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The Potential Role of Nuclear Technology in the Cost-effective Production of Hydrogen in New South Wales

A Submission by SMR Nuclear Technology Pty Ltd to the NSW Legislative Council's Standing Committee on State Development, February 2021

INTRODUCTION AND EXECUTIVE SUMMARY

According to the Australian Government's Technology Investment Roadmap, hydrogen will be a transformative fuel for Australia, provided it can be produced by a low emissions technology at a competitive cost of <A$2/kg.

The process of electrolysis of water to produce hydrogen is likely to be the enabling technology for the achievement of this goal.

Nuclear power produces low-emissions electricity and heat for electrolysis and can potentially produce hydrogen at the target cost.

Variable renewable energy (VRE) (solar and wind) and hydro also produce low-emissions electricity for electrolysis , but may find it difficult to do so at the target cost.

Electrolysis can be made more efficient and can therefore potentially lower costs by supplying some of the required energy as process heat. VRE and hydro cannot produce process heat directly.

NSW has the opportunity to look at developments worldwide and promote innovative technologies that have the potential to produce hydrogen at a competitive cost.

NSW also has the advantage of the Australian Nuclear Science and Technology Organisation (ANSTO) located in Sydney and world-class technology universities within the State.

The development of hydrogen production in NSW would lead to the establishment of an entire new industry with long-term environmental, technological, economic and social development benefits for the people of NSW and its internal regions. These benefits would flow on progressively to other industries.

1 Hydrogen Strategies

Many countries are deploying hydrogen production facilities. A February 2021 paper[1] by the World Nuclear Association provides an up to date review of projects worldwide.

The Federal Government and all of the States and Territories are each developing action plans for the production, supply, use and export of hydrogen (see Appendix A).

Hydrogen may also be competitive in the production of ammonia for export.

Most plans depend on the production of hydrogen by electrolysis, with the electricity supplied by variable renewable energy (VRE) sources (solar and wind). Electrolysis plants work more efficiently and have a longer life when supplied by a reliable source of electricity. VRE sources require additional batteries or pumped hydro as back-up inherently increasing production costs. The CSIRO estimated[2] the current cost of hydrogen production from PV + battery to be $28/kg with the potential to reduce to $11/kg by 2030. This is still far away from the target <$2/kg.

Alternative ideas (e.g. HESC Victoria) propose coal gasification, but commercial scale carbon capture and storage is necessary to make the option viable from an emissions point of view and this again would add to the costs.

There is an increasing number of demonstration projects worldwide using nuclear technologies to produce hydrogen.

NSW has the opportunity to look at developments world wide and promote innovative technologies that have the potential to produce hydrogen at a competitive cost.

NSW also has the advantage of the Australian Nuclear Science and Technology Organisation (ANSTO) located in Sydney and world class technology universities within the State.

2 Hydrogen Production Technologies

2.1 Steam Methane Reforming (SMR)

SMR is the current dominant technology for hydrogen production worldwide. 95% of the 10 million metric tons of hydrogen produced per year in the US is from SMR at a cost of <US$2/kg, depending on the cost of gas.

Natural gas (CH_4) is combined with steam (H_2O) to produce hydrogen and CO_2. Continuing use of SMR in a low emissions future will depend on a heat source other than gas for the steam and carbon capture and storage for the CO_2 both of which increase the cost.
Heat from high temperature reactors can be used to replace natural gas requirements to produce steam for the traditional SMR process.[3]

2.2 Coal gasification

4% of US hydrogen production is by coal gasification. The carbon in coal is treated with oxgen and steam under high temperature and pressure to produce hydrogen.

2.3 Electrolysis

The principle of hydrogen production by electrolysis is for a low emissions technology such as VRE, hydro or nuclear to supply electricity to electrolyse water resulting in the production of hydrogen and oxygen only. There are several electrolytic processes currently commercially available:

Alkaline electrolysis (AE) is a mature technology operating at 30-80°C[4]. The electrolyte is liquid alkaline potassium hydroxide (KOH). Large plants of 95-160 MW have operated in several countries (e.g. India, Zimbabwe, Norway, Egypt) producing 20,000 – 30,000 Nm^3/h generally from hydropower[5] (Nm^3/h = normal gas flow rate at 0°C, 1 bar pressure, i.e. flow normalised for comparison.) This form of electrolysis today accounts for 4% of global hydrogen production. AE plants are best operated at constant load and therefore are not suitable for direct connection to VRE. The disadvantages of AE are the limited current densities, low operating pressure and low energy efficiency. The advantage is the comparative low cost of the plant.

Proton Exchange Membrane (PEM) [6] was developed to overcome the limitations of AE. A PEM electrolyser operates at 20°C – 90°C with lower gas permeability, high proton conductivity, lower thickness, high current density, high efficiency, compact design, high gas purity, fast response and the high operating pressure is suitable for a hydrogen supply system. The cathode is typically a noble metal which makes the plant more expensive than an AE plant[7]. The main challenge is to reduce the cost of the PEM electrolyser.

Solid Oxide Electrolysis (SOE) [8] uses a ceramic metal compound as electrolyte and operates at 700°C – 1,000°C. SOE electrolysers have high efficiency, work at high pressure and use lower cost electrodes. It produces ultra-high hydrogen purity. Because some of the energy required to split the water is provided as thermal energy in the form of steam, it has the potential for higher efficiency using less electrical power. This heat could be provided directly by a nuclear power plant. This is the High Temperature Steam Electrolysis (HTSE) process. France (CEA) and China are actively developing this process. In the USA, there is a 25 kW HTSE test facility at Idaho National Laboratory (INL)[9].

2.4 Chemical Technologies

Several chemical technologies have been developed but have not yet been commercially successful. This could change as process heat from nuclear reactors becomes available. The CSIRO Hydrogen RD&D report (Dec 2019)[10] states "ït is also possible to source the heat required for thermochemical processes from nuclear power, however this technology is not covered in detail in this study". Whilst nuclear power plants are prohibited in Australia, the CSIRO cannot seriously consider nuclear energy sources in their research.

Sulphur-Iodine was invented by General Atomics in the 1970's. It is a 3 step process operating at 360°C – 850°C. The chemicals are recycled and the only products are hydrogen

and oxygen. It has the potential for large-scale, competitive cost and high efficiency production.[11] Japan, China, South Korea and India are actively developing this technology. China[12] has an integrated system demonstration producing 1 Nm^3/hr.
Japan is using 950°C heat from the HTTR Very High Temperature Gas Reactor for this process.

Copper-Chlorine is a 4-step process operating at 580°C[13]. AECL Canada are developing this process for their CANDU reactors[14]. The University of Ontario Institute of Clean Energy Research Lab has a lab-scale demonstration plant. This has the potential for low cost hydrogen.

Hybrid Sulphur[15] was developed in the 1970's by Westinghouse. The electrolysis of a solution of sulphur dioxide in sulphuric acid at 80°C produces hydrogen and sulphuric acid. The sulphuric acid is decomposed at 450°C / 800°C to regenerate sulphur dioxide. This process uses common, cheap chemicals.

3 Light Water Nuclear Power Reactors for Hydrogen Production

The majority of nuclear power reactors operating worldwide, and under construction, are Pressurised Water Reactors (PWR) which operate with a steam outlet temperature of 275°C - 325°C.

Most power plants, including nuclear power plants (NPP), have to buy hydrogen for cooling the generator section of their steam turbine generators.

The US Department of Energy (DOE) is joint funding several demonstration projects under its DOE H_2@Scale initiative[16]. Electrolysers are to be installed at existing NPP sites for self supply of the plant's hydrogen use (offsetting O&M costs) and producing hydrogen for sale including injection into gas pipelines.

- **Energy Harbour** Davis Besse 908 MW PWR, Ohio.
  $11.4m project, DOE providing $9m
  PEM electrolyser producing 800-1000kg hydrogen per day[17]
  Requires ~2MW of electricity from the 908 MW NPP.
  Export hydrogen to supply transport fleets in Ohio

- **Xcel Energy** NPP in Minnesota
  Partnership with Idaho National Laboratory, with US$10m in federal funding
  Pairing high-temperature steam electrolysis with commercial heat to split water and produce hydrogen.

- **Arizona Public Services (APS)** Palo Verde plant Phoenix, Arizona. Largest NPP site in the USA with three PWRs, output 4,000 MWe
  Use hydrogen for peaking gas turbines and transportation

- **Exelon**[18] has the largest fleet of NPPs in the USA. Project with Idaho National Laboratory, Argon National Laboratory, National Renewable Energy Laboratory and

Nel Hydrogen to site a 1 MW PEM electrolyser at a Exelon NPP. Total project $7.2m, $3.6m of this from DOE. (Nel hydrogen has installed over 3,500 electrolysers).

Note: There is an Australian example of a Nel electrolyser installed at a power plant to produce hydrogen for site use. Alinta's Northern Power Station (2 x 260 MW coal fired) required 30 hydrogen cylinders/week. Nel installed a 2 Nm^3/hr PEM electrolyser which supplied all the hydrogen required at higher purity. Like all coal fired power stations in South Australia, Northern PS is now shutdown.

The NuScale Power (USA) Small Modular Reactor is licensed by the US NRC (nuclear regulator) and is ready for deployment. Each 250 MW (thermal) module can generate 77 MWe and a plant can have 4, 6 or 12 modules.

NuScale carried out a study using steam from the reactor at 302^{o}C, boosted to 800^{o}C for a HTSE electrolyser. One module could produce 2,053 kg/hr hydrogen – 50 metric tons of hydrogen/day[19].

The International Atomic Energy Agency (IAEA) has developed the **""Hydrogen Economic Evaluation Program" (HEEP)** which has numerous options to calculate the cost of hydrogen generation, storage and supply. This has been used to study hydrogen production from the new pressurised water reactors under construction in Turkey at Akkuyu.[20] Results show hydrogen production costs of \$3.18/kg H_2 to \$6.17/kg H_2.

4 Very High Temperature Gas Reactors (VHTR)

The VHTR is a helium cooled, graphite moderated, inherently safe reactor with an outlet temperature of >900^{o}C that makes it especially suited to high efficiency hydrogen production.

Construction of the first modern VHTR (HTR-PM) has been competed at Shandong in China with 2 x 250 MWTh reactors coupled to a single 210 MWe turbine generator.

The sulphur-iodine process for hydrogen production, which requires a temperature of 850^{o}C is ideally matched to a VHTR.

In Japan, the 30 MWTh HTTR has been operating since 1998 with an outlet temperature of up to 950^{o}C. the HTTR has been coupled to a hydrogen production demonstration plant. China has a 2 Nm^3/hr integrated system demonstration plant and South Korea and India are also actively developing this technology.

Australia is a member of the GEN IV Forum carrying out the R&D for these advanced reactors. ANSTO's expertise in high temperature materials is making a major contribution to these projects.

The HOLOS microreactor is a VHTR designed to produce heat and electricity for an electrolyser for a hydrogen refuelling station for trucks. Conceptually, 4 x 15 MW modules will supply a fuelling station with 12 truck positions, allowing 576 trucks to be refueled per day. The HOLOS microreactor has been designed to fit within a shipping container.

5 Molten Salt Reactors (MSR)

Molten salt reactors with an outlet temperature of 700 – 800°C are also very suitable for hydrogen production.

A leading contender is Canadian Terrestrial Energy's Integral Molten Salt Reactor (IMSR)[21]. The IMSR design is being reviewed by the Canadian Nuclear Safety Commission (CNSC). They are developing hydrogen production using the hybrid sulphur process.

Australian Nuclear Science and Technology Organisation (ANSTO) is also contributing to the R&D required for molten salt reactors, particularly in developing materials suitable for corrosive salt.

6 UK Hydrogen Program

In February 2021, the UK Nuclear Industry Association submitted its Hydrogen Roadmap[22] to the UK Government claiming that nuclear-hydrogen production would support the Government's ambition to 'level-up' regions of the UK facing economic challenges. The Association estimated that development of a hydrogen market in the UK could contribute up to £18 billion in Gross Value Added (GVA) annually and could add 100,000 jobs to the economy.

7 Conclusions

The Australian Governments's Technology Investment Roadmap has identified hydrogen as a key technology challenge and opportunity. Nuclear technology can make a valuable contribution to achieving this.

Advanced nuclear reactors coupled with higher temperatures, can increase the efficiency of hydrogen production technologies resulting in a cost-effective source of hydrogen with low emissions and minimum land requirements. Hydrogen may also be a competitive application for producing ammonia for domestic use and for export.

Other countries are developing high temperature hydrogen production technologies and could gain a global advantage. There are an increasing number of demonstration projects worldwide using nuclear technologies to produce hydrogen.

NSW has the opportunity to look at developments world wide and promote innovative technologies that have the potential to produce hydrogen at a competitive cost.

NSW has the advantage of the ANSTO being located in Sydney and world class technology universities within the State.

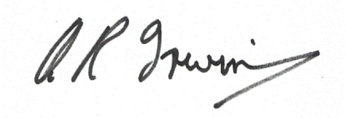
The development of hydrogen production in NSW would lead to the establishment of an entire new industry with long-term environmental, technological, economic and social development benefits for the people of NSW and its internal regions. These benefits would flow on progressively to other industries.

SMR Nuclear Technology Pty Ltd (SMR-NT) has been pleased to provide this submission to the NSW Standing Committee on State Development and stands willing to expand on these and any other issues that the Committee may wish to raise in evidence to the Committee.

SMR-NT is an independent Australian-owned specialist consulting company based in Sydney.

SMR-NT was established in 2012 to advise on and facilitate the siting, development and operation of safe nuclear power generation technologies.

SMR-NT's directors have over 100 years of combined experience in power generation, including nearly 50 years of nuclear power generating experience.



Tony Irwin
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February 2021

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[2] CSIRO 2016 Cost assessment of hydrogen production from PV and electrolysis

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[10] https://www.csiro.au/en/Showcase/Hydrogen

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[16] US DOE https://www.energy.gov/sites/prod/files/2020/10/f79/IND%20FOA%20FY20__%20Summary-Abstract%20ARD-20-22098%20Northern%20States%20Power.pdf

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[19] https://www.nuscalepower.com/benefits/diverse-applications

[20] Sorgulu, F., and I. Dincer. 2018. Cost evaluation of two potential nuclear power plants for hydrogen production. *International Journal of Hydrogen Energy*, 43(23) 10522-10529. https://doi.org/10.1016/j.ijhydene.2017.10.165

[21] https://www.terrestrialenergy.com/

[22] Nuclear Industry Association, Hydrogen Roadmap, February 2021. www.niauk.org

Appendix A – Federal, State and Territory Hydrogen Strategies

Federal Australian Plan:

COAG Energy Council. 2019. *Australia's National Hydrogen Strategy*. Canberra, ACT: Commonwealth of Australia. https://www.industry.gov.au/sites/default/files/2019-11/australias-national-hydrogen-strategy.pdf

- Agreement between the Australian, Victorian, and Japanese governments related to the production and exportation of hydrogen.

CSIRO. 2020. "*National Hydrogen Roadmap*." CSIRO. https://www.csiro.au/en/Do-business/Futures/Reports/Energy-and-Resources/Hydrogen-Roadmap

Shillington, Paul, and Michael Brady. 2020. Australian Hydrogen Projects Paper. *Hogan Lovells*. https://www.hoganlovells.com/~/media/hogan-lovells/global/knowledge/publications/files/2020/australian-hydrogen-projects-paper.pdf?la=en

Northern Territory:

Department of Trade, Business and Innovation. 2020. *Northern Territory Renewable Hydrogen Strategy*. Darwin, NT: Northern Territory Government. https://industry.nt.gov.au/__data/assets/pdf_file/0014/905000/nt-renewable-hydrogen-strategy.pdf

- Large scale and household solar energy production and water to produce hydrogen through electrolysis.

Queensland:

Department of State Development, Manufacturing, Infrastructure and Planning. 2019. *Queensland Hydrogen Industry Strategy, 2019-2024*. Brisbane, QLD: Queensland Government. https://www.dsdmip.qld.gov.au/__data/assets/pdf_file/0018/12195/queensland-hydrogen-strategy.pdf

Trade & Investment Queensland. 2020. *Queensland Hydrogen*. Brisbane, QLD: Queensland Government. https://www.tiq.qld.gov.au/download/business-interest/invest/Queensland-Hydrogen-Prospectus-March-2020.pdf

South Australia:

Department of Energy and Mining. 2018. *South Australia's Hydrogen Action Plan*. Adelaide, SA: Government of South Australia. http://www.renewablessa.sa.gov.au/content/uploads/2019/09/south-australias-hydrogen-action-plan.pdf

- Utility scale solar PV, wind and rooftop solar PV and battery storage to produce hydrogen by electrolysis.
- The Government of South Australia and AGN have proposed an A$11.4 million project comprised of a 1.25MW Siemens PEM electrolyser with the plan to demonstrate the feasibility of blending VRE produced hydrogen into the South Australian gas network, at Hydrogen Park South Australia (HyP SA).

Tasmania:

Department of State Growth. 2020. *The Draft Tasmanian Energy Action Plan 2020*. Hobart, Tas: Tasmanian Government. https://www.stategrowth.tas.gov.au/__data/assets/pdf_file/0011/241112/TREAP.PDF

Hydro-Electric Company. 2019. "Hydrogen." Hydro Tasmania. https://www.hydro.com.au/clean-energy/hydrogen

- Hydroelectric and wind resources to provide energy for the electrolysis of water.

Victoria:

HESC – Hydrogen Energy Supply Chain project

Hydrogen Engineering Australia. 2020. "Hydrogen Energy Supply Chain." https://hydrogenenergysupplychain.com/about-hesc/

Hydrogen Engineering Australia. 2020. "Latrobe Valley." https://hydrogenenergysupplychain.com/latrobe-valley/

2018. Hydrogen Energy Supply Chain. Hydrogen Engineering Australia. https://hydrogenenergysupplychain.com/wp-content/uploads/2018/04/HESC-Fact-Sheet-FINAL.pdf

- Produce hydrogen gas from brown coal in Latrobe Valley, which is then transported to the Port of Hastings by land before being transported to Japan by sea.
- Coal gasification with oxygen to form syngas of CO and H_2. Syngas purification by steam produces H_2 and CO_2 allowing for H_2 separation.

- Commercial-scale carbon capture and storage necessary to make option viable from emissions point of view.

Toyota Australia Hydrogen Centre.

- Education facility related to fuel cell electric vehicles.

Western Australia:

Department of Jobs, Tourism, Science and Innovation. 2021. *Western Australian Renewable Hydrogen Strategy*. Perth, WA: Government of Western Australia. https://www.wa.gov.au/sites/default/files/2021-01/WA_Renewable_Hydrogen_Strategy_2021_Update.pdf

- Utilising solar and extensive wind resources to provide energy for the electrolysis of water.

ATCO. 2019. *Clean Energy Innovation Hub: Project results and lessons learnt*. ARENA. https://arena.gov.au/assets/2018/07/clean-energy-hub-innovation-report.pdf

ENGIE, and YARA. 2020. "ENGIE-YARA Renewable Hydrogen and Ammonia Deployment in Pilbara." ARENA. https://arena.gov.au/assets/2020/11/engie-yara-renewable-hydrogen-and-ammonia-deployment-in-pilbara.pdf

- Feasibility study – YURI Green Ammonia project [announced] by WA government [February 2021].