Aswan high dam, Egypt

Green ammonia at scale

Will the ammonia economy overtake the hydrogen economy?

By **Stephen B. Harrison, sbh4 consulting**

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, when cheap natural gas meant that ammonia production on electrolysers was no longer economic.

In Norway, two mega-projects were in operation using 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 Nm^3/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.

The fertile Nile delta in Egypt was the breadbasket for the Pharaohs. As the population of Egypt grew last century, agriculture intensified, and fertiliser was required. 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 203 MW capacity of atmospheric pressure alkaline electrolysers across 288 modules generating 36,000 Nm^3/hr of hydrogen. A slightly smaller system was implemented using equipment from BBC Electrolyzer System Oerlikon in 1973. As with the case in Norway, the goal was to make ammonia for fertilisers to increase the yield of local food production.

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

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regarded as a fuel with a very low-carbon footprint. 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 include the historic reason: 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 ▶

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Solar panels for green hydrogen and green ammonia.

Rjukan hydropower plant turbines, Norway.

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Aswan dam hydro power plant, Egypt.

to ammonia adds cost at the production location but means that ammonia, rather than hydrogen can be shipped to the end-user 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 grey ammonia production capacity is around 225 million tonnes per year (tpy), of which typically 185 million tpy is utilised.

The global merchant market for traded grey 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 tonnes of liquid ammonia and terminal would typically be built to store twice this capacity. The maturity of the ammonia transportation infrastructure is an attractive reason for considering the use of green ammonia as a traded energy vector.

Merchant grey ammonia pricing has been influenced by natural gas costs and supply vs 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. 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, “ says Gerald Hammerschmid, Product Manager SOEC at Sunfire in Dresden. 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 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

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ammonia to hydrogen is diminishing.

"A solid oxide fuel cell manufactured by Sunfire will also be used on Viking Energy," confirms 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 being used for thermal power generation by JERA in Japan. A demonstration project is underway on unit 4 of the Hekinan coal-fired power station. This unit has a power generation capacity of 1 GW, 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 the green ammonia economy will overtake the green hydrogen economy. gw

Energy Density of LNG Compared to Alternative Liquid Energy Vectors

	LNG, Liquefied Natural Gas	Liquid Ammonia	Liquid Methanol	LOHC – Liquid Organic Hydrogen Carrier (MCH used as anayamnia)	Liquid Hydrogen
Temperature for transportation and storage	-162°C	-33.3°C	Liquid at ambient temperature	Hydrogenation: 150-200°C; Transported at ambient temperature; Dehydrogenation: 250-320°C	-253°C
Pressure for transportation and storage	Close to atmospheric pressure	Close to atmospheric pressure	Close to atmospheric pressure	Hydrogenation: above 20 bar; Transported at atmospheric pressure; Dehydrogenation: below 5 bar	Close to atmospheric pressure
Density	0.46 KG/L	0.68 KG/L	0.79 KG/L	0.77 KG/L	0.071 KG/L
Toxicity	TWA 1,000 PPM	TWA 25 PPM	TWA 200 PPM	TWA 400 PPM	non-toxic
Flammability (% in air)	4-15 %	14.8-33.5 %	6.0-36.5 %	1.2 - 6.7%	4-74 %
Volumetric Lower Heating Value (LHV\(MJ/L)	22.2	12.7	15.7	5.76 - 8.5	8.52
Gravimetric LHV (MJ/kg)	48.6	18.6	19.9	7.48 - 11	120
Intrastructure readiness for large scale deployment in mid-term H/M/L	H	H	H	M	L
Commercialisation status and pilot projects	Many commercial LNG production, distribution, storage and regasification assets worldwide	Many commercial liquid ammonia production, distribution and storage assets worldwide with 120 port locations able to handle ammonia	Methanol is a widely traded commodity with tankers up to 50,000 tonnes	The HySTOC (Hydrogen Supply and Transportation using Liquid Organic Hydrogen Carriers) project in Finland	HySTRA-Hydrogen Energy Supply-chain Technology Research Association – Australia to Japan liquid hydrogen shipping