Australian Academy of Science

Submission to the *National Hydrogen Strategy* discussion paper

The Australian Academy of Science welcomes the opportunity to provide comment on the *National Hydrogen Strategy* discussion paper. The Academy strongly supports the goal of developing a global low- and zero-emissions energy economy, and strongly supports the Council of Australian Governments in developing a strategy that sees Australia playing a strong role in this economy.

The hydrogen economy should ultimately be based on so-called “green” hydrogen, using renewable energy sources. Hydrogen generated using energy from fossil fuels (“black” hydrogen, using coal, or “blue” hydrogen, using natural gas) is not sustainable. Both black and blue hydrogen must be coupled with carbon dioxide sequestration technologies if they are to be considered a low-emission fuel, considerably increasing the expense and the technical requirements. Green hydrogen is generated using heat or electricity produced from renewable sources. Australia would need to implement carbon capture and storage (CCS) at an unrealistically rapid pace over the next 15-20 years to sequester the emissions from fossil fuel based thermochemical hydrogen generation if it was to meet the projected Australian export opportunity[1]. The CCS storage capacity required by 2040 to support the generation of black or blue hydrogen is similar in capacity to the total capacity of all CCS facilities currently operating worldwide[2]. Conversely green hydrogen, produced from renewable sources, has no embedded carbon usage. Australia is already on track to provide the necessary renewable electricity to meet the projected Australian export opportunity by 2040.

Although the submission relates to hydrogen, it should be noted that hydrogen gas is itself only a part of the supply chain, with ammonia as a potential carrier for hydrogen in the supply chain. Furthermore, currently a third of the emissions due to global energy use have no commercially viable alternative to fossil fuels. These include heavy freight, aviation, and industries like iron and steel, cement, chemicals and aluminium. To truly decarbonise, we need to find carbon-free energy vectors and fuels that can replace fossil fuels in a range of sectors.

The Academy’s responses to the consultation questions follow.

What do you think are the two or three most significant recent developments in hydrogen?

There has been steady development in all aspects of the hydrogen usage chain from the catalyst level to the system level. Generation efficiency is improving steadily. These developments have been characterised by gradual improvement rather than major breakthroughs.

The most relevant development in hydrogen is the falling cost of renewable electricity generation over the past ten years, driven by factors such as decreasing supply chain costs, improving technologies and increased competition.[3] The growth of the Australian renewable energy industry will be key to providing zero-carbon embedded electricity for green hydrogen generation.

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[1] See the ACIL Allen report: *Opportunities for Australia from hydrogen exports”,* 2018, for projected Australian export quantities

[2] Calculation, based on data from CSIRO *National Hydrogen Roadmap.* See: *Number-crunching the Hydrogen Reports*, by Fiona J Beck, ANU

[3] See, for example, Lazard’s Levelized Cost of Energy Analysis V 12.0. https://www.lazard.com/media/450784/lazards-levelized-cost-of-energy-version-120-vfinal.pdf

The recent Japanese decision to make hydrogen a significant part of its economy will also drive interest in Australia.

Crucially, the demand for hydrogen is being driven largely by the need for countries to decarbonise and meet their Paris targets. In this context, hydrogen for export that contains embedded carbon may not be a desirable product in the mid-to-long term.

What are the most important safety issues to consider in producing, handling and using hydrogen in Australia?

Handling hydrogen carries risks, particularly in large-scale production facilities. However, there are current regulatory processes that mitigate risks for the production, transport and use of explosive gases. It is expected that these existing regulatory policy processes can be adapted to increased use of hydrogen. In addition, Australian governments will be able to adapt international regulatory structures from economies such as Japan, which use hydrogen. The development of regulatory structures for hydrogen should be a high priority.

It should be noted that hydrogen gas is not toxic, corrosive or oxidising. The chief risk is uncontrolled combustion.

Risks from hydrogen transport can be mitigated using ammonia as a carrier. Accessible detection devices and appropriate action plans would mitigate risks from small scale loss of hydrogen containment.

What environmental and community impacts should we examine?

Production of hydrogen at large scale will encourage large-scale wind and solar electricity generation. These will require consideration of issues relating to land use, including consideration of the impact on traditional owners.

The shift towards mainstream use of a fuel source which is currently relatively expensive may disproportionately affect disadvantaged groups. This impact should be examined and accounted for.

Production of hydrogen at large scale will require access to large volumes of clean water (9 tonnes of water per tonne of hydrogen). If groundwater is used, the implications of groundwater extraction on community access to drinking water and on the environment need to be considered.

How can Australia influence and accelerate the development of a global market for hydrogen?

Australia has vast renewable energy resources, including some of the best solar and wind assets in the world. Additionally, Australia has experience with exporting liquified natural gas, including a skilled workforce, infrastructure, and established trade partners. Because of this Australia has an opportunity to rapidly develop a hydrogen export industry based on renewable energy, which would demonstrate the feasibility of a truly zero-carbon approach to the world.

Meeting the projected demand for Australian zero-carbon hydrogen exports on a short timescale would require water splitting via electrolysis, using electricity. This would require us to nearly double the electricity supply in Australia by 2040. However, Fig. 1 suggests that due to the rapid growth of the renewable energy industry in Australia[4] it is feasible to provide this additional electricity with renewable energy by 2040, if the growth of the renewable energy capacity continues at its current rate. Notably, this projection does not rely on any significant technology improvements or breakthroughs, and only a marginal increase in electrolyser efficiency over the next 20 years.

The expansion of the electricity market would necessarily require significant infrastructure development, in addition to renewable energy installations, to accommodate the growth of the electricity network including grid upgrades and storage (e.g. pumped hydro, batteries, and demand management) to balance the grid. However, hydrogen generation from electrolysis could play a significant role in grid stabilisation, providing grid firming services and a way to store electricity on many different time scales. Australia has the expertise necessary to pioneer these techniques and become a global example of how to manage a 100% renewable national grid.

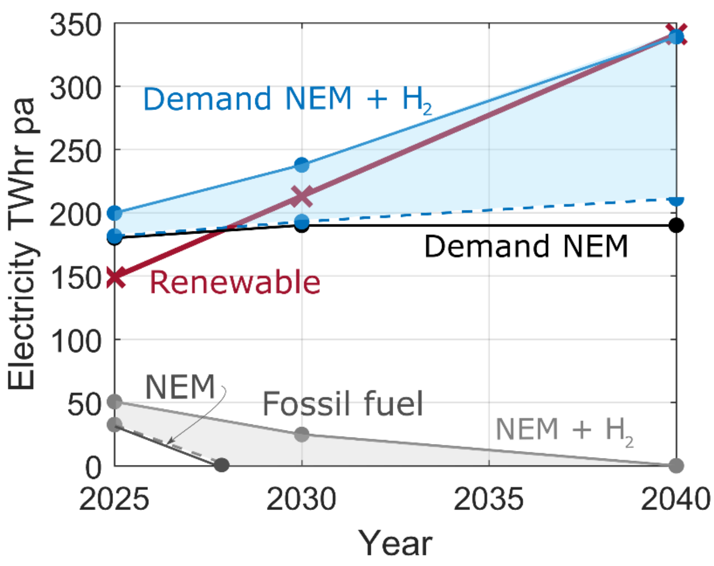

Figure 1*: Electricity demand per annum for the National Energy Market, (NEM black) and with the additional electricity needed to generate hydrogen with electrolysis (NEM + hydrogen, blue). The upper (solid line) and lower (dashed line) bounds representing the high and low demand for Australian hydrogen projected by the recent ACIL Allen report. The red line shows the projected renewable energy electricity generated from per annum (red). The amount of electricity generated with fossil fuels (grey) required to meet the balance of demand is also shown, once again the shaded areas cover the low and high hydrogen demand scenarios. Source: Dr Fiona J Beck, ANU*

What are the top two or three factors required for a successful hydrogen export industry?

The most important factor is price. Hydrogen is currently very expensive compared to hydrocarbon fuels, and will need to be competitive for a viable market. There will need to be improvements in the manufacture of water-splitting devices. The focus should be on increasing the scale of hydrogen production infrastructure. For example, ARENA is currently supporting projects geared at producing

[4] See: Baldwin, Blakers, Stocks: Australia's renewable energy industry is delivering rapid and deep emissions cuts, 2018

hydrogen for an international market. Several of these projects are directed towards manufacturing catalyst-coated components from cheap materials.

Storage and shipping capacity is necessary. Hydrogen is challenging to ship in gas form. Using standard cryogenic methods to provide low temperature, high pressure storage suitable for shipping can use up to a third of the energy value of hydrogen. There is the opportunity to address these challenges by integrating ammonia into the hydrogen chain. Hydrogen reacts with atmospheric nitrogen under high temperature and high pressure conditions in the presence of a catalyst to form ammonia (the Haber-Bosch Process), which can be shipped more easily. This process is currently used to generate ammonia for fertiliser, and the technology for shipping and storing ammonia is well established. Ammonia can be converted back to nitrogen and hydrogen either at a distribution point or at the point of use. Ammonia might in some cases be used directly as a fuel in large vehicles; it is plausible that ammonia could become a staple fuel in a hydrogen economy.

As well as using green hydrogen and atmospheric nitrogen to produce hydrogen, ammonia can be synthesised catalytically using water and atmospheric nitrogen, a process similar to hydrogen generation through electrolysis of water. This will likely be more efficient than using the Haber-Bosch process for applications where the hydrogen is to be used remotely from where it is generated.

What are the top two or three opportunities for the use of clean hydrogen in Australia?

100% renewable energy penetration in the grid: Hydrogen generation by grid-connected electrolysis could help to further incentivise the growth of the renewable energy industry in Australia, and stabilise a 100% renewably powered grid.

Solar generation: Australia has a potentially massive capacity for generation of hydrogen using solar power. NASA insolation data shows Australia receives the largest intensity of solar radiation of any land mass of earth (see Figure 2). A 250 km x 250 km solar farm in Western Australia could generate 25 petawatt hours per year, which was the world's current total electricity usage as of 2016[5]. Active

[5] See https://www.iea.org/statistics/electricity/

pursuit of solar power, and use of solar power to generate hydrogen, would see Australia becoming a major global supplier of energy.

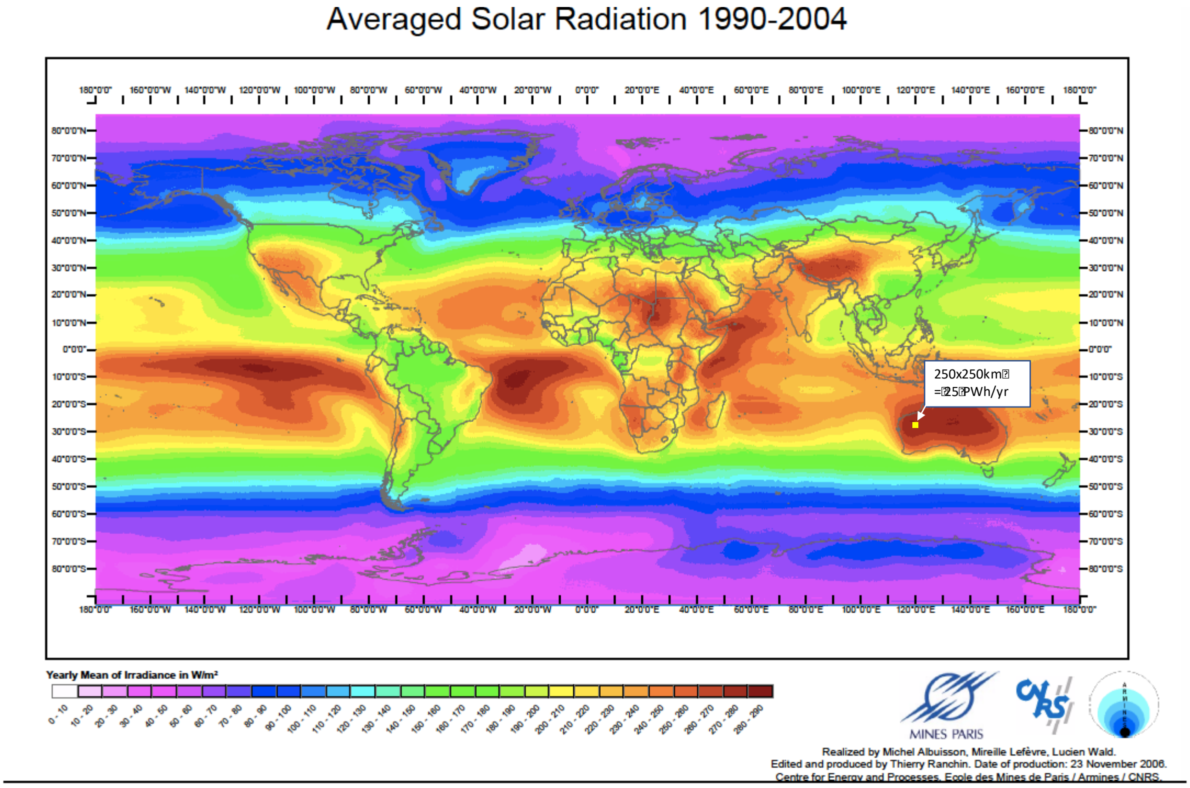

Figure 2. Source: Albuisson et al, http://www.soda-pro.com/documents/10157/272214/map_ed_13_world.pdf/253d2308-333f-42ab-b1f6-cb751d679c4

Vehicles and vehicle fleets: Large organisations with vehicle fleets such as universities, taxi companies, CSIRO, or governments are in a position to make efficient use of hydrogen power, with centralised fuelling stations and other infrastructure. Support for these facilities through mechanisms such as ARENA allows initial hydrogen infrastructure to be installed at strategic sites, which could then be expanded as the technology and policy environment matures.

Expanding demonstrator facilities: A number of demonstrator facilities already exist, such as the Canberra Institute of Technology/Evoenergy hydrogen facility, or the Hyundai hydrogen fuelling station in Macquarie Park. As with the vehicle fleets, these facilities provide a necessary bridge between technology development and widespread adoption.

Power-to-gas: Excess grid power can be used when cheapest to power electrolysis, meaning that hydrogen could be generated flexibly and cost-effectively. Any excess power could theoretically be used, as long as there is infrastructure to store and use the hydrogen.

Ammonia cracker technology: CSIRO cracker technology allows versatile use of hydrogen by catalytically converting ("cracking") ammonia into hydrogen and water at the point of use.

Mining: Demand for catalyst materials will potentially stimulate Australian mining exploration and production.

International research collaboration: Participation in international research consortia will allow Australian research to be integrated with the world hydrogen economy.

What are the main barriers to the use of hydrogen in Australia?

As discussed above, price is currently a barrier. A key component of the price barrier is the capital cost of electrolysis plants. These are currently at an early stage of commercial development and there is substantial opportunity for costs to reduce due to economies of scale, as well as increase in efficiencies. Since the barrier is capital cost, any electrolysis systems installed should be run at as close to 100% capacity as possible: they should be connected to the electricity grid. The limitation of capital cost also means that some applications are likely to become economic much later than others. For example, seasonal storage, where the electrolyser is run for only a fraction of the year, is likely to be economic relatively late compared to other applications.

A clear pricing signal will be important to encourage the growth of a green hydrogen industry.

Current projects are focussed on an export model; the lack of local infrastructure means there is no local market.

Australia must find more mineral deposits to meet the needs of the catalytic process.

Safety and policy frameworks are not in place, which presents a barrier to adopting hydrogen technology.

Public education about the use of hydrogen would be beneficial in generating public demand.

What are some examples where a strategic national approach could lower costs and shorten timelines for developing a clean hydrogen industry?

Support for pilot facilities using hydrogen sources would leverage government investment to demonstrate the potential of the technology. Hydrogen technology aligns with national strategic goals, and should be made a priority.

Support for the entire innovation spectrum, from basic R&D to market development approaches. For example, in R&D it is essential to maintain Australian leadership in hydrogen through near-term research in advanced catalysts as well as longer term research in areas such as photo-electrochemical conversion and microbial conversion of biomass to hydrogen.

Coordination of the national research effort, such as a CRC for Hydrogen, would provide strategic direction to the national research effort.

Continued support for ARENA will allow strategic investment in renewable power research and development. ARENA could usefully be expanded to support international research collaborations directed towards transformational activities.

Market development approaches provide support to new industry when cost is a barrier. In previous decades, support by Denmark for wind and by Germany for solar via feed-in tariffs was instrumental in reducing the cost of renewable electricity to the point where it is now the cheapest form of new electricity. In that case the support was via a fixed price per kWh of generated electricity. More recently, the reverse auctions in the ACT and Victoria have been very successful in lowering the price of large scale renewable electricity in Australia. For hydrogen to successfully develop as an industry, market development mechanisms will be necessary.

What are Australia's key technology, regulatory and business strengths and weaknesses in the development of a clean hydrogen industry?

Australia has a high level of water electrolysis expertise through decades of ARC and CRC investment, and this should be maintained to enable Australia to retain a leading position in hydrogen research. However, there is no hydrogen facility manufacturing capacity at present, and little expertise in the translation of this technology. Downstream expertise needs to be developed.

What workforce skills will need to be developed to support a growing clean hydrogen industry?

Australia should cultivate engineering expertise for the manufacture, installation and maintenance of hydrogen facilities.

Australia's natural gas infrastructure should be developed towards a hydrogen infrastructure, which will require training and skill development. There is potential for retraining people with expertise in existing natural gas infrastructure.

Chemical engineering companies are developing expertise in small and large scale gas engineering.

The hydrogen industry has the potential to evolve quickly once demonstrated, and will require a skilled and specialised workforce. It would be beneficial to train a pool of competent graduates versed in hydrogen production, generation, storage and transportation.

What areas in hydrogen research, development and deployment need attention in Australia? Where are the gaps in our knowledge?

R&D is currently well covered in Australia, but there are benefits in coordinating the research effort through a mechanism such as a cooperative research centre. A H2-CRC would provide strategic direction to hydrogen research and would be focussed on developing deployable, market-ready hydrogen products such as vehicle cells and catalysis plants. It would complement the Future Fuels CRC.

The infrastructure requirements for handling and storage of hydrogen need to be explored, and the readiness for deployment in vehicles needs to be assessed. Infrastructure will almost certainly require government support.

There is a clear opportunity for Australia to take the lead in training and exporting the next generation of skilled hydrogen industry personnel. Training centres will need to be developed to exploit this opportunity.

The Academy also notes a number of areas of potential research interest:

- Combining fuel cells to intermittent electricity storage sources (such as battery, supercapacitor) to supply on-demand energy conversion and reduce the complexity of current fuel cell technologies and small scale hydrogen storage devices.
- Earth-abundant, low mass loading, durable catalytic materials to produce hydrogen from various sources; understanding the synergistic nature between catalyst support and active metal and the translation towards higher throughput synthesis of these materials.

- Solid state electrolyte proton-exchange membrane fuel cells will allow more portable and accessible electricity production.
- Combining various fuel sources to produce hydrogen, which can be used in a fuel cell directly. For example, using alcohol to generate hydrogen which is then used in a fuel cell to generate electricity.
- Regenerative/reversible fuel cell technologies (next generation of devices linked with large scale implementation).
- Holistic/interconnected system solutions and engineering considering the sourcing of renewable energy to generate hydrogen, storage of hydrogen (such as in ammonia, formic acid, or metal hydride bonds), and direct utilization though fuel cells to generate electricity in a rationally controlled way.

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