FE–V

Future of Electricity
Viet Nam

DISCUSSION PAPER

Future Fuels

Australian experience and reflections for the Energy Transition in Vietnam

June 2023

Australian Government

About Future of Electricity Vietnam (FE-V)

Australia and Vietnam are neighbours and peers, facing the same regional challenges and sharing the same aspirations for sustainable, secure, and fair electricity services as the basis of prosperity and economic growth. Our power sectors: share many legacy issues on how energy is generated and transmitted; are blessed with high renewable energy (RE) potential and some of the fastest rates of RE deployment in the world; and are undertaking (or have recently undertaken) major structural reforms to the markets, governance arrangements and infrastructure that underpin the sector in order to take advantage of the opportunity presented by a sustainable energy transition.

Future of Electricity Vietnam (FE-V) is a science-to-policy program made up of policy dialogues aimed at leveraging the Australian experience in energy transition to support Vietnam in exploring practical and feasible interventions for a decarbonised, reliable and affordable power system.

Recognising 50 years of diplomatic relations between Australia and Vietnam, FE-V is an initiative of the Australian Embassy in Hanoi bringing Australian and Vietnamese experts together to share experiences and to co-develop knowledge products of prioritised topics relating to 5 main dimensions of the power sector (generation, fuels, consumption, grid and market) with the Central Economic Commission of the Communist Party of Vietnam (CEC), a strategic dialogue partner. The FE-V initiative is divided into two phases. The first phase focuses on providing high-level inputs for an energy transition strategy, including a review of the 3-year implementation of Resolution 55 which CEC is carrying out.

FE-V is delivered by Australia's Partnerships for Infrastructure (P4I) and the Australia - Mekong Partnership for Environmental Resources & Energy Systems (AMPERES) together with the Australian National University (ANU) and Commonwealth Scientific Industrial Research Organisation (CSIRO). P4I is an Australian Government initiative partnering with Southeast Asia to drive sustainable, inclusive, and resilient growth through quality infrastructure. Led by the Australian Department of Foreign Affairs and Trade, P4I is implemented by EY, Adam Smith International, The Asia Foundation and Ninti One.

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Photo: Vinfast Electric Taxi cars first launch in Hanoi in April, 2023. Photo courtesy of NLD.

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Contents

List of Figures

List of Boxes

List of Abbreviations

Abbreviation	Full name
AE	alkaline electrolysis
AEMO	Australian Energy Market Operator
ANU	Australian National University
ARENA	Australian Renewable Energy Agency
ATR	autothermal reforming
CCS	carbon capture and storage
CCUS	carbon capture, utilisation and storage
CEFC	Clean Energy Finance Corporation
CSIRO	Commonwealth Scientific and Industrial Research Organisation
GSOO	Gas Statement of Opportunities
HESC	Hydrogen Energy Supply Chain
IEA	International Energy Agency
LDAR	Leak Detection and Repair
LNG	Liquified Natural Gas
MCH	methylcyclohexane
NEM	National Electricity Market
NEMDE	National Electricity Market Dispatch Engine
PV	Photovoltaic
PDP	Power Development Plan
PEM	proton exchange membrane
STTM	Short Term Trading Market
SWIS	South West Interconnected System
SMR	Steam Methane Reforming
WA	Western Australia
WEM	Wholesale Electricity Market

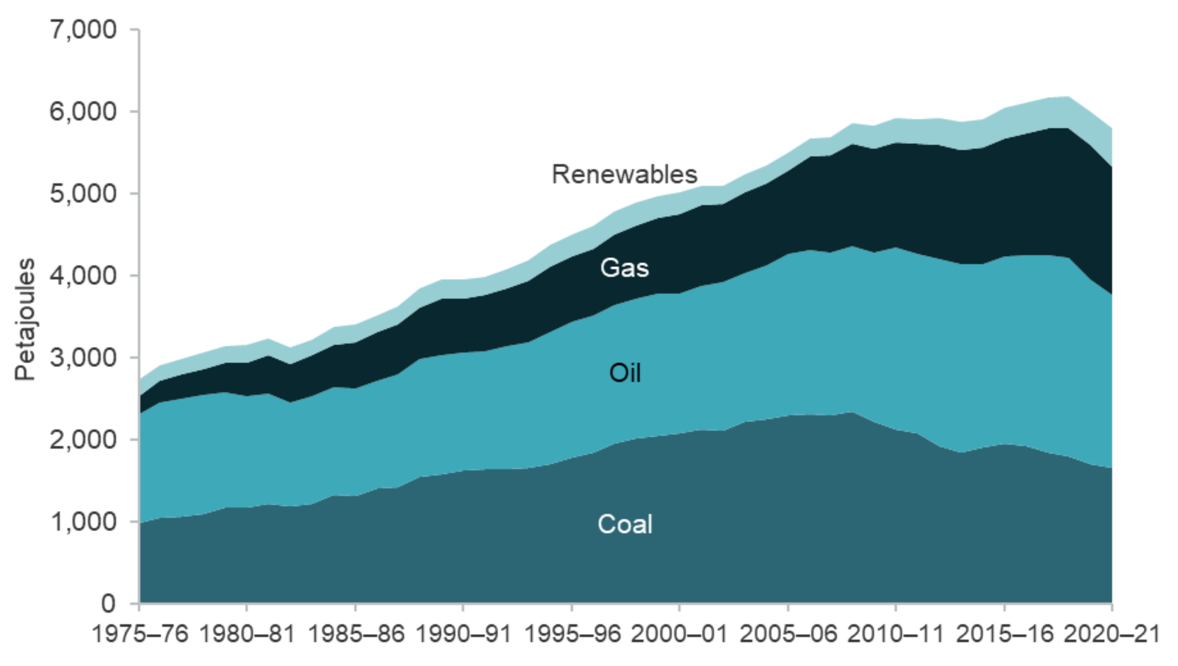
The term "WEM" used across five discussion papers may differ in full-name definitions. Some authors perceived its full name as "Western Electricity Market", while others called it "Wholesale Electricity Market". After internal discussion, we have come to a consensus that the term "WEM" could mean both "Western Electricity Market" and "Wholesale Electricity Market". Note that the market operated in Western Australia enables wholesale electricity sales between generators and retailers, and so is itself a wholesale electricity market. In all discussion papers, we retained the full-text definitions in the text and the abbreviation list according to each author's usage.

A. Thematic Setting

A1 - Overview

Australia's total primary energy consumption in 2020-21 was 5,790 PJ and was 3.6% lower than the previous year largely due to COVID-19 related impacts as can be seen in Figure 1. The largest reduction was seen in the transport sector, mainly due to a reduction in air transport. Oil usage fell by 7% but still represented the largest fuel source at 36% of all fuels. Natural gas represented 27% of the primary energy mix and had a fall of 4% from the previous financial year due to lower levels of liquified natural gas (LNG) production as well as lower use as a fuel for electricity generation in Australia. Coal use represented 29% of energy consumption and renewables were the lowest at 8%. However, renewables have been growing at an annual average rate of 4.6% over the last 10 years and natural gas has grown by 2% on average per year compared to other fuels which have been in decline.

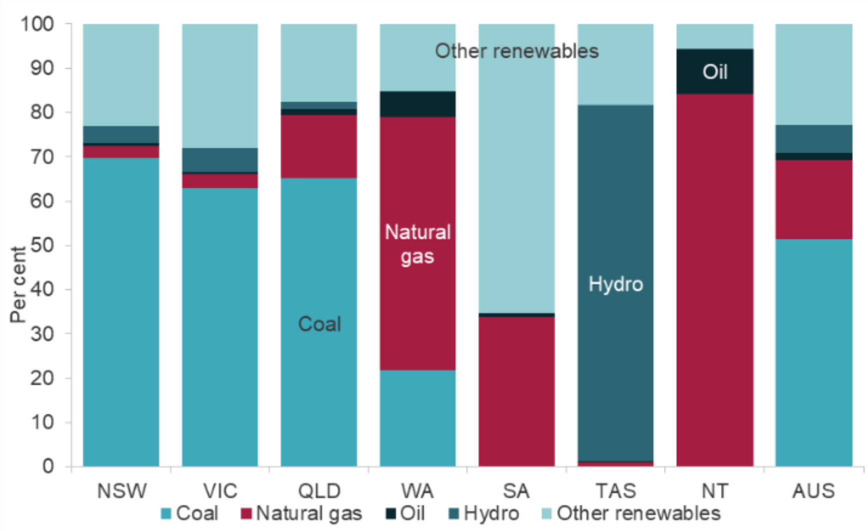
Figure 1 | Australian energy consumption by fuel type.
Source: Department of Climate Change, Energy, the Environment and Water, Australian Energy Statistics, Table C



The electricity generation fuel mix in Australia varies across states and territories. In New South Wales, Victoria and Queensland, coal makes up more than 63% of generation. In the Northern Territory, Western Australia and South Australia, gas accounted for 84%, 57% and34% of generation respectively. In Tasmania and South Australia, renewables accounted for 99% of generation (predominantly hydro) and 65%

respectively. Overall, coal makes up more than 50% of total Australian generation.[1]

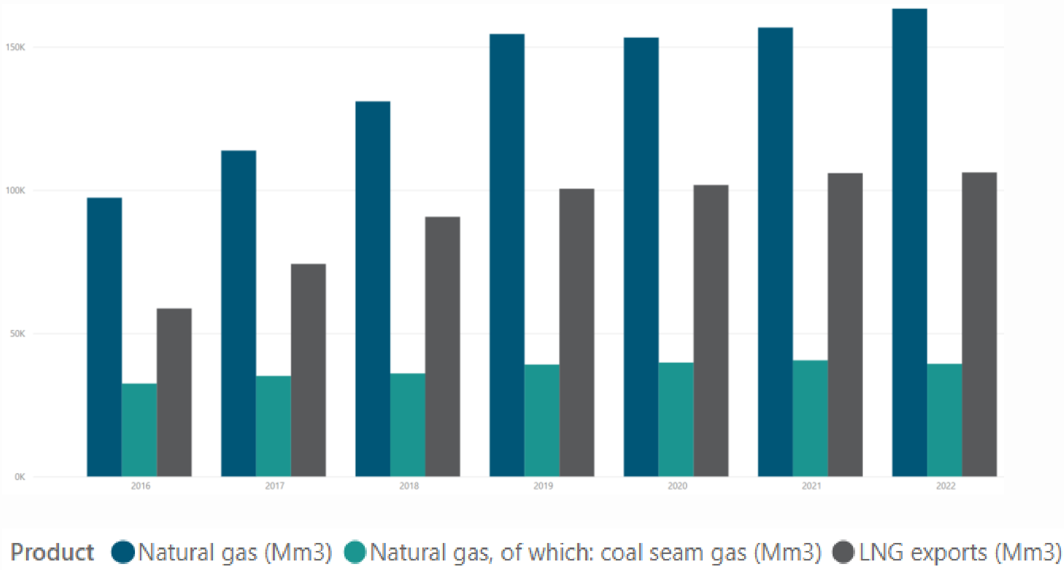
Figure 2 | Australian electricity generation - fuel mix calendar year 2021.
Source: Department of Climate Change, Energy, the Environment and Water (2022), Australian Energy Statistics, Table O



Natural gas use in Australia

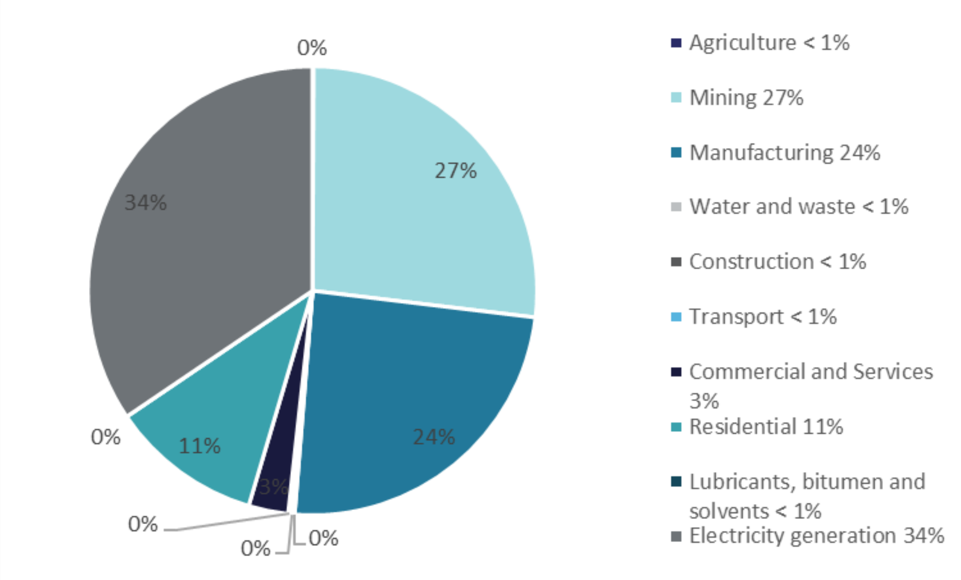
The use of natural gas by sector in Australia is shown in Figure 2 below. The majority of natural gas use is in electricity generation, followed by mining and manufacturing. This figure does not include export of natural gas as LNG, which represents 73% of Australia's natural gas production[2].

Figure 3 | Australian Natural Gas Production, Australian Petroleum Statistics



[1] Department of Climate Change, Energy, the Environment and Water (2022), Australian Energy Statistics, Australian electricity generation – fuel mix calendar year 2021
[2] DCCEEW (2022) Australian Energy Statistics 2022, Table A, Table F and Table G https://www.energy.gov.au/publications/australian-energy-update-2022 Accessed March 2023

Figure 4 | Share of natural gas use by sector in Australia 2020-21.
Source: Department of Climate Change, Energy, the Environment and Water, Australian Energy Statistics, Table H



Natural gas makes up approximately 6-8% of the generation fuel mix in Australia's National Electricity Market (NEM)[3] and 30-40% of the generation fuel mix in Western Australia's (WA's) Wholesale Electricity Market (WEM). The NEM represents the interconnected electricity market in the eastern states of Australia and includes Queensland, New South Wales (NSW), Victoria, Tasmania and South Australia. The WEM represents the wholesale electricity market in the South West Interconnected System (SWIS). The NEM and WEM are the markets where electricity is traded, and these markets are not connected to each other. Natural gas is used for mid-merit (defined as electricity generation plant with a capacity factor of between 10% and 70%) as well as flexible peaking and firming of variable, intermittent renewable energy.

The role of natural gas won't play a role baseload role but rather a supporting role in the transition to net zero by 2050 plan. The role of natural gas is at mid-merit and peaking role where natural gas is applied to compliment variable renewable energy and contributes to the security of the essential system service by ensuring that energy demand and supply is in equilibrium. Outside of these markets, natural gas is used as the dominant form of electricity generation for some remote communities and mine sites.

Hydrogen use in Australia

Hydrogen is mainly used in Australia as a feedstock for industrial processes (approximately 65% for ammonia production and 35% for crude oil refining) and is produced from steam methane reforming (SMR) of natural gas. In 2021, approximately 650 kt of hydrogen was

[3] Australian Energy Regulator (AER) *Generation capacity and outlook by fuel source – NEM*. https://www.aer.gov.au/wholesale-markets/wholesale-statistics/generation-capacity-and-output-by-fuel-source-nem

produced and consumed in Australia[4]. However, the use of hydrogen as an alternative fuel in other sectors is expected to grow as the cost of hydrogen production reduces and hydrogen utilisation technologies reach maturity and commercialise. Hydrogen produces only water when used in combustion or fuel cells. So, if it is generated by electrolysis from renewable electricity, or by other net-zero methods, hydrogen can be a zero-emissions fuel.

A2 - Evolution of the theme

Global efforts to reach net zero emissions by 2050 and recent disruptions to the supply of oil and natural gas, have highlighted the importance of energy security and the transition to renewables and low carbon, alternative fuels. Renewable hydrogen is recognised as an alternative fuel which can be used in many end use sectors and can be produced in one location where it is used, or produced centrally and transported and stored via various means to distant locations ie as overseas exports.

The significance of hydrogen and the opportunities it can provide Australia as a new energy export commodity were highlighted by CSIRO in the 2018 National Hydrogen Roadmap[5]. A combination of factors has led to this being the “right time” to seriously consider the role hydrogen can play in Australia’s energy future. The factors are the low cost of renewable electricity, which will continue to decrease in cost (once short-term inflationary pressures and global supply chain constraints have eased)[6], the maturity of technologies relevant for hydrogen production, Australia’s significant renewable resources and land availability and the global push to reduce greenhouse gas emissions. Water use for hydrogen production is often raised as a potential issue for a dry continent like Australia however hydrogen production could source water from desalination plants or use recycled water. In the case of a large hydrogen export industry, between 500 – 1000 GL of water could be used per year, which is less than the water usage of the mining sector (1300 GJ per year).[7]

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[4] Advisian (2021) *Australian hydrogen market study: sector analysis summary*. https://www.cefc.com.au/media/nhnhwlxu/australian-hydrogen-market-study.pdf accessed April 2023
[5] Bruce S, Temminghoff M, Hayward J, Schmidt E, Munnings C, Palfreyman D and Hartley P (2018) *National Hydrogen Roadmap*, CSIRO, Australia https://www.csiro.au/en/work-with-us/services/consultancy-strategic-advice-services/csiro-futures/energy-and-resources/national-hydrogen-roadmap
[6] Graham P, Hayward J, Foster J and Havas L (2022) *GenCost 2022-23 Consultation Draft*, CSIRO, Australia https://doi.org/10.25919/hjha-3y57
[7] CSIRO, HyFAQ: Interactive hydrogen FAQ tool. https://research.csiro.au/hylearning/hyfaq/ accessed April 2023

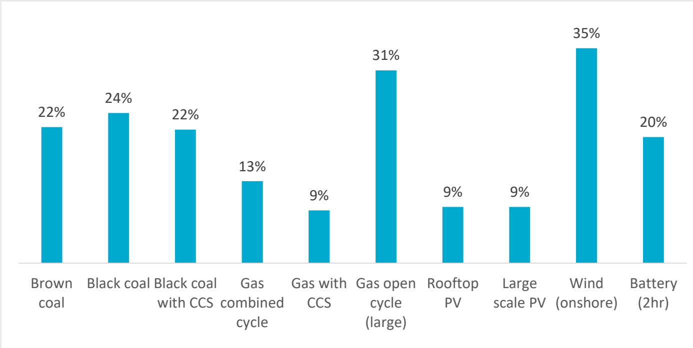
Box 1 | Recent technology cost increases

Recent technology cost increases

Since 2020 and the onset of the COVID-19 pandemic, global supply chain constraints have increased the prices of raw materials needed in energy technologies and freight costs have also increased significantly. The combined impact of these two factors has led to capital cost increases of all electricity generation, storage and hydrogen technologies.

The current cost data indicates that compared to 2021-22 data, technology costs in Australia have increased 20% on average. Costs increases were as low as 9% for solar PV and up to 35% for wind. The difference in cost increases mostly reflects differences in material inputs and exposure to freight costs. Some variation may also represent the extent to which cost increases had already flowed through to the previous year's estimate as we consider the beginning of this inflationary cycle to have started in 2020. Whilst prices had not risen in 2020, it appears cost reductions had started to slow from that time for some technologies[8].

Figure 5 | Increase in current costs of selected technologies relative to GenCost 2021-22[9]



The inflationary cycle is assumed to be at its peak in 2022 and 2023 and to take until 2027 to return to normal costs[10].

In November 2019, Australia adopted a National Hydrogen Strategy to develop a hydrogen industry to enhance Australia's energy security, create jobs and build an export industry valued in the billions[11]. The strategy set the vision for a clean, innovative, safe, and competitive hydrogen industry that could help Australia transition to a sustainable, affordable, and low-emissions future[12]. The national strategy was announced following the release of strategies and actions plans by several Australian state governments in the three years prior. Multiple industry-led hydrogen project investments had been underway in several Australian states and territories, many of which with the support of state governments and federal government agencies such as the Australian Renewable Energy Agency (ARENA) and the Clean Energy Finance Corporation (CEFC). Numerous publicly available studies and

[8] Graham P, Hayward J, Foster J and Havas L (2022) *GenCost 2022-23 Consultation Draft*, CSIRO, Australia https://doi.org/10.25919/hjha-3y57
[9] Graham P, Hayward J, Foster J and Havas L (2022) *GenCost 2022-23 Consultation Draft*, CSIRO, Australia https://doi.org/10.25919/hjha-3y57
[10] This trajectory is based on published forecasts of the Reserve Bank of Australia regard to general inflation and information presented at the 26th October AEMO Forecasting Reference Group on the outlook for fuel prices.
[11] The Hon Angus Taylor MP (15 April 2020) Fast tracking renewable hydrogen projects, https://www.minister.industry.gov.au/ministers/taylor/media-releases/fast-tracking-renewable-hydrogen-projects [media release], Accessed February 2021.
[12] Commonwealth of Australia (2019) *Australia's National Hydrogen Strategy*, https://www.dcceew.gov.au/sites/default/files/documents/australias-national-hydrogen-strategy.pdf

reports helped to shape the strategy, both ones that served as direct input informing the national strategy[13] and ones that had been prepared in the immediate years prior. Such reports included the National Hydrogen Roadmap in 2018[14] and the Hydrogen Research Development and Demonstration: Priorities and opportunities for Australia report in 2019[15], CSIRO and involved widespread industry, government and research sector consultation, input and support in their drafting.

The strategy recognised that Australia has the major attributes needed to create a new clean hydrogen industry: access to clean energy resources, expertise and infrastructure as an existing energy exporter of LNG and committed clean energy trading partners. In September 2020, the Australian government followed the release of the national strategy with the First Low Emissions Technology Statement, the first of a series of annual updates described as a research and development strategy for Australia that "identifies how emerging low emissions technologies can become economically competitive with and replace high emission incumbents"[16]. In this first statement, clean hydrogen was identified as one of five priority technologies, with an economic stretch goal of producing hydrogen at less than AUD2 per kilogram (or 'H_2 under 2') provided as a market activation target. Through analysis that included techno-economic modelling by the CSIRO, achieving 'H_2 under 2' at the site of production was stated as a key step in unlocking hydrogen industry growth in Australia. At AUD2 per kilogram, clean hydrogen becomes competitive in applications such as producing ammonia, as a transport fuel and for firming electricity. Australia has since undergone a change in government and, given it has been several years since the release of the national strategy, an update may be issued in due course.

A3 - Importance of the theme to the Australian electricity service industry

Liquid fuels and natural gas play a critical role in Australia's energy sector. As such, supply disruptions create energy security challenges. There are a range of factors that can cause disruptions or adequacy issues, such as technical or human failures, natural disasters, geopolitical disputes, depleting reserves, cyber-attacks, and other emerging risks.

Hydrogen is currently not produced in large quantities in Australia from grid electricity using electrolysers. However, in the future as green hydrogen is produced for export as well as for domestic uses, hydrogen and hydrogen derivatives may be produced either by large, stand-alone

[13] Department of Climate Change, Energy, the Environment and Water (DCCEEW) (2022) Energy and Climate Change Ministerial Council, https://energyministers.gov.au/publications/reports-support-national-hydrogen-strategy. Accessed June 2021.
[14] Bruce S, Temminghoff M, Hayward J, Schmidt E, Munnings C, Palfreyman D and Hartley P (2018) *National Hydrogen Roadmap*, CSIRO, Australia https://www.csiro.au/en/work-with-us/services/consultancy-strategic-advice-services/csiro-futures/energy-and-resources/national-hydrogen-roadmap
[15] Srinivasan V, Temminghoff M, Charnock S and Hartley P (2019) *Hydrogen Research, Development and Demonstration: Priorities and Opportunities for Australia*, CSIRO https://www.csiro.au/en/work-with-us/services/consultancy-strategic-advice-services/csiro-futures/energy-and-resources/hydrogen-research-and-development
[16] Department of Industry, Science, Energy and Resources (DISER) (2021) *Low Emissions Technology Statement 2021* https://www.dcceew.gov.au/sites/default/files/documents/low-emissions-technology-statement-2021.pdf. Accessed April 2023.

renewable energy giga-projects (such as the Australian Renewable Energy Hub – see Generation discussion paper) or by grid-connected solar and wind farms.

Hydrogen production represents a source of demand for electricity, and as such it can also be used to provide flexible demand for grid support. For example, as the capital cost of electrolysers continues to decline, the major cost component of the cost of hydrogen production will be the cost of electricity. Therefore, it may be economically feasible to dispatch electrolysers when there is excess renewable electricity i.e. when electricity is lower in cost. This will most likely include daylight hours when there is excess solar photovoltaic (PV) generation, and the additional load of the electrolysers may help with grid stability. However, compared to dedicated, off-grid renewable electricity systems with higher electrolyser capacity usage factors, if hydrogen is only generated from short-duration excess electricity, the reduced capacity usage factor for the electrolysers may also increase hydrogen's levelised production cost.

Likewise, stored hydrogen could also be used to generate electricity via fuel cells, hydrogen reciprocating engines or turbines when there is a shortage of supply, such as at night. However, in Australia at least, hydrogen storage and conversion back to electricity is a more expensive form of energy storage than, for example, pumped hydro or batteries17, or other alternatives such as "overbuilding" renewable generation capacity18 (see Generation discussion paper).

A4 - List of key issues: grid stability and energy reliability

The key issues in terms of fuels such as natural gas and hydrogen are:

1. Energy security and reliance of energy imports
2. Role of gas in a net-zero power supply system
3. Entry points for hydrogen in domestic supply and understanding the economic viability of hydrogen
4. Options for hydrogen as an export commodity

Managing competition for renewable energy generation between hydrogen production and domestic electricity demand.

A5 - Relevance to Vietnam

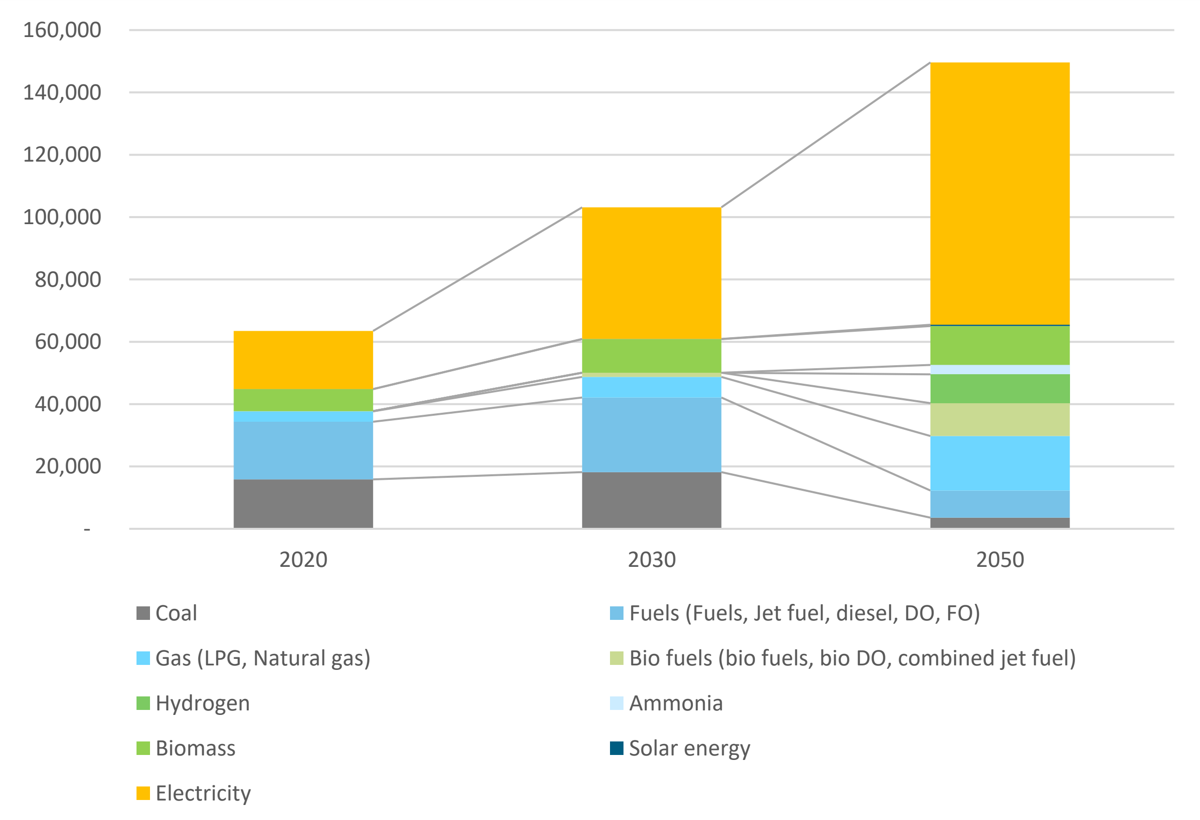
With the development of the whole economy, energy consumption in Vietnam is expected to grow rapidly. Together with the commitment to be net-zero by 2050, the energy sector in Vietnam needs to have a strategy to ensure energy security and to ensure it fulfills its net-zero commitment.

[17] CSIRO (2023) *Renewable Energy Storage Roadmap*, CSIRO Australia https://www.csiro.au/en/work-with-us/services/consultancy-strategic-advice-services/csiro-futures/energy-and-resources/renewable-energy-storage-roadmap
[18] Australian Energy Market Operator (AEMO) (2022) *Integrated System Plan (ISP)* https://aemo.com.au/-/media/files/major-publications/isp/2022/2022-documents/2022-integrated-system-plan-isp.pdf?la=en

Vietnam's Power Development Plan (PDP) was approved on 15 May 2023, while the draft of Energy Development Strategy (Strategy) has been developed and are currently under review and approval. These documents have identified the high-level directions for the energy sector in general and the power sector.

As analysed in the Strategy, the regulated normal scenario of energy consumption in Vietnam is summarized as shown in Figure 6.

Figure 6 | Energy consumption in 2020 and projected for 2030 and 2050 under the regulated scenario (Draft of Energy Development Strategy, 2022)



The regulated normal scenario shows that Vietnam has the intends to transition its energy mix from coal and fuels to electricity and other low emission energy sources. The role of gas is also projected to increase in the mid-to long-term. Hydrogen and ammonia contributions are expected to increase in the future to allow Vietnam to fulfill its net-zero commitment.

As Vietnam is under their energy transition with a greater integration of renewable energy and the potential integration of new sources of energy Australia's experience including the development of national energy strategies such as the Australian hydrogen strategy may be of relevance to assist Vietnam with lessons learnt from the experience.

A6 - Recommendations to Vietnam

As natural gas is considered to have a more important role in the energy transition, it's recommended that:

- The development for LNG and gas infrastructure (pipelines, storages, etc.) should be developed in alignment with the power development plan to ensure the stable gas supply;
- As Vietnam needs to import LNG to meet greater demand, setting collaboration partnerships with countries with LNG availability is also important to manage risks in gas supply;
- Vietnam should have early requirements in the design phase to avoid stranded assets in the future and be prepared for hydrogen blending options;
- Natural gas still produces emissions when being consumed, it's also important to have actions to reduce those emissions.

Vietnam's long term vision is to play a part in hydrogen contribution, with similarities in the potential to produce green hydrogen like Australia. Vietnam can apply the lessons learnt in their hydrogen development as below:

- Develop a hydrogen development strategy to provide the guideline that identify the role of hydrogen in the energy sector (for domestic consumption and for exporting), ensure the overall hydrogen development is harmonised with the development of hydrogen as a solution for peak period generation;
- Continue further research on hydrogen demands and suitable options for Vietnam, particularly focusing on the steps for the initial introduction of hydrogen to the economy.

B. Issues exploration

Issue 1 - Energy security and reliance on energy imports

B1 - Problem Context

The International Energy Agency (IEA) defines energy security as the “uninterrupted availability of energy sources at an affordable price”.[19] The availability and affordability of liquid fuels and natural gas are vulnerable to a wide range of risk factors, including:

- Natural disasters, such as the 2011 earthquake and tsunami in Japan which disrupted oil production and transportation in the region and contributed to higher oil prices.
- Major technical accidents, such as the 2008 explosion and resulting fires at the Varanus Island gas processing plant in northern Western Australia (WA). The plant, which supplied a third of the state's gas, was shut down for almost two months while major repairs were carried out. Gas supply in WA was rationed and many large gas users switched to diesel for power generation, causing a transport fuel shortfall risk.
- Geo-political tensions, such as the current war in Ukraine which has caused significant disruption of oil and gas supplies from Russia. Russia had been a major exporter, supplying nearly a sixth of the global oil and gas supply. The impact has been particularly profound for Europe, which had relied on Russia to meet 20% of its oil needs and 30% of its gas needs. This has had broader repercussions on the price of oil and gas, including for Australia as gas producers have increased LNG imports to supply Europe.

Net import – liquid fuels

Australia is a net importer of liquid fuels, importing approximately 90% of its fuel needs. Australia’s heavy reliance on fuel imports increases its vulnerability to supply disruptions and price shocks. Energy security includes security of liquid fuels, gas and electricity supply.

Liquid fuels are used in transport (including aviation, shipping and automotive vehicles) and electricity generation. Whilst liquid fuel does not make up a significant proportion of the electricity generation fuel mix in Australia, ‘liquid fuel, particularly diesel, is used in several sectors as a backup energy source in times of primary energy outages, such as electricity blackouts’[20] and thus play an important role in energy security. For example, between December 2015 and June 2016 Tasmanian electricity supply was at risk due to a combination of: the interconnector between Tasmania and Victoria experiencing an outage; and low water

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[19] International Energy Agency (IEA) (2023) *Energy Security: Reliable, affordable access to all fuels and energy sources*, https://www.iea.org/topics/energy-security. Accessed April 2023.
[20] Department of the Environment and Energy (2019), Liquid Fuel Security Review – Interim Report, 7

levels in the dams that supply Tasmania's hydroelectric power. Temporary diesel generators were called on to supplement electricity supply. At its peak, the demand for diesel for generators increased Tasmania's overall demand for diesel by approximately 35%.[21]

The IEA's International Energy Program and treaty requires all member states to maintain oil stocks equivalent to at least 90 days of the previous year's daily net oil imports (IEA days) to enable member countries to take collective action to release such oil stocks to mitigate the risk of oil price shocks due to significant supply disruptions.[22] Under the program, member states may be required to release stocks, restrain demand, switch to other fuels, increase domestic production or share available oil, if necessary.[23]

When Australia became a member of the IEA and a party to the treaty in 1979, it was a net exporter of oil and was therefore exempt from the IEA's 90-day stockpiling requirement. Since 2012, Australia has been non-compliant with the requirement as its oil production has declined and the number of refineries in Australia has reduced from 20 down to only two refineries.[24]

Australia only holds a reserve equivalent to 68 days of net imports. Based on Australia's average daily consumption over 2021, current stocks are only expected to last 32 days. As at December 2022, Australia's stocks were only equivalent to 59 IEA days.[25]

In response to liquid fuel security concerns, in 2021 the Australian Government introduced:

- A minimum stockholding obligation to take effect from 1 July 2023, requiring Australia's major fuel importers and refineries to hold baseline level stocks of petrol, diesel and jet fuel:
    - petrol (24 days, increasing to 27 days in 2024).
    - diesel fuel (20 days, increasing to 32 in 2024).
    - jet fuel (24 days, increasing to 27 days in 2024).[26]

Refiners and importers will initially be required to report their stock levels fortnightly, increasing to weekly from 1 July 2024.[27]

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[21] Department of the Environment and Energy (2019), Liquid Fuel Security Review – Interim Report, 49
[22] IEA (2023) Oil Security Policy, https://www.iea.org/reports/oil-security-policy. Accessed April 2023 ; Laidlaw H (2020) *Liquid fuel security: a quick guide-May 2020 update*, Parliament of Australia (aph.gov.au) https://www.aph.gov.au/About_Parliament/Parliamentary_Departments/Parliamentary_Library/pubs/rp/rp1920/Quick_Guides/LiquidFuelSecurity. Accessed April 2023
[23] IEA (2023) Oil Security Policy, https://www.iea.org/reports/oil-security-policy. Accessed April 2023
[24] Laidlaw H (2020) *Liquid fuel security: a quick guide-May 2020 update*, Parliament of Australia (aph.gov.au) https://www.aph.gov.au/About_Parliament/Parliamentary_Departments/Parliamentary_Library/pubs/rp/rp1920/Quick_Guides/LiquidFuelSecurity. Accessed April 2023
[25] IEA (2023) Oil Stocks of IEA Countries – Data Tools. https://www.iea.org/data-and-statistics/data-tools/oil-stocks-of-iea-countries. Accessed March 2023
[26] DCCEEW (2023) Minimum stockholding obligation, https://www.energy.gov.au/government-priorities/energy-security/australias-fuel-security/minimum-stockholding-obligation. Accessed March 2023
[27] DCCEEW (2022) Australia's fuel reserves boosted to strengthen resilience and supply, https://www.energy.gov.au/news-media/news/australias-fuel-reserves-boosted-strengthen-resilience-and-supply. Accessed March 2023

- Payments to domestic refineries for producing petrol, diesel and jet fuel during loss-making periods.[28]

- Grants, with matched funding from industry, to build additional diesel storage capacity. This grants program has since ceased.[29]

Natural gas

The National Gas and Electricity Markets have experienced significant issues in recent years due to reduced availability and increasing prices of domestic gas. The Australian Energy Market Operator (AEMO) annual "Gas Statement of Opportunities"[30] (GSOO) forecasts the adequacy of gas supplies to meet the gas needs of Australian jurisdictions over a 20-year period[31]. In its 2023 GSOO, AEMO highlights continued gas shortfall risks in both the short- and long-term due to:

- On the supply side, gas from northern Australia being exported as LNG and declining production from southern Australia, reducing availability and driving up prices to the NEM.

- On the demand side, coal plant outages or extreme weather conditions (particularly in winter) that drive high coincident peak demand for gas fired generation and direct gas consumption (known as "peak day shortfall risk").

- On the transmission side, insufficient available pipeline capacity to meet peak day shortfalls.

Peak day shortfall risks may be managed by having adequate gas reserves or lowering reliance on gas generation during periods of peak gas demand, for example by:

- Utilising other fuel sources, such as liquid fuels, or storage options; or

- Managing (reducing) demand.

In contrast, WA has not experienced the same availability and price issues as the NEM. This is largely due to WA's "domestic gas reservation policy"[32], which has been in place since 1979 when the state government underwrote the North West Shelf gas project. The policy was formalised in 2006 to secure the equivalent of 15% of WA gas exports for domestic use. At that time, gas made up approximately 60% of WA's electricity generation fuel mix and was also a key input for industry.

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[28] DCCEEW (2021) Fuel Security Services payment, https://www.energy.gov.au/government-priorities/energy-security/australias-fuel-security/fuel-security-services-payment. Accessed March 2023
[29] For more information, see: Boosting Australia's Diesel Storage Program | business.gov.au
[30] The Gas Statement of Opportunities (GSOO) provides AEMO's forecast of annual gas consumption and maximum gas demand, and reports on the adequacy of Australian gas markets to supply forecast demand over a 20-year outlook period. A GSOO is published for both the market in Western Australia as well as the markets in eastern and south-eastern Australia, AEMO Western Australia Gas Statement of Opportunities Dec 2022, Gas Statements of Opportunities for Eastern and South-Eastern Australia March 2022
[31] AEMO (2023) Gas statement of opportunities, 2023-gas-statement-of-opportunities.pdf (aemo.com.au), p 4. Accessed April 2023
[32] The policy is applied during negotiations with export gas producers. For more information, see: https://www.wa.gov.au/government/publications/wa-domestic-gas-policy#the-wa-domestic-gas-policy

Although the proportion of gas in WA's generation fuel mix has significantly reduced since 2006, it still plays an important role in meeting peak demand, firming renewable generation and acting as a feedstock for industry. AEMO has highlighted that out to 2026, WA's domestic gas market could "easily move into surplus or deficit with any delays to demand or supply projects respectively"[33] due to:

- WA's gas production facilities already operating at close to maximum capacity. If one of the production facilities fails, there is limited flexibility to meet the shortfall beyond drawing on linepack from the major gas transmission pipeline and the two storage facilities.

- Disruptions to coal supply or coal plant outages increasing demand for gas generation.

- Anticipated increase in demand from new projects that rely on gas as a feedstock.

- Potential delay to, or conversely shorter time frames for, commencement of production from new gas supply projects, such as Woodside's Scarborough gas project.

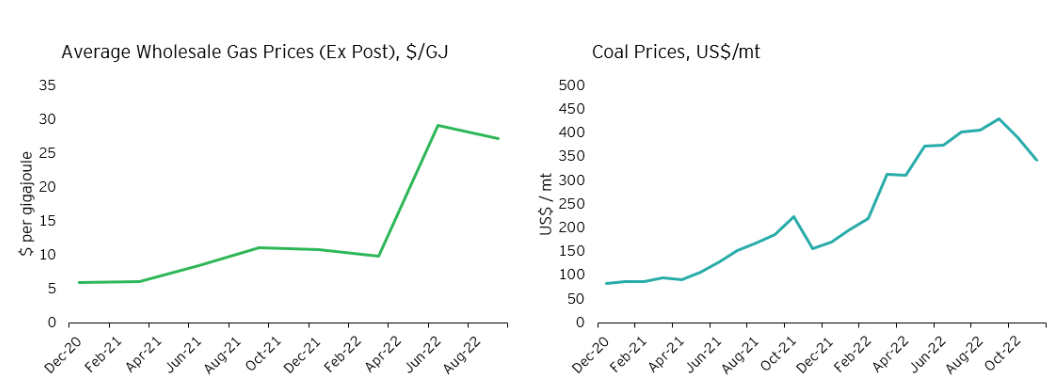
- Anticipated reduction in industrial and mining gas demand as their decarbonisation plans are implemented, which are expected to focus on electrification and renewable energy.

B2 - Strategic setting

Worldwide demand for Australian coal and natural gas dramatically increased in 2022, driven by demand from Europe as the war in Ukraine caused a shift away from Russian supply. This increase in demand has driven higher prices in Australia's domestic markets. Coal and gas prices in Australia are driven by global markets, so any supplies needed outside of existing contracts are subject to volatile international spot prices.[34] During the period between December 2020 and September 2022, gas prices in Australia more than quadrupled, while coal prices increased five-fold (see Figure 7).

[33] AEMO (2022) Western Australia Gas Statement of Opportunities, https://www.aemo.com.au/-/media/files/gas/national_planning_and_forecasting/wa_gsoo/2022/2022-wa-gas-statement-of-opportunities.pdf?la=en, p 8. Accessed April 2023.
[34] Clarke M (2 June 2022) Federal government's 'gas trigger' to keep supplies onshore may not be pulled just to put a lid on high prices, ABC News, Accessed April 2023

Figure 7 | EY analysis of data from Australian Energy Regulator (STTM – Quarterly Prices) and Y Charts (Australia Coal Price)[35]



In June 2022, the NEM was suspended for the first time in its 20+ year history.

The suspension was the result of a confluence of factors across the interconnected gas and electricity markets on the east coast of Australia, including:

- The early onset of winter, which increased demand for both electricity and gas for heating.
- Periods of low wind and solar output.
- A large number of planned generation and transmission outages to allow for routine maintenance in the shoulder season.
- A large number of unplanned coal fired generation outages due to coal supply constraints. In early 2022, New South Wales and Queensland were affected by heavy floods, which hampered the coal production in the country. Also, due to technical problems, the production decreased at two mines (which supply the NEM's biggest coal-fired plant).
- Limited supply due in part to east coast gas projects exporting more LNG to Europe to meet demand for non-Russian gas supply.
- Increased gas prices due to increased LNG prices and limited domestic supply.
- Gas fired generators withdrawing from the market due to high gas prices coupled with price caps.

AEMO was forced to impose price caps and to take generation control, directing generators to produce at unprofitable prices to ensure sufficient electricity supply to meet demand. The emergency measures were introduced on the 15 June 2022 and lasted until 24 June 2022. During

[35] Source: EY Knowledge analysis of data from Australian Energy Regulator (STTM – Quarterly Prices), https://www.aer.gov.au/wholesale-markets/wholesale-statistics/sttm-quarterly-prices-including-ex-post, https://ycharts.com/indicators/australia_coal_price

the period of market suspension AEMO conducted 24 hour look ahead and control of generation dispatch, which became easier to asses once the generating units began to return online from outages. The AEMO established a set of criteria to trigger market reactivation which included pricing via NEMDE (National Electricity Market Dispatch Engine) operated with stability and efficacy for a period of 24 hours combined with: [36]

- Market-based dispatch and pricing would continue to operate effectively with manageable incidence of any unresolved OCD (Over Constrained dispatch) intervals requiring manual intervention,
- The ongoing volume and complexity of directions falling to a level that could be reasonably managed, and
- Confidence that if market suspension were lifted then the conditions that led to suspension would be unlikely to recur within 24 hours, in particular reserve outlooks remaining manageable.

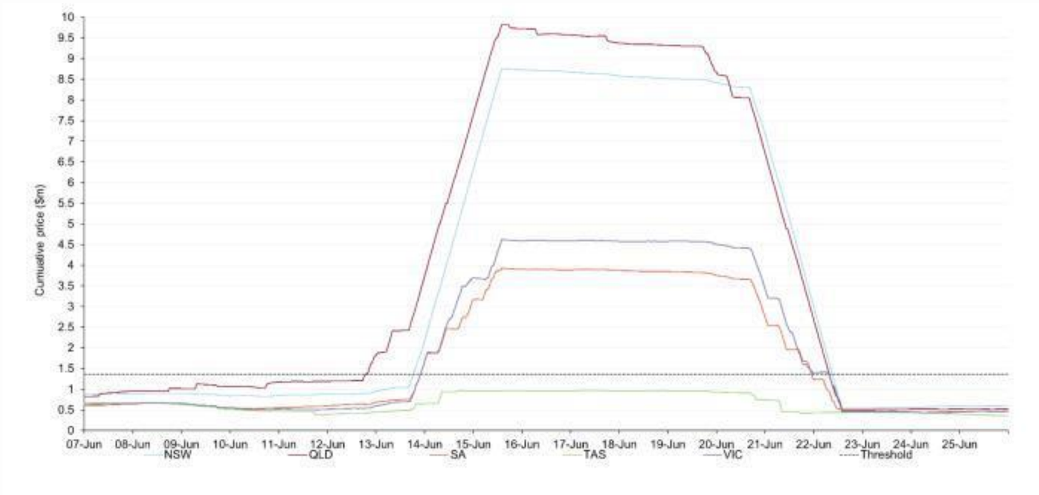
A total of AU$114 million was paid in compensation to market participants to cover the cost associated with the prevention of load shedding during that period. The AEMO noted that the claims were considerable but still 'well below external expectations'.[37]

Wholesale spot prices in the NEM and eastern Australian gas markets rose to unprecedented average levels in Q2 2022.[38] The quarterly average NEM spot price of $264 per megawatt-hour (MWh) was more than double the previous high of $130/MWh recorded in Q1 2019, and more than triple the average of $85/MWh recorded in Q2 2021. Across the east coast gas markets, spot prices averaged $28.40 per gigajoule (GJ) compared with $8.20 in Q2 2021.[39]

[36] AEMO, NEM Market Suspension and Operational Challenges in June 2022 (Aug 2022), pg 45-46
[37] AEMO, NEM suspension costs lower than expected, https://aemo.com.au/newsroom/media-release/nem-suspension-costs-lower-than-expected, Accessed April 2023
[38] AEMO Quarterly Energy Dynamics Q2 2022 (July2022) pg 6.
[39] AEMO Quarterly Energy Dynamics Q2 2022 (July2022) pg 3.

Figure 8 | Gas prices in Short Term Trading Market and Declared Wholesale Gas Market, March to June 2022[40]

Figure 9 | Regional cumulative prices 7 June to 25 June 2022[41]



Across Australia, only WA has a gas reservation policy in place to ensure availability and affordability of gas for the domestic market.

B3 - Solutions

Historically Australia's solution to energy security has been to maintain fuel reserves. However, Countries can strengthen energy security by "diversifying their fuel import partners in the short term and diversifying their energy mix with low-carbon alternatives and improving energy efficiency in the long term".[42]

[40] NEM Market Suspension and Operational Challenges in June 2022 (Aug 2022), pg 13
[41] New Market Suspension and Operational Challenges in June 2022 (Aug 2022), pg 14
[42] World Economic Forum (WEF) (2022) Fostering Effective Energy Transition 2022 Edition, https://www3.weforum.org/docs/WEF_Energy_Transition_Index_2022.pdf. Accessed April 2023

Australia could take a raft of actions beyond stockpiling to reduce its energy security risk and reduce its carbon emissions in the process, including:

- Reducing reliance on liquid fuels and natural gas, through diversity of technologies and replacement fuels such as biofuels, synthetic fuels or hydrogen which can be produced within Australia without relying on imports which is similar to the approach proposed in PDP-8, particularly in regards to PDP-8 plans to provide the fuel switch of existing thermal power plants from coal and gas to biomass, hydrogen and ammonia.

- Prioritising improvements in energy efficiency, such as accelerating the use of high-efficiency appliances and lighting, detecting and fixing gas (and therefore fugitive emissions) leakages, etc.

- Accelerating the roll-out of renewable generation and storage, which could be aided by stronger investor incentives and cutting project approval times, that is also in-line with the PDP-8 directives to actively develop renewable energy sources. .

- Switching from gas to electric heat (electrification), especially through heat pumps, which could be aided through grants or other incentives.

- Introducing a moratorium on new gas connections, such as has been proposed for the Australian Capital Territory.[43]

- Deploying demand side management through formal markets and by encouraging customer behaviour changes.

- Establishing more gas storage facilities close to the point of consumption, i.e. near to gas fired generation, to ride through supply and pipeline capacity challenges.

- Plan for the transition to renewable hydrogen by ensuring any new gas infrastructure, including pipelines, storage facilities and generation units, are hydrogen-ready.

B4 - Expert reflection on Australian experience

Australia is taking steps to manage supply chain risks for its liquid fuel imports and refining. However, this does not completely protect against major disruptions like what has been seen in the global LNG market.

In the NEM, gas shortfalls pose a serious risk to system security as renewables need to be firmed and peak demand needs to be met. Further coal outages and retirements will also drive further gas demand in the near term. AEMO's GSOO shows maximum daily gas demand rising from 2025 to 2033 but average annual gas demand for power generation

[43] Australian Capital Territory (ACT) Government (2021) Everyday climate choices, https://www.climatechoices.act.gov.au/energy/switching-from-gas. Accessed April 2023

decreasing significantly from 2024[44]. This highlights the need to diversify firming technologies and fuel sources.[45]

Whilst there are potential opportunities to develop further gas fields for gas production in Australia, it is costly and not aligned with Australia's commitment to reach net zero emissions by 2050. As such, Australia should consider options to further reduce reliance and manage demand for gas.

Switching from gas to electricity is one way in which reliance on gas could be significantly reduced. Federal or state governments could support the switch by,

- Introducing a moratorium on gas connections for new homes and businesses that do not rely on gas as a feedstock. For households, this is a "no-regrets option that saves money and emissions. And it does not preclude a longer-term switch of existing gas-using households to low-emissions gas substitutes rather than electricity, if it becomes clear that this is the most cost-effective way to deliver low-emissions energy to households." [46]

- Providing grants or other incentives to households and businesses to convert from gas to electricity.[47] In WA, the town of Esperance recently transitioned off reticulated gas. To support the transition, the government owned, vertically integrated regional electricity supplier – Horizon Power – provided customers with advice from energy efficiency specialists and financial assistance to replace or convert standard household gas appliances.[48]

Furthermore, Australia could explore demand-side management in the gas sector as has been operating in the electricity sector. [49] Where operations have flexibility to ramp down gas use, then they could receive payments for doing so during periods of peak gas demand.

B5 - Expert reflection on Vietnamese significance

Vietnam's net energy imports with has increased from 8.4% in 2015 to 48% in 2020. Among the primary fuels, coal had greatest contribution with about 51.2% consistently between 2016 – 2020.

Similar to Australia's net import context, the greater dependence on energy imports raises the concern about the energy security of Vietnam. In the response to the concern, the Vietnamese Government has developed a Draft National Energy Development Strategy, and the Power

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[44] AEMO (2023) Gas statement of opportunities, 2023-gas-statement-of-opportunities.pdf (aemo.com.au), p 4. Accessed April 2023

[45] AEMO (29 July 2022) High international commodity pricing, coal outages, and rising gas-fired generation drives record prices for Q2 2022. Accessed April 2023

[46] Wood T and Dundas G (2020) *Flame out: the future of natural gas* (grattan.edu.au), Accessed April 2023, p 42

[47] Wood T (20 March 2023) The great gas conundrum - Grattan Institute. Accessed April 2023.

[48] Government of Western Australia (31 March 2023) Esperance electrification project an energy transition first [media release] April 2023; Update for Esperance Reticulated Gas Customers (www.wa.gov.au)

[49] Wood T (20 March 2023) The great gas conundrum - Grattan Institute. Accessed April 2023.

Development Plan (PDP) which will direct Vietnam's energy sector to guarantee the energy security is capable of supporting Vietnam's economic development toward the net-zero target by 2050.

The Strategy and the PDP have the common approach to provide a more diverse fuel and generation mix with lower dependency on energy import. The overall directions are set out in the Strategy and include the increase of renewable energy contribution to 60-65% in 2045, refinery capacity to meet 70% of the domestic demand with a strategic oil reserve equivalent to 90 days of the previous year's daily net oil import, and the capacity of LNG import to reach 20 billion m^3 by 2045. The generation mix in the draft PDP also moves toward increase of renewable energy contribution to 52% by 2045.

In terms of demand for imported coal and LNG, the Strategy provides high level direction to diversify coal supply sources and enhance international relationships with countries with LNG sources. Australia has high potential for LNG supply, Vietnam may consider entering into LNG supply agreements with its established trading partner.

The Strategy also considers the demand side with a focus on enhancing the energy efficiency regulation framework (technical standards, ESCO mechanism, energy efficiency and effectiveness fund, etc.). The target for energy savings in the managed scenario in the Strategy is set at 9% in comparison with the base case consumption in 2030 and 20% in 2045. The PDP also specifies that electricity targets are set at 8 – 10% for 2021 – 2030 period.

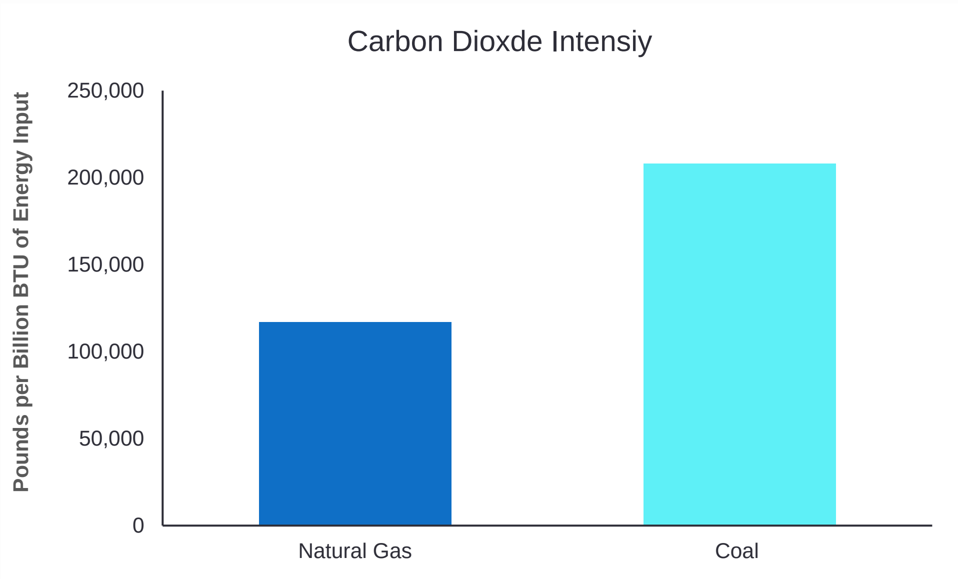
The Strategy also provides high level direction to develop the roadmap LNG power plants to transition increasing its hydrogen use. It is recommended that Vietnam weigh up the risk of potential stranded assets against the cost of designing the facilities from the outset so that they may be repurposed in the future. For example, designing gas generation facilities to be hydrogen-ready and pipelines to be hydrogen or carbon dioxide ready (to transport hydrogen to end users and carbon dioxide to storage facilities).

Issue 2 - Role of gas in a net-zero power supply system

B1 - Problem Context

Natural gas is expected to play an important transitional role in the pathway to a net-zero emissions energy system. Natural gas is considered a cleaner alternative to coal and oil, and its use has already contributed to a reduction in greenhouse gas emissions in Australia and other parts of the world. However, it still emits carbon dioxide when burned, and its production and transport can also result in methane emissions. As such, it is not considered a long-term solution to achieving net-zero emissions.

Figure 10 | Coal v Gas Environmental Impacts – Carbon Intensity [50] (BTU – British Thermal Units)



However, unlike some other countries – particularly the United States – gas is not an energy transition fuel in Australia. In the US, cheap, plentiful supplies of unconventional gas over the past two decades have initially replaced coal-fired generation in the electricity system, and then more recently have been joined by solar and wind[51].

In Australia, gas-fired electricity generation has declined over the past decade or so, from a peak of nearly 22% in 2013-14 to around 18% currently[52]. When coal-fired generators have retired, they have been replaced directly by solar and wind - without using gas as an intermediary (see Fig. B7, Generation discussion paper). This is because the excellent solar and wind resource in Australia combined with decreasing costs of installation have meant that solar and wind have been the cheapest form of new electricity generation for much of the past decade[53].

The IEA projects that global gas use will peak in 2030, then decline in a 'Net zero by 2050' scenario, which causes a reduction in Australian LNG exports[54].

- In the short term, natural gas could play a role in some countries by replacing more carbon-intensive fuels like coal and oil, especially in power generation and industrial processes. Furthermore, it can also serve as a backup source of energy to support intermittent renewable energy sources like wind and solar.

[50] Natural gas vs Coal – environmental impacts (met.com) Accessed April 2023, https://group.met.com/en/mind-the-fyouture/mindthefyouture/natural-gas-vs-coal
[51] US Energy Information Administration (EIA) (2022) Electricity explained,https://www.eia.gov/energyexplained/electricity/electricity-in-the-us.php Accessed April 2023
[52] DCCEEW (2022) Australian Energy Statistics, https://www.energy.gov.au/news-media/news/australian-energy-statistics-2022-edition. Accessed April 2023.
[53] Graham P, Hayward J, Foster J and Havas L (2020) GenCost project data. V9. CSIRO Data Collection. https://doi.org/10.25919/p7nf-9k21
[54] IEA (2021) *Net Zero by 2050 – A Roadmap for the Global Energy Sector (windows.net)*, p175, Figure 4.17. Accessed April 2023.

- To achieve net-zero emissions, it will be necessary to transition away from fossil fuels altogether, including natural gas. This means investing in and scaling up renewable energy sources such as wind, solar, geothermal, and hydroelectric power, as well as technologies like energy storage and grid flexibility to ensure a stable and reliable energy system.

- Overall, while natural gas may have a transitional role to play, it is important to remember that it is not a sustainable long-term solution to achieving net-zero emissions and new gas investments may therefore result in stranded assets. The focus should be on transitioning to a clean, renewable energy system as quickly and efficiently as possible.

According to AEMO, as "Australia transforms to meet a net zero emissions future, gas will continue to complement zero emissions and renewable forms of energy, and to provide a reliable and dispatchable form of electricity generation and may provide potential pathways to incorporate hydrogen and other 'green' gases within Australia's energy landscape".[55]

It is preferable to avoid risk of stranded assets[56] which could occur due to:

- Reduction in demand for gas (only relying on it for firming).

- Assets not being appropriate for hydrogen conversion, including transmission pipelines.

    - For example, in WA, instead of hydrogen blending, a company is looking to build a dedicated hydrogen pipeline from scratch.

There is a need to consider when the tipping point is for the move to hydrogen, and what applications it will be used in.

B2 - Strategic setting

According to the IEA, "achieving net-zero emissions by 2050 is a monumental task, especially against a backdrop of increasing economic and population growth. It calls for an unwavering focus from all governments, working together with industries and citizens, to ensure that the transition to global net-zero emissions proceeds in a co-ordinated way without delay…. There are multiple milestones on the way to global net-zero emissions by 2050. If any sector lags, it may prove impossible to make up the difference elsewhere." [57]

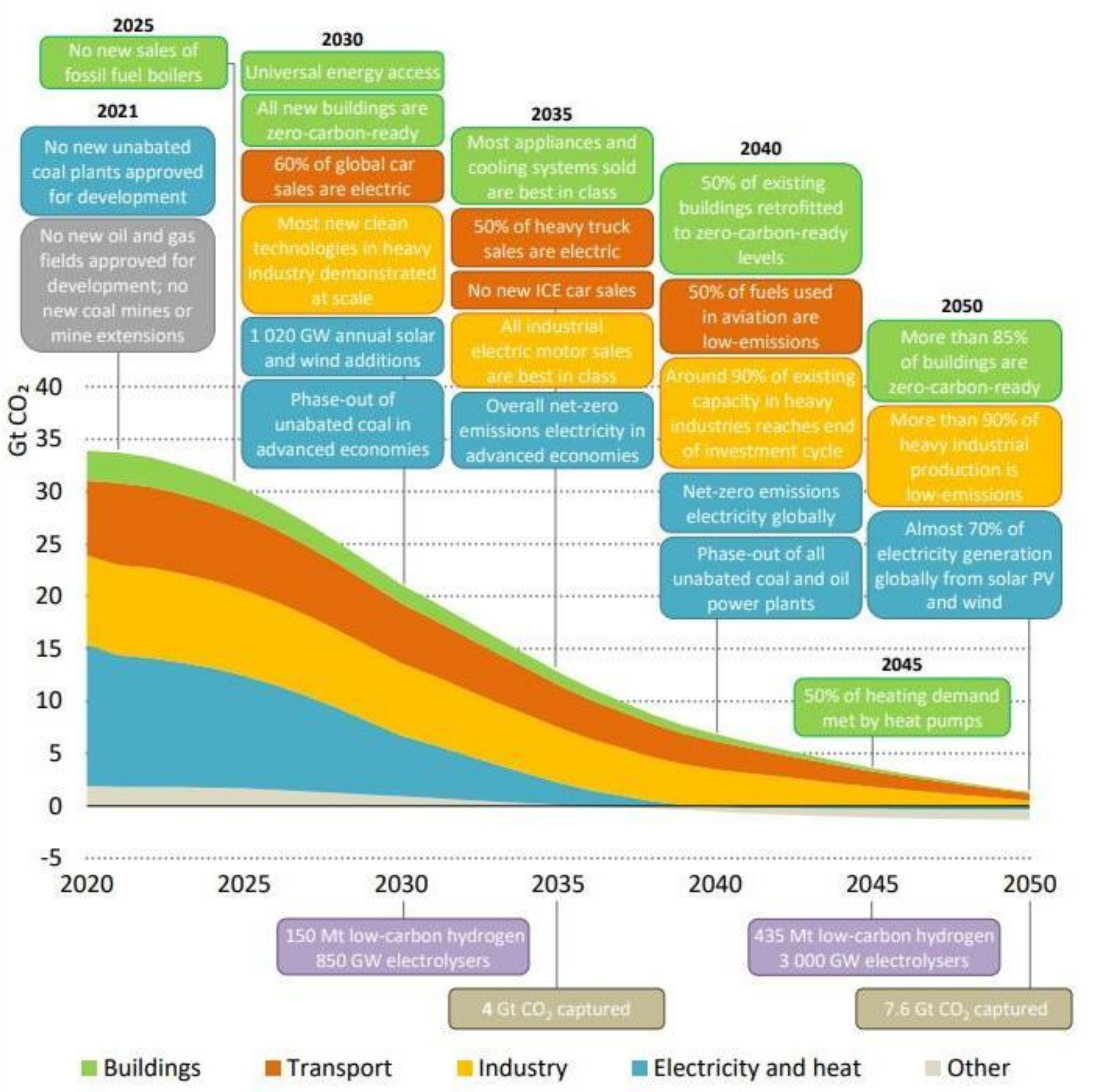
[55] AEMO (2023) Gas statement of opportunities, 2023-gas-statement-of-opportunities.pdf (aemo.com.au), p 4. Accessed April 2023

[56] IEA (2021) *Net Zero by 2050 – A Roadmap for the Global Energy Sector*, "Stranded capital is capital investment in fossil fuel infrastructure that is not recovered over the operating lifetime of the asset because of reduced demand or reduced prices resulting from climate policies. Stranded value is a reduction in the future revenue generated by an asset or asset owner assessed at a given point in time because of reduced demand or reduced prices resulting from climate policies": Net Zero by 2050 – A Roadmap for the Global Energy Sector (windows.net), p102. Accessed April 2023

[57] IEA (2021) Net Zero by 2050 – *A Roadmap for the Global Energy Sector* (windows.net), p152. Accessed April 2023

Shown in Figure 11 below are a set of global milestones identified by the IEA that need to be met in order to achieve net zero emissions by 2050. A major call-out is that there should be "no new oil and gas fields approved for development and no new coal mines or mine extensions" from 2021. This can be interpreted as no additional gas or coal needs to be developed in order to reach net zero by 2050, although some new sources may come online while replacing others. In WA, the Scarborough gas project was approved in November 2021 and is expected to export its first LNG cargo in 2026. The current gas crisis has produced high oil and gas prices in 2022, which will likely weigh in favour of developing projects like Scarborough. As noted below, new developments risk becoming stranded assets.

Figure 11 | Selected global milestones for policies, infrastructure and technology deployment in the Net Zero Emissions scenario[58]



To meet the above milestones, there would be a relatively rapid decline in the consumption of oil and natural gas. As a result, certain oil and gas sector assets are at risk of becoming stranded. This infrastructure could potentially be repurposed for the transmission and storage of hydrogen or carbon dioxide. The benefit of repurposing the assets is that it reduces lead times and the amount and cost of new infrastructure that need to be built. Furthermore, it may "reduce a project's environmental footprint by reducing new material demands and construction needs". As carbon dioxide and hydrogen have different physical and chemical properties to natural gas, it is likely that the assets may need some reconfiguration and adaptation to be repurposed. Each asset would need to be "assessed on an individual basis to determine whether it is suitable for repurposing [for

[58] IEA (2021) *Net Zero by 2050 – A Roadmap for the Global Energy Sector (windows.net)*, p152, Figure 4.1. Accessed April 2023.

hydrogen or carbon dioxide] and what modifications are required".[59] For new assets, it would be beneficial to factor into the design phase the potential for repurposing.

B3 - Solutions

Reduce emissions from natural gas

There are complementary actions that can be taken to further reduce emissions from natural gas in the near- to medium-term, including:

- Reducing routine flaring.
- Reducing fugitive emissions through Leak Detection and Repair (LDAR) and vapour recovery – including waste heat recovery during gas liquefaction.
- Complementing production and use of natural gas with carbon capture, utilisation and storage (CCUS).
- Installing electric drives in place of gas turbines for liquefaction, which are then powered by renewable energy. At present, the capital costs of electric drives are higher than for gas turbines. However, for greenfields projects they have a relatively short pay back when the savings on fuel gas are taken into account. For brownfields projects, there are still retrofitting and operational challenges.

Reduce reliance on natural gas

As outlined in Issue 2 - B3, a raft of actions could be adopted to reduce reliance on natural gas with corresponding reductions to emissions

Planning for transition to other fuels

Natural gas pipelines are still being built, either to replace or expand capacity of existing ones or to connect new areas. It is "vital that developers of this new infrastructure consider the potential to make these pipelines hydrogen- or CO2-ready at the design phase to reduce future repurposing costs and minimise the risk of stranded assets".[60] Making access to public funding conditional on such design requirements is one approach.

Consideration should also be given to whether pipelines or trucking will be more appropriate or pipelines could be smaller sized with larger storage close to the generator.

[59] IEA (2023) *Energy Technology Perspectives 2023 (windows.net)*, p 348. Accessed April 2023.
[60] IEA (2023) *Energy Technology Perspectives 2023 (windows.net)*, p 351. Accessed April 2023.

B4 - Expert reflections on Australian experience

As noted above, gas is not an energy transition fuel in Australia. The retirement of fossil fuel generation will continue to be replaced by solar and wind. Some existing gas generation assets will remain to provide peaking capacity, but little to no new gas generation will be needed.

Australia will need to weigh up the trade-offs between maintaining current production and use of oil and gas versus achieving net zero emissions by 2050. There are a raft of benefits associated with reducing Australia's reliance on oil and gas, including energy security, energy affordability and reduced energy emissions. However, to make the transition Australia will need to accelerate deployment of renewables, storage and alternative fuels such as hydrogen.

B5 - Expert reflection on Vietnamese significance

As mentioned in the Draft Strategy and Draft PDP, the proportion of gas in the future fuel mix and generation mix will increase from about 15.9% in 2025 to 26.7% in 2030, but then anticipated to I lower to 20.7%. in 2045. This contribution trend demonstrates Vietnam's opinion that natural gas is considered a short-term player in the energy transition roadmap. A long term objective of the Strategy is to develop the roadmap for LNG power plants to transition towards incorporating hydrogen in to the mix. The Natural gas (including LNG) contribution in Vietnam is in it's initial stages and only contributes a small amount, but that contribution is critical in demonstrating Vietnam's boarder vision of incorporating LNG in the future energy mix based on while taking into consideration some experiences from Australia, such as:

- Planning for transition to other fuels at the design phase of natural gas pipelines to consider the potential to make these pipelines hydrogen or CO2-ready.
- Considering actions that can be taken to reduce emissions from natural gas.

Issue 3 - Entry points for hydrogen in domestic supply and understanding economic viability of hydrogen

B1 - Problem context

Hydrogen has traditionally been produced and used on the same site, typically as a feedstock for industrial/chemical applications including in refineries and as part of a mixture of gases in steel production. It is also used as a source of heat and to a lesser extent in power generation[61].

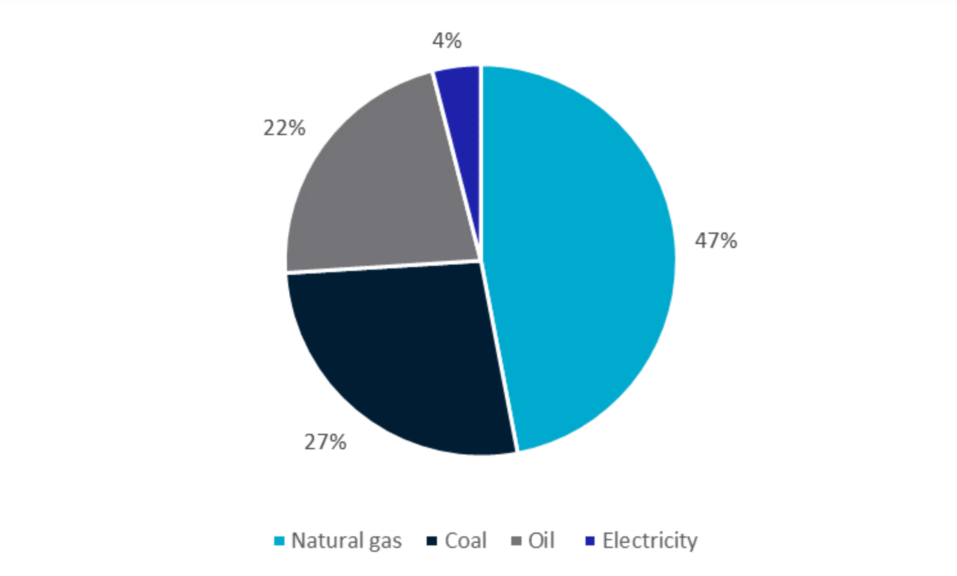
The exception to the trend of onsite production of a hydrogen-based fuel at the point of consumption is the production of ammonia (the production of hydrogen itself might still be at the location of its consumption as a

[61] International Renewable Energy Agency (IRENA) (2022) Hydrogen, https://www.irena.org/Energy-Transition/Technology/Hydrogen Accessed March 2023

feedstock to the ammonia production process), which is being considered as a potential hydrogen carrier for export of hydrogen, as well as a fuel source and industrial feedstock in its own right. Globally, ammonia production is responsible for 2% of total final energy consumption and 40% of this is energy use (natural gas or coal) as a feedstock and the rest of energy use is for the process including heat production[62]. Ammonia is a global commodity and is shipped around the world – Yara Pilbara in Australia is currently the largest supplier of global tradeable ammonia. Currently, 10% of global ammonia production is exported[63].

The majority of hydrogen production as at the end of 2021 is by steam methane reforming (SMR) of natural gas (47%), as shown in **Figure 12**. Hydrogen is also a by-product from oil refineries. The share of hydrogen production using electricity and electrolysers was only 4%. Given that the global average share of renewable electricity generation was 29-33% in 2021[64] [41], only 1% of this 4% can be attributed to renewable hydrogen i.e. produced using renewable electricity generation[65]. However, this attribution to renewable hydrogen will vary by country and region depending on the quantity of renewable electricity generation. The remaining current hydrogen generation processes produce CO_2 emissions.

Figure 12 | Global share of fuels used in hydrogen production. Source of data[41]



Therefore, in order for hydrogen to be able to contribute to global decarbonisation efforts, production needs to shift to using renewable electricity for electrolysers, and to carbon capture and storage (CCS) for both coal and natural gas-fuelled hydrogen production (SMR and autothermal reforming (ATR)). In addition, offsets or other abatement measures are needed to address upstream fugitive emissions for these

[62] IEA (2021) Ammonia technology roadmap, https://iea.blob.core.windows.net/assets/6ee41bb9-8e81-4b64-8701-2acc064ff6e4/AmmoniaTechnologyRoadmap.pdf Accessed April 2023
[63] IEA (2021) Ammonia technology roadmap, https://iea.blob.core.windows.net/assets/6ee41bb9-8e81-4b64-8701-2acc064ff6e4/AmmoniaTechnologyRoadmap.pdf Accessed April 2023
[64] IEA (2022) Renewable Electricity, https://www.iea.org/reports/renewable-electricity Accessed April 2023
[65] IRENA (2022) Hydrogen, https://www.irena.org/Energy-Transition/Technology/Hydrogen Accessed March 2023

fossil fuel hydrogen production methods[66]. Hydrogen production using unabated fossil fuels is presently the least cost method of production.

Hydrogen is being considered as an alternative fuel in a wide variety of applications, including transport, expanding its use in industry as a source of heat to replace natural gas, in pipelines for domestic and commercial use as a natural gas replacement/supplement to reduce emissions, as an export commodity, and as a source of energy storage and electricity generation, similar to objectives of PDP-8 related to transitional refuelling of existing coal and gas power plants. These new application areas may not be (optimally) co-located with the source of hydrogen production. This will require transport and storage of potentially vast quantities of hydrogen.

Therefore, and in addition to the overall inefficiency of conversion of renewables-to hydrogen-to electricity, Australia does not foresee a major role for renewable hydrogen as a generation fuel, and in particular as a mainstream method of fuel switching from existing fossil fuel thermal generation to renewable fuel generation. As stated in the 2022 AEMO ISP[*]: *"building enough VRE to meet the energy needs of winter is likely to be more efficient, on estimated technology costs, than building less VRE but more seasonal storage"* i.e. renewable hydrogen. The same considerations may apply in Vietnam: rather than investing in the renewable energy for the production of hydrogen and other renewable fuels to extend stranded fossil fuel asset lifetimes, it may simply be better to invest in more renewables firmed with storage.

B2 - Strategic setting

The Australian Hydrogen Strategy sets out the strategic framework to ensure the development of the hydrogen industry in Australia. The focus of the strategy is to introduce hydrogen into domestic markets. The use of hydrogen domestically is seen as a way to both decarbonise sectors in Australia that are reliant on fossil fuels but also as a way to scale up the hydrogen industry to allow for large scale hydrogen export.

As a result of the strategy, major national initiatives and commitments have been announced. A brief review is provided below. These initiative support both the domestic and potential export markets.

Accompanying the First Low Emissions Technology Statement in September 2020 was the Australian Government announcement of a AUD1.9 billion package to invest in new energy technologies including the allocation of approximately AUD70 million towards establishing a hydrogen export hub, research collaborations and supply chain studies[67].

The Australian Government subsequently included AUD275.5 million in its 2021-22 budget to accelerate the development of clean hydrogen hubs in

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[66] Longden T, Beck F, Jotzo F, Andrews R, Prasad M (2022) 'Clean' hydrogen?–Comparing the emissions and costs of fossil fuel versus renewable electricity based hydrogen, *Applied Energy* 306, p.118145.
[67] Australian Renewable Energy Agency (ARENA) (2021) Future Fuels Fund (Round 1) https://www.pm.gov.au/media/investment-new-energy-technologies. Accessed June 2021. Includes AUD1.62 million in additional funding to ARENA to invest in technology innovation that leads to emission reduction, some of which may be hydrogen technologies. Includes AUD74.5 million for electric vehicle refuelling infrastructure which may include hydrogen refuelling.

regional Australia and support for the implementation of a clean hydrogen certification scheme[68]. The Australian Government included AUD565.8 million in the same budget towards establishing low emissions technology partnerships and initiatives with key trading and strategic partners[69]. Under the international partnership commitment, a AUD30 million partnership was announced in June 2021 between Australia and Singapore to accelerate the deployment of low emissions fuels and technologies like clean hydrogen to reduce emissions in maritime and port operations, with up to AUD10 million commitment from each country and at least AUD10 million in additional investment leveraged from industry[70].

On the industry development front, the Australian Government funding agency ARENA announced its most recent round of support for commercial-scale renewable hydrogen projects as part of its Renewable Hydrogen Deployment Funding Round in May 2021. The three successful projects have a combined project value of AUD161 million and will access conditional funding from ARENA of AUD103.3. The successful companies and projects were: Engie Renewables Australia, in which ARENA will provide up to $42.5 million towards a 10 MW electrolyser project to produce renewable hydrogen in a consortium with Yara Pilbara Fertilisers at an existing ammonia facility in Karratha, Western Australia; ATCO Australia, in which ARENA will provide up to $28.7 million towards a 10 MW electrolyser for gas blending at ATCO's Clean Energy Innovation Park in Warradarge, Western Australia; and AGIG, in which ARENA will provide up to $32.1 million in funding for a 10 MW electrolyser for gas blending at AGIG's Murray Valley Hydrogen Park in Wodonga, Victoria.

Australia's small and medium-sized enterprises (SMEs) have historically been an important part of Australian industry growth and contributors to innovation. The role of SMEs in the development of an Australian hydrogen industry is expected to be similarly important. In recognition of this, National Energy Resources Australia (NERA), one of six industry growth centres funded by the Australian Government, announced in February 2021 a network of hydrogen technology clusters across Australia that currently stands at fifteen clusters nationwide[71]. NERA provided AUD1.85 million in seed-funding to accompany a range of funding commitments from state and territory governments and industry financial support towards the clusters which will build skills, capability and commercialisation opportunities and facilitate connections and knowledge sharing to accelerate development of the emerging industry.

As a national research and development initiative, CSIRO, Australia's national science agency and innovation catalyst, formally launched a Hydrogen Industry Mission in May 2021. Missions are major scientific and collaborative research programs developed by CSIRO with industry,

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[68] Liberal New South Wales (NSW) (2021) Jobs Boost from New Emissions Reduction Projects https://www.minister.industry.gov.au/ministers/taylor/media-releases/jobs-boost-new-emissions-reduction-projects. Accessed June 2021. Information regarding awarded Regional Hydrogen Hubs can be accessed through, e.g. HyResource https://research.csiro.au/hyresource/regional-hydrogen-hubs-program/ Accessed March 2023.
[69] Mirage (22 April 2021) Cutting emissions and creating jobs with international partnerships https://www.minister.industry.gov.au/ministers/taylor/media-releases/cutting-emissions-and-creating-jobs-international-partnerships. Accessed June 2021.
[70] DCCEEW (2021) International co-operation on high tech and hydrogen, https://www.energy.gov.au/news-media/news/international-co-operation-high-tech-and-hydrogen. Accessed June 2021.
[71] National Energy Resources Australia (NERA) Hydrogen Technology Cluster Australia (H2TCA) https://www.nera.org.au/regional-hydrogen-technology-clusters Accessed June 2021.

government and research sector partners and are aimed at making significant breakthroughs to solve some of Australia's greatest challenges. These challenges are health and wellbeing, food security and quality, national security, a resilient environment, sustainability of energy and resources, and future industries. Building on CSIRO's existing long-term research capability and extensive research and industry network, the Hydrogen Industry Mission aims to enable Australia's clean hydrogen industry development through its unique position in the ecosystem as a connector and to crowd funding and resources for impactful research, development and demonstration partnerships.

In additional to those announcements at a national level, multiple major milestones, initiatives and commitments on an Australian state and territory level play a significant role in Australia's hydrogen industry development. For greater detail on commercial hydrogen developments including on those projects mentioned above and in the following sections see 'HyResource', a collaborative initiative between the CSIRO Hydrogen Industry Mission, NERA, the Future Fuels CRC and the Australian Hydrogen Council[72].

For an overview of Australian hydrogen research activities see 'HyResearch'[73] or the Hydrogen Knowledge Centre, in general for other useful resources. Both HyResource and HyResearch are modules of the Centre and more modules are added as they are completed[74].

Recently, the Australian Hydrogen Research Network (AHRN)[75] supported by a $5 million Federal Government RD&D Hydrogen International Collaboration Program[76] held the first Australian Hydrogen Research Conference (AHRC 2023)[77].

B3 - Solutions

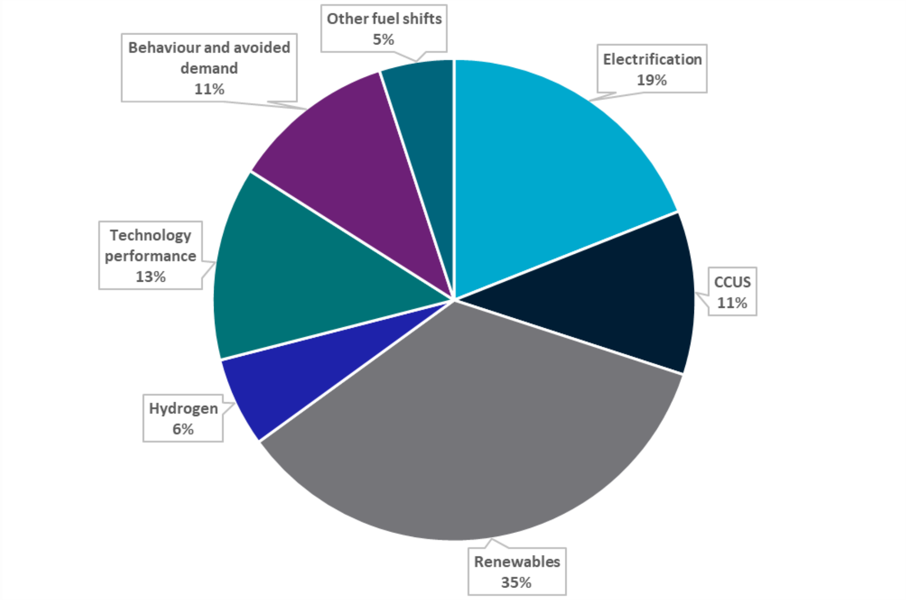
The cost of low emissions hydrogen production will reduce from now and gradually out to 2050 due to a number of factors such as learning-by-doing, economies of scale in manufacturing and technology scale-up. All of these factors will be driven by increased levels of deployment of these technologies[78]. To illustrate this point, projected costs of hydrogen production in the years 2030, 2040 and 2050, compared to costs in 2020, using various low emission methods are shown in **Figure 15**.

The impact of hydrogen production on reducing greenhouse gas emissions is projected by the IEA in their Net Zero emission Scenario to

[72] CSIRO (2023) Hyresource https://research.csiro.au/hyresource/ Accessed April 2023
[73] CSIRO (2023) Hyresearch https://research.csiro.au/hyresearch/ Accessed April 2023
[74] CSIRO (2023) Hydrogen Knowledge Centre https://research.csiro.au/hydrogenknowledge/ Accessed April 2023
[75] Australian Hydrogen Researcher Network (AHRN) (2023) https://ahrn.org.au/ Accessed April 2023
[76] DCCEEW (2021) Building Australia's hydrogen industry through research collaborations, https://www.energy.gov.au/news-media/news/building-australias-hydrogen-industry-through-research-collaborations Accessed April 2023
[77] Australian Hydrogen Research Conference (2023) https://ahrc2023.com.au/ Accessed January 2023
[78] Graham P, Hayward J, Foster J and Havas L (2022) GenCost 2022-23 Consultation Draft, CSIRO, Australia https://doi.org/10.25919/hjha-3y57

be a 6% cumulative reduction over the years 2021 to 2050 as shown in **Figure 14**, representing 60 Gt CO2 avoided emissions[79].

Figure 13 | Projected cumulative impact of greenhouse gas emission reduction measures from 2021-2050. Source IEA[80]



The Net Zero Scenario has global greenhouse gas emissions reaching net zero by 2050. The impact green hydrogen production has on reducing greenhouse gas emissions up to 2030 is projected to be modest, particularly when compared with the impact of renewables on reducing emissions from electricity generation. Hydrogen's impact will be in hard to abate sectors such as industry and will be more apparent in the longer rather than shorter term[81]. Green hydrogen production relies on electrolysers, and electrolyser manufacturing capacity started from a minimal base until in the late 2010's and reached 8 GW by 2021, more than double that of 2020. It is projected to reach 65 GW by 2030[82].

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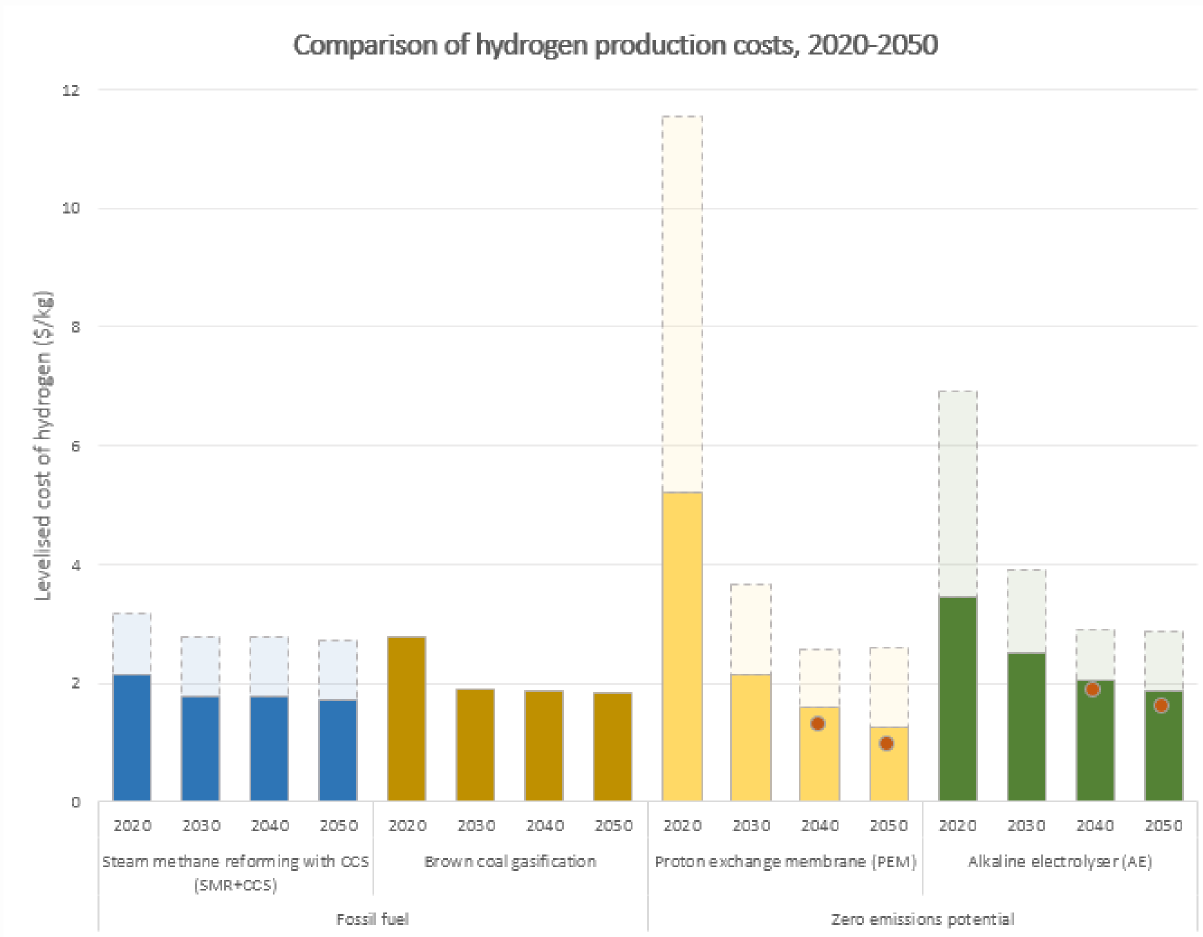
[79] IEA, Cumulative emissions reduction by mitigation measure in the Net Zero Scenario, 2021-2050, IEA, Paris https://www.iea.org/data-and-statistics/charts/cumulative-emissions-reduction-by-mitigation-measure-in-the-net-zero-scenario-2021-2050, IEA. Licence: CC BY 4.0 Accessed April 2023

[80] IEA, Cumulative emissions reduction by mitigation measure in the Net Zero Scenario, 2021-2050, IEA, Paris https://www.iea.org/data-and-statistics/charts/cumulative-emissions-reduction-by-mitigation-measure-in-the-net-zero-scenario-2021-2050, IEA. Licence: CC BY 4.0 Accessed April 2023

[81] IEA (2022), Hydrogen, IEA, Paris https://www.iea.org/reports/hydrogen, License: CC BY 4.0 Accessed April 2023

[82] IEA (2022) Electrolysers: tracking report. https://www.iea.org/reports/electrolysers Accessed April 2023

Figure 14 | Projected year 2030, 2040 and 2050 levelised cost of production of hydrogen (LCOH2) using various technologies[83]



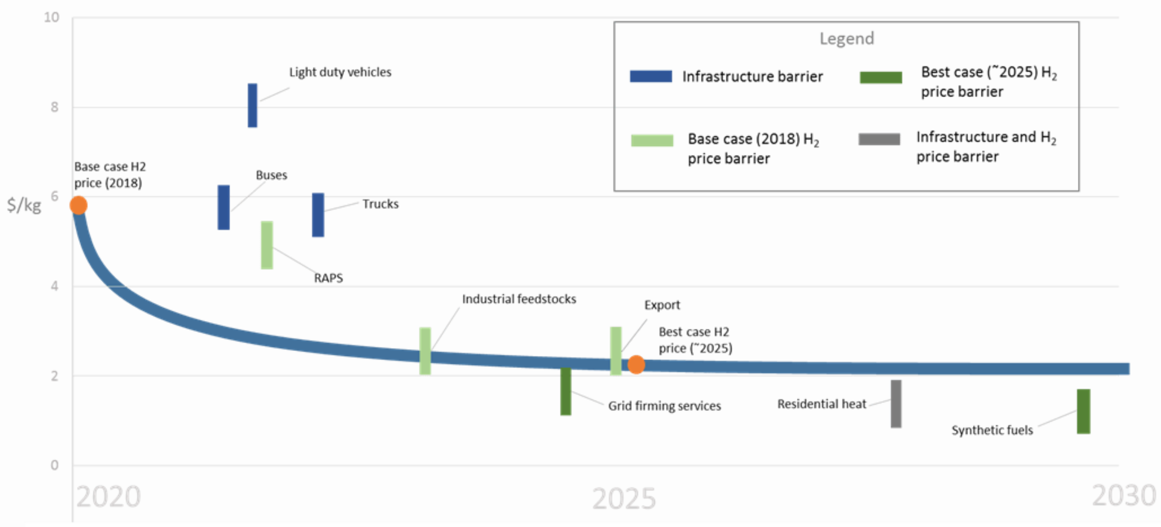
The dotted boxes display the range of costs for a particular production method. For SMR, the lower and upper bounds are based on a gas price of $3.27/GJ and $9/GJ respectively. For PEM and AE, the scenarios resulting in lower and upper bounds of hydrogen costs vary over time. In 2050, the lowest production costs for PEM are $1.25/kg based on capital costs of $206/kw, performance of 43 kWh/kgH2 and off-grid electricity costs $16.6/MWh. AE costs based on the same assumptions results in 2050 production costs of $1.88/kg, with variances driven by different operating expenses, stack lifetimes and stack replacement costs. Detailed assumptions and further results are available in Appendix xx of the technical report. The orange markers in 2040 and 2050 show the impact of selling oxygen as a byproduct of the electrolysis process, which is dependent on the presence of a local buyer.

Creating hydrogen hubs are a central part of Australia's hydrogen strategy. The hubs will become centres of high levels of hydrogen demand, which will allow for scaling up of the hydrogen industry in Australia. Hubs contain shared infrastructure, leading to cost reductions due to economies of scale and sector coupling between the electricity and gas infrastructure. However, in order to create these hubs, the use of hydrogen in key application areas needs to be proven first, such as in transport, gas networks and as part of the electricity system.

Hydrogen will be used in a wide variety of applications across the energy sector. An example of typical applications and the competitiveness of hydrogen in those applications against the incumbent fuels/technologies is presented in **Figure 15**. This analysis was completed in 2018 and will be updated in 2023.

[83] Butler C, Maxwell R, Graham P and Hayward J (2021) Australian Industry Energy Transitions Initiative Phase 1 Technical Report, ClimateWorks Australia

Figure 15 | Competitiveness of hydrogen in targeted applications



The location of each application on the y-axis corresponds to the cost point at which hydrogen is competitive in $/kg in that application. The location on the x-axis is an estimate of when the use of hydrogen in that particular application may occur. Economic competitiveness is not the only factor involved. There are barriers to uptake of hydrogen in various applications which has also been highlighted.

The cost of hydrogen production shown as a curve in the figure is based on the projected cost of green hydrogen production.

Some of the first, novel applications of hydrogen in Australia were injection into gas pipelines and blending with natural gas. Projects include:

- The ATCO Hydrogen Blending Project – which injected renewables-based hydrogen into a section of Western Australia's natural gas distribution network in 2022.
- Hydrogen Park South Australia – has been supplying 5% blended renewable gas to 700 homes and plans on expanding this to 3000 in 2023.
- Western Sydney Green Gas Project – began producing hydrogen from an electrolyser and blending 2% by volume of hydrogen into the Sydney gas distribution network in 2021. The project also includes a microturbine/fuel cell to produce electricity and hydrogen storage.

The gas industry has very few options for decarbonisation and blending hydrogen into existing natural gas pipelines is seen as one way to help decarbonise the natural gas network. However, there is an upper limit on blending ratios at around 15%, determined by embrittlement of the steel joints for some types of steel pipelines. Further, hydrogen molecules are significantly smaller than natural gas molecules so pipelines are therefore subject to higher leakage rates when filled with hydrogen, requiring high density plastic sleeving to be implemented inside existing gas networks.

Biogas is also a possibility but there are limited supplies of this highly-variable in terms of production quantities resource. Hydrogen will need to be distributed around hydrogen hubs so it can be used by multiple applications. Both new and existing pipelines (subject to the comments above) are a cost-effective way to transport large volumes of hydrogen. Therefore, these projects are required as part of hydrogen hub development.

Transport applications are becoming more common, with the construction of hydrogen refuelling stations. Projects include:

- ActewAGL Hydrogen Refuelling Station – refuelling began in 2021 for 20 light passenger fuel cell electric vehicles as part of the ACT Government fleet.
- The Toyota Hydrogen Centre Project in Altona, Victoria – includes onsite hydrogen production using an electrolyser and renewable energy, a fuel cell and refuelling station. This project became fully operational in 2021.

Technologies such as fuel cell vehicles, electrolysers and other equipment in refuelling stations are relatively mature and commercially-available, although considerable investment in research is still needed to drive down the costs to make hydrogen competitive with petrol and diesel. Nevertheless, road transport applications are one of the most prospective options for use of hydrogen, particularly over large distances where hydrogen might compete effectively with heavy battery payloads.

In relation to social licence for hydrogen applications more generally, another factor to consider is that refuelling stations are visible to the public and can showcase a wide range of hydrogen technologies. This helps to familiarise the general population to the use of hydrogen and thus can lead to increased acceptance, uptake and broader markets.

B4 – Expert reflection on Australian experience

The path Australia has taken thus far in supporting the development of a new hydrogen industry in Australia has been promising. It began with the development of the CSIRO National Hydrogen Roadmap[84], which highlighted the competitive advantages Australia has to offer to be a major global player in hydrogen production and export, such as abundant renewable energy resources, land and industry that has world class experience in the development, completion and operation of large-scale energy export projects. This was followed by other studies that delved further into export, the research needed to support a hydrogen industry

[84] Bruce S, Temminghoff M, Hayward J, Schmidt E, Munnings C, Palfreyman D and Hartley P (2018) National Hydrogen Roadmap, CSIRO, Australia https://www.csiro.au/en/work-with-us/services/consultancy-strategic-advice-services/csiro-futures/energy-and-resources/national-hydrogen-roadmap

and Australia's Hydrogen Strategy[85]. There have since been many studies looking at areas that were identified as being important in the hydrogen strategy, such as the development of hydrogen hubs, the opportunities for employment, etc.

Hydrogen projects that are funded at federal and state and territory levels are diverse and are tackling all areas of the hydrogen value chain, from production, to storage, transport and multiple end uses. These projects will not only provide valuable knowledge and lessons learnt but will also help to reduce the cost of hydrogen technologies. One initiative supported by the two most populous states, New South Wales and Victoria, will be the Hume Hydrogen Highway. With the project participants expected to be announced shortly, this mobility-based initiative will support the building of hydrogen refuelling infrastructure for heavy vehicles along a major logistics route between the two states.

The Australian Government also funds industry-led collaborations between industry, researchers and end users through the Cooperative Research Centre (CRC) Program. The topical nature of hydrogen for industry and research sectors is indicated by several CRCs featuring hydrogen themes, such as:

- the Heavy Industry Low-carbon Transition or HILT CRC – the main aim of this CRC is to derisk decarbonisation for heavy industry in Australia so Australian industry can grow into the future[86]
- the Future Fuels CRC - the main objective of this CRC is to enable the decarbonisation of Australia's energy networks, including gas pipelines[87]
- the mobility-focussed iMOVE CRC has been designed to explore future transport challenges in Australia[88]
- the Future Energy Exports or FEnEx CRC is exploring the decarbonisation of Australia's energy exports[89]

A CRC in development specifically focussed on hydrogen, the Scaling Green Hydrogen CRC[90] has submitted its proposal for federal funding in 2023.

Australia is a key partner in global initiatives such as the IEA Technology Collaboration Program on hydrogen and is a co-lead country in Mission Innovation's Clean Hydrogen Mission. Additionally, CSIRO received federal funding[91] to support international delegations representing Australia's research community to build and strengthen hydrogen R&D

[85] Commonwealth of Australia (2019) *Australia's National Hydrogen Strategy*, https://www.dcceew.gov.au/sites/default/files/documents/australias-national-hydrogen-strategy.pdf
[86] https://hiltcrc.com.au/
[87] https://www.futurefuelscrc.com/
[88] https://imoveaustralia.com/
[89] https://www.fenex.org.au/
[90] https://hydrogencrc.com.au/
[91] DCCEEW (2021) Building Australia's hydrogen industry through research collaborations, https://www.energy.gov.au/news-media/news/building-australias-hydrogen-industry-through-research-collaborations Accessed April 2023

collaboration, including funding for research fellowships at international research institutes. Insights gained from the delegations will help further research collaborations supporting Australia's hydrogen industry development.

It has been suggested that funding for hydrogen in Australia is a distraction, and more funding should go towards renewable energy technologies that are able to support more immediate decarbonisation efforts to reach 2030 goals, as well as drive down the cost of renewable electricity – a key component of the cost of renewable hydrogen. Renewable energy technologies, such as wind and solar PV are well advanced, and while there are still challenges with regards to integration of these technologies in the grid (particularly as their penetration is increasing), they are already the lowest cost forms of electricity generation in Australia even without financial subsidies. Large scale renewable generation developments have been supported by the renewable energy target, which ends in 2030. Rooftop PV on households was supported by feed-in-tariffs and small-scale renewable generation certificates with similar support timeframes. The incentives for rooftop PV are already there as it reduces electricity bills for individual households with a payback time of just over three years, with the result that Australia has the highest penetration of rooftop PV per capita. Private investment in renewable technologies continues to grow, with $4.29 billion invested in the December quarter 2022 alone, ten times more than the previous three months and the majority of this investment was in variable renewables and storage[92].

However, more private capital is needed to develop additional renewable energy farms and storage in order to reach the government's 2030 emissions reduction target. It has been suggested that increasing and extending the renewable energy target will assist with this. Therefore, rather than the government providing financial support, further policy support is required.

If wind and solar electricity generation technologies had not been supported by government funding in their early stages of deployment, then they would not be as advanced and as cheap as they are today. The Australian government's investment in hydrogen is in all aspects of hydrogen technologies, and the aim is to reduce the cost of hydrogen production and increasing the maturity of hydrogen technologies so hydrogen can be used as an alternative clean fuel source both domestically and globally.

Whilst significant government support has been provided to these projects, many renewable hydrogen projects have struggled to reach final investment decision due to not having purchaser offtake agreements in place to underpin the long-term projects. Australia is not alone in this experience. The World Economic Forum has observed that "despite a growing pipeline of projects, only 4% have reached final investment decision… Finding and securing offtake agreements is a challenge. This is

[92] Hannam P (9 March 2023) 'Australia invests $4.29bn in renewable energy in December quarter, 10 times more than previous three months', The Guardian, https://www.theguardian.com/australia-news/2023/mar/09/australia-invests-429bn-in-renewable-energy-in-december-quarter-10-times-the-previous-three-months Accessed April 2023

critical as it enables these capital-intensive projects to demonstrate long-term bankability and return on investment."[93]

B5 - Expert reflections on Vietnamese significance

As hydrogen is a new but trending topic, the Energy Development Strategy also mentions it as a solution for a green energy future. As the starting point, it's important for Vietnam to have its Green Hydrogen Strategy. The directions to develop the Green Hydrogen Strategy include: clearly identifying the role of hydrogen within Vietnam's energy sector, ensuring the harmony of renewable energy development and hydrogen consumption. Hydrogen can be considered as a significant part of solution to utilize variable renewable energy effectively, particularly when there is excess supply.

Understanding the potential demand for hydrogen in Vietnam is also important. For instance, there are opportunities for the development of an industrial hub combining renewable energy generation, hydrogen production, green steel and fertilizer production to take advantage of economies of scale and optimise transportation costs.

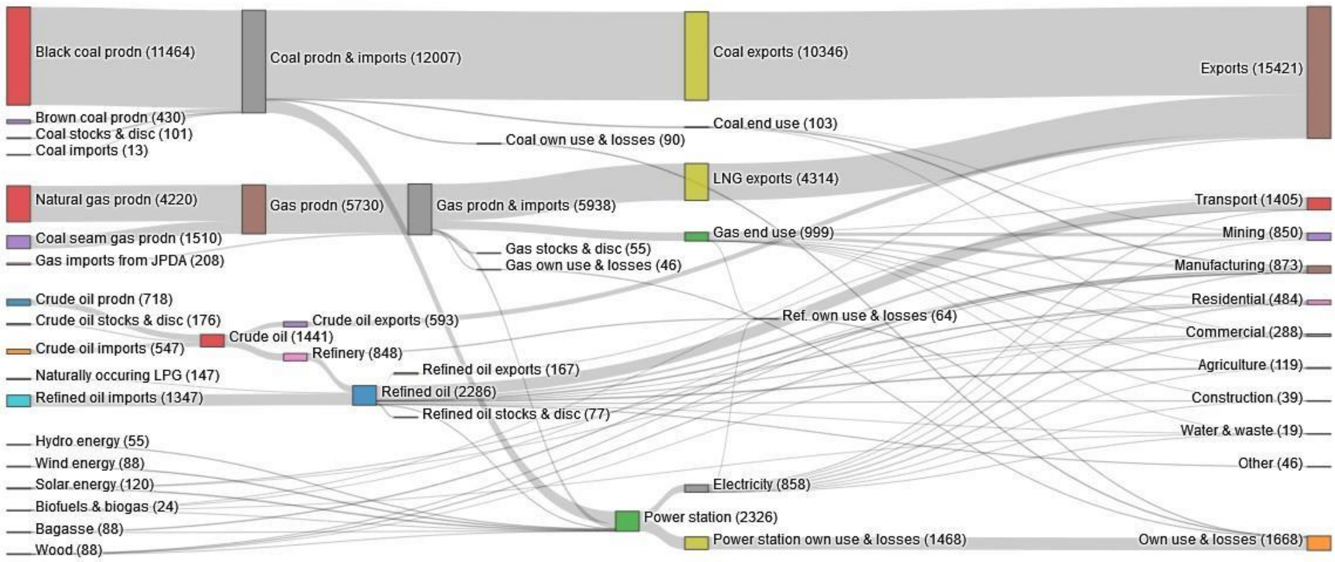
Issue 4 - Options for hydrogen as an export commodity

B1 - Problem context

The energy flows in Australia for the financial year 2020-21 are shown in Figure 16. The largest share of energy flows are exports, which are 73% of the total end use. Of this, 67% are coal exports and 28% are natural gas exports. A challenge that Australia faces is that these energy export markets could potentially disappear as the world approaches net zero emissions. In particular, the main importers of Australia's energy exports i.e. China, Japan and Korea, have policies to reduce their emissions. Japan and Korea have committed to achieving net zero emissions by 2050, and China is aiming to peak in emissions by 2030 and then reach carbon neutrality by 2060. This means Australia is motivated to find ways to export low carbon energy to these key trading partners in order to avoid losing a key source of revenue. In the year 2021, of the top three exports from Australia two were energy-based (coal and natural gas), worth almost $100 billion combined[94].

[93] World Economic Forum (WEF) (14 November 2022) 3 ways clean hydrogen projects can boost their chances of securing final investment decisions https://www.weforum.org/agenda/2022/11/three-ways-clean-hydrogen-projects-can-secure-offtake/ Accessed March 2023
[94] https://oec.world/en/profile/country/aus

Figure 16 | Australian energy flows 2020-21 (Petajoules)[95]



Hydrogen is considered as an energy export replacement for fossil fuels. However, there are different ways of producing hydrogen. So-called 'blue' hydrogen is produced using natural gas either via SMR or ATR with CCS. 'Green' hydrogen is hydrogen produced using electrolysers (alkaline electrolysis (AE) and proton exchange membrane (PEM) are the most common technologies) and renewable electricity. Currently, the cost of producing blue hydrogen is lower than green hydrogen. However, electrolysers are projected to continue to fall in capital cost and improve their efficiency. The major cost component of blue hydrogen production is the price of natural gas, which is variable and can lead to uncertainty[96]. The main advantage of blue hydrogen production is scale and capacity factor: blue hydrogen plants can be sized to large scales and can run at a 90% capacity factor, which can be important for scaling up capacity for an export industry. In order for electrolysers using renewable electricity to have as high a capacity factor they would need to either be powered using hydro or biomass-fuelled electricity generation or include electricity storage and/or arrange a power purchase agreement for 100% renewable electricity.

There is a risk that blue hydrogen production assets may become stranded in the future[97]. The European Union has policies supporting the production and importation of renewable hydrogen only, that is hydrogen produced using non-biological sources of renewable energy[98]. There is a

[95] DCCEEW (2022) Australian Energy Statistics 2022, Table A, Table F and Table G https://www.energy.gov.au/publications/australian-energy-update-2022 Accessed March 2023
[96] Fazeli R, Beck F and Stocks M (2022a) Recognizing the role of uncertainties in the transition to renewable hydrogen, *International Journal of Hydrogen Energy*, Volume 47(65), 27896-27910 < https://doi.org/10.1016/j.ijhydene.2022.06.122
[97] Fazeli R, Longden T, Beck FJ and Stocks M (2022b), *Understanding the risk of stranded assets for blue hydrogen production plants*. Proceeding of 2022 International System Dynamics Conference, 18-22 July, Frankfurt, Germany. https://proceedings.systemdynamics.org/2022/papers/P1182.pdf
[98] European Commission (2023) Questions and Answers on the EU Delegated Acts on Renewable Hydrogen https://ec.europa.eu/commission/presscorner/detail/en/qanda_23_595 Accessed March 2023

risk to blue hydrogen assets that other potential hydrogen importing regions may also follow suit.

Guarantee of origin and other green hydrogen certification schemes are being developed across regions and countries to account for emissions created along the entire hydrogen supply chain[99]. However, there is currently no scheme that is recognised to certify green hydrogen for cross-border trade. This will need to be developed to ensure compliance with importing country greenhouse gas emission policies and regulations[100].

B2 - Strategic setting

The opportunity for exporting hydrogen from Australia was articulated in 2018 in the CSIRO National Hydrogen Roadmap and in *Opportunites for Australia from Hydrogen Exports* by Acil Allen consulting[101]. Subsequent publications have outlined the enormous potential scale of these hydrogen export opportunities[102,103,104].

Australia is in the unique position of having access to vast, cheap renewable energy resources across a large country, the technical skills to create the large scale energy infrastructure needed to deploy hydrogen value chains needed for export, as well as a long history of exporting energy to the world with a focus on Asia, which has led to well established trading relationships. The Australian government has demonstrated its support for hydrogen export through projects such as the Hydrogen Energy Supply Chain (HESC), which has led to the first batch of liquid hydrogen being exported to Japan (produced from brown coal gasification).

B3 - Solutions

To avoid issues with stranded assets, Australia may need to focus on scaling up the green hydrogen industry to focus on export. Certification schemes that are recognised internationally and particularly with key trading partners should be developed. At the same time, other countries are also trying to develop hydrogen export markets. Australia will need to aim to continue to reduce the cost of hydrogen production to be competitive and establish trading relationships to ensure offtake of hydrogen.

The other issue that has not been technically or economically resolved is in what chemical form to export hydrogen. The options are liquified

[99] White LW, Fazeli R, Cheng W, Aisbett E, Beck FJ, Baldwin KGH, Howarth P and O'Neill L (2021) Towards emissions certification systems for international trade in hydrogen: the policy challenge of defining boundaries for emissions accounting, *Energy*, Volume 215 (Part A), 119139 https://doi.org/10.1016/j.energy.2020.119139
[100] IRENA (2023) *Creating a global hydrogen market: Certification to enable trade*, https://www.irena.org/Publications/2023/Jan/Creating-a-global-hydrogen-market-Certification-to-enable-trade Accessed April 2023
[101] Acil Allen Consulting (2018) *Opportunities for Australia from hydrogen exports* https://acilallen.com.au/projects/resources/opportunities-for-australia-from-hydrogen-exports
[102] Burke P, Beck FJ, Aisbett E, Baldwin KGH, Stocks M, Pye J, Venkataraman M, Hunt J and Bai X (2022) Contributing to regional decarbonization: Australia's potential to supply zero-carbon commodities to the Asia-Pacific. *Energy*, Volume 248, 123563 https://doi.org/10.1016/j.energy.2022.123563
[103] "*Superpower*", Ross Garnaut, La Trobe University Press, 2019.
[104] "*Hydrogen*" by Frank Jotzo in "*The Superpower Transformation: making Australia's zero-carbon future*", Edited, by Ross Garnaut, La Trobe University Press, 2022.

hydrogen, which is being pursued in the HESC project; ammonia as in the H2-Hub™ Gladstone project; or liquid-organic hydrogen carriers (e.g. methylcyclohexane (MCH) as in the Neoen-ENEOS Export Project). Methanol is also emerging as a potential hydrogen carrier, as long as there is a source of CO_2 which can be combined with the renewable hydrogen to produce methanol. Each carrier has unique advantages and disadvantages.

- Liquid hydrogen does not require any separation at the importing end to extract pure hydrogen, but it is difficult and energy intensive to produce and there can be significant losses (termed boil-off) from the cryogenic storage vessels (maintained at -253 degrees Celsius) if the vessels are not fully insulated from sources of heat. The ships used to transport liquid hydrogen are still an ongoing development.

- Ammonia is a globally traded commodity and there are many ammonia plants already established that can produce ammonia using renewable hydrogen. However, it needs to be cracked and separated at the importing end in an energy intensive process to extract pure hydrogen.

- MCH is just one example of a liquid organic carrier, for which in the case of MCH each molecule carries six hydrogen molecules/ 12 hydrogen atoms which can be extracted. On extraction of the hydrogen in the importing country the MCH is converted to toluene, which is then shipped back to the exporting country.

- Methanol is used as a feedstock in many chemical processes and can be used as a fuel for transport for example. However, methanol requires a source of CO2 for its production, and it would be used as methanol directly, not converted into hydrogen in the importing country. Therefore, the use of methanol as a carrier is limited to applications for methanol.

Scaling up to a large export industry based on green hydrogen will require significant roll out of renewable electricity, electrolysers, port upgrades and water use. The technologies and expertise to do this already exist, but the scale is unprecedented. Training programs need to be put into place to ensure there is a sufficiently large workforce to construct and operate these new industries.

One of the important industrial applications of hydrogen in a future decarbonised world is in the reduction of iron oxide to form iron in the steel production value chain. A further renewable energy export opportunity for Australia therefore arises because of the proximity of some of the world's largest iron ore reserves to some of the best global solar and wind resources. The generation of renewable electricity to create hydrogen and support a major iron production industry adjacent to these mine sites is another driver for hydrogen production that could see significant additional demand for green hydrogen and renewable energy generation in Australia[105].

B4 - Expert reflection on Australian experience

The Australian experience has explored both the domestic and export opportunity, where activities funded by the Australian federal, state and territory governments are supporting both opportunities since supporting the domestic market will help with scaling up the export market. Therefore, the reader is referred back to Issue 3 – B4 for more information.

Pledged investment in hydrogen in Australia reached $250 billion in 2022[106]. Australia aims to be a global renewable energy export superpower, with hydrogen at the forefront due to its versatility to be used in many end use sectors. The heightened recent interest in renewable hydrogen is due to countries' pledging to reach net zero emisisons by 2050 and seeking alternatives to fossil fuels, particularly for hard to abate sectors such as industry or where there are insufficient renewable energy resources and/or land to allow individual countries the opportunity to decarbonise using their own resources. Increasing energy security by diversifying energy infrastructure is another reason Australia is interested in hydrogen as an alternative energy source[107]. Hydrogen can be produced domestically and used in sectors where imported fossil fuels are currently used.

Australian industry is getting behind the hydrogen export opportunity, and there are now at least ten proposed export projects, many aiming to export hydrogen and hydrogen derivatives (mainly ammmonia), with a total renewable electricity generating capacity exceeding 120 GW. These include, amongst others (see figure below):

- The Western Green Energy Hub, a 50 GW solar and wind facility aiming to produce 3.5 million tonnes of green hydrogen each year[108]
- The Australian Renewable Energy Hub, a 26 GW solar and wind facility aiming to export 1.6 million tonnes of green hydrogen or 9 million tonnes of green ammonia each year[109]
- H2-Hub™ Gladstone – a staged approach will be taken to install 3 GW of electrolysers and produce up to 5000 tonnes per day of ammonia based on green hydrogen. The ammonia will be used

[105] Burke P, Beck FJ, Aisbett E, Baldwin KGH, Stocks M, Pye J, Venkataraman M, Hunt J and Bai X (2022) Contributing to regional decarbonization: Australia's potential to supply zero-carbon commodities to the Asia-Pacific. *Energy*, Volume 248, 123563 https://doi.org/10.1016/j.energy.2022.123563
[106] Packham C (23 March 2022) 'Hydrogen investment in Australia tops $250b', *The Australian Financial Review*, https://www.afr.com/companies/energy/hydrogen-investment-in-australia-tops-250b-20220323-p5a79h Accessed 26 April 2023
[107] Department of Foreign Affairs and Trade (DFAT) (2021) Diversifying Australia's energy infrastructure: hydrogen technology, Business envoy July 2021 https://www.dfat.gov.au/about-us/publications/trade-investment/business-envoy/july-2021/diversifying-australias-energy-infrastructure-hydrogen-technology Accessed April 2023
[108] Intercontinental Energy (2023) Western Green Energy Hub (WGEH) https://intercontinentalenergy.com/western-green-energy-hub Accessed March 2023
[109] BP Australia (2023) Renewable energy hub in Australia https://www.bp.com/en_au/australia/home/who-we-are/reimagining-energy/decarbonizing-australias-energy-system/renewable-energy-hub-in-australia.html Accessed March 2023

domestically but there are export plans where an MoU has been signed with Korea East West Power to look at using this ammonia to decarbonise coal fired power stations in Korea.

- Neoen-ENEOS Export Project – this includes up to 1,200 MW of wind, 600 MW of solar PV and 900 MW/1,800 MWh of battery storage. Electrolysers will be used to produce green hydrogen which will then be converted into MCH for export to Japan.

Figure 17 | Major (>1 GW) renewable energy export projects totalling > 120 GW (labelled anti-clockwise from the top of Western Australia)

Australian Renewable Energy Hub – 26GW

Yara Pilbara – 5GW

Province HyEnergy – 8 GW

Murchison Renewable H_2 – 5GW

Infinite Green Energy – 1GW

Western Green Energy Hub – 50GW

Forrest Future Industries – 2GW

Stanwell – 3GW

Hydrogen Utility – 3GW

Sun Cable – 20GW (electricity)

Australia has been working domestically and internationally over the past three years to develop an internationally aligned emissions accounting framework known as the Guarantee of Origin or GO scheme[110]. The scheme will measure, track and verify the carbon emissions and other attributes of Australian clean energy products (including hydrogen and hydrogen energy carriers) and renewable electricity. This will enable consumers across various markets to identify and purchase products that meet their needs. The scheme is aligned with international work and will be essential to accessing international markets.

The Australian Government consulted on a proposed scheme design in 2022 and is currently considering next steps.

B5 - Expert reflection on Vietnamese significance

Like Australia, Vietnam has built an understanding of the future role of hydrogen and with the great potential of renewable energy in Vietnam, it has the potential to produce green hydrogen. The Strategy has set out the potential markets for hydrogen, which is not only domestic but also international. Vietnam would like to be a part of the global hydrogen value

[110] DCCEEW (2022) Guarantee of Origin Scheme https://www.dcceew.gov.au/energy/renewable/guarantee-of-origin-scheme Accessed March 2023

chain and take advantage of current free trade agreements to export to those markets.

Issue 5 - Managing competition for renewable energy generation between domestic electricity demand and hydrogen production

B1 - Problem context

Green hydrogen production at the scales required for an export industry (even ignoring domestic demand) will require vast amounts of renewable electricity, significantly more than is currently installed in Australia. A study by the Australian National University (ANU)[111] indicates that one future scenario in which Australia continues to export the same amount of energy as at present, and continues to mine the same amount of iron and aluminium ores as at present but converts that into green steel and green aluminium, will require 30 times the amount of electricity currently generated (266 TWh/y) in this fully electrified and renewable energy scenario for Australia – nearly 8,000 TWh/y. This would also represent a significant scale up of steel and aluminium production in Australia.

As discussed earlier, there may be competition for renewable electricity between hydrogen and other embedded renewable energy exports and meeting local electricity demand. There may also be competition for resources, such as the technologies themselves and for critical materials: this will continue to be an issue with current global supply chain constraints.

There will also be competition for sites for renewable energy development, which can be very land intensive. Wind farms in particular require significant spacing between the turbines - typically up to 10 blade diameters to allow for turbulence losses downstream from the prevailing winds. This means that vast areas of land may need to be acquired, even though the turbine footprint itself is a very small fraction (a few per cent) of the acquired land area. In the ANU scenario considered above, a combination of 50% solar and 50% wind generation is used, with the smaller area required for solar (<9,000 square kilometres) located between the wind turbines. The total land area required is ~168,000 square kilometres and is dominated by wind. This is equivalent to ~2% of the continental land area, or somewhat more than 4% of the land used for livestock grazing - a land use that is quite compatible with wind (and solar) farms.

The water resources required for hydrogen production are also significant, and the ANU scenario above would require 865 gigalitres of water per year (or ~80% of the water requirements of the current mining industry). This could not easily be met using the freshwater resources of such a dry continent, so desalination of seawater would be required. The

[111] Burke P, Beck FJ, Aisbett E, Baldwin KGH, Stocks M, Pye J, Venkataraman M, Hunt J and Bai X (2022) Contributing to regional decarbonization: Australia's potential to supply zero-carbon commodities to the Asia-Pacific. *Energy*, Volume 248, 123563 https://doi.org/10.1016/j.energy.2022.123563

energy cost is relatively small (<0.1% of energy for electrolysis), but the upfront capital cost of large desalination plants is not insignificant.

B2 - Strategic setting

Many countries have expressed an interest in acquiring hydrogen from Australia, including Germany, Japan and South Korea. There is demand in particular from regions which foresee a seasonal electricity shortage that can be addressed by hydrogen storage – particularly in the northern latitudes where in winter solar (and sometimes wind) generation is reduced, and hydro is locked up in the snowpack (see Generation discussion paper).

There is also potential competition with supply from other countries with significant renewable energy resources – often dominated by solar. This includes countries with dry continental climates and deserts such as Chile, the Middle East and North Africa. However, Australia has considerable advantages in its combination of some of the world's best solar resource with the best wind capacity factors – especially with complementary generation since the wind often blows at night. This, combined with Australia's vast land availability, it's experience with major resource infrastructure development and its trusted status as an existing major global energy supplier may provide the competitive advantage to retain its role as a world energy powerhouse.

B3 - Solutions

Export industries will be so large that they will need to build new electricity generation capacity many times the size of the current electricity grid. They may not be located near or even connected to the existing grid but have their own dedicated grids as it will be cheaper – with no transmission or grid connection charges. New industries producing green hydrogen, ammonia, fertilisers, chemicals, metals (steel, aluminium) and other embedded renewable energy products may develop off-grid in remote sites where vast, cheap renewable resources are located, often beside major mineral reserves. Therefore, separate off-grid locations for export production of hydrogen may present a solution to the competition for domestic renewable electricity, although competition for infrastructure supply chains may remain. This is well aligned with PDP-8 suggestions of imposing no limits to install off-grid renewables, including ones for hydrogen production.

Further, while there may be no direct competition for renewable electricity between major off-grid export industries and the domestic sector, there may be indirect hydrogen market competition with on-grid production that uses excess renewable generation if electrolyser and other production costs reduce significantly.

B4 - Expert reflection on Australian experience

Australia is in the early stages of developing its hydrogen economy, but now there are major plans to develop renewable energy resources exceeding 120 GW as indicated in the proposed projects listed in Issue 4 – B2.

It is too early to tell yet whether competition between domestic electricity demand and hydrogen production will be a serious challenge, and indeed whether hydrogen produced for domestic use will compete with hydrogen production for export, although there are indications that it may be driven by how large the export industry becomes. This has been major issue with the development of the natural gas industry in Australia, which has seen domestic prices determined by international prices, and domestic shortages caused by diversion of supply to export markets.

Nevertheless, while the domestic hydrogen use may be dominated by hydrogen exports, forward thinking will be required to avoid similar pitfalls, and different challenges may arise from competition for renewable generation. A parliamentary inquiry into Australia's transition to a green energy superpower is currently examining such issues[112].

B5 - Expert reflection on Vietnamese experience

As the development of hydrogen may take a long time to reach its full potential, the competition between hydrogen and other renewable demand is not clearly visible now. At the strategic level, hydrogen is considered a fuel resource and is regulated in a whole energy development strategy to ensure the alignment of RE development and hydrogen production.

[112] Parliament of Australia (11 October 2022) Inquiry into Australia's transition to a green energy superpower https://www.aph.gov.au/Parliamentary_Business/Committees/Joint/Joint_Standing_Committee_on_Trade_and_Investment_Growth/GreenEnergySuperpower Accessed April 2023

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Future of Electricity
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A science – to – policy initiative of the Australian Embassy in Hanoi, in consultation with the Central Economic Commission of the Communist Party of Vietnam

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