Summary

- The Age of Aquarius has connotations of a paradigm shift in outlook, and of course water, of which two-thirds is hydrogen - that makes for an interesting discussion.
- Hydrogen Council studies suggest scale-up of hydrogen production, distribution, and manufacturing system components will be the biggest driver of cost reduction, before any additional impact from technological breakthroughs.
- According to Siemens, with scale-up and sufficient full load operating hours, green hydrogen generated from electrolysis can already compete with fossil-fuel based hydrogen production.
- The Australian Energy Market Operator (AEMO) has invited comments on its Draft 2022 Integrated System Plan for transmission growth planning through 2050, including rapid decarbonisation of the National Electricity Market (NEM).
- This submission explores a potential paradigm shift from the focus of the present AEMO plan to decarbonise through growth of renewable energy generation (with growth in hydrogen production as a desirable by-product), to a focus on rapid scale-up of hydrogen production (with growth in renewable energy generation as a desirable by-product).

AEMO Draft 2022 Integrated System Plan

In its draft 2022 Integrated System Plan and assumptions update, AEMO provides five scenarios, as follows:

1. Slow change - in response to slow economic recovery and load closures, but continued PV uptake (consistent with 2.6 degree warming future).
2. Progressive change (formerly "Net Zero 2050") - to meet a national emission abatement end-goal (consistent with 2.6 degree warming future).
3. Step change - with a focus on energy efficiency, DER, digital energy and step increases in global policy ambition (consistent with global action to limit temperature rises to less than 2 degrees, and with industrialized countries targeting net zero emissions by 2050).
4. Hydrogen Export (formerly Hydrogen Superpower) with Australia leveraging competitive advantage to export hydrogen (the most ambitious global emissions reduction scenario, consistent with limiting temperature rises to less than 1.5 degrees, as well as a strong focus on electrification and hydrogen-based developments).
5. Increased role for molecules ahead of electrons - includes hydrogen delivered through the gas network (a natural extension of the Hydrogen Export scenario).

Clearly, the preferred option, from both nation building and global warming viewpoints is scenario 4, which would also support scenario 5. The major impediment to implementing Scenario 4 would be an inability to economically produce green hydrogen at sufficient scale. It can be demonstrated the ability to produce commercially viable "green" hydrogen at scale already exists, leading to the conclusion Scenario 4 should be adopted now for forward planning purposes. Supportive policies should lead to rapid growth in investment in hydrogen production facilities, providing an assured market for "green" electrons, which in turn should lead to rapid growth in solar and wind power investment.

Rapid Expansion Of Green Hydrogen Production In Australia

Factors relevant to rapid expansion of economic green hydrogen production in Australia:

- The effect of scale on economic production of hydrogen using electrolysis.
- The effect of scale on cost competitiveness of hydrogen applications.
- Policy shifts required to facilitate relatively constant large scale renewable energy generation for the most efficient and economic production of "green" hydrogen using electrolysis.

The effect of scale on economic production of hydrogen using electrolysis

Much of the current thinking on reducing green hydrogen production cost revolves around scaling up electrolysers to larger size units, and improvements in efficiency, particularly at low and variable production rates. It is often said the technology to produce cost competitive hydrogen from electrolysis is yet to be developed. This 2021 dated document from IRENA, "Making the breakthrough: Green hydrogen policies and technology costs" highlights key findings from:

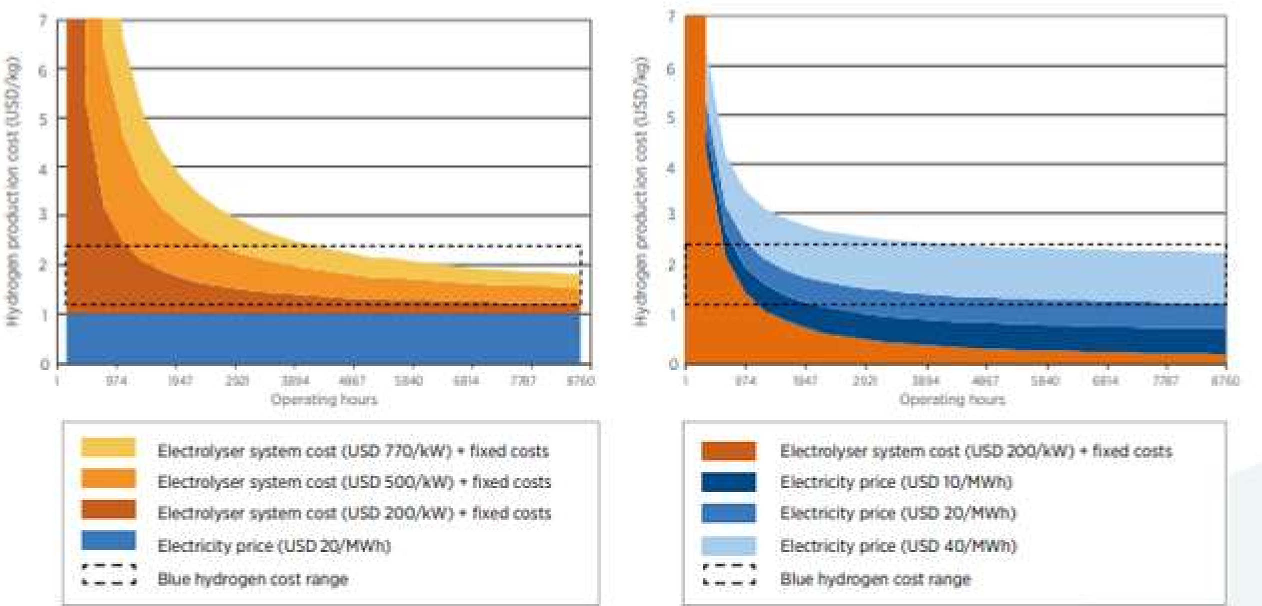
- Green hydrogen: A guide to policy making (IRENA, 2020; ISBN 978-92-9260-286-4)
- Green hydrogen cost reduction: Scaling up electrolysers to meet the 1.5°C climate goal (IRENA, 2020; ISBN 978-92-9260-295-6)

The IRENA document largely reflects the widespread current attitude to hydrogen production being merely a support to existing power system management where at page 22, item 3. Benefits for the power system, it states,

"As the share of solar and wind power, or variable renewable energy ("VRE"), rapidly increases in various markets around the world, the power system will need more flexibility. The electrolysers used to produce green hydrogen can be designed as flexible resources that can quickly ramp up or down to compensate for fluctuations in VRE production, by reacting to electricity prices (Eichman et al., 2014)."

At the same time, Figure 6 below from the IRENA document reveals "Green" hydrogen production by electrolysis is currently cost competitive with fossil fuel based "Blue" hydrogen once electrolyser operating hours increase above ~5,000 hours per year.

Figure 6 **Hydrogen production cost as a function of investment, electricity price and operating hours**



Note: Efficiency at nominal capacity is 65% (with an LHV of 51.2 kWh/kg H_2), the discount rate 8% and the stack lifetime 80 000 hours. Based on IRENA analysis.

Source: IRENA document, "Making the breakthrough: Green hydrogen policies and technology costs"

In Siemen's document available for download, "Power-to-X: The crucial business on the way to a carbon-free world", a similar case is made,

"*In addition to the electricity generation cost, the capacity factor (full-load hours) of the electrolysis is the dominant aspect for the cost of green hydrogen, defining the capital efficiency of the electrolyzer and synthesis plant. With favorably LCoE of US$20/MWh and 6,000 full-load hours availability for some locations, green hydrogen generated from electrolysis can already compete with hydrogen from steam-methane reforming or autothermal reforming of natural gas*."

With a stack lifetime of 80,000 hours, doubling hydrogen production hours from say 3,000 hours to 6,000 hours has greater benefit than just the reduction in economic cost of production per kg of hydrogen. The service life of the stack is reduced from ~27 years (80,000 divided by 3,000) to ~13.5 years (80,000 divided by 6,000). At the end of 13.5 years the stack will likely be replaced by a more efficient stack at a fraction of the cost of the original, leading to further lowering of hydrogen production cost over the balance 13.5 years. There is an opportunity to plan the development of Renewal Energy Zones ("REZ") with a mix of solar, wind and pumped hydro, in conjunction with large-scale green hydrogen production facilities within or adjacent to the REZ, with the intent to maximise electrolyser full load hours, with benefits flowing to all participants. This approach has the potential to accelerate growth in economic green hydrogen production, which is integral to the objectives under Scenario 4 of the AEMO draft 2022 ISP, and supportive of Scenario 5. Potential policy shifts to encourage and facilitate this are discussed further below.

The effect of scale on cost competitiveness of hydrogen applications

Excerpted from Hydrogen Council publication, "Path to hydrogen competitiveness A cost perspective" which provides an evidence base on the path to cost competitiveness for 40 hydrogen technologies used in 35 applications.

On scale up of hydrogen production -

"Our findings suggest that scale-up will be the biggest driver of cost reduction, notably in the production and distribution of hydrogen and the manufacturing of system components. This will deliver significant cost reductions before any additional impact from technological breakthroughs is considered."

Non transport applications benefit most from lower hydrogen cost -

"On average, the cost of hydrogen supplied comprises more than 70 per cent of the TCO for non-transport applications. Delivered low-carbon hydrogen costs are expected to drop sharply over the next decade and will account for up to 90 per cent of the total drop in TCOs from 2020 to 2030 across applications with shorter supply chains."

Transport applications benefit most from scale up of transport equipment manufacture -

"Up to 70 per cent of cost reductions for transport applications are from manufacturing scale-up of end-use equipment - Scaling up manufacturing is another way to reduce costs for many hydrogen applications where costs of end-use equipment comprises a large component of TCO (e.g. fuel cells and tanks in transportation). Large-scale industrialisation of components and vehicle integration, together with lower-cost hydrogen fuel, will halve vehicle TCO in the early stages of scale-up for these and similar applications. The scale in manufacturing of equipment will account for up to 70 per cent of this reduction."

The Hydrogen Council report reveals the importance of accelerating growth in production and distribution of very large volumes of low-cost hydrogen to encourage and enable large scale economical manufacture of hydrogen fuel-based transport and other equipment. "Green" hydrogen price is a major consideration, but so too is volume/tonnes of hydrogen produced to enable large-scale end market growth.

Policy shifts required to facilitate relatively constant large scale renewable energy generation for the most efficient and economic production of "green" hydrogen using electrolysis.

Adopting twin policy objectives for the 2022 ISP -

Among the most important policy shifts would be to recognise "Step Change" and "Hydrogen Export" as two distinct primary objectives. Each objective would be neither subsidiary to nor necessarily reliant on the other but could be expected to be supportive of the other, wherever possible.

"Step Change" (also incorporating molecules vs electrons initiatives) would have the primary objective of developing and maintaining energy infrastructure to service the needs of the Australian domestic market, both industrial and consumer, consistent with de-carbonisation goals. This would include increasing renewable generation and employing strategies to smooth the effects of intermittency of solar and wind power. These strategies could include operation of electrolysers producing hydrogen, as well as battery, pumped hydro and other means of storage.

"Hydrogen Export" would have the primary objective of developing and maintaining very large-scale renewable energy infrastructure that would enable maximisation of electrolyser full load operating hours, which is essential for economic "green" hydrogen production and export in high volumes. Achievement of this objective would also likely accelerate domestic hydrogen use and innovation and support molecules vs electrons initiatives. As discussed further below, “Hydrogen Export” might be more appropriately termed “Green Energy Export” to recognise the different forms in which hydrogen might be exported, and to recognise the potential for export of “green” electrons as proposed with Sun Cable’s Australia Asia PowerLink.

Changing and coordinating the policy settings -

Of high importance -

- The policy settings on hydrogen need to change from a domestic led development focus to an export led development focus.
- There should be greater coordination and consistency between Australia's National Hydrogen Strategy and AEMO's Integrated System Planning.

Coordination and consistency between Australia's National Hydrogen Strategy and AEMO's Integrated System Planning -

The one reference to AEMO in "Australia's National Hydrogen Strategy" states,

“*Future energy market planning and reforms will need to account for how hydrogen will change the way energy systems and markets operate. For example, AEMO's Integrated System Plan and current and future electricity market reforms should consider the impact of electrolyser loads and increased need for generation in electricity systems.*”

Surprisingly, I can find no reference in the AEMO draft 2022 ISP to "Australia's National Hydrogen Strategy" ("ANHS"). The ANHS strategies appear to focus on creating domestic demand for hydrogen, per the strategy paper,

From the ANHS foreword -

"*This Strategy sets a path to build Australia's hydrogen industry. We plan to accelerate the commercialisation of hydrogen, reduce technical uncertainties and build up our domestic supply chains and production capabilities. The Strategy looks to initially concentrate hydrogen use in niche hubs that will foster domestic demand. A strong domestic hydrogen sector will underpin Australia's exporting capabilities, allowing us to become a leading global hydrogen player*."

From the ANHS Executive summary -

"*A key element of Australia's approach will be to create hydrogen hubs – clusters of large-scale demand. These may be at ports, in cities, or in regional or remote areas, and will provide the industry with its springboard to scale. Hubs will make the development of infrastructure more cost-effective, promote efficiencies from economies of scale, foster innovation, and promote synergies from sector coupling. These will be complemented and enhanced by other early steps to use hydrogen in transport, industry and gas distribution networks, and integrate hydrogen technologies into our electricity systems in a way that enhances reliability.iii*"

The ANHS strategy, which it is assumed is guiding government policy, appears not to adequately recognize there is already a huge existing largely untapped and growing market for export of cost competitive "green" hydrogen to Asia and other parts of the world. Where there are references to export opportunities these are qualified as being complementary to and mostly arising out of building the domestic market. This is akin to suggesting back in the 1960s and 1970s when Utah Development Company developed massive infrastructure (mines, roads, rail, towns, water, power, airports, and ports) to exploit metallurgical coal deposits in the Bowen Basin in Queensland, to respond to massive and growing demand for metallurgical coal in Asia, it should firstly have developed demand in domestic markets.

Policy to identify REZs most suitable for "Hydrogen Export" -

The submission from here on concentrates on the "Hydrogen Export" objective, with primary emphasis on potential development of necessary infrastructure in the North Queensland Clean Energy Hub REZ. This REZ area has high photovoltaic power potential, includes the Forsayth high wind area, and has the Kidston Pumped Hydro Project under development. The area is also central to any proposals for a Bradfield-like scheme to dam the Upper Burdekin and other North Queensland rivers to divert coastal flood waters inland. There is an opportunity in this REZ to develop a series of pumped hydro facilities, including one capable of very large-scale storage and generation, with a dual purpose of:

1. Smoothing fluctuations in wind and solar power generation across greater than 24-hour time frames to enable continuous 24/7 high load operation of electrolysers for economically producing "green" hydrogen for export and local consumption; and
2. Progressively lifting, and shifting by gravity feed in a westerly direction, a relatively small percentage of total water turnover from upper reservoir of one PH facility to the lower reservoir of the next PH facility in the series. This would enable gravity feed distribution of irrigation water both East and West of the Great Dividing Range.

A submission along these lines has been made to the Prof. Garnaut led Bradfield Regional Assessment and Development Panel appointed by the Queensland Government. The recommendations of the Bradfield Regional Assessment and Development Panel, currently under review by the government, will be relevant to any decision on the series of pumped hydro facilities, and consequently on development of infrastructure for large scale hydrogen production in the North Queensland Clean Energy Hub.

Potential for coordination of energy distribution facilities for both molecule and electron export

Balancing intermittency in renewables generation can be facilitated by widening the power distribution network. Figure 1 below shows proposed long distance high voltage electric power transmission lines in Queensland (Copperstring 2.0) and Northern Territory (Sun Cable's PowerLink).

Figure 1

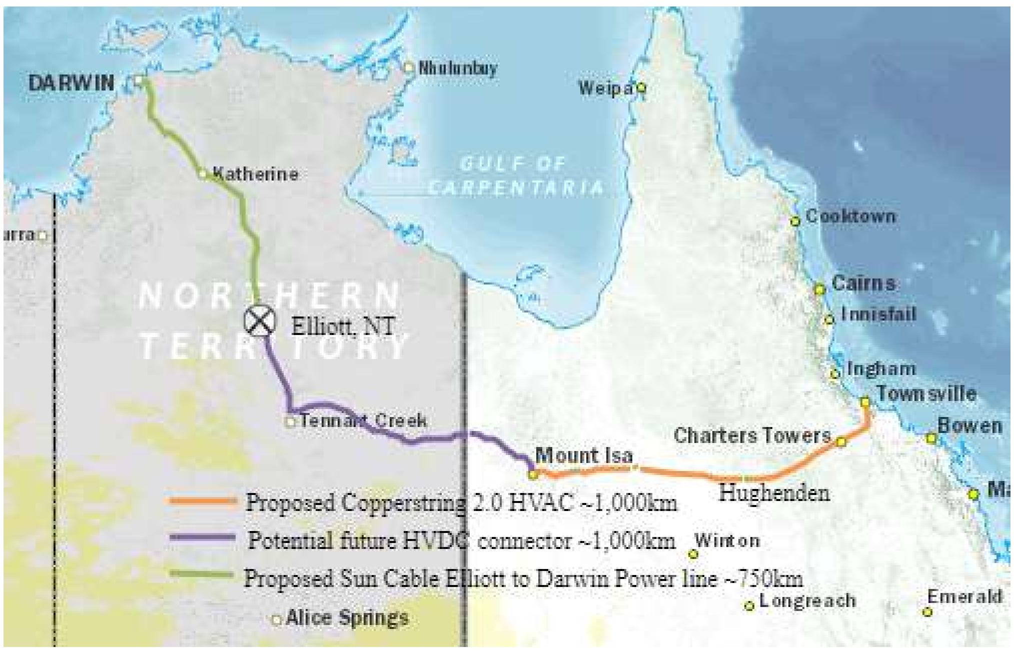


Image source: QTopo Lines and text inserted by author

AEMO's supervisory role does not extend to the Northern Territory. But in the future, there appears to be potential to link Copperstring 2.0 and PowerLink with a HV transmission cable traversing some of the highest photovoltaic power potential land area in Australia. This would effectively link Darwin to the NEM. A March 2019 paper by Prof. Simon Bartlett AM, "Investigation of HVDC Trans-Australian Interconnections" is informative as to likely choice of HVDC-VSC cable to link across the ~1,000 km between Mount Isa in Queensland and Elliott in the Northern Territory. This ABB publication, "Future directions in HVDC transmission Technologies for bulk power transmission are evolving fast", is also highly informative. Some of the advantages are the ability to connect solar and wind farm output along the route of the cable and the capability of bi-directional power transmission, as well as low power losses and high capacities. Prof. Bartlett's proposals included a total of 4,000km of HVDC cable from Queensland to South Australia and across the Nullarbor to Western Australia. A link from Mount Isa to

Elliott would be far less distance at ~1,000km and might have far greater commercial imperatives (extension to Port Hedland W.A. might also be feasible in the longer term - ~1,650km west in a straight line, ~1,900km following existing road network.) Considerable load balancing could be achieved in the East in the North Queensland Clean Energy Hub through a combination of wind and solar and the very large-scale pumped hydro capacity that is possible. Sun Cable plans to load balance with the world's largest battery. Linking both systems should add considerably to load balancing flexibility and to promotion of renewable energy generation growth. There is huge demand in Asia for "green" energy in the form of both electrons and molecules. If end use is for domestic and industrial electricity consumption, then supply of electrons makes more sense than supply of molecules, and vice versa for applications such as FCEV. Excerpts from this publication, "Philippines HVdc interconnector to the Asia Pacific Super Grid" gives an insight into what our Asian neighbour prospective customers are envisioning for exports of neutrons to their countries.

"Highlights

- High voltage submarine cable may interconnect Japan, Taiwan, and the Philippines.
- The proposed route circumvents geopolitical disputes in the South and East China Seas.
- Bathymetric survey shows water depths feasible for submarine power cable installation.
- Super grids eliminate congestion constraints to the expansion of the renewables.
- VSC-HVdc smooths the variability of renewables by supporting bidirectional power flow.

Abstract

High voltage direct current (HVdc) interconnector is an essential component for large-scale high voltage infrastructure expansion, duplication, and integration of existing power grids. High-voltage alternating current (HVac) grids are increasingly facing hybridization with HVdc, due to the augmented penetration of renewable power sources, and the technological maturation of Offshore Power Systems (OffPS). The authors investigate a submarine interconnector route, poorly explored by the literature, linking Japan, Taiwan, and the Philippines. This proposed offshore HVdc interconnector would support power trading between Japan, Taiwan, Philippines, Indonesia, and Australia. The proposal circumvents some contested territorial disputes in the East and South China Seas. The outcome of this research investigation is a Super-Grid topology that unveils some basic requirements of technical feasibility and reveals enhanced technical and environmentally-friend performance as compared to existing isolated national power grids of the affected countries. The proposed interconnector route lays down in seabed depth not exceeding 3 km. It aims at transmitting tens of gigawatts, clearing the path for a more sustainable and renewable-energy society in Japan, Taiwan, and the Philippines. This HVdc interconnector is still in the initial stage of feasibility studies, and it inspires further research on a possible and future Asia Pacific Super Grid."

I confess I am no expert, but all the literature I have read on HVDC versus HVAC, in a world embracing increasing renewables penetration and long-distance power transmission, makes me question why Copperstring 2.0 is adopting HVAC, when it appears to be the least suitable technology for proposed present and potential future use.