pricing volatility of grey hydrogen and lack of availability of excess capacity for international trade are key drivers for the development of green ammonia to supplement existing grey ammonia production.

Energy-efficient production of green ammonia

Green electrons are highly valuable and are the result of significant infrastructure investment in wind and solar parks. Using them carefully to produce green ammonia is essential to optimising project economics and reducing the cost of the energy transition to consumers and industrial energy users.

"Using a solid oxide electrolyser, or SOEC, is ideal if hydrogen is to be converted to green ammonia," said Gerald Hammerschmid, Product Manager SOEC at Sunfire in Dresden.

> "We have conducted a detailed energy balance, integrating our Sunfire–HyLink SOEC with the Haber Bosch ammonia synthesis loop"

The reason for the good fit is that the ammonia synthesis reaction produces excess heat that can be used to generate steam, which is the required feedstock for the SOEC.

Since much of the energy required for splitting water into oxygen and hydrogen enters the SOEC as heat from the steam, this high temperature electrolysis technology requires about 25% less electrical power than low temperature water-fed electrolysis.

"We have conducted a detailed energy balance, integrating our Sunfire-HyLink SOEC with the Haber Bosch ammonia synthesis loop," confirms Hammerschmid. "The result is that the steam generated by the Haber Bosch reactor covers up to 70% of the steam required for solid oxide electrolysis." The implication is that the other 30% of the hydrogen could be provided by an alternative electrolysis technology.

Hammerschmid injects that "we advocate the use of pressurised alkaline electrolysis for the remaining 30% of hydrogen. Our Sunfire-HyLink Alkaline electrolyser is ideal for that purpose because it delivers hydrogen at 30 bar." Haber Bosch ammonia plants generally operate at more than 250 bar and the hydrogen feedstock must be compressed to this pressure.

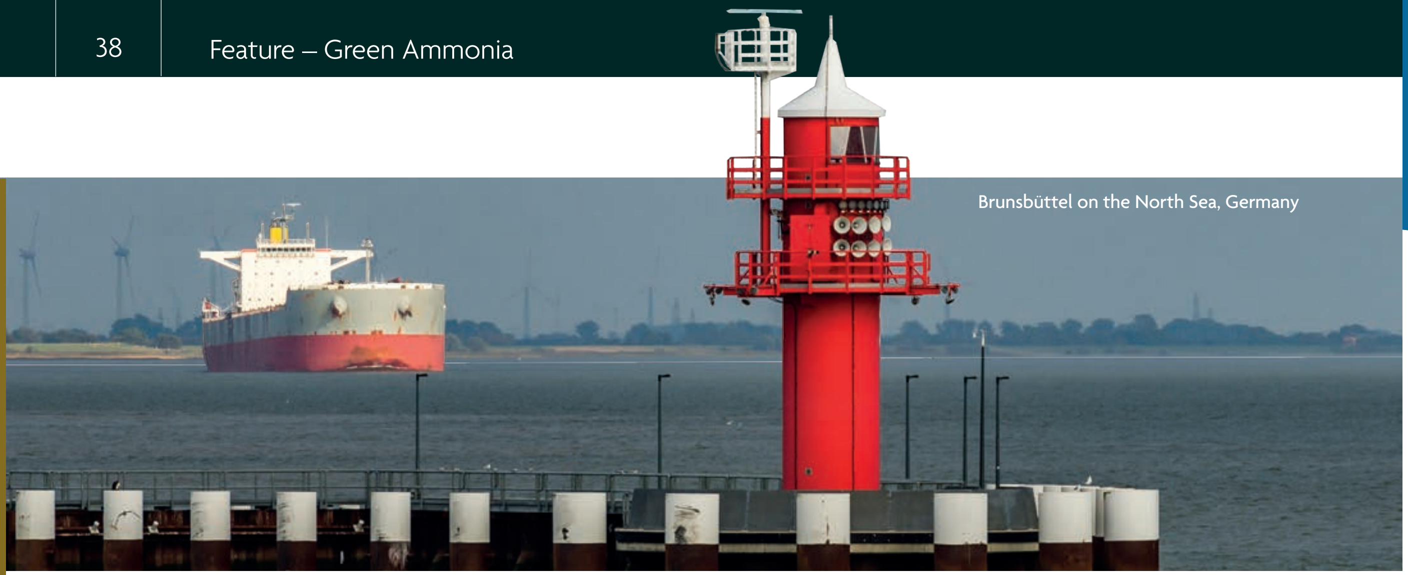
The power required for compression is broadly related to the outlet pressure to inlet pressure ratio. So to achieve 250 bar at the compressor outlet from 30 bar at the inlet is a multiple of just over eight.

To achieve 250 bar from an atmospheric pressure alkaline electrolyser would be a ratio of 250 and therefore a much larger compressor drawing much more electricity would be required. The use of a pressurised alkaline electrolyser can improve the energy efficiency of the overall process because the pressure is achieved by pumping water at the inlet of the electrolyser, and this consumes vastly less power than compression of gas at the outlet.

Ammonia powering the energy transition

Much of the excitement about using hydrogen is related to mobility. In fuel cell electric vehicles (FCEVs), hydrogen is converted to electrical power using catalysts in a fuel cell. The electrical power then drives the vehicle, like a battery electric vehicle.

In mobility applications, the fuel cells are generally >>



Brunsbüttel on the North Sea, Germany

PEM construction due to the requirement to cope with the high vibration environment. PEM fuel cells prefer hydrogen.

For land-based applications and in some seaborne applications solid oxide fuel cells can be used. They are robust enough to serve in these applications, but they are not as tough as PEM fuel cells. Solid oxide fuel cells can operate with a broad range of feedstocks including hydrogen, ammonia, and liquid hydrocarbons such as methanol or diesel.

For many years, the idea of converting green hydrogen to green ammonia has been in question due to the high costs of reconversion of the ammonia to hydrogen at the destination.

Approximately 25% of the energy value of the ammonia is lost through the reconversion process. The cracking technology to perform the reconversion is relatively immature and the equipment is therefore expensive to purchase and operate. However, as more and more use cases for green ammonia are being developed the need to crack the ammonia to hydrogen is diminishing.

"A solid oxide fuel cell manufactured by Sunfire will also be used on Viking Energy," says Hammerschmid. Viking Energy is an oilfield services vessel that operated by Eidesvik in support of Equinor's offshore activities. It will use green ammonia, produced by Yara at Porsgrunn in Norway

There is also potential to use ammonia on maritime internal combustion engines, but the focus of this project is to prove the viability of ammonia for maritime fuel cell applications.

Ammonia will also be used for thermal power generation by JERA in Japan. A demonstration project is underway on unit four of the Hekinan coal-fired power station. This unit has a power generation capacity of 1GW, one quarter of the plant's generation capacity. About 20% of the power generation capacity will be decarbonised by co-firing green ammonia with the coal.

The traded tonnages of green ammonia for power generation applications will most likely dwarf the traded volumes of green hydrogen, giving credibility to the notion that in time the green ammonia economy will overtake the green hydrogen economy.

Bulk ammonia distribution in Asia

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