A fit-for-purpose refreshed NHS: next steps for building Australia's hydrogen industry

Australian Hydrogen Council

August 2023

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Acronyms and abbreviations

Acronym/abbreviation	Definition
AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
ARENA	Australian Renewable Energy Agency
BEV	Battery electric vehicle
BNEF	Bloomberg New Energy Finance
CEFC	Clean Energy Finance Corporation
COAG	Council of Australian Governments
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CCS	Carbon capture and storage
DAC	Direct air capture
DRI	Direct reduced iron
FCEV	Fuel cell electric vehicle
GW	Gigawatt
IEA	International Energy Agency
IRA	Inflation Reduction Act
IRENA	International Renewable Energy Agency
ktpa	kilotonnes per annum
LNG	Liquified natural gas
MJ	Megajoule (10^6 Joules, or 1,000,000 Joules)
Mt	Millions of tonnes
MW	Megawatt
NHIA	National Hydrogen Infrastructure Assessment
NZAu	Net Zero Australia
PJ	Petajoule (10^{15} Joules, or 1,000,000,000,000,000)
TCO	Total cost of ownership
TRL	Technological readiness level
TUoS	Transmission use of system charges
ZLEV	Zero and low emissions vehicle

The Australian Hydrogen Council

The Australian Hydrogen Council, or AHC, is the peak body for the clean and green hydrogen industry.

With over 100 members, we represent the emerging hydrogen industry and connect it with its stakeholders to collectively create a clean and resilient energy future that has hydrogen as a key part of the energy mix.

Our members are companies from the energy, transport, technology, consulting and financial sectors.

We work closely with all levels of government to develop the policy, funding and regulatory settings to enable the hydrogen industry.

Please see https://h2council.com.au/our-members/ for our full list of members.

Executive summary

We have an enormous opportunity in this country to create a vibrant hydrogen industry, both for domestic and export use. Australia has the renewable energy resources, the technical skills, and the track record with international partners to become a global hydrogen leader.

However, the transition to net zero energy emissions – and hydrogen's role within the transition – will require unprecedented rates of investment in new or repurposed energy sources, infrastructure and energy use equipment. This will need to be synchronised with an equally unprecedented exit, stranding or repurposing of existing capital stock (e.g., coal-fired power stations, gas networks, oil import supply chains, coal export supply chains).

Those investments will arise from the interplay of policies and programmes of the Australian Government and jurisdictional governments, regulatory bodies, private sector companies, energy users from households to major industrial consumers, the RD&D community and the governments and companies of our major trading partners.

The scale of this task requires planning, funding, and targeted demand stimulation.

In this early phase of the energy transition the governments and industry have not yet done all the heavy lifting, and so everything seems possible, including wildly optimistic visions of a cost-free transition, a change-free environment, or an economy comprised only of winners.

We would include in this the notion that hydrogen developments can be activated by discrete tasks with surgical precision. Hydrogen is not separate from the energy transition and everything this entails; it fundamentally affects, and is affected by, multiple systems and requires an ecosystem to enable it to be produced, stored, delivered and used efficiently.

For this reason, the AHC has developed this paper as an input to the Australian Government's process to refresh the National Hydrogen Strategy (NHS). We have sought to cover all system elements that need to be in place to have the hydrogen industry develop in the Australian public interest; that is, for hydrogen to play its role in the energy transition and to do this efficiently, sustainably and in the best interests of regions and communities.

We have addressed the issues as per Figure ES 1.

We have developed 53 recommendations to guide the thinking and policy making of the Australian and jurisdictional governments. The recommendation headings are repeated below, and the location of each discussion that supports the recommendation is shown.

Figure ES 1: Topics in this paper.

Government role

The role of the Australian Government is a key element of the refreshed NHS. It needs to set the tone and establish expectations, including on timing. It needs to undertake any analysis required to answer the key questions and to work across portfolios and usual political boundaries.

More broadly, meeting Australia's stated hydrogen objectives requires strong national leadership to plan, collaborate and communicate with partners and stakeholders. Government must drive and lead the creation of the clean hydrogen industry, including stimulating demand. With the world moving to net zero there is no real alternative.

On this point, policy to enable and support the clean and green hydrogen industry must be part of the broader net zero programme. This should be self-evident given that hydrogen is itself the means to decarbonise the parts of the Australian economy that are difficult to decarbonise with electricity and battery storage.

These things are important because to date there has been a lack of an overarching framework or plan, including how to realise Australia's ambitions to be an emerging renewable energy and/or hydrogen superpower.

The energy and industry transition will connect complex systems and require fundamental change, planning and creativity across sector, state, departmental and political boundaries. There is a need for cross departmental steering of net zero work and of the refreshed NHS within that. In the absence of a more obvious choice, this should be overseen by the Net Zero Economy Agency. Australia will not reach net zero without hydrogen, and the infrastructure build to enable the hydrogen industry is not only massive, but also aligns with the Net Zero Economy Agency remit.

Within the overall net zero programme, the refreshed NHS must set priorities and meaningful targets, and there needs to be a government commitment to fill current knowledge gaps to a reasonable degree.

Refreshing Australia's hydrogen strategy provides an opportunity to shift the focus to job creation, retention of manufacturing capability, and assisting industry to decarbonise. It can usefully shape the planning and regulatory environment and help in the development of investable propositions to attract a range of co-investors. It also provides an opportunity to consider a skills plan that is responsive to project needs. For example, the location of many projects is likely to be in regional and remote Australia, making worker attraction and retention difficult and costly and potentially adding to the overall cost of projects, including operational costs.

This cannot be left to chance, or to the whims, complexities, and uncertainties of a nascent market. Significant planning and coordination are required at the national level if we are to meet our objectives. For example, we may be considering a future where vast amounts of renewable energy have been produced (to the point, some have suggested, where electricity is free), but the infrastructure to produce the electricity does not yet exist and will require significant investment.

Importantly, we need to remain attuned to the transition being a shift from one state to another. This means that to achieve net zero, capital must be reallocated away from emissions intensive assets to low emissions technologies, facilitated in large part by Australia's financial system.

Further, the hydrogen industry is not yet commercial and considerable investment is required. It is likely that capital investments to produce hydrogen alone could run to tens of billions of dollars. Until the industry has reached commercial scale, grant funding is essential. Public investment will unlock several times its value from the private sector.

The refreshed NHS needs to address all of these issues and clearly recognise the role for government to lead. It also cannot be the last word from the Australian Government on hydrogen policy. It is imperative that this strategy provides a basis for actions to meet targets and milestones and to allocate responsibility. Detailed implementation plans may need to be by sector or ecosystem element but should be outlined in an overall plan to set expectations.

Topic	Recommendation	Section of paper
Overall	**Recommendation 1**: Commit to significant market making and ecosystem building in the public interest	2.1
	Recommendation 2: Task the Net Zero Economy Agency with overseeing the implementation of the refreshed NHS.	2.1
	Recommendation 10: Support the refreshed NHS with public implementation plans and stakeholder engagement.	2.3

Priorities

It makes sense to set some priorities so that actions can be better targeted, whilst also providing a degree of flexibility within this priority-setting given the industry is still emerging.

For domestic use, focussing on building scale and capability in the sectors and applications that will be hard to abate without hydrogen is the best 'no regrets' approach that can be taken in an uncertain environment. Current evidence supports these industries as being:

- Chemicals, particularly ammonia and methanol
- Low emissions metals, particularly iron and alumina
- Heavy road transport
- High temperature process heating
- Marine and aviation, where hydrogen is a feedstock for future fuel
- Grid support and storage in the electricity market.

This approach should also actively build room for other applications that might value hydrogen at lower prices and with an established (and shared) infrastructure.

For export, there are two main uses of hydrogen: exporting hydrogen and its derivatives as an energy vector and using hydrogen to process ores that are then exported. Both options need to be pursued if we are to grow our international relationships, support regional energy security and build Australia's capability for the future.

Further, much of the capital required for Australia's energy transition will need to come from overseas investors in partnership with Australian businesses and governments, and this investment will be driven through both export types. The need for national leadership across multiple fronts cannot be understated. While the Australian Government has a significant number of MoUs and agreements in place to drive collaboration on climate change and the building of new clean energy industries, the agreements have not – so far – led to implementable industrial decarbonisation policies. There is much more that can be done to support a refreshed NHS, to attract investment, meet trade partner needs, and maximise value to Australia from risk sharing and friend-shoring.

Moreover, while the objective remains renewable (green) hydrogen, there is also a need to consider support for low carbon (blue) hydrogen production in Australia. This message is also coming from Australia's key trade partners who are investing in blue and low carbon hydrogen options right now.

The right projects can boost the establishment of supply chains and infrastructure that can also accelerate green hydrogen uptake.

Topic	Recommendation	Section of paper
Domestic	**Recommendation 6**: Prioritise hard to abate and scalable domestic demand sources.	2.2
Export	**Recommendation 7**: Support hydrogen for export as an energy vector and for value added products such as green iron.	2.2
Emissions	**Recommendation 21**: Remain open to blue hydrogen for regions that can support it without unnecessarily delaying renewable hydrogen developments.	4.2

Targets

The AHC position is that targets are required, but we cannot recommend targets without meaningful data. There is also no point setting demand targets if there is no ecosystem to support the hydrogen industry – much more is required.

We note the recent announcement that the Australian Government will develop sectoral plans for decarbonisation. We look forward to engaging with this process. If industrial targets were to be mandated, they would need to be explicitly aligned with government support for the transition. There would certainly need to be alignment with the safeguard mechanism to inform future baselines.

Topic	Recommendation	Section of paper
Targets	**Recommendation 9**: Set hydrogen targets for 2030 and 2040, with a range for 2050.	2.3

Analysis

Many of the policy decisions that need to be taken rely on data that are not yet collected. The Australian hydrogen industry will require – and will require an understanding of – large-scale electrolysis capabilities, renewable electricity, hydrogen storage, water and water pipelines, electricity infrastructure, carbon capture and storage (CCS), and hydrogen pipelines (which may be repurposed from existing pipelines). Industrial and port facilities will need to be developed to process and export hydrogen and its derivatives, including ammonia. Mineral and chemical companies and other industries will invest in new processes to use hydrogen, and transport and logistics companies will procure new vehicle technologies. Refuelling stations will be required to supply hydrogen for vehicles.

Each of these elements will have its own costs, dependencies, and engineering reality, which in turn affects the business case for different means of producing, storing, transporting and using hydrogen. Several elements will also have long timeframes for project design, feasibility and planning.

Impacts on local economies (regional and metropolitan) will also need to be understood and planned for, as will important community (and societal) questions about competing uses for land and water, and priorities for infrastructure for different purposes. The emerging industry will require a fit-for-purpose regulatory approach with the flexibility to work across sectors and jurisdictions.

The evidence base on each of these matters requires significant bolstering for policymakers to be able to undertake planning and provide the right policy responses on both an economy and sector level.

Topic	Recommendation	Section of paper
Overall	**Recommendation 3**: Task the Net Zero Economy Agency to oversee a rolling programme of industry analysis to support ecosystem planning.	2.1
Costs	**Recommendation 4**: Task the Net Zero Economy Agency to oversee an assessment of cost and clarify investment needs from the public and private sectors.	2.1
NHIA	**Recommendation 5**: Extend and re-run the NHIA analysis to support decision-making for the refreshed NHS.	2.1
	Recommendation 29: Ensure a refreshed NHIA addresses refuelling infrastructure.	4.2
Supply chain	**Recommendation 8**: Assess Australia's hydrogen supply chain risks and opportunities.	2.2
Energy	**Recommendation 20**: Develop consistent energy planning scenarios and cost recovery mechanisms by connecting AEMO, AEMC and energy regulators with the Net Zero Economy Agency and the refreshed NHS.	4.2
	Recommendation 52: Undertake a full energy market and grid impact analysis for wide scale adoption of electrolysers as flexible load in the electricity grid.	5.4
Water	**Recommendation 22**: Develop a national assessment of hydrogen industry water needs and required planning to meet the revised NHS objectives and support long-term water security.	4.2
Pipelines	**Recommendation 23**: Develop a national assessment of hydrogen pipeline corridors, easements, and route alignment.	4.2
Ports	**Recommendation 24**: Develop a national assessment of port capability to meet the revised NHS objectives and targets.	4.2
Storage	**Recommendation 27**: Develop a national assessment of hydrogen storage needs for different purposes, timeframes, and locations.	4.2
Workforce	**Recommendation 34**: Undertake capacity gap analyses to support regional development.	4.3
RD&D	**Recommendation 39**: Develop and articulate RD&D priorities for hydrogen.	4.3

Topic	Recommendation	Section of paper
Regulation	**Recommendation 42**: Undertake and publish a regulatory gap analysis and programme of reform.	4.3
Shipping	**Recommendation 51**: Develop a national assessment of shipping routes and refuelling requirements.	5.3
Aviation	**Recommendation 53:** Work with the Department of Infrastructure, Transport, Regional Development, Communications and the Arts and its Jet Zero Council to consider the next steps for hydrogen for SAF production, using the CSIRO Futures report.	5.5

Ecosystem, engagement and implementation

As is clear already, the development of the hydrogen industry requires engagement with departments, divisions, peak bodies, businesses and other stakeholders from across a number of sectors, and across regional boundaries. Both developing and delivering hydrogen policy means working collaboratively beyond the usual boundaries and with a clear sense of intent.

Further, a commitment to implementation means bolstering funding and programmes that create the ecosystem for the industry. The bankability gap is far from closed, with government policy and funding required to draw through private capital, and a need for more innovative financial risk sharing. Governments must be market creators at this stage of the energy transition. This means levelling the playing field with fossils fuels, using an appropriate mix of policy and funding levers. This is not only about funding for pilots but also about major infrastructure investment in the public interest. The seed funding provided to date by the Australian Government and jurisdictions is welcomed, yet not sufficient to spur the required additional private sector investment.

Tier 1: Short term implementation priorities

Topic	Recommendation	Section of paper
Overall	**Recommendation 15**: Create Hydrogen Economic Zones to support regional hydrogen initiatives and connect the relevant supply, demand, infrastructure and workforce.	4.1
	Recommendation 31: Boost Australian Government ability to attract and deploy private capital.	4.3
Emissions	**Recommendation 46**: Clarify the next steps and fast-track the process to implement the GO scheme.	4.3
Export	**Recommendation 11**: Support the refreshed NHS through a clear investment proposition.	3.1

Topic	Recommendation	Section of paper
	Recommendation 12: Develop joint support packages between Australia and its trading partners to support trade in hydrogen and hydrogen derivatives.	3.1
	Recommendation 13: Explicitly locate hydrogen production and use within the current international agreements on critical minerals.	3.3
	Recommendation 14: Actively seek risk and information sharing opportunities with like-minded international partners.	3.3
Industry capability	**Recommendation 38**: Create a 'one stop shop' and case management to assist with funding and permissions.	4.3
Ports	**Recommendation 26**: Commit to a funding envelope for ports.	4.2
Storage	**Recommendation 28**: Commit to a funding envelope for common user storage.	4.2
Heavy transport	**Recommendation 30**: Commit to a funding envelope for refuelling infrastructure.	4.2
	Recommendation 48: Support hydrogen in heavy road transport with a national ZLEV strategy, fleet trials, transition funds, and either a heavy vehicle fuel efficiency standard or sales target.	5.1
Industrial sectors	**Recommendation 49**: Attract private investment for hard-to-abate industrial processes.	5.2

Tier 2: Medium term implementation priorities

Topic	Recommendation	Section of paper
Community	**Recommendation 32**: Support a new programme of work on community water values and hydrogen awareness.	4.3
	Recommendation 33: Develop messages and communications support for the refreshed NHS to roll out to all governments and industry.	4.3
	Recommendation 45: Work with AEMC and AER on cost and price models to ensure affordable energy bills.	4.3
Industry capability	**Recommendation 36**: Support a lessons learned repository through CSIRO's Knowledge Hub.	4.3
	Recommendation 37: Support the Australian Hydrogen Council to expand the scope of HyCapability.	4.3
	Recommendation 16: Support a nationally connected and coordinated regional network facilitated by the Australian Hydrogen Council.	4.1

Topic	Recommendation	Section of paper
	Recommendation 17: Support Business Renewables Centre Australia to expand its remit and create hydrogen specific modules.	4.1
Supply chain	**Recommendation 18**: Support the development of domestic electrolyser production and assembly through a domestic manufacturing package.	4.2
	Recommendation 19: Secure supplies of raw materials (e.g., nickel and platinum group metals) and other key components.	4.2
Workforce	**Recommendation 35**: Drive coordination of competency standards and training packages for hydrogen.	4.3
RD&D	**Recommendation 40**: Work with CSIRO and the Chief Scientist, and other RD&D leaders to deliver hydrogen RD&D priorities and knowledge sharing.	4.3
	Recommendation 41: Establish common testing and prototyping infrastructure.	4.3
Ports	**Recommendation 25**: Select and support ports with existing industry connections to be demonstration ports.	4.2
Heavy transport	**Recommendation 43**: Harmonise Australian heavy vehicle regulation with international standards.	4.3
Industrial sectors	**Recommendation 44**: Develop harm prevention regulations to support industrial sectors.	4.3
	Recommendation 47: Support Australian-made clean products in hard-to-abate industries, supported by government procurement.	4.3
	Recommendation 50: Develop bespoke packages for other early adopters in high temperature process heating.	5.2

1 What we have learned since 2019

Australia has the renewable energy resources, the technical skills, and the track record with international partners to become a globally significant producer of hydrogen and its derivatives.

This was the premise of much of Australia's National Hydrogen Strategy[1] released in November 2019, where a stated objective of the strategy was to have Australia be one of the top three hydrogen exporters to Asian nations by 2030. Australia was seen as an obvious source for future renewable hydrogen in particular.

But the world has changed since the release of the National Hydrogen Strategy (which we will call NHS v1).

With the pandemic and war in Ukraine we have seen the vulnerability of supply chains and a new focus on building national capabilities and resilience. These factors have amplified the arguments for clean energy and for hydrogen, both for countries to make their own and to partner with countries they can trust to supply what they need.

As a result, many countries are seeing increased focus on clean energy spending and trading relationships to solve several problems: not only decarbonising their economies but also growing new sovereign manufacturing capabilities, boosting self-sufficiency, and de-risking supply chains.

Since its election, the Albanese government has announced net zero aspirations, and set a target of 82 per cent renewables by 2030. The ambition remains for Australia to be a renewable energy and/or hydrogen 'superpower'.

However, our ability to deliver on our aspirations is not guaranteed. The delays are already setting in for the renewables build, with the Chief Executive of AEMO reported in late June 2023 as saying that investment in clean energy was not happening fast enough to replace closing coal power stations, and storage needs to expand by a factor of 30 by 2050.[2] On the hydrogen front, analysis for the Australian Government "suggests that Australia is no longer the global policy leader in developing a new clean hydrogen industry…it still trails many OECD nations in terms of projects proceeding to deployment."[3]

Further, competition for clean technology investment is now fierce. We have seen major financial incentives announced by various countries, but the benchmark is the US Inflation Reduction Act (IRA). With this legislation, the US government has demonstrated that it seeks to be a serious market creator.

And while the IRA is not just about hydrogen, it has been a game changer for our nascent industry. We may have assumed that Australia had time to take up our mantle as a global leader in hydrogen production. But that is a more challenging assumption now.

[1] COAG Energy Council (2019).
[2] Ludlow (2023).
[3] Australian Government (2023a), page xii.

These points have been acknowledged by the Australian Government, such as this quote from the *State of Hydrogen 2022* report:

> Australia risks falling behind other countries who are implementing market-based policy mechanisms and new economic incentives to propel their hydrogen industries, most notable the recent policy announcements in the United States, Canada and Germany. Whilst Australia is advancing on all areas of development of the local hydrogen industry, it is important to check how that progress compares globally with progress by other nations.[4]

Since the *State of Hydrogen 2022* report was released, the Australian Government has announced its Hydrogen Headstart initiative, and the review of the NHS v1 is an important step to identify and deliver necessary shifts in approach and delivery.

This paper sets out what we see to be the necessary elements and considerations for the review of the NHS v1. The theme is that meeting Australia's stated hydrogen objectives requires strong national leadership to plan, collaborate and communicate with partners and stakeholders. Government must drive and lead the creation of the clean hydrogen industry. With the world moving to net zero there is no real alternative.

We have used the original agreements from the NHS v1 and address many of them in this document. Appendix A provides a full mapping of the NHS v1 agreements against the body of this paper and AHC's own recommendations.

The rest of this chapter discusses the key lessons learned since 2019, as follows:

- Significant planning and coordination are required at the national level if we are to meet our objectives.
- The race is on for hydrogen production and Australia has tough competition.
- Exporting hydrogen is not the only story; we need to export hydrogen as an energy carrier, but there is also a compelling case for using hydrogen domestically to add value to raw materials such as iron ore.
- The bankability gap is far from closed, with government policy and funding required to draw in private capital, and a need for more innovative financial risk sharing.

1.1 Significant planning and coordination are required

The *State of Hydrogen 2022* report[5] notes that Australia has made a "promising start" on the path set in the NHS v1, and that "potentially increasing this pace will be crucial for Australia to be a world leader in hydrogen". We agree with these points but suggest that increasing the pace is not potentially crucial but *actually* so.

The report goes on to say that "Australia will need to move from planning to implementation in a range of areas" noting the changes in the global policy environment.[6] While AHC agrees with the

[4] Ibid.
[5] Ibid., page 59.
[6] Ibid.

sentiment to do more and to do it quickly, we are concerned if there is a perception within the Australian Government that planning has occurred as required and that we are ready to move on.

A major issue with the development of the industry to date has been the lack of clear government direction about priorities, milestones and plans to deliver. The NHS v1 took a hands-off approach, reflecting the political reality of having nine governments agree to 57 actions (no small feat) as well as the then federal government sentiment of the need to merely "get out of the way of the market".

Practically speaking, we have also not seen much in the way of coordinated action at a national level since 2019. This is due to several factors, not the least the drain on capacity during the pandemic. There have been some exceptions, such as the federally led work on hydrogen certification, and there have also been good starts, such as the national programme on regulation and work on the hydrogen hubs. But there was never a public implementation plan of the NHS v1, and there has been little clarity on the many streams of work and how these are proceeding.

At the very least, we would hope and expect this to change for the refreshed NHS.

It is also not just about planning and reporting on delivering the NHS but also about what we have learned since 2019, which is that:

- The energy transition as a whole will be complex, expensive and difficult to deliver, and it needs leadership and clear industrial policy. Globally, there is increasing recognition that nation states need to undertake an industrial revolution, with the requisite and commensurate level of spending, over a comparatively short time frame.
- Hydrogen production and utilisation is a necessity rather than a choice, and it requires significant commitment and investment. This is because hydrogen will be the primary way to decarbonise key sectors of our economy, such as ammonia for fertilisers, iron and alumina ores, industrial processes that require high temperatures, and fuel for heavy road transport, aviation and shipping.
- Hydrogen and its derivatives will be the predominant means for replacing the current energy exports (and revenue) from Australia – either in the form of liquid fuels (e.g., ammonia, methanol) or in the form of 'embodied hydrogen' via the onshore processing of Australian iron and alumina ores.
- Making, moving, storing and using hydrogen across a range of applications requires the development and implementation of new technology, the alignment of different sectors of the economy, and significant investment in infrastructure at several points.

To the first point, we have been pleased to see the need for national leadership for the transition acknowledged since the change of government, and note that the main coordinating role is likely to be played by the newly formed Net Zero Economy Agency, which has the following remit:

1. Support **workers** in emissions-intensive sectors to access new employment, skills and support as the net zero transformation continues.
2. Coordinate programs and policies across government to support **regions and communities** to attract and take advantage of new clean energy industries and set those industries up for success.

3. Help **investors** and **companies** to engage with net zero transformation opportunities.[7]

We hope that the Net Zero Economy Agency will include carriage of planning for hydrogen investment and deployment within its remit; that is, to engage with and help deliver the refreshed NHS. Australia will not reach net zero without hydrogen, and the infrastructure build to enable the hydrogen industry is not only massive, but also aligns with the Net Zero Economy Agency remit.

The US National Clean Hydrogen Strategy and Roadmap[8] refers to the task of developing the hydrogen industry as requiring an all of government approach. We have learned this lesson repeatedly over the past four years, with the interconnectedness of the various systems requiring a shift from the usual siloed and incremental policy and regulatory decision-making to new models of thinking and allocating risk.

For example, the energy system is not only the generation and distribution of energy; it also includes upstream industries such as resource exploration and extraction, with associated manufacturing and construction. Transitioning this system, which supports and enables all other functioning in the Australian economy, will require an overarching and holistic analysis. This can then be used to develop the relevant regulatory and financial incentives and rules that can guide investor risk assessments (for existing and new assets) and the attraction of new investment (upstream and downstream industries critical to the energy and industrial transition). Risk appetites must be increased, and governments must design and enter agreements that not only incentivise continued private sector co-investment alongside state actors, but also provide financial returns to taxpayers and citizens who will bear the flow down costs from the energy transition.

1.1.1 Aligned infrastructure needs

The NHS v1 envisaged a domestic hydrogen economy developing in parallel to an export industry and attempted to seed the establishment of hydrogen hubs that co-located hydrogen producers and users to increase the agglomeration effects of any investment made into common user infrastructure (see section 4.1). This was a reasonable start given what was known at the time, but we have since discovered that it also required much faster delivery, much higher state funding, and a far more comprehensive approach to planning and coordination in the public interest.

An Australian hydrogen industry will require large-scale electrolysers, renewable electricity, hydrogen storage, water and water pipelines, electricity infrastructure, CCS, and hydrogen pipelines (which may be repurposed from existing pipelines). Industrial and port facilities will need to be developed to process and export hydrogen and its derivatives, including ammonia. Mineral and chemical companies will invest in new production processes, and transport and logistics companies will procure new vehicle technologies. Refuelling stations will be required to supply hydrogen for vehicles.

None of this is short term, nor is it work that the private sector can undertake in the absence of leadership and planning from government and the public sector. As noted by an International Renewable Energy Agency (IRENA) report on the geopolitics of the energy transition, infrastructure

[7] Australian Government (2023b).
[8] US Department of Energy (2023), page 1.

decisions must be carefully assessed, "given that these decisions are long-lived and the risks (and costs) of stranded assets are high".[9]

Further, many hydrogen industry elements require long lead times, such as for:

- Building the necessary electricity, gas and refuelling infrastructure.
- Vehicle and vessel design, testing, production and deployment, which can take over seven years.
- Major industrial process changes, such as key sectors planning for and purchasing new equipment that is expected to operate for decades. This can also take several years.
- Very large or 'mega' projects, such as in traditional oil and gas, where the process to go from initial investigation to a final investment decision can be as much as eight years.

The various windows of opportunity need to be aligned as far as possible if we are to get to scale and do so competitively. This means planning and co-optimising different assets, and timing needs to address a range of different markets.

Several experts have advocated for common user infrastructure, such as pipelines and ports, as a way of managing some of the complexity and creating efficiencies. This provides an opportunity to share risk among multiple producers and capture efficiencies and allow "users to participate in the hydrogen economy without first mover disadvantage/cost burden".[10]

This is also a key lesson learned from Australia's LNG experience, where a Deloitte[11] survey of LNG leaders found that a lack of forecasting and collaboration between industry players meant that they worked on independent projects in parallel: "In terms of post Final Investment Decision (FID) construction, collaboration among companies was virtually non-existent and this led to a dramatic overbuilding of infrastructure. For example, the three large LNG projects in Queensland don't even share a road". LNG developers were said to race against one other "to build infrastructure at almost any cost".[12]

Researchers from the Grattan Institute explain the need for coordination if we are to compete effectively, using the example of low carbon steel:

> Producing net-zero steel, for example, requires not just a zero-emissions steel smelter, but also a supply of zero-emissions hydrogen for the smelter, which in turn requires zero-emissions electricity. It requires land for hydrogen production and storage. And renewable energy production requires transmission lines from these renewable energy facilities to hydrogen production sites, and so on.
>
> When this needs to be repeated for half-a-dozen facilities in the same geographical area, the benefits of coordination become obvious. Achieving scale will be essential for successful transformation. Other countries will be seeking to transform their industrial sectors at the same time as Australia, and where we are a small producer (for example, of steel, aluminium, or ammonia), individual Australian firms will be well down the queue for equipment suppliers.[13]

[9] International Renewable Energy Agency (2022), page 105.
[10] Advisian (2021), page 16.
[11] Reid and Cann (2016), page 8.
[12] Ibid., page 11.
[13] Wood, Reeve and Ha (2021), page 43.

And it's not only about land and infrastructure; vast amounts of construction activity will require workforce planning and support. Again, there are lessons to be learned from Australia's LNG experience:

> There is a high probability that undertaking several major capital projects within the same geographic area will create resource scarcities, which in turn will drive up costs to unsustainable levels. Yet, in Australia, this likelihood was largely ignored. As a smaller nation, Australia had inherent resource scarcities, particularly in terms of labour. Additionally, LNG companies did not give a great deal of forethought to how stiff competition among multiple operators would affect local wage rates. This resulted in an 'arms race' of sorts in assuring access to scarce resources, with wage rates soaring to astronomical levels. How high is astronomical? As described by one survey participant, a journeyman carpenter, whose task was to build forms for pouring concrete, commanded AU$250,000 per year at the height of the building activity.[14]

The versatility of hydrogen also brings complexity. Hydrogen allows planners to choose between gas and electricity infrastructure to some degree – it allows 'sector coupling', which is a linking of different sectors of the economy, especially different energy sectors, to co-optimise networks and markets. Hydrogen has the potential to become a key technology in this context, bringing the opportunity to create Australian strategic value chains.

We note the creation of the National Energy Transformation Partnership in 2022[15] and its priority topics that include:

> Cooperate on demand evolution and regional-level scenario planning, in the light of increasing electrification and demand management opportunities (including energy efficiency, Distributed Energy Resources, Electric Vehicles and demand response)
>
> …Improve integration between gas and electricity system planning and analysis, including on demand scenarios as end-users decarbonise
>
> …Assess the workforce, supply chain and community needs associated with the pipeline of transmission, renewable energy, storage and industry development opportunities. This will inform domestic on-shoring opportunities, investment needs, identify supply chain risks, and community engagement needs to support a national action plan on these issues

We are not aware of any work that has specifically progressed under these topics and seek clarification on how this work is being led, how hydrogen developments are accounted for, and how this work (which was said at the time to be supported by work streams and consultation)[16] interacts with the remit of the Net Zero Economy Agency.

1.1.2 Cost efficiencies

With new infrastructure comes cost. We may be considering a future where vast amounts of renewables have been produced (to the point, some have suggested, where electricity is free), but the infrastructure to produce the electricity does not yet exist and will require significant investment. Similarly, assets to produce hydrogen do not exist at scale.

[14] Reid and Cann (2016), page 10.
[15] Energy Ministers (2022).
[16] Ibid., page 9.

The team from Net Zero Australia (NZAu) modelled the cost of the transition (which for their project included replacing current energy exports with hydrogen-based exports), finding that the Net Present Value cost of the net-zero scenarios modelled was found to be A$4.8-5.1 trillion.[17] This was $600-900 billion more than the 'do nothing' scenario. It did not include the costs of inaction on climate change and assumed fossil fuel costs remained consistently low over the course of the transition.

In 2022, NAB commissioned Deloitte Access Economics to undertake an analysis of the capital requirements to finance the energy transition.[18] The report noted that over A$70 billion in structural changes (that is, infrastructure) would be required over the decade to the early 2030s, and over A$420 billion in new investment would be required to 2050: "To put this in perspective, the scale of action needed is far broader than the Industrial Revolution and the timeline is roughly half."

The report estimates that by 2050, Australia is expected to invest around A$20 trillion of capital in the economy (net present value), inclusive of investment directly related to the transition (that is, including investment in renewables) and investment not directly related (such as education and health investment). Out of this total expected investment, around A$4 trillion is estimated to reflect the total capital flows and investments across four key economic systems critical to the transition: energy, mobility, raw materials manufacturing and food and land use systems. Of the estimated A$420 billion in new capital expenditure required to achieve Australia's 2050 targets, around A$400 billion will be required across the four key economic systems.

Similarly, in analysis of the needs of industry to decarbonise, the Australian Industry Energy Transitions Initiative advises that the investment required in industry abatement technologies and transitioning the energy system could be as high as A$625 billion by 2050, with annual investment at around A$20.8 billion per year to keep to a 1.5°C global warming scenario.[19]

For hydrogen, based on modelling undertaken for the Australian Government, consultant Arup has suggested the investment required averages around A$25-$30 billion a year from the late 2020s through to 2040. Arup notes there is a large ramp up of investment from 2025,[20] with a "significant" share of investment (44 per cent to 61 per cent) on imported goods, "particularly specialised goods such as solar panels, electrolyser components, wind turbines and compression components".[21]

At a more granular level, indicative costs include:

- New solar at large scale could be A$1 million a megawatt, resulting in 10GW installed capacity costing A$15 billion. Wind is closer to A$1.4-$1.7 million a megawatt.
- The cost to convert one blast furnace to make green steel has been priced at A$2.8 billion.[22] The capital cost for a new 4Mt/year integrated steelmaking facility is said to be around US$4 billion depending on the jurisdiction.[23]

[17] Davis (2023), page 52.
[18] Deloitte Access Economics (2022).
[19] Climateworks Centre and Climate-KIC Australia (2023), page 10.
[20] Arup (2023a), page 57.
[21] Ibid., page 11.
[22] BlueScope Steel (2021), page 10.
[23] BHP (2020).

- Electricity and gas infrastructure costs will also be in the billions: for example, the Dampier to Bunbury pipeline is valued at around A$3 billion,[24] which covers 1,539 kilometres of high pressure pipeline.
- Around A$0.5 million to A$1.7 million per tonne of hydrogen for storage at scale (more than 20 tonnes).
- One ammonia plant could be over A$700 million,[25] and likely closer to A$1 billion for an 800 ktpa plant, depending on the existing infrastructure and availability of utilities.
- Port upgrades could be hundreds of millions of dollars per port; for example, Townsville's current channel upgrade is reported as costing A$251 million,[26] and a full port upgrade will be more than this.

Importantly, we need to remain attuned to the transition being a shift from one state to another. This means that to achieve net-zero, capital must be reallocated away from emissions intensive assets to low emissions technologies, facilitated in large part by Australia's financial system. In terms of the energy system and its ability to reach net zero, the Deloitte report for NAB estimates that around A$25 billion (net present value) must be reallocated away from emissions-intensive to low-emissions assets in the energy system. When it comes to new investments, around A$100 billion in additional capital must flow into low-emissions assets for the Australian economy to be on the path to net-zero.[27]

The Deloitte modelling predicts that the most significant disruption to workers, citizens and industry will occur in the medium term (that is, over the next decade) as decisions regarding the transition begin to take hold. By 2030, nearly A$70 billion needs to flow out of emissions-intensive industries – without significant financial market contribution alongside clear and bold policy from the Australian government, there is a higher risk of stranded assets, worker dislocations, and increased transition costs, due to delayed decision making.

This means that there will be difficult political decisions to make about how to direct investment, and how to do this as efficiently and fairly as possible. This is not a matter for markets but for government decision-making in the long-term public interest. It is also about working closely with our international partners and investors to support the flow of capital into the country.

1.2 The race is on

In 2019 the prevailing sentiment was one of apparently unbounded optimism: Australia would be a top exporter of hydrogen (and when we all said top three, as per the NHS v1, we meant the top one). This optimism was vital for sowing the seed of the possible and starting Australia down our current path. Australia is looked to as a world leader in this space.

Despite this early engagement on hydrogen, developments to realise Australia's hydrogen ambitions are not sufficiently advanced. In 2019 the year 2030 seemed long enough in the future that we could still contemplate future GW scale electrolysers in mega projects. In July 2023 the year 2030 is only

[24] AGIG (2020), page 99.
[25] Milne (2021).
[26] Port of Townsville (2023).
[27] Deloitte Access Economics (2022).

77 months away. Major projects would have to be at the Final Investment Decision (FID) stage imminently to be able to deliver at scale in 2030.

(On this point, we note that the Hydrogen Headstart program has a tentative start date of 2027-28. For this timeframe to be met, project developers will have already had to have completed – or be close to completing – placing orders for long lead items, securing all approvals, appointing EPC contractors and securing financing.)

Other countries have also experienced delays – and we cannot forget there were unprecedented world changes in 2020 and 2022 – but many countries have nevertheless progressed at a faster pace than Australia. Further, many of our international counterparts do not share our federal political system. Our 'Team Australia' presence is hampered by multiple states who are engaging with trade partners on terms that cause confusion. The need for national leadership across multiple fronts cannot be understated.

So, what is actually at stake? Global estimates of global hydrogen demand by 2050 range between just over 500 Mt to 800 Mt, meaning that hydrogen reflects between 12 per cent and around 20 per cent final energy demand.[28] This is an enormous opportunity for any and all nations with access to hydrogen production inputs to build their industries. It is a fundamentally necessary move for those countries looking at significant stranded assets as the world decarbonises, particularly major oil exporters such as the United Arab Emirates and Saudi Arabia.

The Australian Government's *State of Hydrogen 2022* report shows the countries with announced plans for exporting hydrogen by 2030, as adapted from the IEA – see Figure 1.

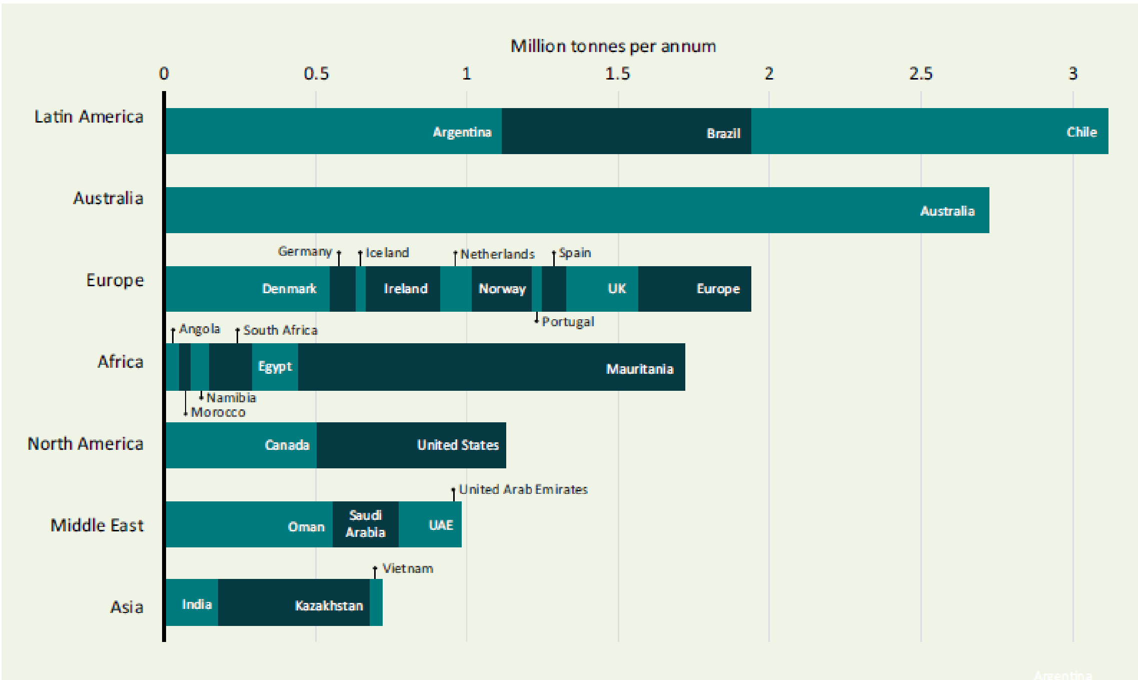

Figure 1: Planned hydrogen exports by country 2030, SOURCE: Australian Government (2023a), page 5, adapted from IEA Global Hydrogen Review 2022, page 165.

[28] International Renewable Energy Agency (2022), page 20.

We know that Australia is particularly well-positioned to play a key role in the hydrogen export market with its abundant renewable resources, existing bilateral trade relationships with Japan and Korea, and low sovereign risk.

However, the window of opportunity will not exist forever. We can see most of the world has regions with major export ambitions, and the ambitions have no doubt increased since the data were collected by the IEA. Competing hydrogen producers across the globe are seeking a share of the international market and are scaling up hydrogen production in their respective countries. Many of these countries have similar strengths to Australia, including abundant renewable resources, access to low-cost gas for blue hydrogen production, carbon capture and storage capabilities, large areas of land for solar installations, and proximity to key hydrogen export markets. Countries such as Chile and India have also stated ambitions to explore the use of hydrogen for the production of steel, posing another competitive risk for Australia.

Significant financial incentives have been announced by various countries, with each jostling for first mover advantage. The international funding and policy approaches announced to date demonstrate governments' recognition that a profound restructuring of the energy system is required and that this is about maintaining economic prosperity for their nations.

The standout policy is the US Inflation Reduction Act (IRA), which is part of a suite of legislation aimed at increasing US capacity and competitiveness in new and emerging industries. With new government spending of over US$200 billion a year for the next ten years (across the US policies) private sector co-investment is inevitable for both large scale infrastructure projects and smaller, high risk technology commercialisation.

With this legislation, the US government has demonstrated that it seeks to be a market creator, mobilising significant public and private capital and spurring the development of similar schemes globally.

There is clearly a nation building role for the Australian Government. This is not only to manage risk but to have Australia benefit from global pressures. There will be geopolitical consequences from the energy transition that will need to be accommodated. IRENA[29] refers to this as a "democratising effect" – driven by the fundamental physical differences between fossil fuels and renewable technologies in how they are produced and at what scale.[30] This will fundamentally change the long-term value of global energy markets as different countries explore their alternatives and opportunities for self-sufficiency.

The good news is that Australia does not have to be the first mover but can act fast with those who are. As noted above, the US National Clean Hydrogen Strategy and Roadmap[31] has its first priority to target strategic, high impact uses. Importantly, the document then notes that "Additional longer-term opportunities include the potential for exporting clean hydrogen or hydrogen carriers and

[29] International Renewable Energy Agency (2019), page 23.
[30] For example, renewables are not as geographically concentrated as fossil fuels, reducing the importance of current energy 'choke points'. Renewables are also largely inexhaustible and harder to disrupt than fossil fuels. Renewables are also deployable at 'almost any scale' and are compatible with decentralised energy production and use.
[31] US Department of Energy (2023b).

enabling energy security for US allies”. This bodes well for Australia to benefit from the US expenditure on hydrogen and its comprehensive RD&D programme.

However, this is not to encourage complacency. Accepting Australia as not having to be first of the first movers is not a relaxed stance but a pragmatic one that still requires swift action – time has already been lost and building a hydrogen industry requires much more than shared information and RD&D. As Deloitte[32] notes, at a global level long term contracts will drive first mover advantages and positive economic spillover effects:

> A key characteristic of the emerging hydrogen market is the long term nature of contracts. This means that locking in contracts can lock others out of the market for considerable periods of time. In an economic sense it means that the demand curve is lumpy and non-continuous.

Further, the infrastructure build cannot be carried out on a ‘just in time’ basis, and neither can the development of the people required for future hydrogen developments.

1.3 Exporting hydrogen is not the whole export story

The geopolitics of global trade are going to change significantly as we move away from fossil fuels. While no one is likely to give up traditional industries quickly, the economics will favour countries with significant low-cost renewables to do processing and manufacturing onshore and then export the product. This is Australia’s long-term play.

IRENA has calculated the economic benefits of relocating production of several fuels and commodities to locations with low renewable energy costs relative to the cost of shipping.[33] The analysis indicates that low renewable energy costs could provide a strong incentive for production to relocate. This could boost Australia’s existing production capability and allow for the growth or establishment of industries such as ammonia and methanol, which can also benefit greatly from low-cost renewable energy.

This means that export for hydrogen is not only about hydrogen and its derivatives (including ammonia, which is both a hydrogen carrier and has enormous and separate value for fertilisers). There is also the prospect of green iron and steel, alumina and aluminium, and methanol, where each of these could be grown as Australian export markets, with the potential for new high-value jobs. (Of course, it will be necessary to decarbonise these sectors to protect Australia’s exports at the very least. In 2020, 64 per cent of Australia’s aluminium and 40 per cent of Australia’s steel was exported to countries which had or were considering a carbon price.)[34] As noted by Deloitte “Australia’s competitive position in renewable hydrogen could tip the playing field back in Australia’s favour as a manufacturing economy by lowering input costs and accelerating agglomeration effects in industrial clusters”.[35]

The Australian Government’s *State of Hydrogen 2022* report also notes that: “By cooperating with our major customers, Australia can support the emergence of a global low and zero emission steel

[32] Deloitte Access Economics (2023), page 9.
[33] International Renewable Energy Agency (2022).
[34] Muller et al. (2021), page 20.
[35] Deloitte Access Economics (2023), page 5.

industry". This would mean Australia processes the ore and produces iron to then send to overseas steel makers. Quoting leading studies on the matter, the report notes:

> Results suggest Australia has an economic opportunity to firstly develop the beneficiation and processing technologies for onshore processing of ore, followed by development of iron making in Australia. By 2050 a hydrogen-driven iron making industry in Australia feeding Electric Arc Furnace steelmaking in Japan and Korea is a globally competitive scenario.
>
> Modelling on the economic benefits out to 2040 and 2050 by Accenture and the Grattan Institute finds significant economic potential from developing the green iron and steel manufacturing opportunity. Accenture's modelling found that the potential development of green iron and steel sector in Australia could create $35.3 billion in exports, $20.1 billion in direct and indirect value add and create up to approximately 111,000 direct and indirect jobs by 2040.[36]

The efficiency of 'onshoring' hydrogen that might otherwise be exported to achieve the same outcome is also greater. Less Australian energy is required to produce hydrogen and use it domestically to produce a value-added export such as iron, than if the hydrogen and the ore were each exported. This is because exporting the hydrogen – whether as hydrogen or a derivative such as ammonia – requires energy for conversion and transportation. The NZAu project notes that onshoring "is expected to be significantly cheaper than the other net-zero scenarios".[37]

The issue that then emerges is how Australia policymakers understand and quantify the risks, costs and benefits of different export opportunities with different trade partners. We note that regardless of onshoring opportunities for Australian hydrogen for minerals processing and other manufacturing, countries like Japan, Korea and Germany still need to import energy and are looking for hydrogen (and its derivatives, such as ammonia) to meet that need.

1.4 The bankability gap is far from closed

The clean and green hydrogen industry is pre-commercial: there is no merchant market for hydrogen, and bankable offtake is required to obtain project finance. Offtake is hard to secure because hydrogen is competing with existing fossil fuels in an environment of limited to no carbon pricing, and there is no established ecosystem to support hydrogen production, storage, distribution and use.

This means that government plays a key role to enable industry developments and to level the playing field, via direct funding and other economic and non-economic policy measures.

The good news is there is a suite of government funding announcements and policy developments. However, the seed funding provided to date by the Australian Government and jurisdictions has not proven sufficient to spur the required additional private sector investment. As we know, despite public funding rounds from ARENA and several state governments, very few projects have reached financial close. Deloitte notes: "Many projects are trapped in a bankability gap between offtake negotiations, persistently high electricity prices, and constrained supply chains".[38] We discuss the development of the Hydrogen Headstart initiative in section 4.3.1, and for now will note that this will also not ensure the industry gets to scale.

[36] Australian Government (2023a), page 7.
[37] Davis et al. (2023), page 54.
[38] Deloitte Access Economics (2023), page 7.

This delay in projects reaching final investment decision has been recognised by the Australian Government: the recent *State of Hydrogen 2022* report showed a comparison of Australian projects with other jurisdictions (see Figure 2), and the Minister for Energy explicitly called out in his introduction that most of Australia's project announcements are yet to reach final investment decisions.[39]

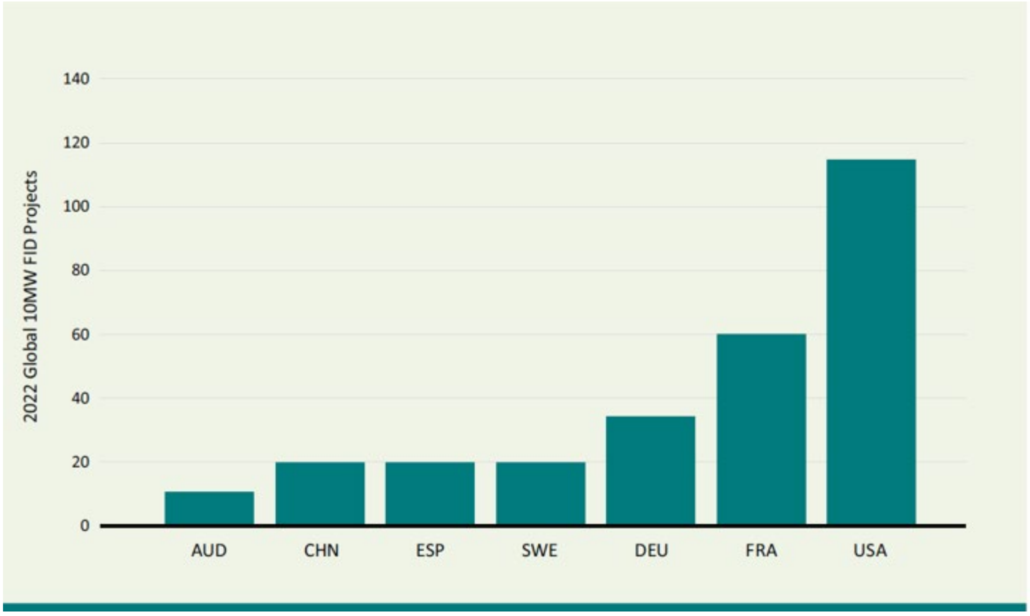

Figure 2: 10MW projects at FID in 2022; SOURCE: Australian Government (2023a), page 56.

So why is this? In discussions with our members and others, we have regularly heard that the main issues that have impeded the ability for the private sector to invest in hydrogen are:

- Hydrogen does not currently have an offtake at the scale required. The cost of hydrogen is much higher than current customers' willingness to pay, even against rising gas prices. (This is of course directly related to not having a hydrogen industry at scale to begin with: cost competitiveness with fossil fuels will not happen without extensive government policy and subsidies.) Further, major industries that will use hydrogen to replace fossil fuels – such as heavy transport and steel – do not have existing infrastructure or expertise. The investment decisions of the 'hard to abate' sectors are long-lived, with a real risk of stranded assets.
- Hydrogen represents an entirely new energy carrier and supply chain, requiring a comprehensively reskilled/retooled ecosystem that needs to cover – and connect – different sectors of the economy. It is very difficult for investors to put together all the pieces required, including the various risks associated with the array of legislative and regulatory instruments and the deficit of a workforce where it might be needed. While similarities to the development of LNG, solar and wind power do provide salutary lessons in how we might proceed, they were nonetheless industries producing a known energy source, with existing uses.[40] As noted above, there is no end use market for hydrogen as a clean or green energy

[39] Australian Government (2023a), page i.
[40] See also Craen, S. (2023) for a discussion of the key differences between LNG and hydrogen.

carrier – the current market relates to fossil fuel hydrogen in its chemical capacity (such as to bind with nitrogen to make ammonia).

- The lack of coordination across the jurisdictions and across sources of funding is making investors' decisions unnecessarily difficult. And it is not just hydrogen-dedicated funding but the broader funding envelope. The *State of Hydrogen 2022* report identifies A$28.9 billion available for hydrogen from broader funds on top of what is said to be available for hydrogen specifically (A$6.3 billion).[41] It is almost impossible for investors – particularly those from overseas – to make sense of the patchwork of approaches, authorities and conditions rolled into this figure. Given the task ahead and our relatively lower level of government support (compared with jurisdictions like the US) Australia should be seeking to be especially *easy* to do business with rather than constructing barriers to investment.
- Related to the previous points, the lack of experience of our own financial system to understand and accommodate the risks is chilling developments in hydrogen. This is not merely the usual uncertainty argument but goes to a more basic inability for financiers to even price the uncertainty and take more risk. The lack of projects itself leads to a higher cautiousness in lenders because they have not yet undertaken due diligence on a sufficient number of hydrogen business cases to engage further.

Current problems also include vastly increasing construction costs, equipment from international vendors that needs to meet different standards in Australia, and issues finding the workforce to complete projects. These are issues that affect each part of the supply chain.

Most of the issues experienced are not specific to Australia,[42] and a lack of hydrogen offtake is always raised in international fora.

Looking beyond hydrogen to broader green investments, it is instructive to note what stakeholders told the UK Government (2023) they needed to see, as below.

- Long-term clarity on the pathways for key sectors and technologies that will underpin getting to net zero.
- Public finance institutions crowding in and de-risking investment in key sectors and technologies.
- All parts of the project development and investment chain, including local government and businesses, having capacity to develop investor ready projects and raise capital.
- Improved technical capacity of emerging markets to attract green investment and use public finance levers to de-risk investment and build new export markets. [43]

These are useful themes to refer to in developing solutions, and we will return to this in section 4.3.1.

[41] Australian Government (2023a), page 14.
[42] See McKinsey & Company (2022), US Department of Energy (2023a), pages 56 and 68.
[43] UK Government (2023), page 29.

The UK government's response to the concerns raised has been to set out a Green Finance Strategy, where it has committed to exploring how it can "enable key transmission channels through which financial markets can support businesses to grow as part of a net zero, resilient and nature positive economy".[44] Among other things, it will:

- Seek to "improve the ease and speed at which businesses can access capital, and investors can deploy it, by both broadening the investor base and attracting new market entrants".
- Implement Solvency UK, "creating the potential for over £100 billion of productive investments from insurers in the next ten years, all while maintaining high standards of policyholder protection".
- Develop mechanisms "to lower the financing costs businesses face when seeking to fund capital expenditure for activities aligned with the transition".
- Build partnerships with emerging markets, including actions to enhance sharing of lessons from green finance implementation in the UK.[45]

It would seem prudent for Australia to similarly seek to understand investors' risk perceptions and work on a strategy to ensure the Australian financial system is fit-for-purpose to unlock private finance for the transition, and for hydrogen in particular given its relative newness but need for scale:

> Knowledge of the risk-return profiles that the private sector, particularly institutional investors, are seeking helps the public sector identify the role it needs to play to mitigate risk factors that might otherwise raise the cost of capital to punitive levels that discourage investment.[46]

This is all the more important for enabling transition finance for heavy industries to undertake deep decarbonisation over a longer time period.

As a final point, and linking back to the earlier concept of capital reallocation, there is starting to be a call for governments to develop clearer policy on how the transition will be effected across different forms of infrastructure.[47] To this point there has been little public discussion about who pays for new assets and how costs are recovered to pay for existing sunk assets so they aren't stranded.

The usual approach in the energy industry is for the Australian Energy Regulator (AER) to undertake periodic reviews of regulated transmission and distribution networks (asset values and forecast capex and opex) to determine how much the asset owners can charge their customers. These charges comprise around half of a consumer's energy bill.

Energy bills to small customers have always been problematic, with affordability concerns raised for at least the past 25 years. However, they are arguably at their height now, and we continue to see announcements from electricity and gas companies that indicate worse is to come.

Hydrogen cost recovery can exacerbate this situation. So far, hydrogen targets (which we welcome) are being met through obligations on energy businesses, that then recover costs via consumer energy bills.

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[44] Ibid., page 10.
[45] Ibid., pages 10-11.
[46] International Renewable Energy Agency (2023), page 13.
[47] See Wood, Reeve and Suckling (2023), Australian Energy Regulator (2023).

The transition forces a rethink on how system costs are recovered, and we argue that it is not appropriate for costs to be recovered from people paying for essential services. While we all will need to pay for the transition, doing so through the tax system is a better approach. This is addressed further in sections 4.3.1 and 4.3.6.

1.5 Conclusion

We know more about the transition than we did in 2019, including that it involves the global reallocation of trillions of dollars,[48] and hundreds of billions in Australia. Recent analysis has suggested that the cost to build the Australian hydrogen industry is in the vicinity of A$25 billion a year from 2040.[49]

These are large numbers, but as noted by the Australian Industry Energy Transitions Initiative they have precedent: "in Australia, A$305 billion has been invested in new LNG projects over the past 13 years…and the economic response to COVID-19 has reached A$291 billion since the start of the pandemic".[50]

In 2023, it should not be controversial to point out that Australia needs to have a funding and financial system that aligns with net zero and hydrogen goals; that is, risk-sharing mechanisms, funding allocations and investment settings that are sized appropriately to our ambitions and timelines.

Funding and financing the transition in an orderly way is clearly challenging already. The sheer complexity of the transition, combined with the inevitable perception of winners and losers from capital reallocation, create economic, social and political risk. And for hydrogen, the transition becomes more challenging when we recognise the early technological and (non-)commercial readiness of the processes and equipment to make, move, store and use clean and green hydrogen at scale.

However, there really isn't a choice. Australia will not reach net zero without hydrogen for sectors such as ammonia for fertilisers, iron and alumina ores, industrial processes that require high temperatures, and fuel for heavy road transport and shipping. And our energy and resources export markets will be lost without it.

Cost competitiveness with fossil fuels will not happen without extensive government policy and subsidies. Governments must be market creators at this stage of the energy transition. This means levelling the playing field with fossils fuels, using an appropriate mix of policy and funding levers. This is not only about funding for pilots but also about major infrastructure investment in the public interest. It is also about setting expectations about future policy intent, where this can be anticipated.

Government policy is the catalyst, where funding from public sources must attract and 'crowd in' or 'back in' the necessary private sector capital.[51] Incentives to deliver increased generation and lower

[48] See UK Government (2023) and Net Zero Australia (2023), also International Renewable Energy Agency (2023).
[49] Arup (2023a).
[50] Climateworks Centre and Climate-KIC Australia (2023), page 10.
[51] International Renewable Energy Agency (2023).

power costs also inevitably increase the pace of manufacturing investment. Australia can grow sovereign capabilities across a range of sectors, which provides both growth opportunities and a degree of economic resilience to external shock.

The private sector also needs to perhaps learn to expect some level of equity stakes for government backers, to ensure citizens are also rewarded on the upside not just taking the risk (a reversal of socialising the risk and privatising the reward).

In its *Global Hydrogen Review 2021*,[52] and as shown in Table 1, the IEA suggests five key recommendations for all countries, which we believe are reasonable pillars for a refreshed NHS and align with our proposed approach.

We go into more detail on the last three elements, because Australia's aspirations to be a major hydrogen exporter will require huge investment from a range of sources.

IEA recommendations	This paper
1. Develop strategies and roadmaps on the role of hydrogen in energy systems	Chapter 2 – Required approach of refreshed NHS
2. Create incentives for using low-carbon hydrogen to displace unabated fossil fuels	Chapter 5 – Market stimulation measures
3. Mobilise investment in production, infrastructure and factories	Chapter 3 – International engagement Chapter 4 – Building the ecosystem
4. Provide strong innovation support to ensure critical technologies reach commercialisation soon	Chapter 4 – 4.3.5 RD&D
5. Establish appropriate certification, standardisation and regulation regimes	Chapter 4 – 4.3.6 Regulation

Table 1: IEA recommendations against this chapters in this paper; SOURCE: International Energy Agency (2021) page 9.

[52] International Energy Agency (2021a).

2 The required approach for the refreshed NHS

The Australian Government's *State of Hydrogen 2022* report countenances a changed approach to the refreshed NHS, noting that to be a global leader in the hydrogen industry by 2030, there will need to be an accelerated delivery of key actions of the NHS v1, particularly "the advancement of priority pilot projects, the establishment of hydrogen hubs, and the assessment of supply chains will be essential to achieving the scale necessary to compete internationally".[53]

In this context, the report also states that "Australia may need to reconsider the need for targets and incentives and other measures to ensure its industry is globally competitive".[54] AHC supports the principles behind these statements, but we also urge the Australian Government to do much more than this.

The refreshed NHS needs to properly set expectations and provide some direction as to government priorities.

Key questions need to be asked and answered, such as:

- Where will we produce, store and use hydrogen domestically?
- What is Australia's value proposition and competitive offering? Will we export and what will we export?
- How do we best support RD&D and supply chains; what else are we good at?
- What is the Australian Government's role in reducing project and investment risk and in increasing the relative attractiveness of investment and projects in Australia? When does it act?

Expert views on the answers to these questions are starting to find common ground, where the answer to domestic uses is the hard-to-abate areas of the economy: low emissions metals, chemicals, and heavy transport. The export narrative is splitting into valuing both hydrogen (and its derivatives) as an energy carrier for our partners who need it, such as Japan, and for exporting iron, or alumina, which has been produced with hydrogen. We are finding that there is more work to be done to answer what we are good at, but there are opportunities for filling some of our own supply chain gaps for hydrogen, such as for electrolysis and key equipment.

The role of the Australian Government is a key element of the refreshed NHS. It needs to set the tone and establish expectations, including on timing. It needs to undertake any analysis required to answer the key questions and to work across portfolios and usual political boundaries.

These things are important because to date there has been a lack of an overarching framework or plan, including how to realise Australia's ambitions to be an emerging renewable energy and/or hydrogen superpower.

In contrast, other nations have situated their energy and hydrogen policies firmly within broader industry policy, infrastructure planning and national level commitments to lower national scope 1, 2, 3 emissions in line with international obligations (in effect, ensuring that domestically produced

[53] Australian Government (2023a), page xii.
[54] Ibid.

goods in trade exposed industries remain competitive, particularly as nations develop carbon border tax schemes).

For example, the US National Clean Hydrogen Strategy and Roadmap[55] looks for opportunities for clean hydrogen to contribute to national decarbonisation goals across multiple industries and sectors of the US economy. The document:

- Provides a snapshot of current hydrogen production, transport, storage, and use.
- Presents a strategic framework for achieving large-scale production and use of clean hydrogen, via a range of scenarios for 2030, 2040, and 2050.
- Establishes targets, market-driven metrics, and an implementation plan.

The requirement for development of the strategy and roadmap is set under the US *Infrastructure Investment and Jobs Act* (also known as the *Bipartisan Infrastructure Law* (BIL)), which also requires review of progress and refresh of the strategy and roadmap every three years.

The US approach provides a gap analysis via an infrastructure and industry assessment, focused on the higher order goal of whole-of-economy decarbonisation. Its recommendations relate to high-value use cases for hydrogen across the economy.[56] This is supported and enabled by the funding and regulatory regime of the IRA.

This is the model for Australia that the AHC is seeking from the refreshed NHS.

This chapter discusses how the refreshed NHS can be most effective given what we currently know. The overarching themes are to:

- Clarify government objectives and accountability for the refreshed NHS.
- Set priorities and targets for the sector to guide current and future policy and investment.

2.1 Clarify government objectives and accountability

It is important that there is transparency in what is expected from the future hydrogen industry, and that government actions to enable and regulate the industry are then aligned with the ambitions.

Given previous commitments and policy against Australia's NHS v1 aimed for Australia to be a top three exporter to Asian markets, and more recent political statements stating that Australia can be a renewables/hydrogen superpower, it is reasonable to note that our walk and talk are not well matched.

We are hearing this message from domestic players, but the message is clearest from our trading partners, who are expressing great concern that Australia is not acting in accordance with their expectations. While some may claim that this is inevitable given interests do not always coincide, we should note how much Australia's energy transition will rely on our trading partners, for innovation, investment, trade and materials.

[55] US Department of Energy (2023b).

[56] The US is not alone in this strategy: the EU, the Singaporean government, the Japanese, UK and Korean governments all have taken the similar approach of systematically evaluating the means and mechanisms for achieving decarbonisation of their power and industrial sectors and sought to embed the built out of a hydrogen (and derivatives) industry within this broader analysis.

National coordination requires a much stronger approach that brings together various political portfolios, data and analysis and a better Team Australia support of Austrade and DFAT. It requires alignment with broader energy and decarbonisation policies, embedding hydrogen value chains within other industry and manufacturing packages. It also requires a whole-of-government view on how the energy transition as a whole is paid for, recognising that as an externally imposed transition imperative it will require significant direct government support.

The energy and industry transition will connect complex systems and require fundamental change, planning and creativity across sector, departmental and political boundaries. There is a need for cross departmental steering of net zero work and of the refreshed NHS within that. In the absence of a more obvious choice, this should be overseen by the Net Zero Economy Agency.

This is a significant task, with a need to draw on modelling and planning from a range of sources. Comprehensive and published planning information – defined here as projections and assessments of future energy supply and demand pathways – would assist governments, the private sector and the public to make informed decisions about their options and actions. As should be clear, we are suggesting broader net zero planning here rather than for hydrogen alone.

No such planning and reporting information is currently being produced. AEMO's Integrated System Plan (ISP) is the nearest example but it does not cover oil, energy exports, the consumption of electricity and gas off main grids, or the achievement of policy and programme goals. So, while the ISP would be important input to a national energy planning document, it serves a different, more specific, and limited purpose.

In our White Paper in 2021 we proposed that the Australian Government developed an evidence-based approach to planning and coordinating the transition to net zero – including the development of hydrogen infrastructure – and reporting progress.

> The proposed planning information would need to be updated regularly to update supply demand, technology costs and other parameters that underlie projections. Scenarios would be employed, and subjected to sensitivity analysis, to inform policy, commercial and community decisions rather than advocate preferred directions. Actual results for the relevant parameters would also be reported (e.g. emissions, renewable energy share, vehicle fleet emissions, energy consumption and technology costs) and compared to earlier forecasts and Federal and State targets. The impact of policies would be assessed where feasible.
>
> Exports of energy (coal, LNG, hydrogen) and commodities that could be processed with clean energy (e.g. iron ore, steel) would be in scope of forecasting and reporting.
>
> Non-energy indicators of related economic and social impacts (e.g. employment in relevant sectors and regions, energy costs, productivity impacts, land use change due to energy production, air quality and associated health outcomes) would be forecast and reported.
>
> The volume, type and price of offsets could be included in the projections and reporting, as could non-energy emissions.[57]

[57] Australian Hydrogen Council (2021), page 30.

Since the release of this paper in 2021, it has also become clear that data should be regional, and regional by sector, to best assess relative strengths, and identify gaps, to inform development of infrastructure and project investment propositions.

We note the recent announcement that the Australian Government will develop sectoral plans for decarbonisation.[58] This is for six key sectors (electricity, industry, resources, agriculture, transport and the built environment) with the intent of targeted cost-effective strategies, reinforcing the circular economy, as well as providing the confidence to attract new investment in decarbonisation. This strategy will also inform an updated 2035 emissions target for Australia, which is currently with the Climate Change Authority for advice. We look forward to engaging with this process.

So far, the most comprehensive work undertaken for the Australian Government that addresses future needs for hydrogen is the National Hydrogen Infrastructure Assessment (NHIA) undertaken by Arup (2023b), which we have used throughout this paper.

The NHS v1 envisaged an update to the NHIA at least every 5 years. Given the current fast pace of hydrogen industry development and uncertain wider energy landscape, it would be advantageous to update this assessment more regularly.

As a final point, the role of the refreshed NHS as a tool for communication, or the basis for further communication, should not be underestimated. The strategy, and supplementary documents, are setting the scene and sending messages to investors, communities, and related/dependent industries who either provide inputs to the emerging hydrogen sector, or who rely on outputs from the hydrogen sector to run their operations. In the Gartner hype cycle, it can be argued that hydrogen is very much at the peak of inflated expectations. But the long lead time required to build the infrastructure and begin production of hydrogen and its derivatives means that some in the Australian community, and perhaps even political backers, will become disillusioned with the hydrogen industry and its potential to scale rapidly enough for the necessary energy and industry transition.

If we look at the needs of investors, as discussed in section 1.4, investors are struggling to see the value and need help to recognise opportunities and available assistance. We are also hearing from international companies and trading partners that they don't know who to engage with in the Australian Government on hydrogen – there is no clear ownership of issues and with changes in government even past relationships do not provide adequate assistance. We note that this puts Australia at a disadvantage with international parties, with IRENA explaining that 'hydrogen diplomacy' is now an important part of economic diplomacy:

> Access to hydrogen is often seen as an element of energy security, and overall national resilience, particularly for industries where other solutions are not feasible or uneconomical. Some countries that expect to be importers are already engaged in dedicated hydrogen diplomacy. Germany and Japan have been trailblazers, but other countries are following close behind them. Potential exporters are deploying similar strategies, with many including hydrogen – green hydrogen in particular – at the highest levels of their diplomacy.[59]

[58] Bowen (2023).
[59] International Renewable Energy Agency (2022), page 12.

It is not clear whether communities and smaller energy and fuel consumers would engage with the refreshed NHS, but it should set the scene for further information and material explicitly, including noting what might trigger more comprehensive community engagement from governments and industry.

Looking at related and dependent industries, these include:

- the electricity and gas industries,
- major future users of hydrogen, such as transport and heavy industry,
- the water sector, and
- the education, skills and training sectors.

The NHS v1 did outline the importance of these matters but lacked any clear implementation approach that allowed for sharing information between industries and sectors.

Recommendation 1: Commit to significant market making and ecosystem building in the public interest.

The Australian Government should commit to the following for the emerging hydrogen industry:

- **Priorities, planning and coordination**: Match the refreshed NHS to broader climate targets and align with other policy for cross government approach. Commit to nationwide planning for critical energy, including hydrogen infrastructure. See Recommendations 6-10.
- **Targeted and ambitious international engagement**: To secure the investment required, support 'Team Australia', and provide clarity on objectives and communication channels for our trade partners. See Recommendations 11-14.
- **Investment in infrastructure**: Commit to investments in key infrastructure that meet public interest tests for common user infrastructure and prioritise investment and sequencing of government-funded projects to seek investors and partners. See Recommendations 15-47.
- **No regrets market development and support**: Commit to further revenue support mechanisms and target setting for industries that are most likely to rely on hydrogen to decarbonise, and undertake further analysis as needed. See Recommendations 48-53.

This work must embed the refreshed NHS within the Australian Government's broader programme of work for reaching net zero.

Recommendation 2: Task the Net Zero Economy Agency with overseeing the implementation of the refreshed NHS.

The Australian Government should task the Net Zero Economy Agency with overseeing the implementation of the refreshed NHS, with ultimate reporting responsibility to Cabinet.

The Net Zero Economy Agency should work with a cross-departmental group of senior leaders from central agencies and line areas to advise on the refreshed NHS as part of the overall net zero project. This should be via a formal steering group, supported by a secretariat, with quarterly reporting to the group on implementation of the refreshed NHS actions. The steering group should be supported by a technical advisory panel and an investor panel (local and international).

Recommendation 3: Task the Net Zero Economy Agency to oversee a rolling programme of industry analysis to support ecosystem planning.

The Net Zero Economy Agency should oversee a rolling programme of industry analysis to support ecosystem planning in line with broader net zero targets and the refreshed NHS. This needs to be a sector by sector, commodity by commodity analysis to assess relative strengthens and identify gaps to inform development of infrastructure and project investment propositions. This could be undertaken in phases to match industry priorities and may overlap with the sectoral decarbonisation plans.

This work should seek to stimulate the right programmes of investigation, connect different bodies, and encourage discussions about different forms of the future to serve policy and planning.

Recommendation 4: Task the Net Zero Economy Agency to oversee an assessment of cost and clarify investment needs from the public and private sectors.

Connecting with the analysis recommended above, the Net Zero Economy Agency should oversee an assessment of the cost of the energy transition as a whole, and the capital reallocation required, and then a matching of public funding to de-risk qualified projects.

Within this, the Net Zero Economy Agency should oversee a review and schedule for the effective lives of key assets (as per application priorities) that may require fuel switching to hydrogen, and set policy to support replacement options and investment cycles.

Recommendation 5: Extend and re-run the NHIA analysis to support decision-making for the refreshed NHS.

The Australian Government should undertake the NHIA again in 2023 for the refreshed NHS to account for the changed assumptions and inputs since 2020.

The NHIA should then be repeated every two years, up to industry establishment (that is, over the next two decades). Updates should also align with other energy planning and infrastructure implementation planning such as the AEMO ISP (Integrated System Plan) and broader federal and jurisdictional energy planning and infrastructure planning pipelines (e.g., the Infrastructure Australia priority infrastructure list). This work should also support and inform the analysis in Recommendation 4, particularly regarding major asset lives and replacement schedules.

2.2 Use what we know now to set priorities

Assuming the Australian Government's objectives for hydrogen still align with those of the jurisdictions, and that the shared aspiration for hydrogen remains high, explicit targets and priorities are now needed to set government and industry expectations and drive action.

The NHS v1 covered priorities in different ways, with the overall topic choices across the 57 agreements obviously representing the first selection process, and the depth of examination of the issues providing further indication of government priorities at the time.

In terms of what the NHS v1 explicitly said about priorities, Agreement 12 (under the heading "Supporting research, pilots, trials and demonstrations along the supply chain") provided a list that was useful at the time but there were too many applications to truly be 'priorities'. It is also not clear how this agreement was to be delivered in part or as a whole. This approach needs upgrading to prioritise particular applications and clarify how priority work is delivered (and with what funding).

We note that after the release of the NHS v1 the areas of work that saw the most attention related to changes to hydrogen certification (the guarantee of origin) and necessary changes to national gas legislation to allow hydrogen into networks. This work is well advanced and requires less strategic focus now compared to other, less developed, topics.

We acknowledge that there are challenges in what an overarching and nationally led strategy can influence for topics that are largely run or regulated by the jurisdictions, such as public transport and worker health and safety. However, more can be done at a national level to support an orderly transition, or at least avoiding a disorderly one.

2.2.1 Application priorities

Starting with how we can frame priorities, it is useful to consider the global expectations for hydrogen developments. IRENA suggests that globally the 2020s "could be the era of the big race for technology leadership" and "initial trading routes could be established". For IRENA, "Demand starts to take off from 2035, and during this period, and international trade of hydrogen and derivatives could then grow significantly.[60]

By 2050, IRENA projects (for its 1.5°C scenario) that hydrogen and its derivatives account for 12 per cent of final energy use and 10 per cent of CO_2 emissions reductions. Hydrogen plays an important role in harder-to-decarbonise, energy-intensive sectors like steel, chemicals, long-haul transport, shipping and aviation. It also helps balance renewable electricity grids and serves as long-term seasonal storage. To achieve this, around 5,000 GW of hydrogen electrolyser capacity is needed, up from just 0.3 GW today. Producing green hydrogen and its derivatives uses 30 per cent of the total electricity demand in 2050. Of the total production, at least two-thirds of total production is green hydrogen, with blue hydrogen as the remaining third. [61]

The broad brushstrokes of this analysis – and we should note, most international analysis[62] – can be seen as follows:

- Hydrogen is not everything in the energy transition, but 12 per cent still reflects significant heavy lifting. This is all the more because of the role hydrogen must play in harder-to-decarbonise, energy-intensive sectors.
- These sectors are primarily steel, chemicals, long-haul transport, shipping and aviation, and electricity (seasonal energy storage).
- Producing renewable hydrogen – which comprises the bulk of hydrogen production – requires significant new electricity build.
- There is a still a role for blue hydrogen.

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[60] International Renewable Energy Agency (2022), page 22.
[61] Ibid.
[62] Examples of major reports that align with the International Renewable Energy Agency include US Department of Energy (2023a, 2023b), Energy Transitions Commission (2021), International Energy Agency (2021a, 2021b).

- Work to create the ecosystem must be over the next 10-12 years, with a focus now on enabling longer term decisions (for post 2035), building technology capability and locking in international trading.

In Australia, several reports align with these global perspectives, including Advisian (2021), Climateworks Centre and Climate-KIC Australia (2023), Net Zero Australia (2023) and Arup (2023b).

Looking at overall volumes of hydrogen demand, Figure 3 shows a comparison of three Australian studies:

- **Arup (2023b)**: The 2022 NHIA, using the Central scenario. This was based on Arup modelling and Frontier scenario building.
- **Net Zero Australia (2023)**: The 2023 NZAu model, using its scenario E+, which is the closest to a central scenario and has electrification proceeding but not with a highly ambitious renewables build. (Note, NZAu also provides an onshoring scenario not shown here.)
- **Deloitte (2019)**: As a reference point, work undertaken by Deloitte for the NHS v1, where:
    - NHS – EOF refers to the *Energy of the future* scenario, which was the most hydrogen-optimistic of the scenarios and considered an extremely aspirational scenario.
    - NHS – TD refers to the *Targeted deployment* scenario, which was the best reasonable scenario that anticipated meaningful hydrogen developments but not as optimistic as *Energy of the future.*

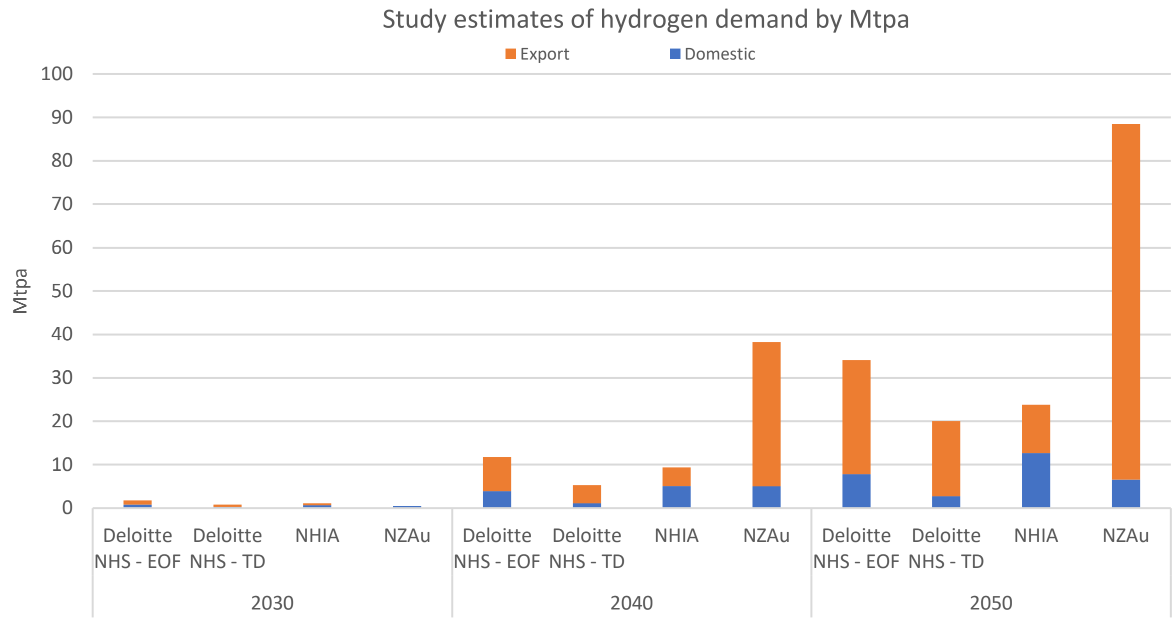

Figure 3: Total hydrogen demand figures across three different studies.

We can see that the optimistic case from 2019 (Deloitte NHS – EOF) is not radically higher than the central/reasonable mid cases from the NHIA and NZAu. The NZAu case does stand out as having a very high estimate of export demand, but this can mostly be understood as the result of the authors starting with the condition that the modelling was about assessing how to decarbonise not only existing domestic energy use but also Australia's export markets, currently 15EJ of exports. On this basis, the vast bulk of hydrogen demand for Net Zero Australia was to make ammonia for export, replacing (calorific value) of the existing energy exports.[63]

Given this, it is useful to examine the domestic figures further, as shown in Table 2. This shows that the NHIA and NZAu estimates are not substantially different, except for NHIA providing a much higher estimate in 2050.

Study	2030	2040	2050
NZAu – E+	0.5 Mtpa	5.0 Mtpa	6.6 Mtpa
NHIA – Central	0.7 Mtpa	5.1 Mtpa	12.7 Mtpa
Deloitte NHS v1 – Targeted deployment	0.3 Mtpa	1.1 Mtpa	2.7 Mtpa
Deloitte NHS v1 – Energy of the future	0.8 Mtpa	3.9 Mtpa	7.8 Mtpa

Table 2: Domestic hydrogen demand/production figures across three different studies.

It is worth noting that the NHIA and NZAu economic models favoured hydrogen produced through electrolysis. Each also found that in the long-term hydrogen would be transported by pipeline. Interestingly, the domestic figures highlight that the study considered to be highly ambitious in 2019 – Deloitte's *Energy of the future* scenario – does not appear too ambitious in 2040 and 2050 compared with the more recent assessments.

On the application priorities for Australia, we have compared the NHIA and NZAu modelling with work undertaken for the Clean Energy Finance Corporation by Advisian in 2021, and a paper by Deloitte released this year.

Study	Finding on priority domestic applications
NHIA 2022	Demand is initially driven by use in the transport sector (assuming necessary refuelling).[64] Hydrogen in mining in the near term, particularly at off-grid and fringe-of-the-grid locations. A growing role for hydrogen in industry, aviation, shipping and dispatchable power generation, as well as green steel production.[65]
CEFC 2021	Applications with a high dependence on hydrogen are marine shipping (methanol and ammonia), aviation (international and regional), steel, ammonia, methanol, some high-grade heat. Still dependent but to a lesser degree are heavy vehicles (line haul and mining), ferries, remote power and grid balancing.[66]
NZAu 2023	Hydrogen has "major role" in decarbonising the industrial sector, and for the hard-to-abate areas in particular.[67] Strong role for hydrogen in buses and heavy duty vehicles, reaching around 30 per cent sales share by 2030 (and staying there).[68] A lesser role in light duty vehicles from around 2030, but only reaching a maximum sales share of around 15 per cent of total light duty vehicles.

[63] Pascale et al. (2023), page 3.
[64] Arup (2023a), page 10.
[65] Arup (2023b), page 125.
[66] Advisian (2021), page 87.
[67] Davis et al. (2023) page 26.
[68] Ibid., page 22.

Study	Finding on priority domestic applications
Deloitte 2023[69]	Strong role for hydrogen for steel, ammonia, methanol and oil refining, long haul transport, aviation and shipping, with all from 2030 except shipping, which is from 2040. Possible use in cement, trains, and other chemicals in favourable circumstances. Role in balancing the grid when renewables penetration is high.

Table 3: Hydrogen domestic priorities according to Australian studies.

We can make some observations on the studies addressed in this section:

- As in other countries, renewable hydrogen comprises the bulk of hydrogen production and requires significant new electricity build.
- The sectors identified in international studies are also the sectors for Australia; that is, steel, chemicals, long-haul transport, shipping and aviation, and electricity (seasonal energy storage).
- In line with the global view on time to get to scale, the years to 2030 are not going to be a period of significant hydrogen production. This is the time to build what's required and grow capability.
- Australia seeking to export the same energy value in hydrogen as current exports (as per the NZAu export case) is an even more extraordinary undertaking. In any event, we will need deep water ports with available berths and storage.

In summary, the evidence is clear that focussing on building scale and capability on the sectors and applications that will be hard to abate without hydrogen is the best 'no regrets' approach that can be taken in an uncertain environment. This approach should also actively build room for other applications that might value hydrogen at lower prices and with an established (and shared) infrastructure.

Recommendation 6: Prioritise hard-to-abate and scalable domestic demand sources.

The Australian Government should prioritise growing demand for hydrogen in the applications that are more likely to require clean hydrogen to decarbonise, and more likely to achieve large scale. Ideally these should demonstrate an ability to open the market to other applications, through knowledge/technology sharing, geographic proximity, and/or cost reduction. Current evidence supports these industries as being:

- Chemicals, particularly ammonia and methanol
- Low emissions metals, particularly iron and alumina
- Heavy road transport
- High temperature process heating
- Marine and aviation, where hydrogen is a feedstock for future fuel
- Seasonal storage for the electricity market.

[69] Deloitte Access Economics (2023).

2.2.2 *Export priorities*

We discussed in section 1.3 that exporting hydrogen as is not the whole story. Export for hydrogen is not only about hydrogen and its derivatives but also the prospect of using hydrogen to produce and export green iron and steel, alumina and aluminium, and methanol.

Direct reduced iron (DRI) is produced by removing oxygen from the iron ore. This makes metallic iron without melting it. Currently, natural gas is used to produce reduced iron; however, steelmakers are considering the use of hydrogen for DRI manufacturing to make the steelmaking process CO_2-free, and several projects are in train.

India is currently the world's largest producer of DRI, mainly through coal gasification and some LNG. As part of broader policy changes progressing the decarbonisation of India's power and industrial emissions, the country has seen significant investments in a range of trials and pilots utilising a range of technologies for the production of DRI, including hydrogen.[70] India's National Steel Policy, which has a target of 300 Mtpa domestic capacity by 2030, alongside the Modi Government's continued investment in renewable energy generation and commitment to achieving net zero by 2070, has seen some significant investments. For example, in 2022, ArcelorMittal Nippon Steel India, a joint venture between ArcelorMittal and Nippon Steel, commenced the Rs600 billion (A$7.2 billion) expansion of the Hazira flat steel plant in the Indian state of Gujarat.[71]

While Australia is not a first mover on DRI with hydrogen, we are the largest exporter of iron ore, and so there is a market opportunity. This is particularly as decarbonisation policies start to bite and we can produce hydrogen cleanly. For example, in the European Union the overall greenhouse gas emissions reduction target for 2030 requires sectors covered by the Emissions Trading System (ETS), including steel, to reduce their emissions by 43 per cent compared to 2005 levels. Free ETS allowances for steelmakers are to be phased out between 2026 and 2030.[72] Steel making using DRI – and therefore having a high reliance on secure supply of hydrogen – looks to be a critical element in European steel makers' considerations for compliance with the new ETS regulations.[73]

Further, in December 2022, the POSCO Group CEO announced that POSCO would invest US$40 billion in Australia by 2040: US$28 billion in hydrogen manufacturing (renewable energy and water electrolysis) and US$12 billion in green steel with its local partners to manufacture 1 Mt of hydrogen in Australia by 2040.[74] By any measure, this is an extraordinary sign of confidence.

However, as noted by the Australian Industry Energy Transitions Initiative, Australia could still be left behind in the global move to green steel.[75] The bulk of the iron ore currently mined for export in

[70] Mallett and Prosanto (2022).
[71] Mining Technology (2022).
[72] Kinch (2022).
[73] We note also whilst much of the focus has been on the use of hydrogen in DRI production, research being undertaken at the Max Planck Institute in Germany is exploring the use of ammonia in DRI, arguing that the direct use of ammonia takes advantage of existing global infrastructure for ammonia transport and removes the need for either hydrogen transport and storage or cracking ammonia on arrival. See Ma et al. (2023).
[74] Jung (2022).
[75] Climateworks Centre and Climate-KIC Australia (2023).

Australia is incompatible for use in the production of DRI as the ore contains too many impurities.[76] We briefly discuss this in section 4.3.5 as an RD&D priority.

The Australian Industry Energy Transitions Initiative report calls for Australia to actively plan for a green steel future, rather than simply respond to global investment trends and innovation cycles. Given that the technologies currently being piloted and trialled (direct reduction furnace technology, electric arc furnace) are not expected to be deployed at scale until the late 2030s, Australian governments and corporates have significant motivation and lead time to ensure investment in the secure supply of hydrogen feedstock for DRI.

In summary, we observe that the expert consensus in Australia is starting to land on the concept that it may be better for a philosophy of 'use it where you make it'; that is, for Australian hydrogen to process ores rather than exporting hydrogen and its derivatives – with the attendant compression and conversion matters – as an energy vector. As we noted in 1.3, the efficiency of 'onshoring' hydrogen that might otherwise be exported to achieve the same outcome is also greater.[77]

This is important as an opportunity and must be taken seriously. However, we would caution against this being prioritised to the degree that Australia does not also pursue developing the export markets for our trading partners who need energy. Japan, Korea, Germany and others may import green iron from Australia in the future, but they also need energy and are seeking to engage on, and invest in, hydrogen and hydrogen derivatives to meet energy demand and diversify supply.

Given how much Australia's energy transition will cost, and how reliant the nation is on continued foreign direct investment (for power generation, transformation of existing manufacturing and new innovation) both export types need to be pursued, and in conjunction with domestic activity. This is also a matter of Australia helping support energy security in the region. Chapter 3 discusses international engagement in further detail.

Recommendation 7: Support hydrogen for export as an energy vector and for value added products such as green iron.

In the absence of extraordinary evidence to the contrary, the Australian Government should continue to build an export market for hydrogen (and its derivatives) as an energy vector.

There is also a need to prioritise and plan for domestic use of hydrogen to build Australia's processing and manufacturing capabilities, which will provide new long-term value for the economy. The design of the funding support mechanism and guidelines for the Hydrogen Headstart program provide an opportunity to incorporate this thinking and set these priorities.

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[76] Australia exports two main types of iron ore: hematite and magnetite. Hematite is mined in Western Australia's Pilbara. It's a naturally higher-grade ore (56–62 per cent iron). Magnetite is a lower grade ore (25-40 per cent iron) which needs extra processing, and this processing – including the use of magnets to separate iron from waste rock – produces ore with more iron content, fewer impurities and less waste rock than hematite. Earlier this year, the Fortescue Metals Group (FMG) commenced production of magnetite iron ore from the Iron Bridge mine with an annual capacity of 22 million tonnes.

[77] Davis et al. (2023), page 54.

2.2.3 Supply chain priorities

The hydrogen supply chain will vary to some degree, depending on definitional boundaries, and based on what choices are made in production, distribution and storage technologies, and the application priorities we discussed in the previous sections. Whether there are gaps in the supply chain – or conversely, any internal demand – for supply chain components will also depend on choices made on volumes and timeframes.

As we noted earlier, work is ongoing to determine what Australia is particularly good at, at least insofar as there is value domestic manufacturing instead of importing needed goods.

In its HETS report for NERA, Arup[78] sought to determine the high priority areas for Australian hydrogen supply chains. Using a matrix that valued complexity and local advantage, the principle was that hydrogen segments that were high in both dimensions represented the areas of high potential that can leverage Australia's technical capability and experience. Figure 4 shows the findings.

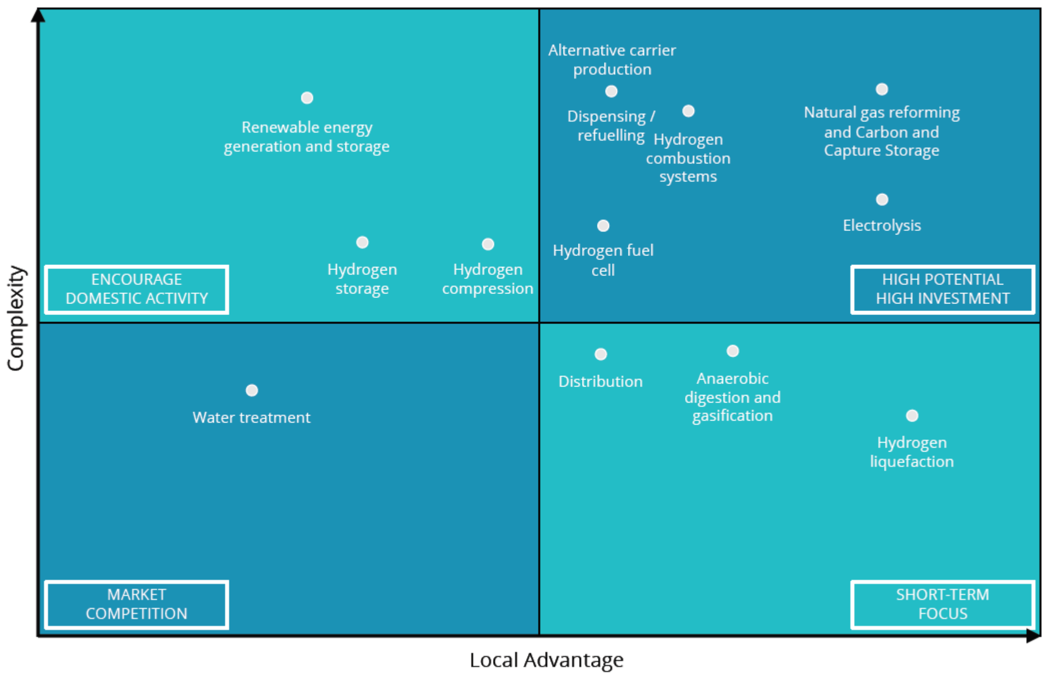

Figure 4: Matched pairs analysis on complexity and local advantage; SOURCE: Arup (2023a), page 59.

As can be seen in Figure 4, the hydrogen segments that are highest potential for both local advantage and complexity are electrolysis and natural gas reforming and CCS.

The electrolysis segment reflects a common theme in industry discussions at the moment, which is that this represents a means of addressing risks in our own supply chain and a link with use of critical minerals. We discuss this further in sections 3.3 and 4.2.1.

While the natural gas and CCS segment may be controversial it nonetheless shows some opportunity. We return to this in section 4.2.2.

[78] Arup (2023a).

Anecdotal evidence points to increasing delays in hydrogen project proponents accessing equipment and technical services. This is only likely to increase as competition increases. It is important that hydrogen production and market priorities set by government also accommodate and value the supply chain issues and opportunities available. Much of this is connected with RD&D, but the industry supply chain essentially covers every aspect of the topics we address in Chapter 4 regarding physical, social and institutional infrastructure.

Recommendation 8: Assess Australia's hydrogen supply chain risks and opportunities.

The Australian Government should assess the supply chains needed to match the objectives and priorities of the revised NHS, noting the need to assess both the risks to industry growth and the opportunities to seed and support Australian innovation.

2.3 Develop targets and action plans to support the refreshed NHS

The NHS v1 stated that mandatory national targets would not be appropriate (at that time) but should be re-considered periodically (Agreement 7).

It now seems reasonable for there to be a national target (or targets) for hydrogen. Since 2019 stakeholders have regularly commented that they wished the NHS v1 had provided targets in some form, as this demonstrates government commitment. It also becomes a means of measuring progress and building business cases if people are pulling in the same direction.

The trickier questions are then:

- Are we talking about production targets, infrastructure targets or demand targets?
- What assumptions are we making? Are we assuming entire sectors in or out?
- Are we setting a lofty ambition or a minimum standard?
- Is the target mandated in regulation, so that a cost is incurred for non-compliance? Is it fair to establish costs for a highly ambitious target or one that turns out to not be supported?

The problem in setting detailed targets, or targets with costs attached for non-compliance, is that there is no one source of truth for data to inform decisions. The NHIA is the best assessment, but the data are from 2020, and the Australian Government has also not signalled an intent for the NHIA model to be used in this way. For industry, it is therefore not clear what is and out of scope and what next steps are intended.

The US National Hydrogen Strategy and Roadmap was built on comprehensive modelling, with a high level of transparency on the findings. The US Department of Energy (2023a) *Pathways to Commercial Liftoff: Clean Hydrogen* report provides an analysis of various cost gaps, the impact of the production tax credit from the IRA on different sectors, and a range of figures that can then be debated and interrogated. The US Government has apparently seen that in an uncertain environment, for a pre-commercial and complex industry, it is the logical party to do the analysis on market settings and to then inform the wider industry and community.

Unfortunately, this has not been the position of the Australian Government.

The AHC position is that targets are required, but we cannot recommend targets without meaningful data. If we pick a target based on what is known now, we can see that around 0.5 Mtpa could be domestic demand for clean and green hydrogen by 2030, based on the figures in Table 2 from the medium cases of NZAu and the NHIA (page 42). This is also around the same number as the current grey hydrogen produced in Australia for ammonia and other purposes (493 ktpa).[79]

While it is vital to decarbonise current grey hydrogen – and so 0.5 Mtpa should be a minimum standard in the long run – it would not seem likely that the current processes using this hydrogen will have decarbonised in only 7.5 years. Discussed in later sections 4.3.5 (RD&D) and 5.2 (industry processes), these industrial processes require more time to reach technological and commercial readiness.

If the 0.5 Mtpa figure is largely based on road transport demand (which we assume to be the case), this then shows the need for policy to support uptake, which we address in sections 4.2.7 (refuelling) and 5.1 (market mechanisms).

In either case, we note that there is no point setting demand targets (even mandatory ones) if there is no ecosystem to support the hydrogen industry – much more is required. We address the various elements of the ecosystem in Chapter 4.

For 2040, according to the medium cases from NZAu and the NHIA, domestic hydrogen demand reaches 5 Mtpa. Again, depending on what data and assumptions underpin this, it could be a reasonable target, but this needs to be examined through data.

It is not possible to recommend targets for past 2040 at this stage. Similarly, it is not currently possible to set export targets while we do not have a clear policy on what export is likely. The analysis discussed in 2.2.2 should inform export targets, as should further interrogation of:

- What volumes of imported hydrogen (and derivatives) our trading partners are seeking, and by when. We note, for example, that Korea is planning to import 1.96 million tonnes/year of clean hydrogen from abroad by 2030.[80]
- When the contracts need to be signed for the milestones above, and what other decision lead times are involved.
- Whether Australia can, or wants to, meet these expectations.

In any event, the demand for each major sector (outlined in section 2.2) needs to be clearly articulated and the NHIA remodelled as necessary to answer the question on targets. Further, the domestic figures need to be aligned with broader net zero analysis so that the links to industrial decarbonisation are clear. If industrial targets were to be mandated, they would need to be explicitly aligned with government support for the transition. There would certainly need to be alignment with the safeguard mechanism to inform future baselines.

As a last point, the refreshed NHS cannot be the last word from the Australian Government on hydrogen policy. It provides a basis for actions to meet targets and milestones and to allocate

[79] Australian Government (2023a), page 10.
[80] See Australian Government (2022).

responsibility. Detailed implementation plans may need to be by sector or ecosystem element but should be outlined in an overall plan to set expectations.

Recommendation 9: Set hydrogen targets for 2030 and 2040, with a range for 2050.

Based on modelling undertaken by/for the Net Zero Economy Agency and the revised NHIA, the Australian Government should decide and announce domestic and export targets for hydrogen production for 2030 and 2040. Consideration should be given to industry specific targets, for example dedicated hydrogen production to support green steel production. Given the uncertainty about 2050 capability, any target for 2050 could be a range or guide. These targets should be set out in the refreshed NHS and also drive further financial packages and investment attraction activities, to match goals and delivery mechanisms in direction, volume and timing.

Recommendation 10: Support the refreshed NHS with public implementation plans and stakeholder engagement.

The Australian Government should ensure the refreshed NHS is supplemented by actions to meet targets and milestones, with responsibility clearly allocated. Detailed implementation plans may need to be by sector or ecosystem element.

2.4 Conclusion

The refreshed NHS needs to be a much more structured, targeted and accountability-setting document than its predecessor. In the absence of a more suitable body, it should be led by, and implementation overseen by, the Net Zero Economy Agency.

Within the overall net zero programme, the refreshed NHS must set priorities and meaningful targets, and there needs to be a government commitment to fill current knowledge gaps to a reasonable degree.

The good news is that the NHIA model already exists, and there are some basic assumptions that can likely form the basis of actions, which we have discussed in this chapter. To summarise, these are:

- Most hydrogen will be made through electrolysis, requiring significant new renewables build and electrolysers, also desalinated and/recycled water facilities. There will also be a need to understand and secure adequate critical minerals for electrolysers, batteries and fuel cells.
- For domestic purposes, hydrogen will most likely be moved as compressed hydrogen gas. For larger volumes, hydrogen pipelines will be required.
- For export purposes, ammonia is considered the most likely energy vector, but options remain on the table, including liquefied hydrogen. Iron and other ores processed with hydrogen present an enormous long-term opportunity as well.
- The most prospective applications for hydrogen in Australia are for steel, chemicals, long-haul transport, shipping and aviation, and electricity (seasonal energy storage).
- Longer-term hydrogen storage will be in naturally occurring or constructed salt caverns, with nearer-term and/or smaller-scale storage in tanks and vessels.

- The social and institutional support for hydrogen is significant, with a need for fit-for-purpose regulations, financial and funding approaches, for community support for the changes, for a skilled workforce in the right location, and for suitably funded and targeted RD&D.

Chapter 3 discusses the issues in attracting international capital, which will be vital to meet any targets set.

Chapters 4 and 5 go into detail about the need to build the hydrogen ecosystem and to stimulate domestic markets. The detail in these build on the framework in this chapter and must be enabled by the refreshed NHS regardless of which policy or implementation document addresses the detail.

3 International engagement

The Australian Government has a significant number of MoUs and agreements in place to drive collaboration on climate change and the building of new clean energy industries, including hydrogen. These include:

- **Germany**: the Australia-Germany Hydrogen Accord, including the German-Australian Hydrogen Innovation and Technology Incubator (HyGATE).
- **India**: the Australia-India Letter of Intent on New and Renewable Energy Technology, including the recently formed Australia-India Green Hydrogen Taskforce reporting to the Australian-Indian Ministerial Energy Dialogue.
- **Japan**: the Australia-Japan Partnership on Decarbonisation through Technology, focused on clean hydrogen and ammonia as well as low emissions steel and iron ore.
- **The Republic of Korea**: the Australia-Republic of Korea Low and Zero Emissions Technology Partnership.
- **Singapore**: the recently announced Australia-Singapore Initiative on Low Emissions Technology for Maritime and Port Operations, incorporating the A$30M joint R&D funding focused on shipping and maritime decarbonisation.
- **The United Kingdom**: the Australia–UK Clean Technology Partnership.
- **The United States**: in addition to the agreements focused on clean energy more broadly, Australia-United States Net Zero Technology Acceleration Partnership.
- **The Netherlands**: the Australia-Netherlands Memorandum of Understanding on Cooperation in the Field of Hydrogen.

Whilst this level of collaboration is laudable, it has been relatively passive. The agreements have not – so far – led to implementable industrial decarbonisation policies. With the notable exceptions of HyGATE and the Singapore agreement, the agreements are unfunded and do not carry an expectation of any investment taking place.

Overall, hydrogen export options for Australia are likely but not guaranteed in any particular type, volume or timeframe. The value to be gained (or lost) is enormous. There is much more that can be done to support a refreshed NHS, to attract investment, meet trade partner needs, and maximise value to Australia from risk sharing and friend-shoring.

3.1 Meeting local trading partner needs

One of the stated objectives of the NHS v1 was for Australia to be a ‘Top 3 exporter to Asian markets by 2030’.

The two key markets for Australian hydrogen and derivatives are commonly held to be Korea and Japan, and views from these markets are concerning.

3.1.1 The Korean opportunity

Korea is a highly industrialised economy whose economic prosperity has largely depended on hard to decarbonise sectors such as steel and petrochemicals. The Hydrogen Economy Roadmap of Korea[81] sets a target for hydrogen supply in 2030 at around 1.9 million tons per annum and at over 5 million tons in 2040 (vs 130,000 tons in 2018) with some estimates indicating that around 85 per cent of this target will need to be imported.

The Roadmap also includes price targets: the price of hydrogen is predicted to fall from about KRW6,000 per kilogram (kg) ($US15.18/kg) today, to KRW4,000/kg ($US2.59/kg) by 2040, noting that these targets were originally set pre-IRA and other incentives in producer countries.

The Korean Government has also recently launched a hydrogen power generation bidding market that will allow power producers to sell electricity generated from hydrogen or hydrogen compounds to state-owned Korea Electric Power Corporation and other domestic power utilities.[82] A total of 1,300 GWh will be auctioned in 2023 across two auctions. Initially, the hydrogen supply is expected to be grey, but from 2024, MOTIE has noted that it will be looking to secure 3,000 – 3,500 GWh per annum of clean hydrogen. Whilst only utility companies can tender, they need partners for the supply of clean molecules which has led to increased investment activity by the Korean chaebol.

MOTIE is currently consulting on the establishment of a clean ammonia tender for industrial use and petrochemicals, though this program is still currently under design.

3.1.2 The Japanese opportunity

In Japan, a revised Basic Hydrogen Strategy has just been released. The Strategy covers hydrogen as well as ammonia, synthetic methane, and synthetic jet fuel (SAF), setting out four key targets:

- increase supply of hydrogen and ammonia in Japan, to 3 million tons by 2030, to 12 million tons by 2040 and to 20 million tons by 2050;
- reduce hydrogen supply cost in Japan, to JPY 30 per Nm3 by 2030 and to JPY 20 per Nm3 by 2050;
- expand the number of electrolysers with Japan-made parts in them, to approximately 15GW globally by 2030; and
- attract public and private investments into the hydrogen and ammonia supply chain sector, of more than JPY 15 trillion over the next 15 years.

The updated strategy incorporates Japan's definition of low-carbon hydrogen of 3.4kg of CO_2-equivalent per kilogram of hydrogen produced, on a well-to-gate basis (up to and including the point of production), a target promoted by PM Kishida at the recent G7. This CO_2 target is aligned with European definitions of low carbon hydrogen (which is 3.38kgCO_2e/kgH_2) but stricter than US or South Korean definitions of "low carbon" hydrogen — 4kgCO_2e/kgH_2.

The signature policy announcement by the Japanese government is the proposed establishment of a Contract for Difference support mechanism, under the Green Transformation Act. The draft legislation (currently under review) proposes the issuance of around US$150 billion in Japanese

[81] HyResource (2023).
[82] Tam (2023).

government green bonds, with the aim of catalysing US$1 trillion of developments over the next 10 years. The package covers all aspects of the green transition, from nuclear to renewables, grid upgrades, energy efficiency measures, electric vehicles, carbon taxes, an emissions trading scheme and a border adjustment mechanism. However, more than US$60 billion of the funding is earmarked to build "clean" hydrogen and ammonia value chains. Whilst some of the money will be spent domestically, much of it will be invested overseas. The funding covers hydrogen and ammonia production and transport facilities, but not storage infrastructure in Japan which is covered by the Clusters Support package.[83]

The establishment of international supply chains has also previously been funded and supported by the Japanese government's Green Innovation Fund,[84] largely a series of technology grants administered by NEDO on behalf of METI, to seed demonstration supply chain projects globally, including the JSE project in Victoria.

In recognition of the risks associated with the establishment of international supply chains, particularly in the current investment climate, the Strategy notes that the Japanese Government intends to provide support for the financing of projects related to the establishment of such supply chain, for example, by encouraging the introduction of relevant insurance in the private sector and by considering ways in which Japan's public-sector agencies can take some of the supply chain-related risks.[85]

In parallel to the Green Transformation Act, the Japanese parliament is also considering a series of amendments to the Japan Bank for International Cooperation (JBIC) Act. The Draft Bill proposes to expand the scope of possible JBIC financings to *non-Japanese* borrowers (where the project involves the production of assets which benefit a supply chain to Japan), and in the context of hydrogen and ammonia projects could allow the Japanese companies to invest in the best technologies globally in order to deploy them at home. It also significantly widens the scope of potential JBIC financings for supply chain projects developed by non-Japanese borrowers, which are currently tied to the export of Japanese goods and services, the ownership of a project by Japanese companies, or the offtake of products by Japanese companies.

In addition, recent legislative changes have also broadened the scope for JOGMEC (Japan Organization for Metals and Energy Security) and NEXI (Nippon Export and Investment Insurance) to participate in decarbonisation investments including hydrogen, ammonia and CCUS, and earlier this year the two organisations signed an MoU for further cooperation and collaboration.[86]

3.1.3 The Singapore opportunity

In 2022, the Singaporean government released its hydrogen strategy, noting that hydrogen was seen as a key decarbonisation pathway for Singapore – not only for power generation, but also for maritime refuelling as well as sustainable aviation fuels (SAF):

> Low or zero-carbon hydrogen has the potential to support Singapore's decarbonisation efforts and achieve net zero emissions by 2050. The EOI will enable us to explore the use of low or zero-carbon

[83] Komachi et al. (2023).
[84] New Energy and Industrial Technology Development Organization (n.d.).
[85] Bocobza and Tanabe (2023).
[86] Nippon Export and Investment Insurance (2023).

> fuels such as hydrogen and ammonia for power generation, alongside other low-carbon alternatives such as electricity imports and domestic renewable energy sources. Low or zero-carbon ammonia may also have multiple end-use pathways for power generation and bunkering. Beyond the power and maritime sectors, low or zero-carbon hydrogen and ammonia are also promising decarbonisation pathways for our energy, chemicals and aviation sectors. [87]

One of the first actions undertaken by the Singaporean Government under the strategy is the issuing of an expression of interest for co-firing of ammonia in the power sector, as well as the use of ammonia for marine bunkering.[88] Tenders closed in late April 2023 and garnered significant investor interest, as international trading houses (particularly those from Japan) look to position themselves at the forefront of the emerging trade in hydrogen and derivatives. It is expected that an announcement on the tender is imminent.

Singapore is trying to cut its reliance on natural gas – the city-state depends on the fossil fuel for 90 per cent of its electricity. Since the release of the strategy, Singaporean energy companies have made a number of key announcements; for example, in late 2022, Keppel Energy took FID on a 600 MW hydrogen ready combined cycle gas turbine on Jurong Island,[89] as well as having joined the CQH2 project in Queensland.[90] Similarly, in May this year, Sembcorp also took FID on a 600MW hydrogen ready power plant, also on Jurong Island.

In 2021, Temasek and the Civil Aviation Authority of Singapore ran a tender for the supply of SAF for a blending trial for use at Changi Airport, part of a series of trials undertaken by airlines.

The broader conversation in Singapore, among investors as well as officials, is the recognition that Singaporean demand alone is unlikely to be sufficient offtake for at scale (and therefore lower cost) production of hydrogen or derivatives. Singapore is therefore looking to partner with the countries of North Asia, as they secure their much larger supply chains. The Singapore-Australia Green Economy Agreement,[91] alongside the Hydrogen Headstart funding, could position Australia as a front runner for the establishment of supply chains to both Singapore and North Asia. The Australian Government could lead multilateral discussions to position at least one of the projects selected for support under Headstart to be a supplier of hydrogen or derivatives to Singapore, Japan and Korea under their respective hydrogen programs, thereby securing offtake for the Australian projects, improving the economics of the supply chain, as well as meeting the energy and import needs of key trading partners and progressing decarbonisation targets across the broader region.

3.1.4 Current views from the market

Japanese and Korean companies – producers, trading companies, industrial players, as well as in some instances power companies and shipping companies – are demonstrating a willingness to seek out and enter agreements and make investments to secure their position in the emerging supply of hydrogen and ammonia to their respective markets.

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[87] Maritime and Port Authority of Singapore (2022).
[88] Energy Market Authority & Maritime and Port Authority of Singapore (2022).
[89] Keppel Corporation (2022).
[90] Stanwell (2023).
[91] Department of Foreign Affairs and Trade (2023).

AHC travelled to Korea, Japan and Singapore in June 2023 to better understand local intentions for hydrogen and perceptions of Australia. Five themes were repeated in the various discussions:

- Australian planning is seen as hampering our competitiveness on two fronts: at a national level it is lacking, with no guidance or central management to guide complex projects on matters such as access to electricity, land and water; and at a local level it is overly slow and complex to deal with regulatory and environmental processes. There remain concerns about sovereign risk from changed Australian policy regarding measures such as the safeguard mechanism and domestic gas reservation.
- Project costs of operation are too high relative to our competitors largely due to labour costs, as well as the higher costs of transport and logistics in remote regions where projects are more likely to be located.
- While green/renewable hydrogen was seen as the future, there was increasingly a view that blue/low carbon hydrogen would be utilised in the first instance as the cost of producing green hydrogen reduces. This is also because each market has little to no willingness to pay a green premium or to bear the costs of decarbonising faster than their competitors.
- Our trading partners are seeking partnerships and have expressed frustration with what appears to be a transactional approach from Australia. There is a need to build on our existing relationships and demonstrate commitment to sharing the costs of building this new industry and trade. Countries (and companies) are keen to build multilateral supply chains across the region and potentially also enable technology transfer to increase the pace of decarbonisation efforts across ASEAN and other resource constrained regions.
- Interestingly, all mentioned the need for Australia to focus on building domestic demand; to focus on and invest in the local use of hydrogen and ammonia rather than only exporting. This would serve to de-risk investment in export supply chains as it demonstrates a commitment from government and local industry to the continued production, storage and utilisation of hydrogen and derivatives. It also assists in building social licence, stimulates training of skilled workers, and is seen as more likely to foster a robust research and development sector focused on hydrogen and derivatives.

Several of the issues raised do not lend themselves to easy solutions, at least not without potentially increasing Australia's own financial, social and political risk beyond currently acceptable thresholds. However, there seems to be room for improvement in Australia's positioning.

Australia's trading and political partners in North Asia will not cease investing in Australia; however, in the development of hydrogen and ammonia production capacity, where price sensitivity of off takers (whether for power users or for industry) is a key consideration, Australia may be overlooked for initial offtake agreements to meet targets in the late 2020s and early 2030s.

For Australia to remain competitive in the negotiations of future investments, the Australian Government should as a matter of priority signal its willingness to negotiate government-to-government development and funding of critical supply chains to Korea and Japan that also serve to meet Australia's domestic decarbonisation goals, such as DRI, green fertiliser, and clean minerals processing.

The size, scale and complexity of the first large scale hydrogen export projects will require bilateral agreements between governments for bespoke joint support packages. These will need to meet the specific strategic and economic interests of each party, as well as allocate appropriate levels of risk across private and public sector partners. The agreements are likely to include significant expenditure on the required infrastructure, as well as provision of underwriting support for the trade itself.

It will also be necessary to set expectations on potential future reservation policies and royalties.

Recommendation 11: Support the refreshed NHS through a clear investment proposition.

The Net Zero Economy Agency should use the modelling and cost analysis from Recommendation 4 and the targets from Recommendation 9 to engage with DFAT, Austrade and the jurisdictional trade and investment offices to create an investment proposition to take to international markets. This work will need to be sufficiently funded and will also require clear coordination across posts, with reporting lines through to the Net Zero Economy Agency.

Recommendation 12: Develop joint support packages between Australia and its trading partners to support trade in hydrogen and hydrogen derivatives.

The Australian Government should develop bespoke joint support packages between Australia and its trading partners that underwrite trade and support necessary infrastructure.

These should also cover multilateral agreements to incentivise investment and collaboration, for example, between Australia as a producing country, Singapore as a key intermediary for shipping and the nations of North Asia as key customers for hydrogen, its derivatives and also products produced using hydrogen.

3.2 Looking further afield

The export options for Australia relate not only to Asian markets but also further afield. For example, the partnership with Germany has produced co-funded research development initiatives HySupply and the German-Australian Hydrogen Innovation and Technology Incubator (HyGATE). Under the auspices of a bilateral energy policy group between the German and Australian Governments, AHC also co-chairs a hydrogen working group, with the German-Australian Chamber of Industry and Commerce (AHK).

Further, the Port of Rotterdam has signed MoUs with the Queensland, South Australia, Tasmania and Western Australia governments and commenced investigations into Australian export projects. The attractiveness of Rotterdam is the existing and future infrastructure to be one of the main ports to import hydrogen into mainland Europe.

The HySupply project found that while transportation costs to get hydrogen from Australia to Europe were not insignificant, they were not a deal-breaker for the business case. The consensus was that ammonia would be the best vector for hydrogen, but there remain issues with the end use and conversion costs.

These are all positive green shoots, but they are not enough.

We observe a similar challenge in our European relationships as with our Asian relationships, which is that our partners are reporting inconsistent messaging from different parts of the Australian Government, from industry, and across the jurisdictions. This has potentially been amplified by the fact that Australia's aspirations to export hydrogen and derivatives beyond our region are not clear. This is, in turn, a product of there being little clarity about what European partners are wanting to import (including at what emissions intensity) and at what price. For example, the German Government has suggested an Australian window to Germany's state-funded H2Global contract-for-difference scheme is a possibility, with financial contribution from the Australian Government. However, it is not publicly clear what this entails because the end price (and thus the price gap) is unknown.

What we do know right now is that German governments and industry are willing to invest in our region to support the development of hydrogen, and this is likely to be regardless of whether Australia exports hydrogen as an energy source. This willingness existed prior to the Russian invasion of Ukraine and has continued to increase. Germany needs to import vast amounts of energy and is seeking to diversify where it obtains it. For example, Germany's recently updated and ambitious hydrogen strategy includes a doubling of the 2030 national target for green hydrogen production, from 5GW to 10GW. This is expected to be equivalent to 26-35 per cent of the hydrogen demand in Germany and a separate import strategy is being developed to bridge the remaining gap.

Additionally, while only green hydrogen production will be directly subsidised, the renewed strategy also recognises applications utilising blue, turquoise and orange hydrogen, which can also receive state support.[92] This inclusion beyond green has been described as necessary to achieve the rapid development required, deliver on the ambitious greenhouse gas limit and support the technological transition until sufficient green hydrogen becomes readily available, [93] [94] with the German Federal Research Minister, Bettina Stark-Watzinger, referring to the inclusion as "practical and important."[95]

Even if Australia does not ultimately export hydrogen to Germany as an energy source, our future role as a renewables and hydrogen producer in our region means that Australia could be a significant user of German technology. Further, actions to reduce prices in our region could also have an effect closer to Europe, potentially bringing prices down in Germany's local markets.

It is important that Australia does not get left behind as major economies such as Germany start to make calls and invest in future markets with the clear understanding that Europe will need to import green molecules in the long term. As recommended throughout this paper, the Australian Government needs to identify the opportunities and risks for Australia and better communicate its intentions and ambitions. This is more than just a transactional view of exporting molecules (or not) but about being able to identify other opportunities to grow our capability and attract global capital.

[92] Wettengel (2023).
[93] Collins (2023).
[94] German Government (2023).
[95] Kurmayer (2023).

3.3 Risk sharing and friend-shoring

The term friend-shoring is an attempt to extend the notion of nearshoring to refer only to partner or allied nations. It was first used by US Treasury Secretary Janet Yellen in a speech in Korea in July 2022:

> Supply chain resilience is a key focus of the Biden-Harris administration … Working with allies and partners through friend-shoring is an important element of strengthening economic resilience while sustaining the dynamism and productivity growth that comes with economic integration.[96]

The term is a catch all to describe the practice of manufacturing and sourcing from countries that are considered geopolitical allies (in other words, the re-formation of trade blocs). Internationally, the concept of friend-shoring or safe-shoring has also been promoted as a response to emerging geopolitical complexity rather than simply an economic imperative, reducing the dependence of a nation's economy (and security) on nations that are deemed high risk.

3.3.1 Critical minerals

In a 2021 report on supply chain risk, the Biden administration noted that: "the United States has a strong national interest in US allies and partners improving the resilience of their critical supply chains in face of challenges [including] geopolitical competition with China."[97]

The critical minerals sector is considered a test case for friend-shoring, placing Australia in a strong position to negotiate significant investments into the development of critical mineral capabilities, alongside the significant infrastructure required to develop supply chains.[98]

Internationally this is being progressed through the Quadrilateral Security Dialogue[99] (the Quad) and the Five Eyes Alliance,[100] driven by concerns about China's domination of critical minerals processing.

The concept of friend-shoring was also present in the G7 leaders' communique in Hiroshima this May, with leaders committing to "coordinate our approach to economic resilience and economic security that is based on diversifying and deepening partnerships and de-risking, not de-coupling."[101] Item 29 of the communique focused on critical mineral supply chains, though stopping short of analysts' expectations that the G7 would call for the creation of groupwide supply chains for strategic goods.

Prime Minister Albanese and President Biden signed the *Australia – US Climate, Critical Minerals and Clean Energy Transformation Statement of Intent* in the margins of the G7 and launched the related Compact in late May 2023. The agreement calls on Australia and the US to co-ordinate policies to strengthen and diversify clean energy supply chains, support the expansion of clean energy industries, and invest in the Indo-Pacific. It remains to be seen how much of the Compact will be applicable to negotiations related to clean hydrogen production – from the establishment of mineral

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[96] Tan (2022).
[97] The White House (2021).
[98] McDonagh (2023).
[99] Australian Government (2023c).
[100] Kissin (2023).
[101] The White House (2023). See also Meti (2023).

supply chains, through to manufacturing capability of the technology required for green hydrogen production.

Under the Compact, the leaders committed to establishing an Australia-US Taskforce on Critical Minerals to deepen cooperation on critical minerals as a vital input to the clean energy transition. It was also "agreed to investigate how Australia's critical minerals supply can *support the implementation* of the US CHIPS Act and contribute to a resilient global semiconductor supply chain".[102]

President Biden also intends to ask the US Congress to add Australia as a 'domestic source' within the Meaning of Title III of the Defense Production Act.[103] This would enable more streamlined collaboration with, and investment in, Australian critical minerals, energy and other technology projects. The agreement potentially gives Australian companies access to $US1 billion currently set aside for investments in American and Canadian produced and manufactured goods and services that are deemed so essential they are prioritised as having a wartime level of urgency.[104]

This is a critical opportunity for Australian policymakers to present a coherent value proposition for investment in whole-of-supply chain development, from renewable energy generation and hydrogen/derivative production, through to the mining and processing of minerals and the port infrastructure required for export. This is also an opportunity to ensure that we negotiate favourable investment terms for processing and downstream manufacturing to also occur in Australia; effecting a shift from Australia as a raw resources exporter to a manufacturer.

Recognising that the attraction of manufacturing facilities to Australia is a long-term activity, Australian negotiators could seek to negotiate a quid pro quo of sorts: should Australian minerals be used to produce electrolysers in the US, that Australian projects be placed (if not first) high up on the order book for those manufacturers. This would ensure that one of the key risk factors for projects, the long lead times for electrolysers, was significantly de-risked by the Australian Government.

3.3.2 Hydrogen

Hydrogen can be part of the critical mineral partnerships discussed above, and it *should* be included given the importance of critical minerals for electrolysers to make hydrogen and for Australia's further manufacturing opportunities (see section 4.2.1).

In developing the refreshed NHS, it is also worth considering the detailed plans of our partners and friends, as this can help identify Australia's competitive advantage and negotiating position.

For example, the US Strategy and Roadmap sets out several actions across four topics (clean hydrogen production, delivery and storage infrastructure, end-use and market adoption, and enablers and environmental and energy justice) and three timelines (2022-2025, 2026-2029 and 2030-2035).[105] The 2022-2025 actions alone number 43 in total. These actions can be assessed and

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[102] US Department of Commerce (2023).
[103] Dougherty (2023).
[104] Cranston (2023). Note that contrary to the expectations of many Australian investors, Australia's inclusion in the Defense Production Act is separate from the incentives in the IRA, which apply only to US based projects or elements/components secured from countries with which the US has a free trade agreement in place.
[105] US Department of Energy (2023a), pages 70-72.

mapped to Australian intentions both to understand how we are tracking, what timeframes to match or beat, and the topics that we could engage further on with the US Department of Energy.

We discuss a range of RD&D topics in section 4.3.5, noting the extensive US coverage of the issues through the Department of Energy's national laboratories. Working with these laboratories presents an opportunity to progress friend-shoring objectives for the hydrogen industry here and in the US. We understand some collaboration already takes place, but this seems ad hoc and is not national.

The US Centre for Strategic and International Studies has recommended something similar, suggesting a US-Australia research and innovation consortium in clean hydrogen, focussed on "reducing production cost and enhancing the understanding of emissions implications from producing, applying, and trading clean hydrogen".[106]

Recommendation 13: Explicitly locate hydrogen production and use within the current international agreements on critical minerals.

The Australian Government should seek to explicitly locate hydrogen production and use within the current international agreements on critical minerals and the need for both diverse minerals supply and for diverse minerals processing.

The proposed Australia-US Taskforce on Critical Minerals presents an opportunity for Australian policymakers to present a coherent value proposition for investment in whole-of-supply chain development, and to ensure that we negotiate favourable investment terms for processing and downstream manufacturing to also occur in Australia.

Recommendation 14: Actively seek risk and information sharing opportunities with like-minded international partners.

The Australian Government should closely review the US and other key trading and investment partners' hydrogen strategies and roadmaps to guide the revised NHS on the topics and timing of industry evolutionary steps and favourably position Australia's policy and funding priorities.

[106] Nakano and Majkut (2022), pages 50-51.

4 Building the ecosystem

A mature hydrogen industry will allow for a range of models of production, storage, distribution and use. This should mean greater diversity in infrastructure and a more decentralised energy supply with hydrogen able to be produced in many more locations than fossil fuel extraction. There is also the possibility of greater efficiencies where supply chains can converge, particularly where use cases are co-located. For example, we can imagine a future industrial precinct where hydrogen is substituted not only for diesel and natural gas, but also provides a feedstock for chemical and e-fuels manufacturing. This is the idea behind the development of hydrogen hubs.

The issue that arises is that almost all the infrastructure required for a future hydrogen industry at scale is new, and it is long-lived with long planning lead times. The future industry requires new solar and wind farms, electricity transmission upgrades, new water pipelines, new desalination plants, new hydrogen pipelines, large-scale storage for each of hydrogen and carbon dioxide, port upgrades and refuelling capabilities.

The US has stated that even after its production tax credit has been accounted for, at this stage US$85-$215 billion in cumulative investment is required to scale the domestic hydrogen economy through to 2030 (10 MMT pa), with *as much as half* of this funding required to develop the midstream or end-use infrastructure.[107]

And it is not just about physical infrastructure. Significant social and institutional support will be required: to enable the reallocation of capital within the funding and financial system; to gain the tacit and/or explicit community acceptance for what will be a major infrastructure build into shared environments; to build the RD&D, regulatory framework and business connections to support emerging business models.

Workforce is also increasingly being recognised as a matter of some concern: it is already difficult to find workers in many regions and yet the infrastructure required for the energy transition is not yet built. Hydrogen is also new for many uses and so the future workforce must have the appropriate skills in handling hydrogen in various circumstances.

These are the key elements of the future hydrogen ecosystem, and integrating these elements within the ecosystem remains one of the most challenging parts of risk allocation and project development. As discussed in Chapters 1 and 2, government has a vital role to play in planning and coordination to create the industry, and this includes identifying the minimum physical, social and institutional infrastructure needed to meet Australia’s objectives, and then deploying public funding and targeted policy to unlock private capital.

This chapter discusses the various elements of the ecosystem and provides recommendations for government action with areas of strategic interest falling into 18 categories, as shown in Figure 5.

[107] US Department of Energy (2023a), page 42.

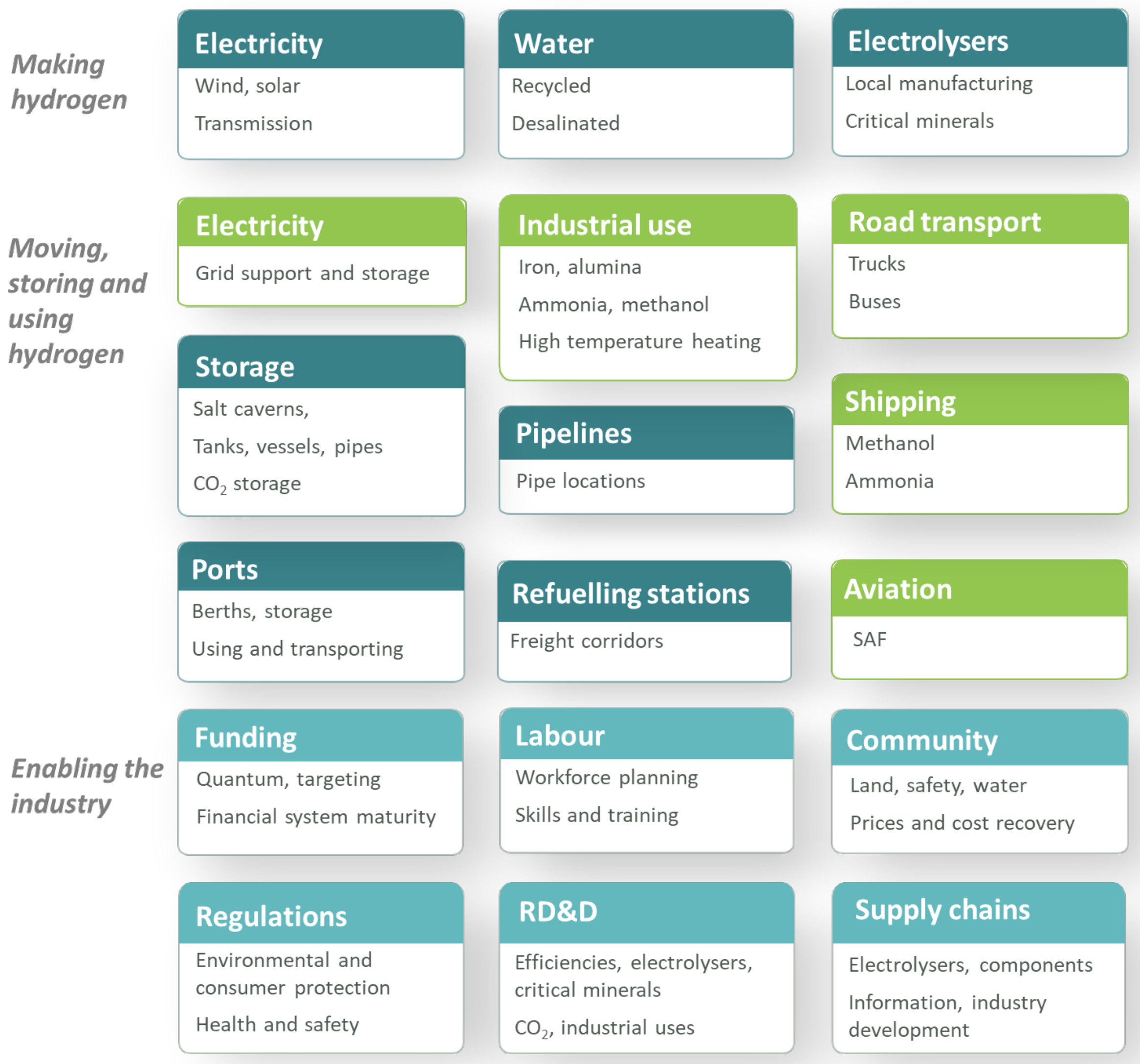

Figure 5: Areas for government policy and support for the emerging hydrogen industry.

4.1 Demand centres and regional development

Hydrogen opportunities may be far more spread across Australia than the footprint of the traditional fossil fuel and renewable energy industries, but there are still loci of activity. As is clear both in the NHIA and in the current announced projects, the demand for hydrogen is concentrated in and around population centres, industrial zones, and export locations. This means hydrogen developments will both support and compete with the needs of other stakeholders.[108]

[108] Arup (2023b), page 48.

4.1.1 Supporting the transition for workers in carbon-intensive industries

Where it overlaps with current fossil-based industry locations, the future hydrogen industry can be a means for workers in carbon-intensive industries to be reskilled and employed. As discussed in previous chapters, we are seeing a new consensus of experts supporting the idea that Australia's manufacturing capabilities can be improved with using hydrogen here for processing minerals for export. For example, green steel (green iron) is a manufacturing opportunity that could plausibly provide tens of thousands of new jobs. In 2020, the Grattan Institute stated that it makes sense for Australia to export steel to countries with relatively high wages, such as Japan or Korea, and to export direct reduced iron to countries with lower wages, such as Indonesia. The Grattan Institute also modelled a future green steel industry based in central Queensland and the Hunter Valley, where iron ore is transported from WA to the east coast.[109] This industry scenario has 40 million tonnes of steel exported per year to our regional trading partners, to a total value of A$65 billion, and capital investment of A$195 billion. Conservatively, this would mean 25,000 ongoing plant jobs in the region (just for steel manufacturing), to supply 6.5 per cent per cent of the world's steel.

The manufacturing options with hydrogen are longer term but they are some of the most important aspects of future hydrogen planning and regional development.

4.1.2 Hydrogen hubs

The NHS v1 proposed the concept of regional developments, where hubs co-locate users and producers to allow for a degree of cost-sharing for infrastructure and improvement in the economics of individual business cases. The hubs model was subsequently explicitly supported by the Hydrogen Hubs initiative, which announced A$464 million in federal co-funding for seven projects in early 2022. It is not clear where the process is currently at as a whole but we are starting to see announcements about individual hub projects proceeding.

While the NHS v1 supported the hub model "as a prospective early-stage approach to achieve the scale needed for a competitive industry" (Agreement 8), the approach taken to date has been too slow, too distributed, and too small to see any developments build scale.

General perspectives on this matter have shifted from the initial embracing of hubs. While capital expenditure grants are still welcomed, they do not themselves create markets, and operating cost remains an issue. Hub projects will be extremely useful; however, they will be less about building scale and more about gaining experience, developing the workforce, and creating working relationships.

We also should note that the different uses of the term 'hubs' has led to a mixed stakeholder understanding. The hubs that have been granted federal funding are welcome but they do not represent all possible hubs or all models for hubs – we prefer the term Hydrogen Economic Zones, as below.

[109] Wood, Dundas and Ha (2020), page 30. The more recent modelling from NZAu also supports the idea of producing hydrogen on the east coast of Australia and using this to process iron ore from Western Australia. When a sensitivity was run on the NZAu onshoring scenario that allowed relatively high WA labour and construction costs, the model chose to send iron ore to Queensland, NSW and Victoria for processing and export.

4.1.3 Regional planning to manage competing needs

The energy transition will require new and upgraded infrastructure for a range of purposes, not the least for decarbonising the electricity grid and connecting regions. This matter is being addressed by several parties, including AEMO and the state-sponsored renewable energy zones (REZs), but it is still early in the process.

The REZs should be a model for how to address and integrate hydrogen, but they are on different timelines with different approaches, and lack the national coordination required to build a national industry with national export objectives.

While we do have hubs, these are regional projects and are not connected by 'spokes'. They are also not the result of top-down planning but of consortia bidding for capital funding (and in an extremely truncated period). This is not to say that the projects will not be successful, but we do note that at least one of the projects announced will not proceed.

In Chapter 1 AHC stated that planning and coordination is vital for the energy transition as a whole, and hydrogen has a vital part to play. In Chapter 2 we proposed that collaboration across multiple portfolios and jurisdictions is needed, as well as a comprehensive approach to data collection and analysis.

We realise this is asking a lot of the Net Zero Economy Agency and any secretariat staff. However, we believe there is a way to effectively manage this work.

First, we are not starting from a blank page, and there is perhaps a better argument to streamline and align different work programmes than to consider too much from first principles.

Second, where intensive analysis and masterplanning is required, this can be localised to a degree.

Hydrogen Economic Zones

It is easier to manage and deliver complexity with some boundaries. We suggest the creation of Hydrogen Economic Zones as a means of setting boundaries which foster more intensive engagement between parties with some degree of central coordination.

It is not ideal to create yet another category of project, but so many of the challenges with creating the hydrogen industry at scale have been exacerbated by not having an adequately comprehensive model or framework for hydrogen policy. Hydrogen projects touch everything and are touched by everything but lack any organising principle for decision-making.

While REZs are not a perfect match for hydrogen economic zones because they do not account for non-electricity matters (and it is not clear how they may grapple with the energy workforce and one-stop-shop permitting), the REZ model can be built on and supported to ensure coverage of hydrogen for industrial use and transition matters. The hubs are too small and localised to themselves be hydrogen economic zones, but they provide the starting points for future hydrogen economic zones. The process of awarding hub funding should itself have provided the Australian Government with data to inform this work, even if funding was not granted.

Australia has many regions scoping out how they can leverage the emerging hydrogen industry as a producer, storer and user to maximise economic diversification and decarbonisation targets. Australian governments, industry and not-for-profits must ensure we create a collaborative and connected industry culture that proactively shares non-commercial lessons learned. This will ensure regions and industry make more informed and efficient technical, social and economic decisions.

The network of regional hydrogen clusters seeded by NERA goes a long way to provide a framework for this to occur and could be further enhanced by renewed regional and national coordination. The benefit of this network is that it not only caters to the regions that have secured government funding for hub activities but includes regions that are scoping opportunities and wish to learn from the regions moving first. Issues that regions can collaborate on include:

- Aggregating and educating potential regional demand
- Delivering better community engagement
- Mapping regional capability
- Developing local training and education capabilities.

Combined with the industry and regional development work being undertaken by individual state and territory governments, regionally focused organisations and local councils, we have many of the right actors in place.

Educating future demand

Feedback from AHC's engagement with members and across regions suggests that many Australian large, medium and small companies are interested to understand how hydrogen could support their decarbonisation targets, but they are time poor and don't know how to proceed. Many government, industry and not-for-profit organisations observed this same phenomenon several years ago when the renewable energy industry was growing.

In 2018, Climate-KIC Australia, Institute for Sustainable Futures (UTS) and WWF-Australia[110] launched the Business Renewables Centre Australia. Since its inception it has provided independent training, connection, guidance, and fundamental 'how to' resources for companies seeking to decarbonise their business through renewable energy procurement. This model could be adapted to help the time-poor yet information-hungry potential users of hydrogen fast track the decisions they need to make.

Recommendation 15: Create Hydrogen Economic Zones to support regional hydrogen initiatives and connect the relevant supply, demand, infrastructure and workforce.

The Net Zero Economy Agency should oversee the development of Hydrogen Economic Zones that link hydrogen production targets to locations via hydrogen economic zones that incorporate REZs and ports, as well as likely requirements for hydrogen storage, CCS, refuelling, pipelines, and workforce.

This work should adopt work already undertaken by the jurisdictions.

[110] With initial funding from the Australian Renewable Energy Agency (ARENA) and the Victorian, New South Wales and Queensland Governments.

Recommendation 16: Support a nationally connected and coordinated regional network facilitated by the Australian Hydrogen Council.

The Australian Government should fund the Australian Hydrogen Council to seed the development of a Regional Collaboration Lead that works across state borders and into regions to maximise the efforts of industry funding to share lessons and best practice.

Recommendation 17: Support Business Renewables Centre Australia to expand its remit and create hydrogen specific modules.

The Australian Government should encourage the BCRA – an existing, independent organisation with expertise, funding streams and governance arrangements – to expand its remit to offer an increasingly needed service covering hydrogen.

4.2 Physical infrastructure

The physical infrastructure of the hydrogen industry requires more targeted government policy than suggested through the NHS v1. As discussed in Chapter 1 the infrastructure needs are massive; there must be planning and co-optimising of different assets to address a range of different markets and to also not over-burden consumers' and taxpayers' willingness to pay, or communities' willingness to tolerate construction in their midst.

We have used the NHIA as a key information source for this document, but we note that the data collected for the NHIA are from 2020 (and considered out-dated) and that the process is only likely to be repeated every five years. We also note that the NHIA was itself delayed relative to the NHS v1 period of its completion "by 2022" (Agreement 10).

We recognise the challenge in taking a delayed and significant process and asking that it is repeated on a more frequent basis, but we would expect that the original model can now be re-used to a large degree and that NHIA updates and releases can be more current and frequent. The NHIA should also be explicitly linked to any targets set, with clear reporting on delivery of outcomes.

Just as we are not collectively starting from a blank slate with regional planning and relationships, we are also not starting afresh with infrastructure. It is important to assess the existing evidence base for different infrastructure options, and the NHIA provides a useful starting point. Arup ran a scenario that assessed the ability to use existing railway and natural gas pipeline infrastructure to transport hydrogen, noting that further feasibility work would be needed.[111] The findings were:

- The model preferred transportation via railway infrastructure for the initial, lower demand as the industry develops. When the modelled hydrogen demand becomes large enough to justify 100 per cent hydrogen pipelines, rail use decreases.
- While there was a possibility of repurposing some of the existing natural gas transmission network, most of the pipelines are expected to be newly built.[112] However, the NHIA report notes that by 2050 the amount of dedicated pipeline infrastructure required might create opportunities to convert the existing natural gas pipelines to 100 per cent hydrogen: "The suitability of existing infrastructure to be utilised for hydrogen transportation would be

[111] Arup (2023c), page 29.
[112] Arup (2023b), page 126.

unique to each existing natural gas pipeline and further analysis outside of this techno-economic model would be required to assess the cost and technical feasibility of converting each pipeline".[113]

- The NHIA model did not prefer hydrogen blended into the existing natural gas transmission network. Arup suggests this is mainly due to the cost of extracting the hydrogen from the blended natural gas/hydrogen mixture at the demand node.[114]
- Arup further states that the overall lowest cost of hydrogen from the observed optimal cost supply chains "does not differ noticeably from the base case, suggesting major cost savings from utilising existing infrastructure are not immediately evident and the usage of this infrastructure might be very individual to each piece of existing infrastructure".

Arup also reviewed the assets used for Australia's current hydrogen production (around 650 ktpa), where hydrogen is made using unabated natural gas and consumed by either ammonia synthesis (65 per cent) or crude oil refining (35 per cent). The report notes that legacy assets (ammonia plants, oil refineries and other processing facilities) are unlikely to be re-purposed for merchant hydrogen production.[115] We note that NZAu had a different perspective, suggesting that oil refineries could be used for hydrogen processing, and this in itself highlights the different pathways that corporates, governments and regions can take as the global hydrogen industry scales up and a merchant market develops.

It is important that the NHIA explicitly covers a range of assets and can also map major asset replacement schedules and investment cycles for carbon intensive processes, including port upgrades. This work can inform energy transition analyses as a whole and hydrogen economic zones in particular. We have already provided suggestions to this effect in Recommendations 4 and 5.

4.2.1 Electrolysis

The NHIA has found that large scale electrolysis facilities will be required. By 2030, approximately 7 GW of electrolyser capacity is estimated to be needed Australia-wide to meet the demand in the central scenario. In this scenario, this capacity is modelled to grow to 130 GW by 2050.[116]

NZAu has also modelled electrolysis needs for its scenarios as shown in Figure 6. Using the closest to a mid-case (E+), we can see that by 2060 the electrolyser capacity is over 1,590 GW. (We note that as this table is based on 2020 analysis, the electrolysis technology chosen does not reflect recent advancements across all electrolyser technologies. It also does not reflect an AHC preference.)

[113] Arup (2023c), page 29.
[114] Ibid.
[115] Arup (2023b).
[116] Ibid.

Selected aspect of electrolysis	REF	E+	RE+	RE–	E–	ONS
Dominant technology type	NA	PEM	PEM	PEM	PEM	PEM
Hydrogen produced (EJ HHV) in 2060	0.0	18.0	19.4	8.4	18.9	10.0
Electrolyser capacity (GW) in 2060	0	1,591	1,697	618	1,656	884
Footprint electrolyser and switchyard (km^2) in 2060	0	95	102	37	99	53
Solar PV capacity (GW)	4	2,714	2,902	860	2,830	1,531
Onshore wind (GW)	0	30	46	68	40	12
Offshore wind (GW)	2	20	12	247	19	19
Battery storage at electrolysis node (GWh)	0	704	850	512	785	395
Underground hydrogen storage at electrolysis node (TWh)	0	43	58	11	56	23

Figure 6: Selected aspects of electrolysis techniques sites for export (and onshored industry in ONS) by 2060; SOURCE: Pascale et al. (2023), page 8. Even the onshoring option (where hydrogen is not exported as a fuel or energy carrier but is used for iron processing) has electrolyser capacity at 884 GW.

Figure 7 shows that the electrolyser plant supply chain is complex in its own right. There are already delays in purchasing electrolysers, with a two to three-year lead time currently reported for orders. This represents both a risk to be managed and an opportunity for Australia. As described in the HETS report for NERA, Australian companies "capitalise on the lengthy lead time for equipment from international suppliers" through building local capacity.[117] This is particularly appealing given Australia's reserves of platinum, iridium and nickel, which are required for electrolysers.

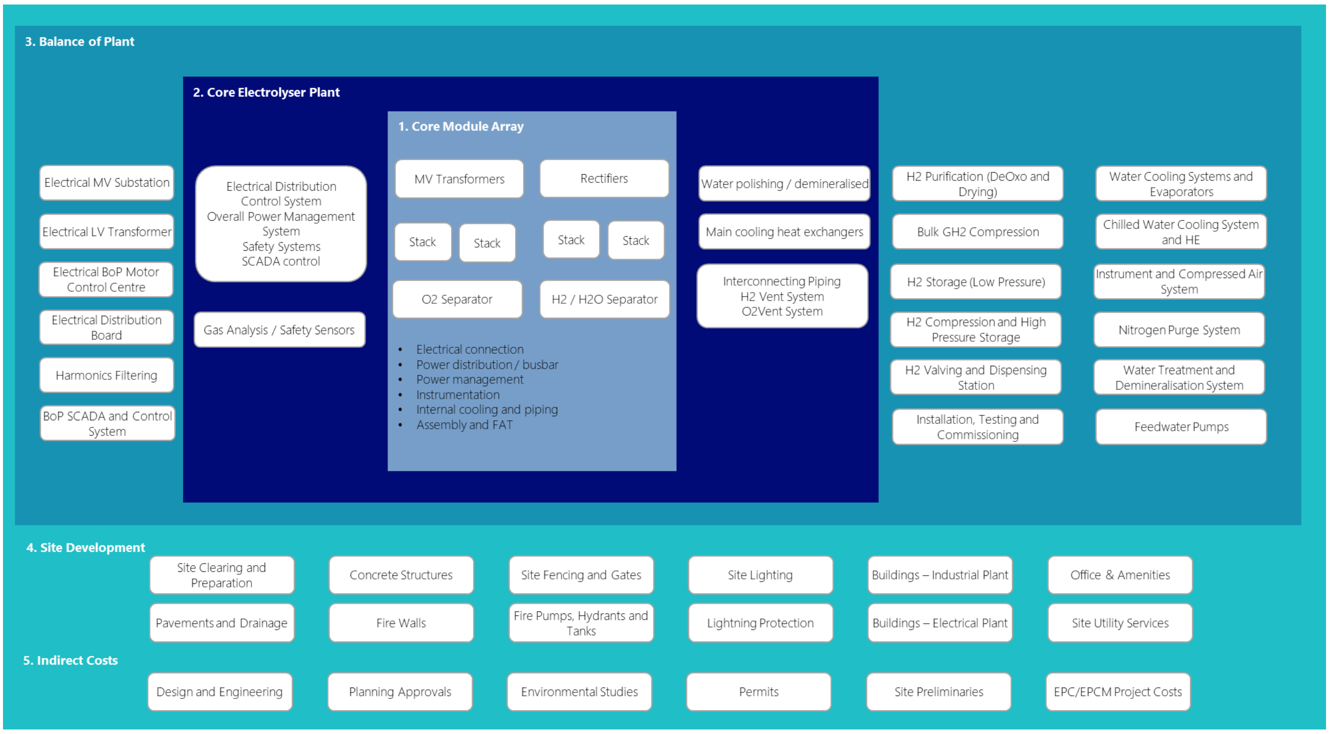

Figure 7: Electrolyser plant components; SOURCE: Arup (2023a), page 30.

[117] Arup (2023a), page 13.

Fuel cells for mobility and stationary energy are also an opportunity given their similar configuration to electrolysers. IRENA notes that estimates point to a US$50-60 billion market potential for electrolysers and a US$21-25 billion market for fuel cells by the middle of the century. While China, Europe and Japan have developed a strong head start in producing and selling electrolysers, the market is still nascent and relatively small.[118] The US has also identified the need to expand domestic manufacturing, including for electrolysers, and like Arup (2023a) has suggested that stakeholders across the hydrogen industry should consider exploring consortium-based procurement entities for critical components. The US has also suggested that public sector support can extend to direct incentives for electrolyser supply chains to crowd-in private capital, "analogous to the CHIPS Act for semiconductors".[119]

Australia has experience and capability with advanced manufacturing in supply chains for global primes/OEMs and complex energy projects (e.g., defence, mining and previously automotive) that we can leverage to create and sustain an electrolyser industry. The Australian Government has recognised this opportunity through the development of the National Reconstruction Fund, but that fund will be stretched across the multiple priority sectors and the electrolyser pipeline will need to progress well into 2030 and beyond.

See section 4.3.5 for a further discussion of RD&D needs and opportunities for Australian electrolysis.

Recommendation 18: Support the development of domestic electrolyser production and assembly through a domestic manufacturing package.

The Australian Government should lead a partnership with jurisdictional governments to attract and retain investors to establish electrolysis manufacturing and assembly in Australia. The governments should underwrite risk through long term local electrolyser targets, aligned with a package that could include funding, taxation relief, and streamlined approvals.

Recommendation 19: Secure supplies of raw materials (e.g., nickel and platinum group metals) and other key components.

The Australian Government should partner with industry to leverage the critical minerals reserves that are required in electrolysers, as has been the case with lithium for batteries.

4.2.2 Energy

Energy is the fundamental input to produce hydrogen, whether this is electricity for the electrolysis process (and to power balance of plant) or gas/coal for traditional hydrogen production. We are prioritising renewable electricity for renewable or 'green' hydrogen but will also briefly address the role of CCS in producing blue hydrogen from fossil fuels.

In practice, the issue will not be about colour labels but about emissions intensity and robust measurement and reporting. However, the green and blue labels continue to be used in discussion.

[118] International Renewable Energy Agency (2022), page 15.
[119] US Department of Energy (2023a), page 64.

Green hydrogen

The NHIA found that future electrolysis will be powered by behind-the-meter wind and solar PV (approximately even shares). The renewable electricity required from solar PV and wind will be nearly 20 times the renewable generation in 2020.[120]

The challenge for Australia is that we *still need to build* the renewables capacity that we are relying on to power our future renewable superpower ambition. This is on top of what is required to decarbonise the grid and provide system reliability.

The need to build renewables to produce hydrogen is one of the most significant matters for the refreshed NHS to consider, where government will be confronted with – and will need to explicitly manage, if not accommodate – competing priorities.

This also relates to electricity prices, where electricity pricing is a key driver of hydrogen costs. Australia is not on track so far, with Deloitte noting that "renewable power contracts can currently be struck in the US or Gulf countries at less than half the price as those in Australia".[121] Given that Australia's potential renewable superpower status is founded on anticipated future cheap electricity prices, this is also a matter of some importance for the refreshed NHS. Policy initiatives that support hydrogen projects include concessions or exemptions on TUoS charges, as previously suggested by AHC in various fora.

The electricity sector is already subject to a degree of national planning, via AEMO, and according to rule-setting and enforcement by the AEMC and AER respectively (and ERA in Western Australia). AEMO provides some market modelling that accounts for hydrogen somewhat, but as addressed in Chapter 1, this is not fit-for-purpose hydrogen planning. It is also not fit-for-purpose energy transition planning, as noted by the Institute for Energy Economics and Financial Analysis, as follows:

> In the absence of a comprehensive plan, the Australian Energy Market Operator's (AEMO) scenarios are used by many to support planning and investment decisions. However, the scenario presented as most likely only meets some but not all of the government's objectives and doesn't meet Victoria's emissions reduction targets. Its electricity and gas scenarios also materially contradict each other, and AEMO's choice of assumptions has been questioned by clean energy investors.[122]

What is needed now is much more comprehensive modelling and ownership.

The good news is that for large scale hydrogen production, the NHIA techno-economic model preferred moving molecules to moving electrons (that is, making hydrogen where the electricity is and then moving the hydrogen), which should mean limited need for transmission upgrades, but this will need to be dealt with per region.[123]

It is also worth briefly addressing energy affordability, which is a social licence matter, and is also addressed in section 4.3.6. The NHS v1 (Agreement 36) addressed the impact of hydrogen on energy

[120] NZAu modelled Australia maintaining its current energy value for exports but replaced with low to zero emissions products and found that exports (mostly hydrogen to make ammonia) will drive total electricity generation to as much as 23 times current levels, and almost all electricity serving this market comes from solar PV (1-3 TW).
[121] Deloitte Access Economics (2023), page 29.
[122] Denis-Ryan and Gordon (2023).
[123] Arup (2023b), page 126.

costs, noting future changes may be required to energy affordability and consumer protection policies.

As we have already discussed, there is a risk to rolling hydrogen costs into bills for essential services. Ideally, hydrogen for priority industries becomes part of the larger supply chain and passed through as any input to a larger process would be. For businesses that need to switch fuels for broader legislative and/or ESG reasons, this should be less about energy affordability via the lens of hydrogen and more about how government supports businesses through the transition more broadly, such as through grants and transition or concessional finance. It is important that the Australian Government provides clarity on the matter of who pays for the energy transition – the current incremental regulatory approach that assumes the current regulatory assets will be maintained is flawed. More detail on the regulatory change required is provided in section 4.3.6.

Recommendation 20: Develop consistent energy planning scenarios and cost recovery mechanisms by connecting AEMO, AEMC and energy regulators with the Net Zero Economy Agency and the refreshed NHS.

The Net Zero Economy Agency should engage closely with energy bodies to coordinate energy transition scenario assessments and regulatory practice. Priorities include:

- Linking AEMO's ISP with the Australian Government net zero programme (which includes Hydrogen Economic Zones) and with REZ jurisdictional planning.
- Connecting discussions on grid stability and long-term storage with hydrogen storage policy.
- Linking AEMC rulemaking and regulators' compliance enforcement with net zero policy to ensure infrastructure can be paid for, and via the right mechanisms. Importantly, the Australian Government should set policy that ensures initiatives to build the market (both capital and operational) are not passed through to small energy users via bills for essential services. See Recommendation 45.
- Encouraging jurisdictional governments to provide exemptions on TUoS charges for hydrogen projects, and concessions on state schemes that add cost.

Blue hydrogen

For hydrogen without renewables, the NHIA found blue hydrogen was part of the lowest cost supply chain for 2030; however, it was not featured in 2040 when considering the medium-cost electrolyser sensitivity and central demand scenario.[124]

The NHIA report notes that there might be a role for blue hydrogen in the future, but this would likely be limited to specific projects that have particularly favourable conditions and that might be able to share carbon transport and storage infrastructure.[125]

We note that Asian markets are currently pursuing blue hydrogen projects, reportedly because the cost of green hydrogen is beyond end consumers' willingness to pay. Examples of recent Japanese

[124] Arup (2023c), page 32.
[125] Arup (2023b), page 128.

and Korean announcements that were raised with AHC by overseas companies demonstrate deal flow for blue projects include:

- MOL Group and Clean H2 Works in Louisiana, 7.5Mtpa blue ammonia production;
- Marubeni and Pembina Pipeline in Western Canada, 1Mtpa blue ammonia;
- Exxon and SK Materials in Texas, Corpus Christie Port, basic purchase agreement for blue ammonia shipping to Korea in 2027/28, looking at similar to Japan;
- JERA and CF Industries in US Gulf Coast, 1Mtpa blue ammonia;
- Lotte, RWE and Mitsubishi in Texas, Corpus Christi Port, up to 10Mtpa blue ammonia with export to Korea, Europe and Japan;
- Approtium and Tallgrass in the US Midwest (Oklahoma), 800 ktpa blue ammonia;
- Approtium and HyPhen in West Africa, 250 ktpa blue ammonia;
- Ma'aden and ABIC (subsidiary of Aramco) and Lotte Fine Chemicals in Saudi Arabia, 50 ktpa blue ammonia from 2022. Note: Aramco plans to produce 11Mtpa blue ammonia by 2030 and 1.3Mtpa green by 2025;
- CF Industries and Mitsui in the US Gulf Coast, 1–1.4Mtpa blue ammonia;
- Ta'ziz, Fertiglobe, Mitsui and GS Energy in Abu Dhabi, 1Mtpa blue ammonia.

The HESC project in Victoria also represents significant investment from Japan and was notably considered by the Japanese proponents as the most prospective project of the options available – both green and blue.

Even Germany – which previously only engaged globally on green hydrogen discussions – has recently accepted blue hydrogen as at least a short-term measure to build the hydrogen industry to support the German economy.[126]

Further, all reports, globally and domestically, point to the need to have CCS for the energy transition as a whole, and this will need to be a long-term measure.

The challenge is of course how to consider the role of blue projects in the energy transition, and the issue is a divisive one that is also not agreed among AHC members. The overall AHC position is that if hydrogen is sufficiently low emissions to meet regulatory, investment and buyer criteria (we expect this is around 95 per cent capture), we are agnostic as to the production method. However, renewable/green hydrogen is the longer-term scale solution.

Recommendation 21: Remain open to blue hydrogen for regions that can support it without unnecessarily delaying renewable hydrogen developments.

The Australian Government should remain open to blue hydrogen projects for regions that can support it without unnecessarily delaying renewable/green hydrogen developments.

In practice, the issue is not one of colour but of emissions intensity, supported by robust measurement and reporting.

[126] See Wettengel (2023) and Collins (2023).

4.2.3 Water

The NHIA notes that water infrastructure is required for the extraction, treatment and supply of water for hydrogen production. Water volumes and infrastructure requirements vary considerably depending on the water quality source, supply method (e.g., water pumps, pipeline), treatment requirements (e.g., desalination, purification) and cooling method (air or water cooling).

Figures from the Water Services Association of Australia[127] indicate that treating wastewater to a potable water equivalent (such as deionised water for electrolysis) would be cheaper than desalination. Water services businesses are keen to engage with the hydrogen industry to find uses for wastewater, and this could be a logical fit with hydrogen needs. The challenge here will be producing enough wastewater at any given location, and the potential security of supply – there will be future sources of competition for this water, which may include community needs that are currently met with potable water. Wastewater is also used for environmental flows.

There are also other trade-offs that need to be understood; for example, desalination is the obvious choice for security of supply, but the desalination process requires significantly more energy than treating wastewater. Finally, further processing of hydrogen to its liquid form, or to make ammonia, will also increase water use. Given the discussions about hydrogen are not limited to its gaseous form, this needs to be understood.

AHC was concerned that we did not have a reliable source of water consumption figures for Australia. We held workshops to unpack and seek to understand the matters described in Figure 8.

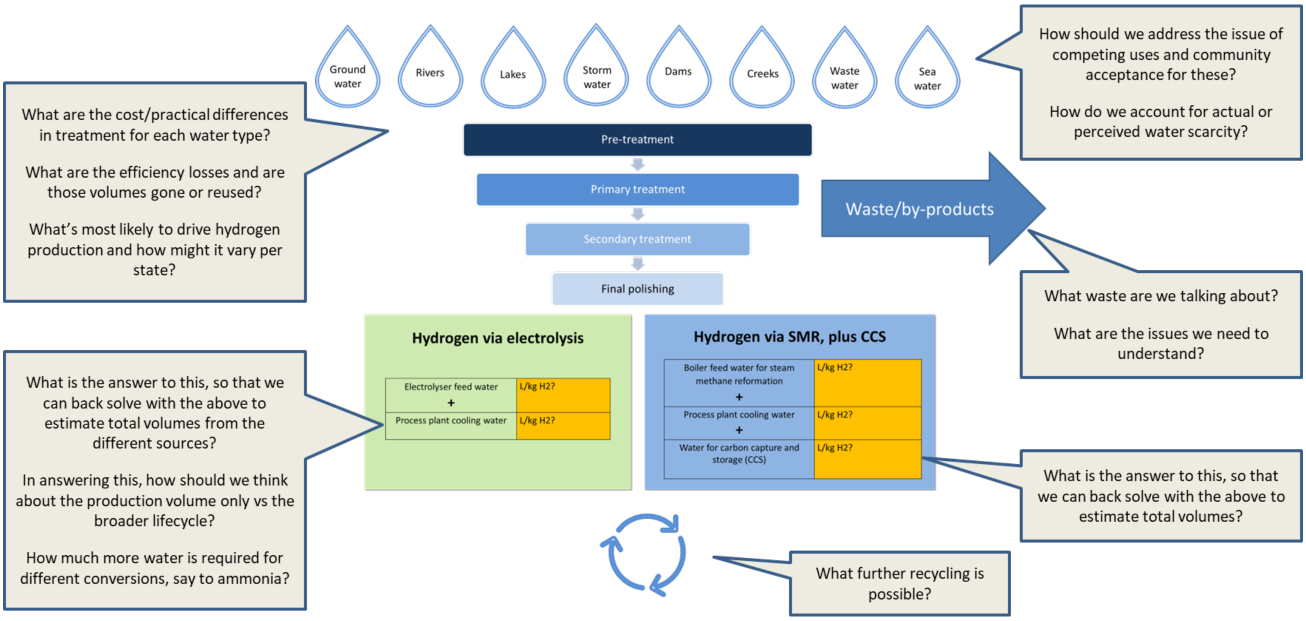

Figure 8: AHC water questions.

127 Water Services Association of Australia (2020), page 3.

To start to answer these questions, in 2022 we co-led with DCCEEW the development of a water technical report, carried out by Arup.[128] Arup was chosen to ensure the assumptions were consistent with the work being undertaken for the NHIA.

The paper addresses water volumes for hydrogen by source, by product, and by cooling process and by wet/dry zones. Consumed water for a dry zone evaporative cooling option ranges from 28 litres/kg H2 (surface, ground and recycled) to 76 litres/kg H2 (seawater). Consumed water for wet zone evaporative cooling ranges from 20 litres/kg H2 (surface, ground and recycled) to 56 litres/kg H2 (seawater).

Figure 9 shows surface water consumption[129] figures compared with volumes of recycled water and seawater. We have chosen dry zone figures because much of the best solar electricity production is expected to be in the northern half of Australia.

The first line of each table on the left shows data from the Arup water report – this is water consumed to make green hydrogen in a dry zone. The two Deloitte lines under each one relate to the most ambitious hydrogen scenario that Deloitte provided for the NHS v1, where by 2030 Australia is producing 1.8 Mt hydrogen, and 34.1 Mt by 2050. We have applied water to these figures as if the hydrogen is green but that is not necessarily what Deloitte assumed.

Dry zone, evap cooling	**Surface**	**Recycled**	**Seawater**
Water volume, litres per kg	28	28	76
Deloitte 2030, GL for 1.8Mt H2	50.4	50.4	136.8
Deloitte 2050, GL for 34.1Mt H2	954.8	954.8	2591.6

Dry zone, air cooling	**Surface**	**Recycled**	**Seawater**
Water volume, litres per kg	14	24	24
Deloitte 2030, GL for 1.8Mt H2	25.2	43.2	43.2
Deloitte 2050, GL for 34.1Mt H2	477.4	818.4	818.4

Figure 9: Water volumes from Arup as measured against the NHS v1 Deloitte's Energy of the future scenario.

We can see that the hydrogen industry in 2050 could be consuming something between 500 and 1000 GL of surface water for dry zone green hydrogen facilities, depending on cooling type. This is around the same volume of water that is consumed by the mining industry.[130] This number changes when using recycled water, to 800-1000GL, and up to 2500GL for seawater with evaporative cooling. These are large numbers but are not unrealistic for an industrial process.

For the hydrogen industry, most of the active hydrogen projects to date have not had to grapple with water supply; they have been small enough to use potable water from the existing water distribution system. Further, the industry sees the estimated cost of water to be relatively low.

However, for the water sector, the volume may still be vast by water standards. The water utility in each region plans for a secure water supply, and the process takes 2-4 years to look at a 25-50 year horizon. This planning is vital because of water scarcity and stress – which is only expected to

[128] Arup (2022).
[129] Consumed means it is not able to be returned to the environment.
[130] See *ABS - 4610.0 Water Account, Australia, 2019-20*, released October 2021. Totals are use that's self-extracted or distributed, minus flows returned to the environment, and have taken out energy and water because too large (hydropower).

increase – and the fluctuations in water by climate/location and season. While there is desalination and recycling capacity in some regions, this will be called on in times of drought. Further, it can take years to build a new desalination plant or new water pipelines (6-10 years).

Closer engagement between the hydrogen and water sectors would help to support necessary water planning processes to support future water use. This also extends to how we collectively think about reductions in water use from declining fossil fuel industries.

It is important that the Australian Government addresses water availability, the role of hydrogen in maintaining water balance, and how we get to large scale additional desalination and recycled water for hydrogen production. Hydrogen policy settings should be incorporated into the revised National Water Initiative; this has value in itself as well as guiding hydrogen-specific water planning.

Recommendation 22: Develop a national assessment of hydrogen industry water needs and required planning to meet the revised NHS objectives and support long-term water security.

DCCEEW should engage across the hydrogen and water divisions and with water utilities and state/territory jurisdictions to analyse and report back on:

- Total water availability, mapping across Hydrogen Economic Zones.
- The role of the hydrogen industry in maintaining Australia's water balance.
- A national plan with water utilities that specifically addresses likely needs and timeframes for manufactured water and water infrastructure for hydrogen.

Hydrogen policy settings should be incorporated into the revised National Water Initiative.

4.2.4 Pipelines

As noted previously, the NHIA model preferred hydrogen pipelines to transport hydrogen, and particularly once hydrogen volumes grew to justify the cost (this was after 2030). This finding is consistent with international assessments, including in the US.[131]

The NHIA report noted that while there was a possibility of repurposing some of the existing natural gas transmission network, most of the pipelines are expected to be newly built.[132]

The question of pipelines is not just about how hydrogen is transported, but *whether* it is transported. There has been a question of how to optimise building new infrastructure across both electricity and hydrogen transmission – generally referred to as whether to 'move electrons or molecules'.[133] As noted previously, the general consensus is that for larger scale hydrogen production it is more efficient to locate hydrogen production 'behind the meter' and build pipelines to move the hydrogen to where it is used, rather than electricity transmission lines to move electricity to where hydrogen is then produced and used.

This general finding demonstrates how the planning for hydrogen production facilities involves an assessment of the best balance of two different types of infrastructure, each of which tends to be viewed as a separate economic, planning and regulatory cost-recovery endeavour. This highlights

[131] US Department of Energy (2023a), page 14.
[132] Arup (2023b), page 126.
[133] See Advisian (2021) and Australian Hydrogen Council (2021).

the need for broader planning, and will also be reflected in other infrastructure matters, such as how electricity is taken to transport sites (either for batteries or on-site hydrogen production).

It is worth noting that NZAu also undertook comprehensive modelling of future hydrogen pipelines, noting a need for significant hydrogen pipeline infrastructure across all modelling scenarios. This comes to 3.2-6.5 Mt-H_2/year (1,300-2,500 TJ/day, 15-29 GW) of domestic inter-regional connections built by 2050, with some further expansion to 2060.[134]

The largest transmission build is largely associated with export projects, where – like NHIA – hydrogen transmission via pipeline was found to be the favoured mode of bulk energy transport for the export system, compared with electricity transmission.[135] Domestic inter-regional hydrogen transmission infrastructure is much smaller than export, where pipelines provide hydrogen from regions of good renewable (and therefore green hydrogen) resource to demand locations for synthetic fuels production, industry and transport. In the NZAu model, hydrogen is transferred to both export ports and domestic locations using hydrogen pipelines along pre-determined potential corridors.

NZAu downscaled the model's volumes and mapped these to specific routes, with considerations of the number of parallel pipelines (each allowing a maximum throughput 1,900 TJ/day), minimum pipeline capacity thresholds (50-100 TJ/day depending on route length), and estimated widths of hydrogen corridor rights-of-way. We note that the NHIA report advised that easement identification and environmental studies will be required in the short-medium term for hydrogen transmission pipelines and suggest the work of NZAu would be a useful resource for this.[136]

Finally, the need for pipelines shifts based on how hydrogen is used domestically. If hydrogen produced in Australia is used at large scale – such as to process iron ore into iron for export – the nature of the infrastructure required changes. For example, NZAu ran an onshoring scenario, where hydrogen was diverted from export as energy (the E+ scenario) to be used to process metals on shore (the ONS scenario). Figure 10 and Figure 11 provide a comparison.

[134] Davis et al. (2023), page 38.
[135] Noting that NZAu has much higher export volumes than NZIA, see section 2.2.1 of this document.
[136] Arup (2023b), page 126.

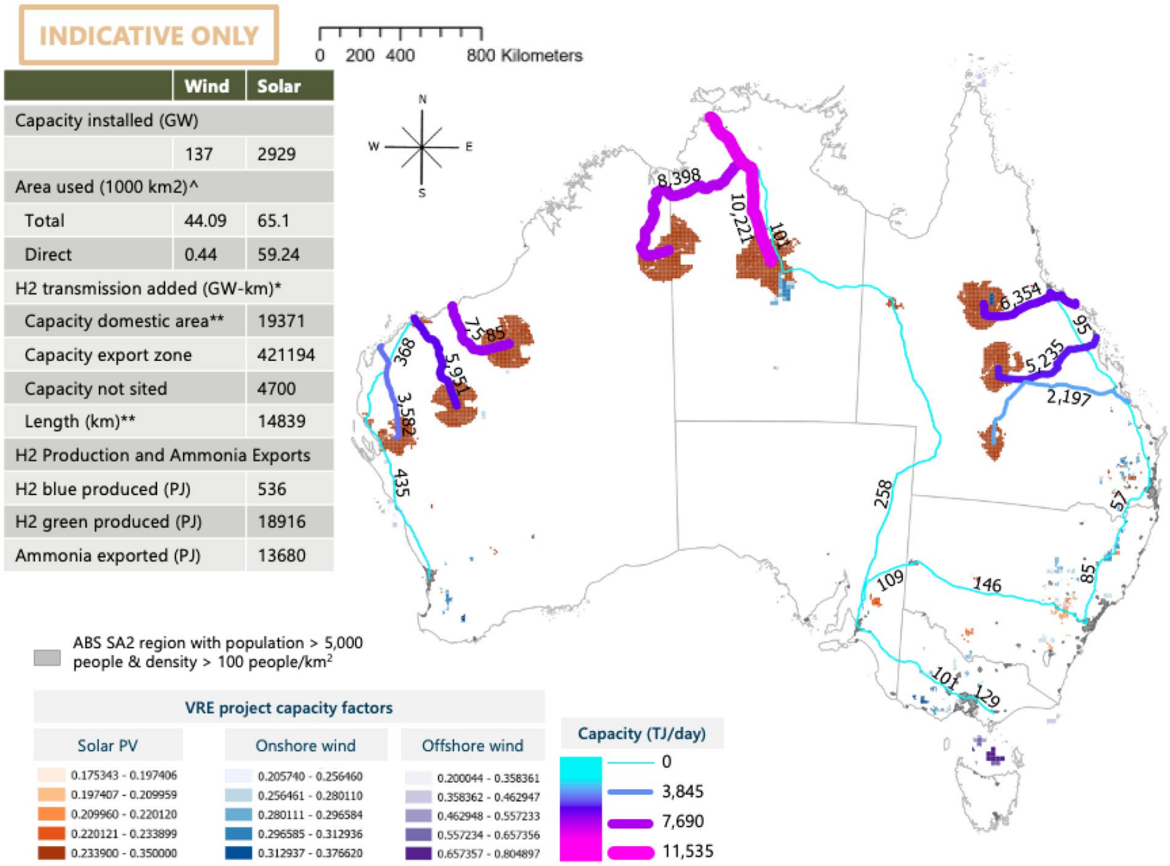

Figure 10: NZAu notional mapping for the hydrogen pipelines for the E+ scenario in 2060 (in TJ/day), along with the variable renewable resources powering export (and domestic) infrastructure; SOURCE: Davis et al. (2023), page 24.

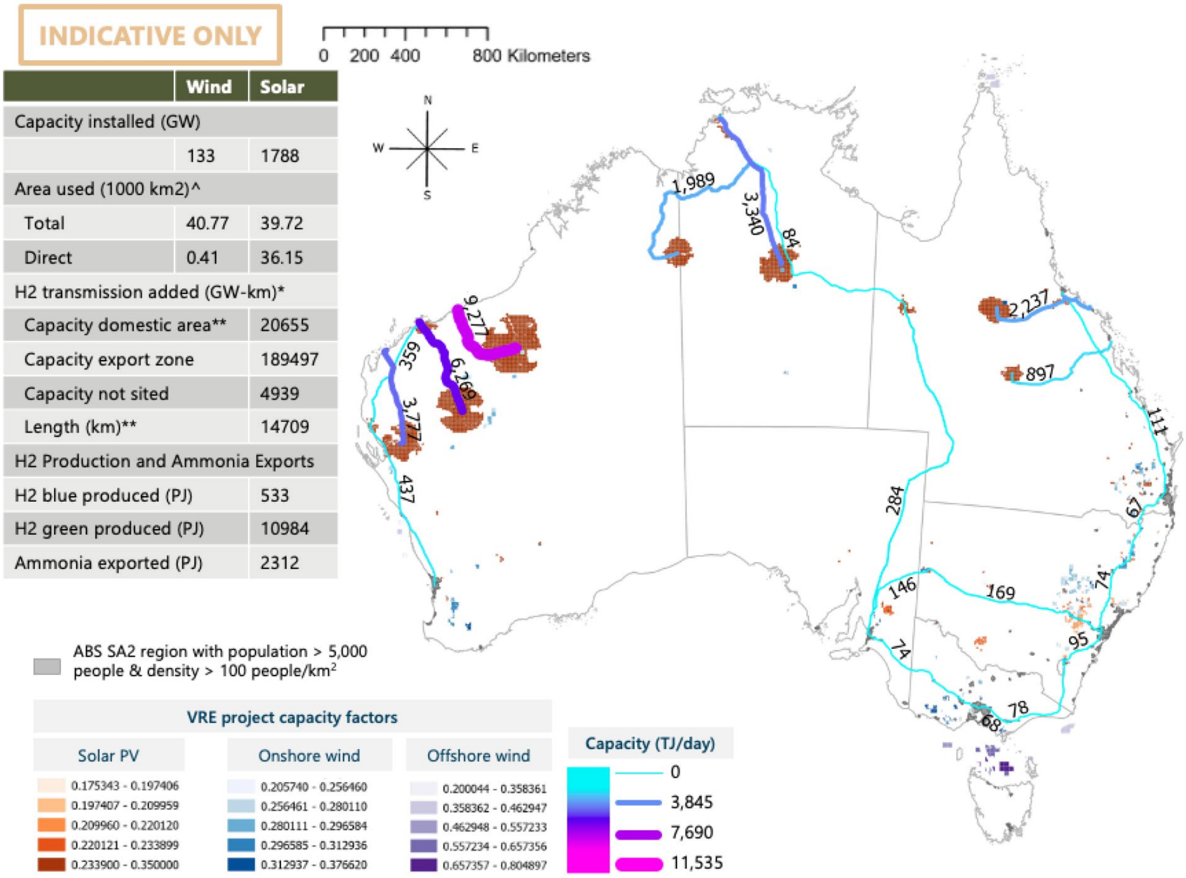

Figure 11: NZAu notional mapping for the hydrogen pipelines for the ONS scenario in 2060 (in TJ/day), along with the variable renewable resources powering export (and domestic) infrastructure; SOURCE: Davis et al. (2023), page 26.

Looking at these figures, we can see different pipeline capacity requirements per region for hydrogen transmission lines across Australia, and less energy required overall.

In summary, it is important that the Australian Government addresses the need for, and availability of, 100 per cent hydrogen transmission pipelines to meet the needs of the emerging hydrogen industry. This is addressed indirectly through AEMO and the AER but not sufficiently for hydrogen planning purposes.

Recommendation 23: Develop a national assessment of hydrogen pipeline corridors, easements and route alignment.

DCCEEW should engage with pipeline companies, AEMO and the AER to analyse and report back on:

- The location of easements, and particularly as they relate to Hydrogen Economic Zones
- The fitness for purpose of the easements from a regulatory, safety and community acceptance perspective, and any unnecessary regulatory barriers that should be addressed.
- If more easements are required, where and by when.

This work should be able to address the refreshed NHS targets and policy priorities, and it should inform further policy on necessary coordination, co-funding and regulation.

4.2.5 Ports

The NHIA report states that hydrogen export will shape the future development of ports, in much the same way as the export of LNG has shaped our current port infrastructure. There will be a need for suitable shipping berths and storage for one or more hydrogen carriers:

> From an infrastructure point of view, the key requirements for a marine terminal to support the export of hydrogen are a deep sea (or dredged) port consisting of favourable metocean [meteorology and physical oceanography] factors, a suitable sized wharf structure, dedicated pipelines and marine loading arms, onshore bunkering and a berth utilisation rate of typically less than 65 per cent.[137]

The NHIA report notes that ports without deep sea/dredged capacity can still carry hydrogen (and derivatives) but need long jetties or offshore marine loading buoys to get the product on and off the ship. Where marine terminals need to be constructed outside of an existing commercial port, supporting port functions are required. These include tugboats, pilots, security, pollution response, maintenance and customs.

Ports must also grapple with a variety of land issues: storage will be required for current exports, for inputs such as solar panels and wind turbines, and for future exports (which are themselves unclear but need to be addressed in the refreshed NHS). Some of Australia's ports are also juggling the magnitude of landing and storage requirements for the equipment needed for the emerging offshore wind industry. Ports in populated regions will be limited in how they can expand, and ports in remote regions will need upgraded infrastructure and an available workforce. Ports will also need suitable infrastructure across each of the physical infrastructure types previously discussed.

There may also need to be conversion facilities at ports, with the NHIA report noting that if liquid hydrogen became the preferred export carrier, liquefaction plant and loading facilities will need to be co-located with the wharf to minimise boil off losses when loading onto ships.

On this point, it may be sensible to produce hydrogen at or near some ports, given this reduces the transportation challenges for export and there is also likely to be better local access to hydrogen inputs such as desalinated water, treated water, workforce and freight corridors (for transport uses of hydrogen), and perhaps offshore wind. The trade-off will be access to land and potential safety concerns in populated areas; there may need to be separation distances around production and storage facilities due to hazard and risk contours.

We note that Australia currently provides limited bunkering for ships in the region – this is mainly done at a ship's home port or in Singapore. However, there is an opportunity to increase Australia's bunkering facilities where we are producing the future shipping fuel (likely to be ammonia or methanol, made with hydrogen).

The Singapore-based Global Centre for Maritime Decarbonisation (GCMD) has released an ammonia bunkering study,[138] to coincide with Singapore's tender for the purchase of clean fuels for utilisation in the power sector and for industrial usage. Citizen sentiment around large scale ammonia bunkering within proximity to communities, alongside the lack of internationally consistent training for workers across the value chain on ammonia handling, adds additional complexity to the

[137] Arup (2023b), page 127.
[138] DNV (2023b).

economic challenge of securing investment and structuring assets to enable ammonia production, storage and transportation.

Ports have an important further role, which is as the entry point to the country of the vast amounts of equipment to build the solar and wind farms required for the energy transition. Given the importance of this, as well as their role as facilitators of export markets, there should be a clear policy understanding that ports provide an essential service for the industry and that reasonable access is to be ensured. Each will also have its own decarbonisation strategy and could be central for regional refuelling infrastructure.

Internationally there are several ports that are centring hydrogen production at the port, as a feedstock for existing industry, as well as enabling multiuser infrastructure (storage in particular). These include the PORTHOS project in Rotterdam, Kawasaki City in Yokohama, and Singapore. Ports like this provide examples for Australian ports, particularly those that have an existing petrochemical industry (for example Kwinana in WA).

It is challenging to call for national coordination of ports: they are highly variable in their size, land availability nature and ownership, and are state regulated. Port preparations for hydrogen are tailored to the port involved and will remain that way. However, a revised NHS requires national visibility of port assets and capability. Such an assessment will also help identify funding needs – there will be a need for co-funding to enable the readiness of certain ports to deliver on national objectives and international promises. This is likely to be around $20-$30 billion to the early 2040s.

Recommendation 24: Develop a national assessment of port capability to meet the revised NHS objectives and targets.

DCCEEW should engage with port corporations and peak bodies to analyse and report back on port capability for future exports, in line with the objectives and targets set by the revised NHS and connected with Hydrogen Economic Zones.

This should lead to an understanding of how ports can collaborate without triggering unforeseen regulatory hurdles and future government support for common use infrastructure.

Recommendation 25: Select and support ports with existing industry connections to be demonstration ports.

Australian governments should work with ports to identify appropriate demonstration sites for hydrogen development. To mirror international developments this could include ports that have existing industrial connections.

Recommendation 26: Commit to a funding envelope for ports.

The Australian Government should undertake to support port redevelopments to 2045. The national assessment will clarify what is required, but this is expected to be around A$20-$30 billion.

4.2.6 Storage

Hydrogen storage is vital to meet any of the ambitions for the industry, whether it is storage of hydrogen, ammonia or methanol at a port for later export, storage at an industrial site for later use, or storage of hydrogen as a means of storing energy to feed back into the electricity grid in the event of a longer-term renewables drought.[139] Storage needs will be driven by the decisions made on volumes of hydrogen to be stored, by the form of hydrogen (or derivative or product), by the duration of storage, and by the locations of production, distribution and use. The costs and options for storage of different scales and types of hydrogen will also, in turn, impact the business case and thus drive decisions on volumes, forms and locations.

Figure 12 provides some examples of physical (as compared to chemical/metal) hydrogen storage alternatives.

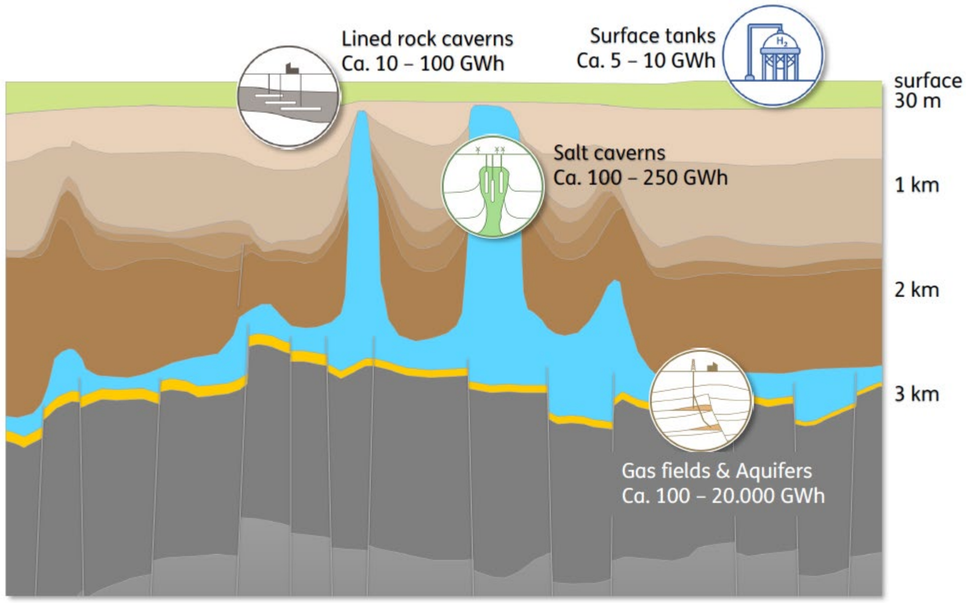

Figure 12: Physical hydrogen storage options; SOURCE: Groenenberg (2023).

The NHIA found that long-term storage of hydrogen at scale would be most cost effective using salt caverns.[140] This is consistent with international and domestic expert views to date.[141] Interestingly:

> The model includes four salt cavern locations, positioned in remote areas of Western Australia, Northern Territory and Queensland. Despite the large distance between these locations and the main hydrogen production and demand areas, the low hydrogen storage cost justifies the use of these locations when the hydrogen demand is sufficiently high to justify their development.

While the NHIA model allowed for large-scale hydrogen storage in depleted gas fields, the NHIA report advises that this technology did not appear in the results. This was said to be because of a higher levelised cost of hydrogen storage in depleted gas fields compared to salt caverns – a result of a higher capital cost but mostly lower allowed charge/discharge cycles per year (assumed six charge/discharge cycles per year for salt caverns and one cycle per year for depleted gas fields). We

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[139] As noted by Srinivasan et al. (2023), seasonal energy storage is likely to be commercial only for pumped hydro and for underground hydrogen (page 48), and by 2050 it will likely be cheaper than pumped hydro (page 55).

[140] Although Arup (2023b, page 129) notes the techno-economic model assumed the demand of hydrogen to be always in the form of hydrogen gas.

[141] For example, US Department of Energy (2023a), page 17.

note that this cycle assumption may not hold true for all applications, which could change the model preference; for example, one cycle per year may be required/favoured for inter-seasonal summer-to-winter deep electricity storage.

On salt caverns, the challenge for Australia is that we do not have significant salt caverns (or in the right locations for all projects), and there will need to be pipeline connections created. It is possible to create new salt caverns, and Geoscience Australia is mapping opportunities and investigating means of finding new salt prospects. As noted in the *State of Hydrogen 2022* report, "Australia appears well placed to develop its own salt resources for underground hydrogen storage with several well-suited sites already discovered".[142] There is little further information on this process.

As noted by the NHIA, small and medium scale storage can be via a range of means, including tanks and vessels for gaseous hydrogen, pipeline line packing, metal and chemical hydrides and liquid organic hydrogen carriers (LOHCs). For this smaller scale storage, the NHIA model chose LOHCs in the form of methylcyclohexane (MCH) tanks, with conversion/reconversion facilities. However, with the uncertainty around the cost and efficiency parameters for MCH storage, the NHIA report cautions that this "should not be considered as an indication of clear preference for MCH storage over other hydrogen storage technologies".[143]

NZAu also modelled energy storage needs, including hydrogen storage. The project found that hydrogen storage is "rapidly installed into the domestic energy system from 2035 in all scenarios and could comprise 40,000-100,000 t-H2 (6-14 PJ, 1.6-3.9 TWh) energy storage capacity".[144] Against expectations, this hydrogen storage is *not* used for firming the electricity grids but to support hydrogen supply "for transport and industry sectors across days, seasons and years".

Hydrogen storage for export purposes was modelled as requiring between 4 and 25 times the hydrogen storage of the domestic system, at 0.5-1.5 Mt-H2 (72-220 PJ, 20-60 TWh). This storage is located within the designated renewable energy export zones (where hydrogen tends to be produced), and also at the exporting ports.

The NZAu modelling assumed pipe storage rather than in natural formations, and the NZAu report provides the number of storage facilities and total land footprint of storage in 2060 at key locations. However, the authors note that figures indicate that the modular facility size used as a reference for NZAu modelling "is much too small for the hydrogen storage challenge faced by an ambitious clean energy export system":

> It is expected that once design engineers tackle the challenge of designing (non-natural formation based) hydrogen storage systems aimed at the scale discussed in NZAu, both facility numbers and footprints would decrease significantly. Alternatively, if storage costs play a sizable role in the transition, a hydrogen focused export economy might put greater consideration into sites that offered the potential for lower cost natural storage formations.[145]

[142] Australian Government (2023), page 42.
[143] Arup (2023b), page 128.
[144] Davis et al. (2023), page 37.
[145] Pascale et al. (2023), page 23.

Other studies provide further insights; for example, CSIRO modelling found that:

- Decarbonising the four alumina refineries' calcination phases in south-west WA with hydrogen would mean that by 2050 there would need to be approximately 250 t per day (42 PJ) of hydrogen storage. [146]
- To fill a large ship 14 kt liquefied hydrogen would be needed to be stored as a buffer at the port. A further 270–860 t of gaseous hydrogen would need to be stored as a buffer to ensure there is a reliable supply of hydrogen available to support the liquefaction process.[147]

The assessments provided are instructive but also suggest that much more needs to be done to map the parameters of what might be needed for future storage of hydrogen. This is also important to progress considering that storage will be expensive and may require years to develop.

If salt caverns are a logical path, then the process to create each one will take time and will need to pass a range of land access, safety and environmental tests. We note that Geoscience Australia is testing "new remote sensing salt prospecting techniques" and may also look at depleted gas reservoirs.[148]

An underground storage technology report for the IEA's Hydrogen Technology Collaboration Program (Task 42 on Underground Hydrogen Storage) outlines the typical challenges and key questions to be addressed as shown in Table 4. This list usefully differentiates different domains of coverage and expertise and should be a key reference for Australian Government thinking as it develops the refreshed NHS.

Domain	Key questions
Geological Domain	• Which geological formations are suitable for storing and recovering hydrogen? • How does hydrogen flow in the subsurface under different geological conditions? • How is hydrogen impacted under different geological conditions, including losses and reaction by-products? • How do hydrogen and reaction products impact the subsurface? • How do any of the above impacts propagate to the technical, system and social domain?
Technical Domain	• What technical components and designs are needed for a safe and effective injection and recovery of hydrogen? • To what extent can existing infrastructure be repurposed and will legacy wells impact underground hydrogen storage? • How do hydrogen and its reaction products impact wells, facilities and materials? • What is the safe operating window for injection and recovery of hydrogen? • How do geology and storage demand influence the facility design, location and costs?
Energy System Domain	• How much storage capacity is required, where is it required, and when? • What are the hydrogen grid requirements with regards to hydrogen injection and recovery including rates, cyclicity, availability and quality? • What are the business models for underground hydrogen storage?

[146] Srinivasan et al. (2023), page 91.
[147] Ibid., page 96.
[148] Geoscience Australia (n.d.).

Domain	Key questions
	• What are the viable alternatives?
Social Domain	• What are the environmental impacts of underground hydrogen storage? • What are the social benefits and costs? • Which stakeholders are involved and what are their roles and responsibilities? • What policies, regulations, engagements and financial resources are needed for a timely and socially accepted development of underground hydrogen storage and to secure clean and affordable energy and feedstock resources?

Table 4: Overview of typical challenges and key questions for underground hydrogen storage; SOURCE: Hydrogen TCP-Task 42 (2023), page 8.

In summary, there is clearly a need for a more comprehensive research and policy effort to identify the future needs for hydrogen storage. This fits within the broader net zero programme of planning for future electricity grid stability and the role for hydrogen in conjunction with, or as a substitute for, pumped hydro for seasonal storage. As noted by CSIRO in its recent energy storage roadmap:

> Although the Australian Government has recognised energy storage as a priority in its *Powering Australia* plan, significant knowledge gaps remain that require further investigation to support informed action. This includes a greater understanding of the scale and nature of Australia's storage needs across different decarbonisation scenarios and geographies, as well as the ability to deploy storage technologies in the electricity sector and different end-use sector contexts. Understanding these elements can reveal factors that influence investment decisions and inform future decision making.[149]

Recommendation 27: Develop a national assessment of hydrogen storage needs for different purposes, timeframes and locations.

DCCEEW should engage with pipeline and gas storage companies, AEMO, Geoscience Australia and the AER to analyse and report back on:

- The economic benefit of hydrogen storage, including in supporting the electricity system.
- The need for different types of storage for hydrogen, at what scale/volume and in what timeframe.
- The fitness for purpose of existing storage measures, including current and new salt caverns, depleted gas reservoirs, line packing in pipes, and above-ground solutions.
- If more storage is required, the next steps to develop this as needed, including cost recovery mechanisms as required for users.

This work should be able to address the refreshed NHS targets and policy priorities.

Recommendation 28: Commit to a funding envelope for common user storage.

The Australian Government should undertake to support common user storage developments to 2045. There is a particular need to fund demonstration and pilot projects for large-scale underground hydrogen storage.

[149] Srinivasan et al. (2023), page 3.

4.2.7 Refuelling

The NHS v1 set out four agreements relating to refuelling infrastructure for hydrogen for transport, where the two main agreements identified the value for refuelling stations on major freight and passenger road corridors, and also for consortia for building refuelling infrastructure.

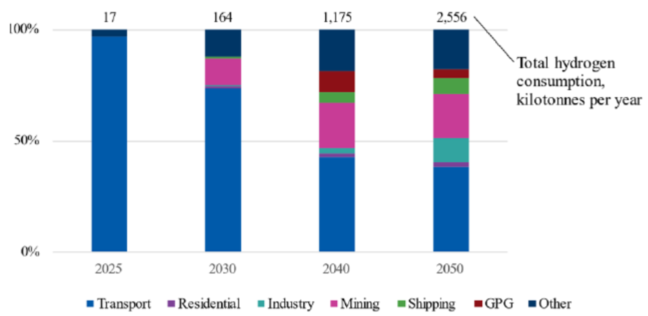
There has not been a specific programme led by the Australian Government to develop a refuelling network, with the main commitment being a funding match commitment for state and territory developments.

In terms of current infrastructure, and as noted by the *State of Hydrogen 2022* report,[150] Australia has only a few operating refuelling stations, and most are not at commercial scale. Despite the relatively long range of FCEVs, provided the dispersed locations and distance between refuelling stations, there is a risk even if only one of these is inaccessible or under maintenance that travel becomes uncertain and compromised.

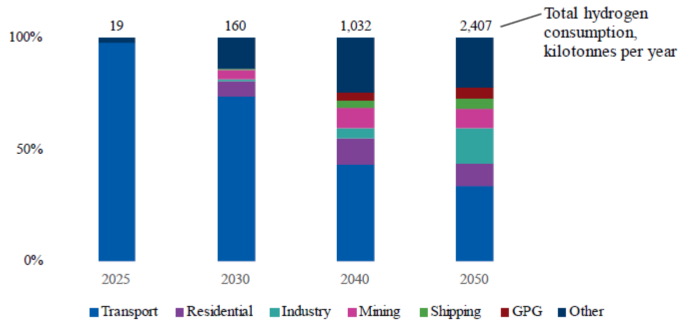
The NHIA modelling found that domestic demand across all jurisdictions is initially driven by use in the transport sector. Despite this, the *State of Hydrogen 2022* report[151] identifies light and heavy transport to be two of the four slowest advancing hydrogen sectors. Both reports point to the importance of refuelling infrastructure to support this demand, with an emphasis of locating infrastructure in major cities and along heavy haulage routes. While there is a pipeline of committed, publicly funded refuelling projects, further infrastructure investment is required to expand this network along these and additional corridors, combatting range anxiety and empowering commercial vehicle owners to transition their fleets to ZLEVs.

We have shown the figures from four states in Figure 13 shows the NHIA figures from four key states, where we can see from the bright blue in the columns that transport as an application is a major contributor to demand through to 2040. The NHIA did not clarify the coverage of the transport category, but we can likely assume it is mostly road transport, at least until 2040.

Queensland demand



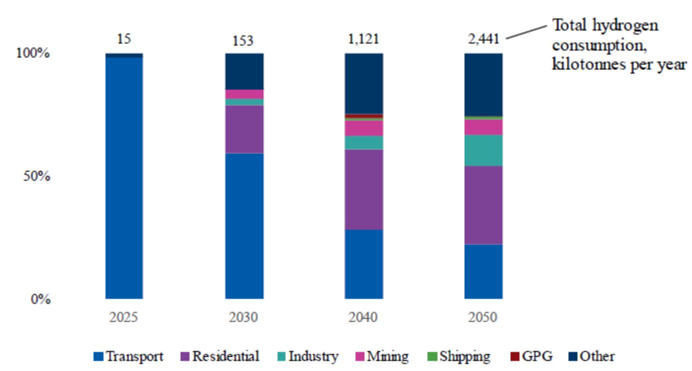
NSW demand



150 Australian Government (2023b).

151 Australian Government (2023a), page 11.

Victoria demand



South Australia demand

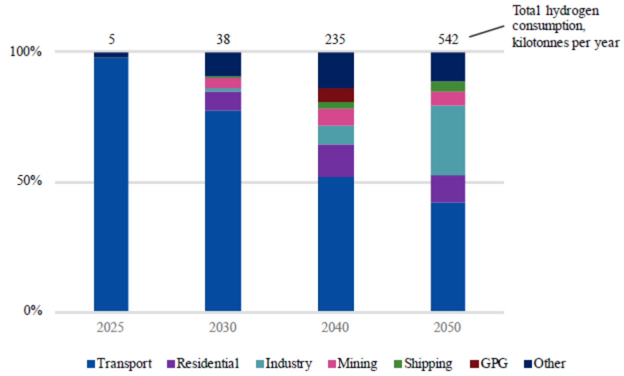


Figure 13: Comparison of key interconnected states – hydrogen demand from NHIA base case; SOURCE: Arup (2023b), pages 81, 89, 96 and 107.

The NHIA report notes that the transport modelling assumed refuelling infrastructure would be present as required. The NHIA did not model refuelling.

Given this, it would seem sensible for refuelling infrastructure for key applications and routes to be expedited.

This is all the more important as future fuels policies take hold and heavy transport companies need to invest in new fleet. The heavy transport industry is developing hydrogen ZLEVs (mostly fuel cell electric vehicles, or FCEVs), many of which will be available in the second half of this decade. A study of heavy transport across Europe, USA, China and India noted that FCEVs will cater for up to 50 per cent of long-haul transport in these regions and would expect total-cost-of-ownership (TCO) parity with internal combustion engines between 2032 and 2037 (excluding India which is expected to take longer) based on current policy ambition and fuel prices.[152] In order to decarbonise the transport sector and help Australia meet our net zero ambitions, we need strong policy to bring FCEV price parity forward. However, this will be halted if there is insufficient refuelling infrastructure to support this.

Furthermore, there is a necessary role for the Australian Government to coordinate a public refuelling network with nationally standardised consideration of access, suitability and consistency of hydrogen form (referring to liquid or compressed gas at specific pressure). Without a nationally consistent infrastructure strategy, ideally based on international standards, the TCO of FCEV is severely impacted.

AHC used the data and images in the NHIA to arrive at some estimations of refuelling requirements for states in Figure 13, as shown in Table 5. We calculated that by 2025 there would need to be at least 33 refuellers operating nationally (assuming 600kg a day refuelling capacity and in operation 82 per cent of the time). This figure jumps significantly for subsequent years.

If these were targets, we are clearly some way off.

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[152] Mission Possible Partnership (2022), page 10.

Year	2025	2030	2040	2050
Refuelling stations assuming 600kg a day and used 300 days pa	33	203	779	1,367

Table 5: AHC estimate of future national refuelling station needs for NSW, QLD, VIC and SA.

Using estimates of the transport percentages from these states, Figure 14 plots the estimated demand in Mt per year. This clearly shows NSW and Queensland as the leaders and so we might also assume that more refuelling stations are required in those states relative to the other jurisdictions.

Clearly more work is required to understand the need for refuelling to support hydrogen transport applications, and to also consider how refuelling needs can be reduced with back-to-base operations.

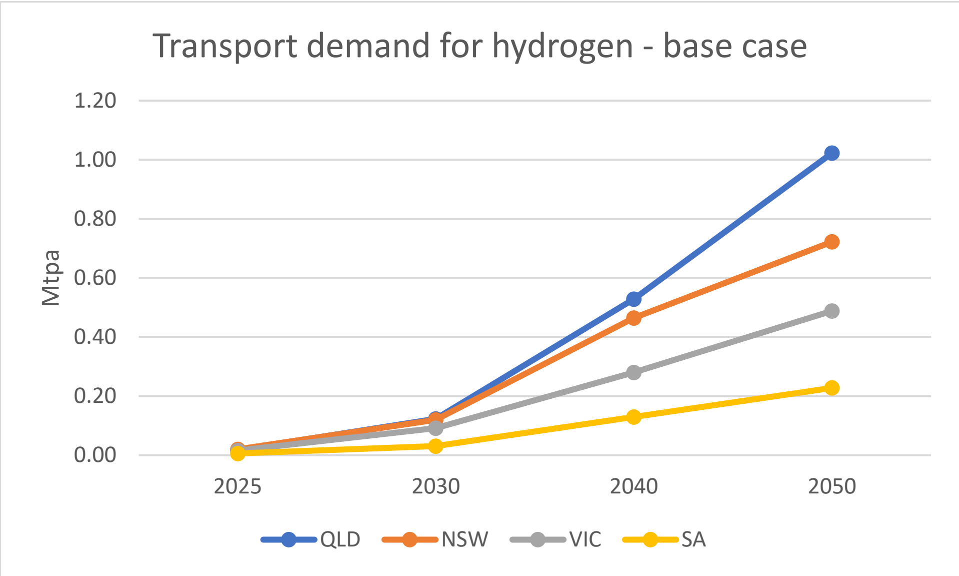

Figure 14: Transport demand base case for key states; SOURCE: AHC based on Arup (2023b).

Recommendation 29: Ensure a refreshed NHIA addresses refuelling infrastructure.

Building on Recommendation 5, the NHIA analysis should address refuelling needs for hydrogen in heavy transport. If the NHIA is not rerun, this requires separate analysis and reporting.

This should lead to an understanding of future government support for refuelling infrastructure, which then needs to be costed for different options.

Recommendation 30: Commit to a funding envelope for refuelling infrastructure.

The Australian Government should undertake to support refuelling station development until the uptake of FCEVs reaches a level sufficient to sustain the expansion and infill of a national hydrogen refuelling station network. The NHIA and cost analysis will clarify what is required. This funding may be provided as the infrastructure element of a combined refueller and vehicle trial, as discussed in Recommendation 48. Funding could be matched by states and territories for key projects and split so that one funding stream defrays capital costs and the other provides long term underwriting for contracts.

4.3 Social and institutional support

With the energy transition being touted as the next industrial revolution, we can expect the impacts will be felt, and support will be required, across all parts of the economy.

Hydrogen is a key part of the transition, but the industry's nascent state means that much more needs to be done to establish its social and institutional architecture. This relates to risk and financial literacy about hydrogen to provide an attractive investment proposition, community support and meaningful jobs, and means to support innovation and industry development with RD&D, connections and the clarity of good regulation.

4.3.1 Funding and the financial system

As we have discussed, governments have a role to pull together bankable, viable projects that can attract a range of investors.

On the funding and economic policy side, the NHS v1 set out six relevant agreements, that cover:

- The need to develop clean hydrogen supply chains (Agreement 5).
- Considering "the most appropriate support to scale up the industry and activate markets in light of global signals" (Agreement 6).
- Mandatory national targets, as discussed in section 2.3, where the NHS v1 noted there would not be mandatory national targets, but that this "should be re-considered periodically as the market develops" (Agreement 7).
- Potentially facilitating larger hydrogen projects through coordinating respective funding arrangements (Agreement 14).
- The NHS v1 position on the topic "Certainty around taxation, excise and other fees or levies for hydrogen" that there would be no change to the current revenue arrangements for hydrogen, with the option to review them in the future (Agreements 38 and 39).

Overall, the agreements addressed the topics superficially, and it is challenging to view the piecemeal and fragmented activity since the NHS v1 as having been direct implementation of Agreements 5, 6 and 14. There has been little coordination other than where states supported some hub funding applications (see section 4.1). A lack of coordination in funding opportunities has regularly been identified (by AHC members and others) as a major issue and also relates to the discussion in section 1.1.

The good news is that several billion dollars have been committed to hydrogen across the jurisdictions, and both the hydrogen hubs and Hydrogen Headstart initiatives are very welcome commitments from the Australian Government. ARENA and CEFC, in their respective roles as supporting commercialisation through grant funding and in providing concessional financing, have been vital to the progress made to date and they have the institutional capability to close the bankability gap if funded sufficiently.

The bad news is that is we are still a long way from where we need to be: as discussed in section 1.4, the bankability gap for hydrogen projects is far from closed.

As an illustration of the various parties and risks with hydrogen projects, it is useful to unpick the financial structures that project developers and financiers are engaging with. Figure 15 from the Green Hydrogen Organisation provides an example green hydrogen project structure, where we can see the various parties that need to be at the table, where each brings risk and potential cost-blowouts and delays to a project.

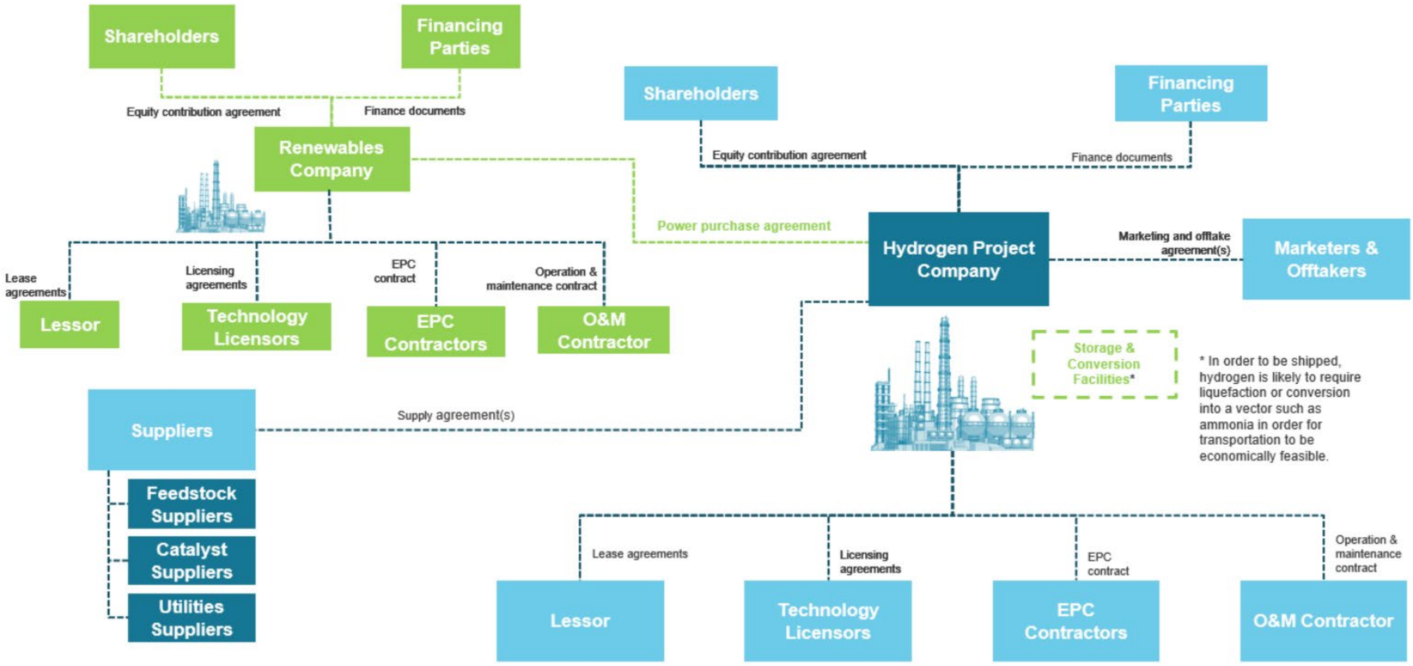

Figure 15: Illustrative green hydrogen project structure; SOURCE: Green Hydrogen Organisation (2022), page 29.

Major hydrogen projects are commonly expected to use debt-funded project finance. Project finance is traditionally used for complex energy and infrastructure projects, where the project is off-balance sheet for a parent company and the costs need to be recovered from an end user via an offtake agreement. The best case is a long-term, fixed price offtake contract with a credible counterparty. It is on this basis that bankers will finance projects.

The problems that arise for hydrogen projects like the example in Figure 15 are then:

- Significant uncertainty at different parts of the chain, making end-to-end financing challenging. Problems range from the inevitable (but still significant) matters for any major construction project in the current environment, to newer issues with integrating technologies for the first time and access to equipment within the required timeframe.
- The uncertainty and lack of experience are self-amplifying – 'new' technologies and risks (or integrated technologies) result in uncertain and cautious market observers and financiers. As observers stay cautious – to the point where they won't engage with a project or consider new means of engagement – the experience stays 'new' and uncertain.
- The money only flows from the customer once the hydrogen flows, and yet the infrastructure required to produce, move and store the hydrogen may need to be built or

repurposed. At scale, costs for new transmission pipelines, underground storage and purpose-built desalination plants can go to billions of dollars.

- There is minimal demand for hydrogen – there is little to no hydrogen trading, and current users make their own (fossil fuel-based) hydrogen onsite. Once all risks are costed, the resulting price for hydrogen is much higher than anyone's willingness to pay compared with the fossil alternative.

We build on demand side market mechanisms in Chapter 5; for now the issue is how governments can help package up investment cases and support risk management to get the market going. As noted by the Green Hydrogen Organisation:

> The challenge for green hydrogen projects is to structure an acceptable risk profile for financing by allocating risks to those best able to take them, whether this be sponsors, insurers, financiers or ultimately in some cases, governments. The project finance lending community are experts at assessing and pricing risk and, whilst they can be expected to accept some risk on early projects, their approach to risk is traditionally conservative, with a low tolerance for default.[153]

As discussed in section 1.4, stakeholders told the UK Government (2023) they needed to see a range of improvements to green investing. The issues raised (clarity, funding, investment attractiveness and technical capacity) are the same as reported by AHC members.

If we apply the UK lessons learned to hydrogen in Australia, the suggestions would be for the Australian Government to:

- **Aim for clarity:** Improve the long-term clarity in the pathways for hydrogen and its derivatives, as part of a resilient and net zero economy. An appropriately detailed refreshed NHS and implementation plan should meet this need.
- **De-risk through public finance**: Work closely with CEFC and ARENA to deploy appropriately scaled public levers that will crowd in and de-risk investment in hydrogen. This means more investment than the current A$300m for the CEFC, and follow-up packages to the Hydrogen Headstart. We have previously asked the Australian Government to underwrite demand through a revenue support mechanism (such as contract for difference) intended to incentivise domestic production of critical chemicals and metals that are of strategic and economic importance to Australia, such as iron, alumina, ammonia, urea, methanol and key derivatives.[154] There also needs to be consideration of government underwriting and insurance of projects, including where projects may not see out their planned operating life or where their technology has been radically superseded.

  AHC has provided a response to the Australian Government's recent Headstart consultation paper,[155] and we are hopeful that the process will result in the establishment of robust guidelines that can be rapidly scaled up and rolled out with any additional funding announcements. This also means a close alignment with the refreshed NHS. Ideally, the current and future iterations of Headstart will:

[153] Green Hydrogen Organisation (2022), page 29.
[154] Australian Hydrogen Council (2023b).
[155] Australian Hydrogen Council (2023a).

- Incentivise demand or assist project developers to manage demand side risk. This includes accepting a higher level of technology risk (to encourage orders from new providers), developing demand side policies, by supporting and funding common use infrastructure (particularly port side), by pushing for expanded program funding and clarifying how the existing suite of Australian government funding can support end to end project developers.
- Prioritise timeliness, to build momentum, to align prospective projects with the timelines for regional offtake (e.g., the Singapore tender, Korean auctions, the Japanese CfD scheme) and as a response to the investment challenge posed by the IRA.
- Avoid additional sources of risk for the bankability and financeability of projects, such as via claw back provisions.

The current and future funding should also propose industry-specific criteria to make the best use both the funding and potential applicants' scarce resources to make a case. Further, consideration should be given to ARENA and CEFC simultaneously conducting due diligence on the shortlisted projects and promoting a 'fast fail' approach; that is, communicating that a project is deemed ineligible for the funding as soon as this is known rather than waiting for diligence on all shortlisted projects to be completed. All short-listed projects remain eligible for debt financing by the CEFC.

- **Build attraction capability**: Ensure all parts of the project development and investment chain, including local government and businesses, have the capacity to develop investor ready projects and raise capital. As discussed in Chapter 1, the sentiment we hear from many hydrogen players is that the complexity and uncertainty of the investment environment and the overall ecosystem (multiple states, regulatory differences, permitting within states) is making their decisions unnecessary difficult. There is a need for investors and other decision makers to recognise meaningful investments in new infrastructure and technology, and the current environment is not conducive to this. Government thus has a role to direct investors' attention to the opportunities; to help create value propositions that investors recognise.
- **Build technical capacity**: Improve the technical capacity of the emerging hydrogen markets to attract green investment and use public finance levers to de-risk investment and building new export markets. As noted by IRENA:

> Low-cost capital availability is essential to the implementation of energy transition projects; new institutional structures are therefore required to rationalise risk assessments, provide more investor certainty, and more effectively manage the real or perceived risks associated with energy transition projects among investors.[156]

The technical capacity may also relate to the financial, legal, data and accountancy experts who support transactions. For example, the UK Government has announced that it will undertake a Transition Finance Market Review to "consider what the UK financial and professional services ecosystem needs to do to become a leading provider of transition

[156] International Renewable Energy Agency (2023), page 71.

financial services and innovative instruments on the pathway to 2050".[157] In June 2020 the UK Government also launched the Green Finance Education Charter (GFEC, since re-launched as the Sustainable Finance Education Charter, or SFEC). This charter aims to "build the knowledge and skills of finance professionals, and the capacity and capabilities of the finance sector" to support UK and global net zero and sustainability targets.

Further, there is also a need to not only build new infrastructure, but also to manage *existing* infrastructure as discussed in section 4.1. Governments could support the steps above by constructing packages of options for investment to cover a variety of investor risk appetites – from institutional/pension funds looking for long term returns on infrastructure through to project equity and venture capital looking to fast track development and deployment of new technologies. An example of this type of project is a port re-development alongside creation of an onshore or offshore renewable energy zone, as well as pre-approvals for an industrial zone in proximity, with perhaps additional procurement of transmission or pipeline infrastructure as required.

The Portland region in Victoria would be suitable for this type of intervention. It is a regional economy highly reliant upon a trade exposed, high emissions industry (aluminium) with one large investor (Alcoa) that employs a significant number of people across a range of skills. The port area is a designated industrial zone that would enable production of chemicals with potential for significant additional and dedicated renewable energy generation to be built offshore, as well as transmission and storage investments. This type of investment zone could also include a range of incentives for investors such as accelerated regulatory approvals, accelerated depreciation of technology investments and wage subsidies for hiring local workers.

Recommendation 31: Boost Australian Government ability to attract and deploy private capital.

Building on Recommendations 4 and 11, build capacity within the Australian Government to work more closely with the financial sector to better anticipate and manage roadblocks to deploying and re-allocating private capital, and to develop investment and value propositions that work to secure private capital interests and meet the Australian governments' aims for the hydrogen industry.

See also Recommendation 38.

4.3.2 Community engagement and acceptance

The scale of the energy transition requires us to understand and plan for impacts on local economies. This is particularly important if we are to avoid the worst from Australia's previous boom-bust cycles and surges of economic activity.

The sheer scale of construction and development will also raise important community (and societal) questions about competing uses for land and water, and priorities for infrastructure for different purposes. There will be a diverse group of stakeholders and connections to be built.

[157] UK Government (2023), page 21.

Issues for communities

Given the early stage of the hydrogen industry, there is not much community awareness or community engagement with hydrogen businesses. We can also expect most issues to be around physical supply while the infrastructure is being built. Table 6 provides some examples of issues that have been raised in various fora to date.

Issue	Existing/past social licence issues
Making hydrogen	*Electricity transmission infrastructure*: visual impacts, land access and use, health, biodiversity, bushfire risk and community compensation.
	Solar farms: land, past developer behaviours, decommissioning and waste management.
	Wind farms: onshore (land, noise, birdlife, visual impacts, past developer behaviours) and offshore (animals, birdlife, fishing, visual amenity); also decommissioning and waste management.
	CSG production: land, 'fracking' and effects on water, including waste management, procedural fairness.
	Raw water use: stakeholder concern about water allocation and the effectiveness of water markets.
	Seawater use: known issue of brine waste from desalination and effect on sea life, economic cost of desalination plants for communities.
	CCS/CCUS: existing scepticism about fossil fuel interests and success rates, international concerns about land value (e.g., Barendrecht case) and safety.
	Mining: coal and iron ore for jobs, and hydrogen production.
Export	*LNG export*: local economy boom and bust, lack of coordination for proponents, and domestic reserve policy.
	Ports: workforce concerns and consultation.
Storage	*Hazardous goods*: e.g., 2020 Beirut port explosion from ammonium nitrate; CCS – see safety above.
End user experience	*Natural gas*: access to supply/contracts, which may be seen as a need for future hydrogen reserve policies.
	Energy retail prices: concerns about affordability and energy company price gouging for smaller consumers.

Table 6: Social licence matters connected to the future hydrogen industry.

The issues in Table 6 are almost all related to existing industries rather than uniquely to hydrogen. However, these issues could all be amplified by the emergence of a commercial scale hydrogen industry. If major problems in these existing areas arise and are blamed on hydrogen this could be enough to (unnecessarily)[158] delay progress. Further, hydrogen is already being affected by these existing social licence concerns. We particularly note here the current delays in building renewable

[158] Any major issues that require a rethink of how things progress in hydrogen are assumed to be valid - we are talking here of mistaken or mischievous perceptions.

generation and transmission lines, and the range of expert concerns about the impact this is likely to have on future system reliability.[159]

Affordability is worth separate attention, and we have addressed energy affordability already under section 4.2.2. If our recommendation is accepted, then hydrogen affordability on energy bills should not be a social licence issue. However, hydrogen does not only touch on energy markets; for example, using hydrogen in industrial processes will affect end prices for industrial products. If we consider green steel, it has been reported that in 2050 the cost of green steelmaking could be between 15 and 30 per cent more than today. The impact for end consumers for products such as cars will be minimal (around 0.3 per cent in 2050) because steel is not a major contributor to cost; however, manufacturers of intermediate steel products, such as for car manufacturing “will be greatly affected by the 15–30 per cent cost increase of green steel”.[160]

This illustrates the need for strong government awareness of the issues and tailored support for different industries using hydrogen in the next decade or so.

We return to how industry might better work with communities – particularly regarding renewables and hydrogen production – later in this section.

Hydrogen-specific social licence concerns

There are two further areas of social concern that are specific to the hydrogen industry: safety and the use of water.

On safety, hydrogen and its derivatives have been handled safely by the existing industry for decades. There are existing standards and regulations that relate to how hydrogen, ammonia and methanol are safely produced, handled, stored, and used.

The clean and green hydrogen industry will be extending hydrogen (and derivative) production, handling, storage and use beyond these industries, and so it is important that there is a suitable awareness and training for workers new to hydrogen about how to prevent accidents, and how to detect and respond to any safety incident.

The good news is that the industry and regulators are acting to fill knowledge gaps and to roll out training. We will return to this in sections 4.3.3 and 4.3.6.

Turning to water, it is a key input to produce renewable hydrogen, with the main part of the process being an electrolyser splitting water into its components: hydrogen and oxygen. At its most basic level it takes 9 litres of pure water to make 1 kg of hydrogen gas. However, the actual volume will be more than this, depending on the source of water and resulting treatment, and the equipment and cooling process used. This was discussed in section 4.2.3.

Less treatment is required for good quality surface water than for wastewater or seawater (or heavily saline ground water). Social acceptance issues arise at both ends of the treatment spectrum.

- Potable water, and water that requires little treatment, will already have high value to other water users, as well as for environmental flows. There may also be limitations for access to water rights in existing water markets.

[159] For example, Ludlow (2023).
[160] Climateworks Centre and Climate-KIC Australia (2023), page 36.

- Water that needs significant treatment may be more plentiful (such as seawater), but the treatment may itself have social acceptance issues. This will be particularly where new infrastructure is required, such as desalination plants, which local communities often do not like, or new recycled water treatment facilities and pipelines in populated areas.

Further, desalination (and all treatment of highly saline water, which might include some groundwater) will produce brine as waste, which will need to be dealt with. This water tends to be disposed back into the ocean, which creates further concern in some locations about effects on coral reefs.

As noted in section 4.2.3, from a hydrogen industry perspective the water volumes required and the costs (as currently understood) are not prohibitive. However, from a water sector perspective the water needs are significant and must be built into long term planning for water security purposes. While the future hydrogen industry may use the same volumes as (and substitute for) the mining industry, the need for water will likely cover different areas and thus water sources. It is also unlikely that social licence for the emerging hydrogen industry will provide the same concessions as the traditional mining sector.

From a water value perspective, larger volumes are less of an issue if the bulk comes from manufactured water (recycled and desalinated water), but these need to be planned for many years in advance. Each of these forms of manufactured water then needs to sit well in the existing landscape, with other water needs, and have an equitable means of cost recovery.

In summary, social licence to use water in large volumes for hydrogen is far from assured. Much like other industrial water uses and major infrastructure projects, organisations seeking to use water and build water infrastructure need to ensure that communities are consulted and engaged, that local water values are understood and accounted for, and that the matter of who pays for new infrastructure is handled transparently and fairly. Further, hydrogen for export may be particularly concerning for communities concerned about water use and seeing hydrogen consumption as a loss to the community.

It is also important to note the processes already in place for water utilities on community acceptance. For example, at least two major regional utilities have surveyed their communities on infrastructure for water recycling, needing acceptance over a certain threshold. This kind of approach will no doubt apply across the country in one form or another and may need to drive hydrogen proponents’ own early planning for working with communities and supporting water utilities to do the same.

Recommendation 32: Support a new programme of work on community water values and hydrogen awareness.

The Australian Government should either lead a cross-sector engagement forum, or support one led by water and hydrogen peak bodies, that seeks to connect hydrogen and water organisations in community engagement regarding water values and planning.

This would naturally lead from analyses and planning from Recommendation 22.

Sharing benefits

Agreement 48 of the NHS v1 required the AHC to develop an industry undertaking (such as a charter) to guide the development of Australia's hydrogen industry. The undertaking was to specify appropriate principles to safeguard the community, communicate issues and engage with regulators.

Consistent with community expectations of social licence undertakings, the industry is also expected to provide accurate information and respond to community concerns in a way that meets both legislative requirements and community expectations. Industry is also expected to work with local communities to ensure benefits are distributed as fairly as possible.

In February 2020, the AHC created a working group of members and representatives from governments and academic institutions to address the matter of social licence and the industry undertaking. To support the working group, AHC surveyed its members and key stakeholders in May 2020 to obtain views about how it might consider and develop the industry undertaking.

Following further discussion with the working group about the survey outcomes and the best direction for the project, it was determined that in the first instance the undertaking would:

- reflect a set of principles for working with local communities;
- demonstrate an intent to avoid harm and share benefit;
- be based on relevant precedents and approaches; and
- be complemented in time with fact sheets and other communications.

The AHC assessed similar undertakings from the renewable energy, finance, and mining industries, and the UN's Sustainable Development Goals, and drafted principles that were then discussed and revised by the AHC working group. The final principles were released in September 2021, and are as follows:

1. Working with communities

a) We will listen, share information, and engage fairly and respectfully with project host communities, including Traditional Owners of the land.

b) We will proactively seek input from relevant stakeholders on project impacts, benefits and outcomes for host communities, and will prioritise addressing negative impacts identified.

c) We will provide transparent, timely, and responsive community access to relevant project decision-makers throughout a project's lifecycle.

2. Supporting and developing people

a) We will support local economies by providing training, employment, and manufacturing/procurement opportunities where possible throughout the project's lifecycle.

b) We will design and manage projects using leading practice in safety standards as a commitment to our employees and host communities.

3. Managing natural resources responsibly

a) We will demonstrate responsible resource and water management and seek to maintain and enhance the ecological and cultural value of land within host communities.

b) We will work with communities to determine and maximise local benefits resulting from the responsible decommissioning or refurbishment/repowering of sites.

c) We will work proactively and transparently with regulators.

We also released two drafts of a Guidance Note for using the principles, but then received views from key parties that the work overlapped too much with other similar work, such as the Energy Charter and the CEC Best Practice Charter for Renewable Energy Projects[161] (which was in fact the original inspiration for the NHS v1 on agreement 48).

Given that much of the future community engagement is about renewables it makes sense to liaise closely with the electricity infrastructure processes. AHC and CEC are exploring how we can work together to go beyond principles and into supporting delivery.

We are also keen to engage with the Community Engagement Review as announced in July,[162] as well as developments in the First Nations clean energy strategy.

Communications

At the same time as we were working on the undertaking, the AHC became concerned that there needed to be national leadership on communications, founded on a strategic understanding of the issues, who the various audiences were, and what the messaging to stakeholders needed to be.

In early 2022 we approached the Australian Government and the jurisdictions and asked to lead the development of broader communications. The AHC then developed a social licence strategic communications approach, and socialised this with stakeholders from academia, government and industry. We used this as the basis for over 200 questions and answers that are searchable on multiple levels. These questions and answers were then tested and socialised further and uploaded to the CSIRO HyLearning website in early December 2022.

Much of the material in this section draws on material AHC developed in 2022. Appendix B provides the more comprehensive discussion and analytical model shared with stakeholders at the time.

Table 7 shows the key stakeholder groups we identified; people whose lives are touched in some way by hydrogen. The idea behind this approach was to consider and address how communications and engagement would need to consider different perspectives, and these groups are at the heart of all our communications as well. These groups are not mutually exclusive – we would anticipate that many people would at different times have interests in multiple groups.

Stakeholder group	People
Group 1: Users of land and natural resources	People who highly value their use of the environment (land, water and air) for business or lifestyle, e.g., communities, neighbours,[163] councils, local businesses, landowners, residents, farmers, tourism operators, tourists.
Group 2: Hydrogen workforce and	a. Future direct and indirect employers and employees of the industry, e.g., engineers, technicians, mechanics, gas fitters.

[161] Clean Energy Council (n.d.).
[162] Australian Government (2023d).
[163] 'Neighbours' indicates people affected by projects but not as landowners.

Stakeholder group	People
required holders of skills	b. People supporting social services, e.g., emergency services.
Group 3: Active hydrogen consumers	People and businesses choosing to buy hydrogen or related products via: - fuel markets - vehicle and equipment markets, e.g., car, bus, truck, fleet, tractor, stationary fuel cell and appliances - service markets, e.g., FCEV maintenance via mechanic.
Group 4: Passive hydrogen consumers	a. People who don't choose to buy hydrogen but still use it, e.g., natural gas users receiving blended gas, users of FCEV public transport. b. People who may choose in the future (become Group 3) when the market evolves, e.g., future FCEV purchasers.
Group 5: Societal influencers	People engaging on hydrogen issues and/or industry reputation by: - observing and commenting, e.g., environmental activists, media - making connections, e.g., industry associations - advocating and sharing information, e.g., various comms people, local leaders.
Group 6: Owners of outcomes	People creating the markets/seen to own the outcomes, e.g., governments, councils, regulators.

Table 7: Draft stakeholder groups for communications purposes.

We also considered the key topics that need to be addressed through communications and engagement, as shown in Figure 16.

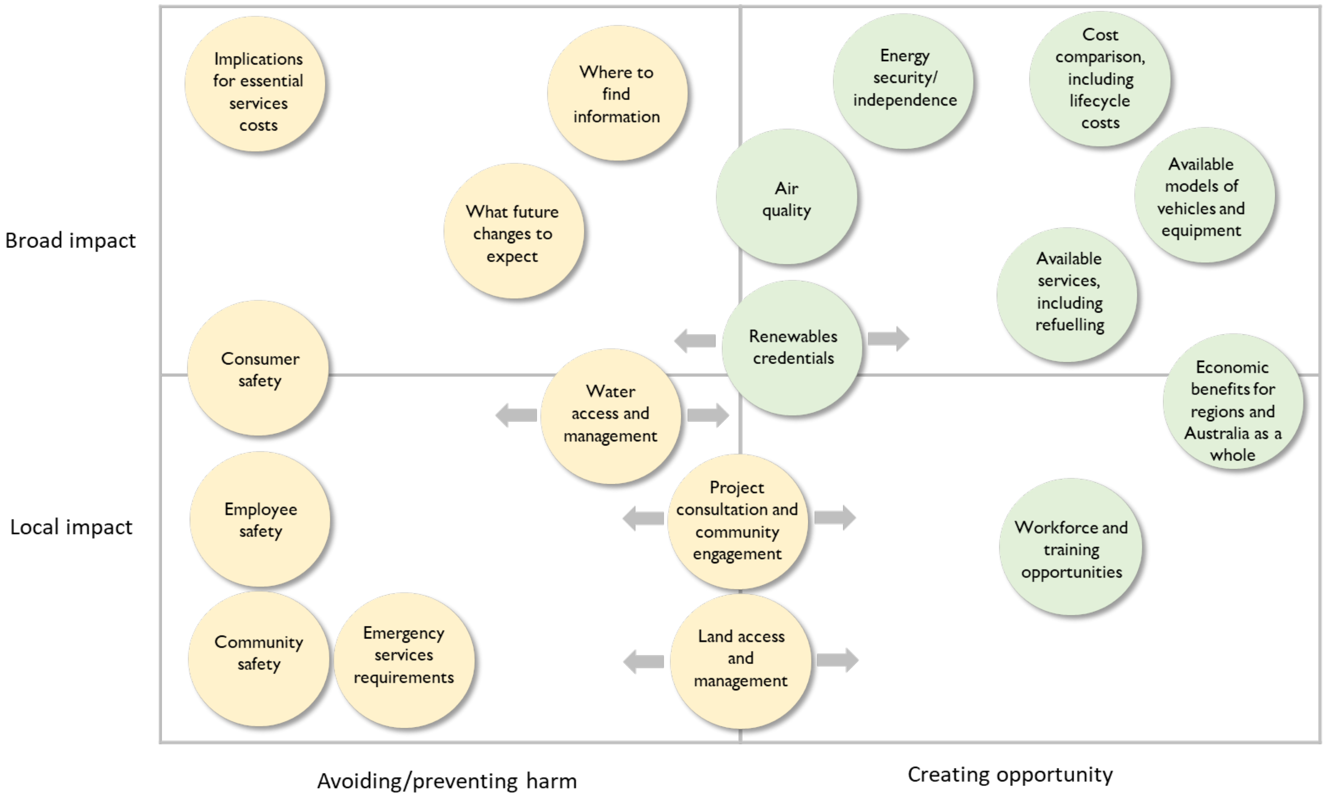

Figure 16: Hydrogen topics for public communications across key dimensions.

From this basis we developed a strategic communications framework which provided a structure for the questions and answers in HyLearning. Figure 17 shows this framework, which provides a means of organising communications to a range of audiences. We shared this framework with the Australian Government and jurisdictions, AHC members and a range of stakeholders.

The AHC has been considering developing public education videos, and working with experts on a schools programme, but we observe that the environment is already crowded and there has also not been a clear national plan that might help set expectations. This should change once a revised NHS is released. In the meantime, the water engagement we propose in Recommendation 32 should be pursued.

Recommendation 33: Develop messages and communications support for the refreshed NHS to roll out to all governments and industry.

The Australian Government should support government and industry communications on the refreshed NHS by developing clear messages about hydrogen, with links to industrial decarbonisation objectives and achieving net zero for the economy.

The strategic approach should be based on the existing AHC-drafted communications model, and outcomes should inform changes to HyLearning.

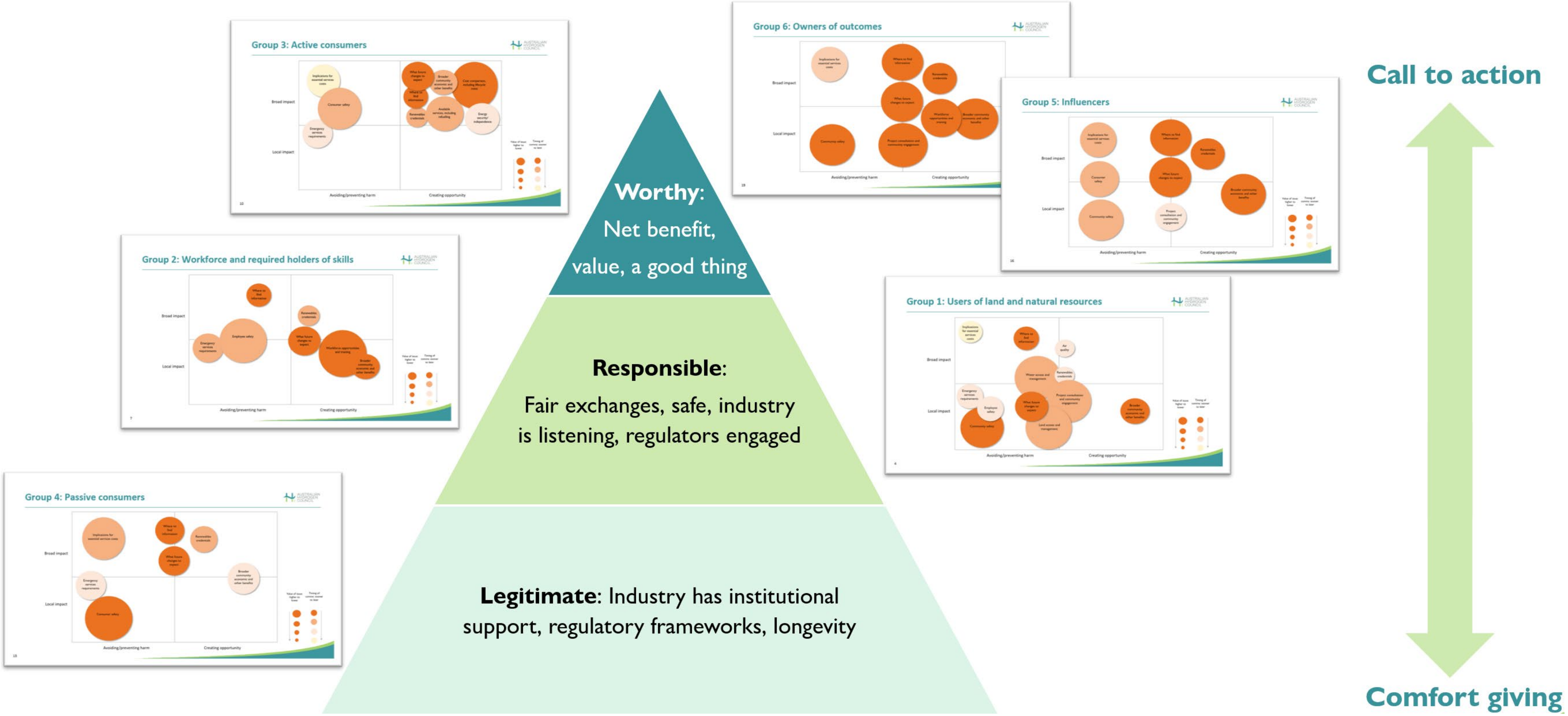

Figure 17: AHC model for hierarchy of messaging.

4.3.3 Labour

It is important to differentiate between the two related, but different, concepts of workforce and skills. Much of the work undertaken for the NHS v1 was focused on skills, and specifically what skills might be required and if this was covered in existing training packages. This work then became challenging without an overarching view of how many people might be needed with the skills identified, and by when.

Workforce planning

There have been several recent attempts at modelling the future workforce demand of the emerging hydrogen industry. The most notable include the workforce modelling of the Hydrogen Superpower scenario from AEMO's Integrated System Plan (ISP), NZAu, and NERA's Hydrogen Equipment Technology and Services report (Arup, 2023a). These projections vary considerably in scope and modelling assumptions, which impede direct comparison. For example, each study differs in its coverage of the hydrogen supply chain, timelines studied, geography, inclusion of indirect jobs, and limitations.

Their key findings are as follows:

- AEMO's ISP requires a doubling of the energy workforce relative to the Step Change scenario by 2030 and a tripling by 2040, with peak employment of 237,000 workers.[164] Importantly, this only includes jobs in electricity generation – hydrogen production and the supply chain are not modelled due to a lack of robust employment factors. The research notes that boom-bust construction cycles are likely in the absence of planned deployment of projects. In-demand occupations face rapid increases, which entail high risk of skill shortages, risking delays and increased project costs. Queensland, South Australia, and Tasmania are leading employers in the Hydrogen Superpower scenario. Annual hydrogen production in 2050 is 17 Mtpa.
- NZAu found that total gross jobs vary between 610,000-840,000 in 2060.[165] Gross domestic sector employment has relatively small variation between most net zero scenarios, requiring between 216,000-262,000 jobs in 2050. This is a significant increase on the 74,000 jobs required for the reference scenario. The domestic workforce doubles between 2020-2030, and doubles again by 2035. Gross export jobs, which provide coverage of most of the hydrogen supply chain, vary between 348,000-511,000 jobs in 2060. These is an order of magnitude increase on the reference scenario, which has 57,000 workers in 2060. Export jobs are unevenly distributed, mainly in the sunbelt states of Queensland, Western Australia, and the Northern Territory. Annual hydrogen production in 2060 is between 135-145 Mtpa for most scenarios.
- Arup (2023a) estimates 60,000-70,000 ongoing jobs (13,500-17,500 direct, 44,000-55,000 indirect) and between 170,000-200,000 construction jobs to 2040 to produce 9.5 Mtpa. This is the most comprehensive analysis of job creation across the hydrogen supply chain, and includes inputs, production, compression, storage, and distribution, end-use and export. However, the modelling uses input-output tables, which are less transparent than the

[164] Rutovitz et al. (2023).
[165] McCoy et al. (2023).

employment factors used in the previous studies and impede understanding the composition of the indirect jobs.

Each study notes that most jobs will be in the construction and operation of electricity generation in regional areas. However, the location of hydrogen production and the supply chain is uncertain and depends on assumptions regarding whether molecules or electrons will be transported to industrial hubs and ports. No study has factored in the workforce costs associated with additional workforce pressures that would come from building hydrogen infrastructure in the regions.

Only two studies have analysed job and skill projections against regional capacity, with both concluding that there are major shortfalls in worker supply in most Renewable Energy Zones. These studies demonstrate the importance of looking at regional employment availability, rather than aggregated state or national results. Of note, both studies provided limited coverage of the hydrogen supply chain; the former used the same methodology as the Integrated System Plan discussed above, and the latter only includes direct jobs in construction and installation across electricity generation and hydrogen production.

A comprehensive accounting of all processes and technology lifecycle stages required by the hydrogen industry would reveal additional workforce pressures on local communities. These studies also exclude the indirect and induced jobs resulting from of an influx of workers to regional communities. As a result, the full impacts on communities of an emerging hydrogen industry are poorly understood.

There is more work underway to map the workforce requirements, as follows:

- The Clean Energy Capacity Study is a national research project delivered by Jobs and Skills Australia. This project analyses different scenarios for how we could reach net zero by 2050, understanding how many workers will be needed (and where) and who will have the skills to take on those jobs. It is not limited to hydrogen. The work:
    - Examines the possibilities for workers in emission intensive sectors to transition to new roles in their communities that will build on their existing skills and experience.
    - Identifies the education, training and migration pathways that we should be developing, and the underlying system settings needed to enable those pathways.
    - Explores how the workforce opportunities created by clean energy can be shared across regions and with First Nations Australians, women, people with disability and Australians from culturally and linguistically diverse backgrounds.

  The study is working closely with stakeholders from government, unions, education and training and industry bodies and will publish its final report by September 2023.

  If done correctly, this study will provide the government with a solid macroeconomic understanding of the workforce requirements of the clean energy transition, including to establish Australia as a renewable energy superpower. It may face challenges regarding the occupation and skill requirements of the emerging hydrogen industry and across the supply chain.

- The South Australian Department of Industry Innovation and Science (DISS) has produced a hydrogen workforce taxonomy, which has mapped occupations to existing ANZSCO roles.

DIIS has also built a bottom-up workforce model, which projects the jobs and occupations required to build and operate the SA hydrogen project pipeline to 2030.

- The NSW Government has recently agreed to lead the NHS v1 task previously allocated to the SA Government. NSW will deliver a national top-down workforce model based on the DIIS work. This can then be used to produce detailed workforce and skill capacity analyses for a given REZ. These analyses might be based on the existing project pipeline or a detailed projection to understand the direct workforce and skills impacts on a region, and the education and training requirements. In turn, this may inform decisions regarding the siting of hydrogen projects.

It is important to note that regional Australia faces unique challenges in attracting and retaining the skilled workforce needed to support an emerging hydrogen industry, including:

- **Location and lack of social infrastructure**: Attracting qualified graduates to the regions is challenging. The regions are remote and may have lower quality public services such as health and education when compared with metropolitan areas, which present barriers to prospective workers.
- **Housing**: Securing sufficient accommodation during the construction and operations phases of a project is a growing challenge. An influx of workers can affect local house prices, adversely impacting locals who are priced out of their communities.
- **Training capacity**: While the clean energy industry is already experiencing a critical lack of training capacity, notably in electrical trainers, this issue is amplified in the regions. Registered Training Organisations require additional support to expand their competence and offerings in relevant fields, which includes the availability and maintenance of key training equipment and environments. Low population density also provides thin training markets.
- **Worker mobility**: Workers currently face barriers to mobility between projects. Lack of coordination of construction efforts can lead to boom-bust construction cycles, with protracted periods of unemployment.
- **Low population density**: While unemployment is low nationally, many regions are experiencing functionally full employment. A lack of underutilised capacity means that increased demand will pull local workers away from existing opportunities. Locals may have trouble in accessing trade labour such as electricians or plumbers.
- **First Nations**: NZAu found that 43 per cent of projects would need to be built on land covered by Native Title. This presents a unique opportunity for projects to establish partnerships with local First Nations people and contribute to the just transition, but may also present challenges and increase discontent if managed poorly.

These challenges could culminate in major impediments to achieving and maintaining social licence, which will only increase over time with growing scale. They are also largely outside of the scope of developers to solve, and will require a high level of coordination and cooperation between federal, state, local governments and communities.

Skills and training

Research to date has found that there are few new roles with entirely new job descriptions and associated new skills required to support the emerging hydrogen industry. However, there is a growing and increasingly urgent need for new training capacity and offerings to be developed.

In the short term, the LNG industry will likely be a key source of workers for hydrogen projects in construction and production, although we note this industry already has difficulty finding workers. These roles will require upskilling to become familiar with the unique properties of hydrogen, handling processes, and the pressures at which it needs to be stored to work safely. Other impacted roles include gas fitters, plumbers, process operations and pipeline welders. There are also significant impacts for roles such as automotive mechanics and electrical trades that are currently unfamiliar with safely working with gases in general, and hydrogen specifically.

There are no tertiary degrees dedicated to hydrogen offered in Australia, and only six VET training products, said to cover only 15 per cent of the hydrogen-specific capabilities required by industry. The VET products are new units of competency created for the national Gas Industry Training Package that focus on commissioning and maintaining electrolysers and working with gas storage systems. Of note, there are no qualifications in the automotive industry which reference hydrogen, and no training available in fuel cell electric vehicles for drivers or other transport workers in Australia.

In the short term, we need a suite of micro-credentials to address skills gaps while training packages and other programs are developed. Deakin University is currently developing these micro-credential products to provide coverage for a range of competencies, including hydrogen fundamentals, safety, emergency response, regulations, electrolysis and compression, fuel cells, appliance installation, batteries, transport bottles, fuel cell service and small-bore tubing skills.

National leadership will help align training options and products, which in turn requires a clear hydrogen regulatory framework.

Arup recommends the creation of a coordinating body that can define the type of skills required and work with federal and jurisdictional governments on health and safety (H&S) and environmental regulations to clarify expectations for hydrogen.[166] Among other things, the body would implement early workforce upskilling and transition pathway plans nationally and ensure collaboration with education institutions.

National coordination must also account for training trainers, because skilled trainers with extensive hydrogen knowledge and contextualised workplace skills will be difficult to find and competitive to recruit. Education and training providers may need to upskill trainers from other related sectors, including fertiliser, ammonia, gas and plumbing.

Recommendation 34: Undertake capacity gap analyses to support regional development.

As part of the analyses recommended above for sectors and regions within Hydrogen Economic Zones, the Net Zero Economy Agency should oversee workforce capacity gap analyses of regional areas in which hydrogen infrastructure is being proposed.

[166] Arup (2023a), page 14.

Recommendation 35: Drive coordination of competency standards and training packages for hydrogen.

The Australian Government should coordinate jurisdictional training package development, collaborate with education institutions, and connect with regulators. This work should build on outcomes from the Clean Energy Capacity Study, and the hydrogen workforce modelling of the SA and NSW governments.

4.3.4 Connections and information to support supply chains and industry development

According to Arup's report for NERA, by 2040 the hydrogen equipment, technology and services (HETS) sector could account for one per cent of Australia's Gross Value Add (annual revenue of approximately A$30 billion), and 13,000 – 17,000 direct jobs.

Figure 18 from this report demonstrates the complexity of the hydrogen supply chain. For example, each of the basic grouping of aspects – such as feedstock, or equipment – has within it a range of options, old and new technology, and unprecedented scale. As already discussed, several of these supply chain elements have significant infrastructure requirements, complex manufacturing processes, RD&D developments, and a long-term view. All will require a skilled workforce. And the combination and integration of the different elements, including combining different business models presents a challenge to conservative financiers.

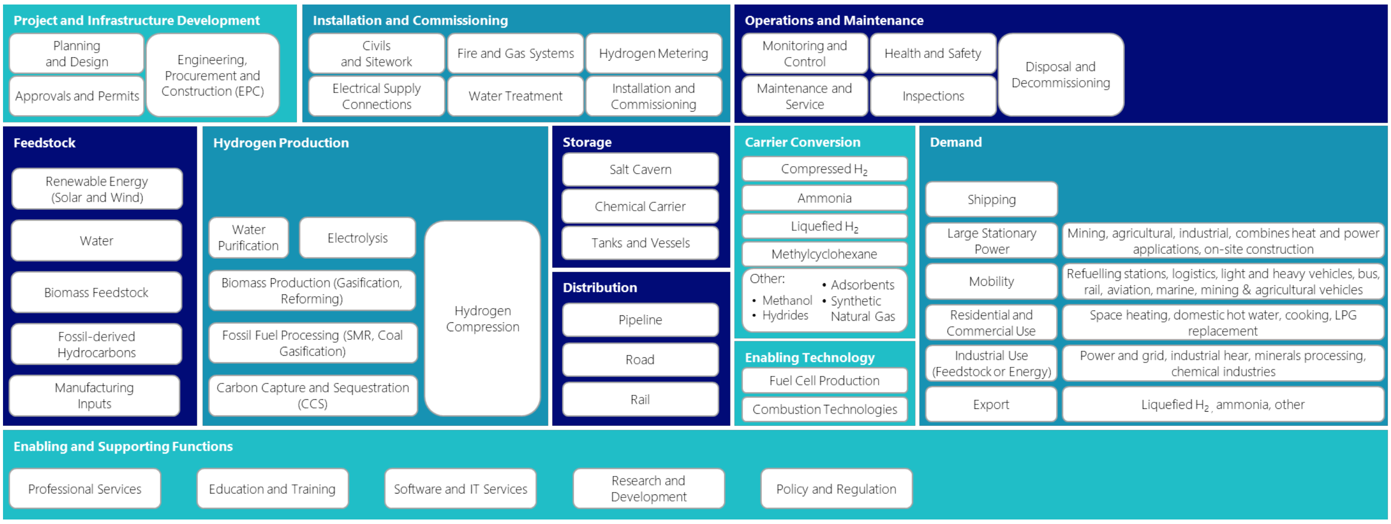

Figure 18: Supply chain framework; SOURCE: Arup (2023a), page 24.

To realise the HETS potential for Australia, there must be coherent policy to support industry sophistication across the disparate elements shown above. In many situations, each section of this supply chain is considered a complex and global industry in its own right. We have already suggested how policy can support financial, infrastructure, RD&D and workforce needs, and will now focus on the improvements to connections and information that may boost efficiencies and industry capability, as follows:

- Information flows, from disseminating lessons learned, to connecting established and newer industry players.

- Streamlining the various touchpoints required for businesses seeking to enter the industry and/or develop new projects.

Information flows

Information flows in the emerging industry provide some challenges, most obviously the central issue being little to share at this early stage. But it's also an opportunity for pre-competitive matters such as community engagement and capability mapping to be shared and progressed collaboratively. There is a market developing for consultants and other information brokers to make sense of the complexity, but this is for paying customers – governments and industry – in an already financially squeezed environment.

The Industry Growth Centres (such as NERA) were created by previous Australian Governments to facilitate such activities across Australia with governments, all segments of industry and academia. But there is now a gap in the market for the trusted broker.

ARENA's funding rounds already address information sharing to some degree. The return on investment for ARENA is the information obtained from grant participants, and material is publicly released. However, there is no overall repository of lessons learned or narrative produced, and the sharing can be expanded.

While industry itself can support better sharing of information – and AHC is well placed to take a lead – industry players do not have access to the material obtained by government through funding applications. For example, the hubs funding process undertaken by the Australian Government in 2022 would have been an excellent source of information at the time about the state of the market. This would have provided the government with an invaluable source of data that could be de-identified, aggregated and communicated more broadly in the form of a narrative about the readiness of the industry, of the challenges and developments in project finance and integration, and in useful next steps for industry and RD&D. (On this point, this process, and lessons learned since then in the formation of contracts to deliver on the hubs funding, should lead to key insights for the development of the refreshed NHS.)

The industry is taking the lead with HyCapability, a platform for businesses to promote Australian capabilities across the supply chain to domestic and global customers. HyCapability was created by NERA in 2021. NERA has since closed its doors, and HyCapability transitioned to AHC in July 2023. We are scoping the opportunity to expand HyCapability over the next 12 months to enable:

- Companies to connect with one another to support engagement. This includes domestic and international customers.
- Industry to track and measure the growth of the companies in the supply chain. This includes employment, revenue, number of companies entering the supply chain and where are they located.

We would welcome government support for this initiative, ideally through sustained financial support as provided to CSIRO for the Hydrogen Knowledge Hub to provide this public good.

CSIRO's HyResource is an excellent source of general information, and we support this being well funded and resourced to inform on industry and policy changes. It has been a very helpful tool to highlight to domestic and international interested organisations how the Australian hydrogen pipeline has grown over the past few years. The Hub could also be the logical home for future information sharing initiatives.

The need to provide for information sharing also relates to joining the dots across different government departments and government owned corporations. For example, transport departments tendering bus contracts need to engage in new ways with energy departments to ensure that policy to develop low emissions bus routes has also addressed how new electricity load on the grid is catered for. We are hearing about how, in some jurisdictions, an absence of policy connection and thinking at the procurement stages, or in the process to scale up past the trial stage, appears to leave bus companies to build and pay for electricity transmission upgrades. This is a situation for which they have neither planned, nor have expertise in.

We can expect that there will be similar experiences across other sectors if there is not better communication across different departments.

These are some of the reasons why we have recommended a cross-portfolio approach in the delivery of the refreshed NHS.

Finally, there is also the need to think about international connections to support our supply chains, both in their number and strength. As noted by Deloitte (2021), the resilience of the Australian economy is at risk because we are on the periphery of the global network and have insufficient global connections:

> We have very few industries connected to global networks and very few connections to other countries. The more high-quality connections a country has, the more its supply chains are prepared for and can capitalise on unexpected events. Businesses heavily reliant on strong but few connections are also inherently fragile. There is a need for Australian organisations to better connect and contribute to the global economy to improve their resilience.[167]

Similar to Australia's LNG investment boom of the early 2000s, project developers will quickly be seeking an Australian supply chain that is globally connected and competitive to solve technical challenges that will arise. Australia should aim to be exporting more than just molecules and green materials by 2030 and beyond; we have the opportunity to export our HETS expertise and products.

As noted in Arup's report for NERA, it is worth encouraging international manufacturers to onshore their manufacturing capabilities in Australia. This could take the form of "partnerships, competitive and innovative commercial models and eliminating or reducing structural barriers such as quotas".[168] Australia needs to ensure we grow a HETS industry in synch with the production and use cases for hydrogen. As Australian HETS capabilities are developed, tested and proven they will need Australian Government support to 'go global' and find new markets. Orica is a great example of a mining equipment, technology and services company that has grown to become a global leader in its field; Australian industry and governments need to ensure the emerging hydrogen industry uncovers and fosters equivalent companies.

[167] Deloitte Access Economics (2021), page 41.
[168] Arup (2023a), page 13.

Recommendation 36: Support a lessons learned repository through CSIRO's Knowledge Hub.

The Australian Government should expand the remit of CSIRO's Knowledge Hub to collect lessons learned and provide key messages to a public audience in a digestible and consistent way. This will need to align with the intent and values of the refreshed NHS, and current and future ARENA information collection practices and format.

Recommendation 37: Support the Australian Hydrogen Council to expand the scope of HyCapability.

The Australian Government should work with, and co-fund, AHC to align the development of HyCapability to help deliver on the objectives of the refreshed NHS through becoming a globally leading platform to highlight Australian capability and enable business connections domestically and internationally.

Case management and streamlining permissions

Our members and other stakeholders regularly raise concerns about the time to go through permitting processes, and this has been raised with AHC by international partners as well. This is a much larger issue than just hydrogen, and we note that other jurisdictions are developing responses to their own version of this problem, such as:

- Establishing a single point of contact for streamlined permitting processes, such as the Renewable Energy Directive (REDII) which requires Member States of the EU to designate a "one-stop shop" for granting permits, and which covers the operation of renewable generation assets. South Korea has also introduced a licensing system (including a one-stop-shop approach) intended to reduce the period for project development.[169]
- Mandated maximum lead times to grant permits with additional discretionary time allowances:

> In December 2022, the European Union issued new rules, under which Member States must speed up permitting for all new wind energy projects. They must now grant permits to repowering projects within six months, including the EIA and grid permits. If repowering results in a capacity increase of less than 15 per cent, the grid connection should be permitted within three months. [170]

In section 4.1 we recommended the creation of hydrogen economic zones and suggest that these could at least provide boundaries for future streamlining attention. We note that this could also incorporate shared infrastructure corridors for streamlined approvals, as suggested by Arup for the NHIA:

> Linear infrastructure corridors must navigate numerous land parcels and account for landowners increasing the risk of incompatible land use and/or impacted stakeholders. Designated shared infrastructure corridors provide an opportunity to streamline approvals for projects and minimise potential impacts on surrounding land use. [171]

[169] International Renewable Energy Agency (2023), page 74.
[170] Ibid.
[171] Arup (2023b), page 130.

There is also a need for streamlining across regional boundaries to support investor decision-making and develop infrastructure and generation investment propositions to attract private and institutional capital (as discussed in section 4.3.1). A range of funding support packages and programs have already been announced by Australian governments, aimed at supporting renewable energy projects, potential hydrogen projects, and targeted industry and skills development. There is currently no national mechanism for a streamlined approach to applying for programs, coordinated regulatory approvals or applications for funding that can combine grant and loan applications. There should be a ‘one stop shop’ for permitting support and packaging to simplify investor decision-making and to develop infrastructure and generation investment propositions to attract private and institutional capital.

Recommendation 38: Create a ‘one stop shop’ and case management to assist with funding and permissions.

The Australian Government should establish a ‘one stop shop’ approach to permitting support and packaging financial options for hydrogen and related low emissions infrastructure.

This should include a case manager within government to assist project developers and funders to tie all potential sources of support together, as well as assist in the coordination of planning and approvals.

4.3.5 Research, development and demonstration

In its HETS report, Arup assessed the technological readiness levels (TRLs) of key hydrogen technology and the opportunities for further development in Australia. [172] A TRL of 9 and above is usually considered commercially scalable.

Arup found that for electrolysis and fuel cells there are “opportunities for suppliers to innovate and produce competitive equipment if adequate investment is provided”. The main example used is solid oxide electrolyser technology (TRL 7), which has better electrical efficiency (~90 per cent) compared to traditional PEM and alkaline fuel cells (60-75 per cent). Solid oxide electrolysers do not currently operate in reverse as fuel cells, but they could.[173] The benefit of this technology is also that it does not require rare earth materials, which offers “a significant advantage over existing alternative technologies when considering supply chain material constraints”.

Further, PEM electrolysers require PFAS ionomers, which are being phased out in the EU and likely to be regulated out in the US by the EPA. There is currently no acceptable alternative to using PFAS in PEM electrolysers,[174] which could also be an RD&D opportunity.

RD&D can also seek to improve the efficiency of critical mineral use, and so reducing volumes required for electrolysis and fuel cells. The US has also identified recycling critical minerals as an RD&D opportunity and has provided funding toward this.[175]

Hydrogen carriers and storage are also important for further work, with Arup advising that hydrogen storage “is one of the primary technology challenges for large-scale hydrogen production”, requiring

[172] Arup (2023a), page 65.
[173] Ibid., page 66.
[174] US Department of Energy (2023a), page 46.
[175] Ibid., page 64.

89.5 kt storage in Australia by 2040, which costs up to A$0.7-$0.9 billion (for salt caverns and methylcyclohexane, a liquid organic hydrogen carrier).[176] Given that the NHIA model optimised for salt caverns and MCH (at TRL 6), these developments are vital.

Further, CSIRO has recommended several programmes of work to develop the knowledge base for hydrogen storage, as well as RD&D to improve compression and liquefaction processes and storage to reduce costs and manage boil-off. This could include improving the energy efficiency of liquefaction and using new designs or materials for tank insulation.[177]

The Arup report for NERA suggests that in the near term, government should:

- Ramp up investment in R&D of novel and emerging electrolyser and fuel cell technologies to improve asset lifetimes, efficiency and cost. Early investments offer large long-term payoff potential.
- Undertake a detailed evaluation of Australian technologies within other attractive supply chain nodes. For example, in hydrogen storage (e.g., safe and low-cost hydrogen storage technologies), salt cavern technology, alternative carriers, MCH conversion technology, and in transport, carbon capture and storage (CCS), MCH and liquid hydrogen tankers.
- Accelerate investment into nearer-term technologies close to commercial viability to bridge the gap. This includes technologies with high Technology Readiness Level (TRL) ratings, such as liquid hydrogen storage tanks and tankers for distribution.[178]

Looking more at the TRL of large-scale storage, Dutch organisation TNO has set out the different lead times for salt caverns and reservoirs, as shown in Figure 19.

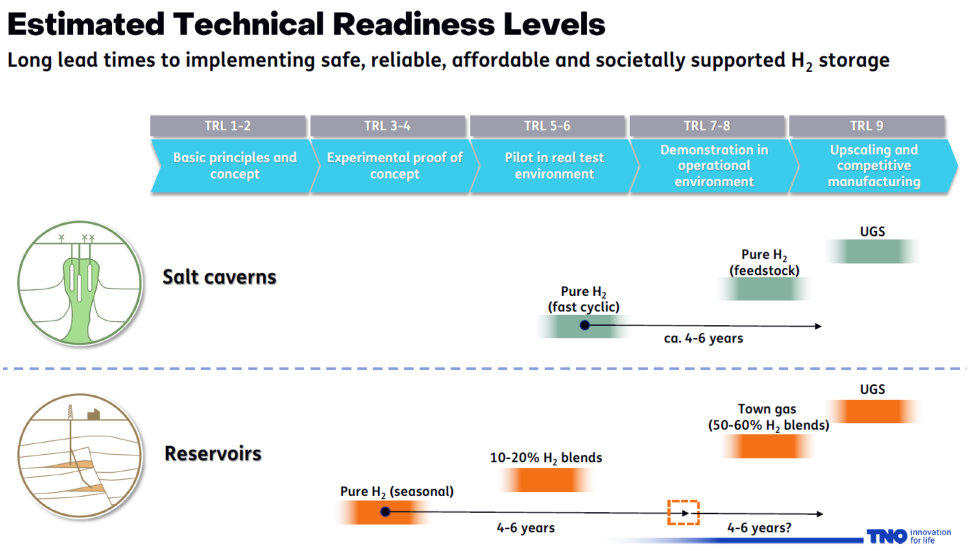

Figure 19: TNO assessment of salt cavern and reservoir TRLs (note UGS is underground gas storage, which is different from underground hydrogen storage, or UHS); SOURCE: Groenenberg (2023).

[176] Arup (2023a), page 91.
[177] Srinivasan et al. (2023), pages 116-117.
[178] Arup (2023a), page 14.

This shows that while underground gas storage in underground reservoirs and salt caverns is at an advanced TRL, there is still at least 4-6 years for 100 per cent hydrogen to be stored at a similar level of operational and financial confidence.[179] Given that Australia does not yet have the required salt cavern capacity (as discussed in section 4.2.6) this can complicate matters further and indicates that a direction needs to be set urgently.

Hydrogen has enormous potential to support e-fuels of the future, particularly methanol for shipping and sustainable aviation fuels. However, this requires a source of clean CO_2. Direct air capture (DAC) is one of several scalable options that are likely to be acceptable in the long term, but it is currently very expensive and energy intensive. RD&D opportunities exist to innovate in carbon capture technologies and understand performance parameters under different conditions.[180] For methanol, the process for alternative methanol production shows a TRL of 8–9, as the synthesis as well as the alternative hydrogen production have a TRL 9. However, economic hurdles still need to be overcome.[181]

There are RD&D opportunities in industrial processing as well:

- **Iron**: Using hydrogen to reduce iron ore to iron through the DRI making process. DRI with natural gas is already established and working on a large scale. DRI with hydrogen has yet to be proven on a large scale and is said to be at TRL 5-8,[182] and available from 2030.

  Also, Australian iron ore is predominantly hematite-goethite, which, while a higher-grade ore, is not ideal for the DRI process because processing it to the required standard is currently difficult. Magnetite is a lower grade ore but can be processed (a process called beneficiation) for use in DRI processes. As noted by the Australian Industry Energy Transitions Initiative:

  > Developing new methods of processing hematite-goethite for its use in green steelmaking (especially DRI-EAF) could allow continued use of existing mines and infrastructure and preserve Australia's current iron ore markets. The processing of hematite-goethite for use in DRI-EAF technologies is poorly understood and will require R&D to enable commercially viable methods. Furthermore, yield losses during beneficiation will need to be addressed so as to not decrease the economic viability of this route.[183]

- **Alumina**: The Bayer process of refining bauxite into alumina requires very high temperatures, currently reached with combusting natural gas. Hydrogen can substitute for natural gas, where this is at a TRL level of 6.[184] The TRL for a hydrogen burner for process heat is 4-5.[185]

- **Ammonia**: The Haber-Bosch process and water electrolysis for hydrogen production are at TRL 9, but the combination and the complete process concept is said to be 8–9.[186]

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[179] See also Srinivasan et al. (2023), page 21.
[180] See IEA (2022).
[181] Neuwirth et al. (2022), page 4.
[182] Ibid. and IEA (2022).
[183] Climateworks Centre and Climate-KIC Australia (2023), page 56.
[184] Deloitte (2022).
[185] Neuwirth et al. (2022), page 4.
[186] Ibid., page 14

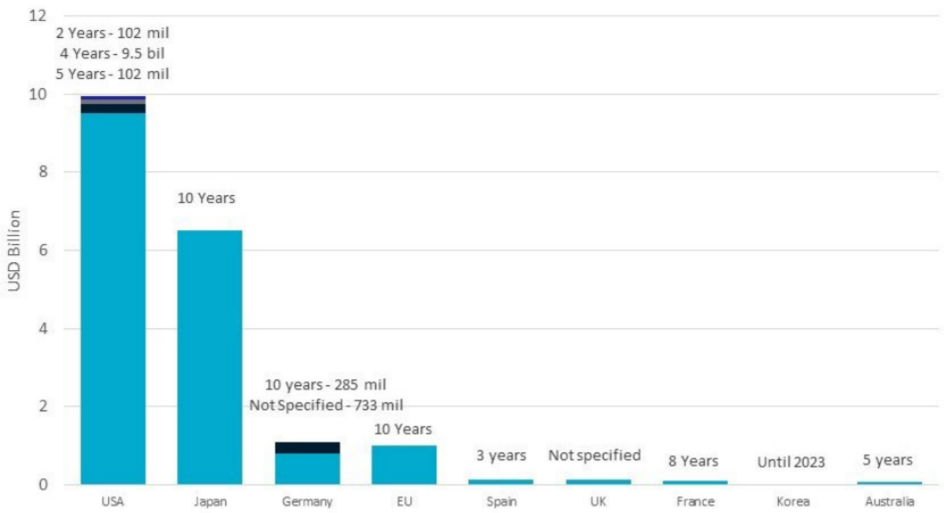
- **Cement**: Hydrogen can be used to heat lime at 900-950°C, and melt the material at 1,450°C. The TRL for a hydrogen burner in a rotary kiln is 4-5.[187]

We note that there are some challenges in positioning Australia to take up the RD&D challenges. Initiatives and funding for RD&D in Australia appear fragmented, uncoordinated, and some way behind other nations.

Starting with the initiatives, the current research landscape comprises CSIRO and many separate research institutions, generally universities. CSIRO has not provided overall scientific direction and advice since its hydrogen roadmap in 2018.[188] While the Office of the Chief Scientist took a leadership role in the NHS v1, this office has not had an apparent role since 2019.

Funding also appears to be less than ideal. On RD&D funding, CSIRO authors developed a comparison as of 2021,[189] as shown in Figure 20. The funding shown for Australia is significantly lower than the US, Japan and Germany. It is difficult to judge the actual funding for Australia from this graph, but the *State of Hydrogen 2022* report shows that public funding for hydrogen R&D in 2021 was around A$180 million, *dropping* to around A$95 million in 2022.[190]

Obviously, the economies of the US, Japan and Germany are several times that of Australia, but it seems that Australian public expenditure on RD&D is misaligned with our ambitions to be a world leader in hydrogen developments.



Derived from IEA (2021) Global Hydrogen Review 2021; IEA (2021) Net Zero by 2050 – A roadmap for the Global Energy Sector; Yoon Y (2020) Current Status of the Korean Hydrogen Economy. H2Korea and MOTIE; Infrastructure Investment and Jobs Act, H.R. 3684 (2021) 117th Congress of the United States of America.

Figure 20: Public funding for major R&D programmes; SOURCE: Delaval et al. (2022), page 13.

[187] Neuwirth et al. (2022), page 4.
[188] Bruce et al. (2018).
[189] Delaval et al. (2022), page 13.
[190] Australian Government (2023a), page 38.

The US Hydrogen Strategy provides an overview of the modelling and systems analysis work in the US, as shown in Figure 21. This is clearly an extensive programme of work, and reflects the significant funding of US research, most notably via the DOE National Laboratories.

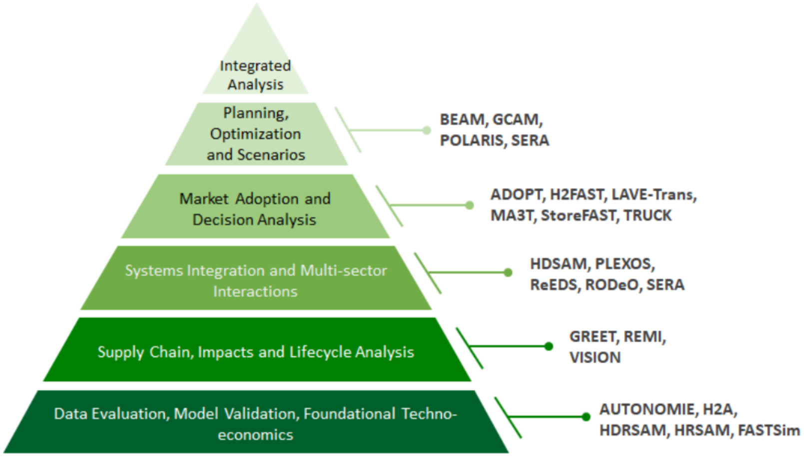


Figure 42: A suite of tools and models support systems analysis work from fundamental model validation and techno-economic work, to planning, optimization, and integrated analysis.

ADOPT: Automotive Deployment Options Projection Tool; **Autonomie**: (a vehicle system simulation tool); **BEAM**: Behavior, Energy, Autonomy, and Mobility; **FASTSim**: Future Automotive Systems Technology Simulator; **GCAM**: Global Change Assessment Model; **GREET**: Greenhouse gases, regulated emissions, and energy use in Technologies Model; **H2A**: The Hydrogen Analysis Project; **H2FAST**: Hydrogen Financial Analysis Scenario Tool; **HDRSAM**: Heavy-Duty Refueling Station Analysis Model; **HDSAM**: Hydrogen Delivery Scenario Analysis Model; **HRSAM**: Hydrogen Refueling Station Analysis Model; **LAVE-Trans**: Light-Duty Alternative Vehicle Energy Transitions; **PLEXOS**: (an integrated energy model); **POLARIS**: (a predictive transportation system model); **ReEDS**: Regional Energy Deployment System; **REMI**: Regional Economic Models, Inc.; **RODeO**: Revenue Operation and Device Optimization Model; **SERA**: Scenario Evaluation and Regionalization Analysis; **StoreFAST**: Storage Financial Analysis Scenario Tool; **VISION**: (a transportation energy use prediction model)

Figure 21: US systems analysis; SOURCE: US Department of Energy (2023b), page 76.

To our knowledge, there is no equivalent in Australia for these tools and models, with analysis instead completed on an ad hoc, fragmented and often confidential/private basis.

In February 2023, CSIRO held its inaugural Australian Hydrogen Research Network (AHRN) conference, where the various research topics and issues were canvassed over two days. The organising committee of the AHRN conference has published key insights from the proceedings and follow-up activities.[191] Paraphrasing the report, these include suggestions for:

- **Priorities**: Clarity on what's important; for example, whether there should be more research in Australia on developing electrolysers or focus on the advanced electrolysis field developing overseas:

  At this early stage of the hydrogen industry, Australia needs to clarify the prospects for the industry and commit to our emerging competitive advantages. Research needs to focus on accelerating Australia's strengths and address supply chain gaps to determine what technologies we should develop here in Australia, what technologies we should adopt from overseas, and what our investment framework overall should be.

- **Coordination**: Improved coordination between researchers, industry, and policy makers.

[191] CSIRO (2023).

- **Critical materials**: Critical mineral requirements for the hydrogen industry of the future and can they be sourced locally, reliably, cheaply, and quickly. Understand what alternatives are available.
- **Integration of systems**: Assessments of how renewable hydrogen can be optimally integrated into energy systems during the energy transition.
- **Industrial use of hydrogen**: Research on new industrial applications of hydrogen might benefit from system-level integrative opportunities (energy co-location including excess heat, chemical by-product streams etc.).
- **Distribution and storage**: Research and innovation into distribution and storage to reduce costs and enable new storage and transport options along the supply chain.

The overall recommendations from the AHRN convenors (including the Australian Chief Scientist) are relevant to the refreshed NHS, with the first recommendations suggesting there needed to be "a mechanism to help identify, monitor, and refine Australia's hydrogen RD&D priorities", which might be led from the Office of the Chief Scientist, and reported in the refreshed NHS.

As a final point, it must be noted that not all RD&D occurs in university labs or in large corporates. Australia can harness industry solutions through our start up community. Over the past decade, this community has been growing its capability from working with mining, renewables, oil and gas, Industry 4.0 and on other climate tech related challenges. Startup Muster will be undertaking its annual survey (funded through Atlassian and NSW Government) of the Australian start up ecosystem and has agreed to specifically ask about hydrogen technologies.

Startups are usually providing a software or hardware solution for industry. Given software is IT based, its testing, prototyping and iterating processes are relatively cheaper than hardware solutions. Hardware innovations such as electrolysers and storage are expensive to commercialise as they need bespoke components and machinery to build.

Anecdotally many startups and SMEs have expressed that coordinated and funded soft common user infrastructure, such as testing facilities with all the adequate machinery and other equipment, would not only save them time and money but could be a draw card for international startups to set up in Australia. Technology accelerators and incubators exist across a range of emerging industries; however, there are no dedicated comparable programs for clean tech more broadly or hydrogen specifically. Startups and SMEs are not seeking free access to testing facilities and are willing to pay for access; the issue is that there is no facility and therefore unnecessary and expensive duplication is occurring across Australia, and opportunities are missed.

Recommendation 39: Develop and articulate RD&D priorities for hydrogen.

The Net Zero Economy Agency should work with CSIRO and the Office of the Chief Scientist to develop RD&D priorities in line with broader revised NHS priorities, and based on commercial opportunities, with a view to make the emerging industry resilient to supply chain issues. Priorities should include:

- Novel and emerging electrolyser and fuel cell technologies, addressing asset lifetimes, efficiency and cost.
- Storage, particularly salt caverns, depleted gas reservoirs and MCH.

- Industrial processing to support iron, alumina, steel and cement production.
- Forms of sustainable/clean carbon capture for the production of e-fuels, including direct air capture.
- Opportunities and capacity to develop natural hydrogen resources.

Recommendation 40: Work with CSIRO, the Chief Scientist and other RD&D leaders to deliver hydrogen RD&D priorities and knowledge sharing.

Based on hydrogen priorities established in Recommendation 39, and in collaboration with CSIRO, the Net Zero Economy Agency to task and resource the Office of the Chief Scientist to lead a hydrogen RD&D work programme that:

- Quantifies required Australian public investment in hydrogen RD&D to 2040.
- Establishes timeframes and milestones for delivery.
- Establishes and manages a knowledge sharing approach with key international parties, such as the US DOE National Laboratories and the German Fraunhofer Institute.
- Aligns with other support for Australian innovation such as that provided through the Commercialisation Action Plan and National Reconstruction Fund, as well as include dedicated funding for attraction of cleantech scale ups looking to expand to Australia, particularly from the Asia Pacific region.
- Establishes annual public reporting on each of the above.

Recommendation 41: Establish common testing and prototyping infrastructure.

The Australian Government should consider the creation of soft common user infrastructure – such as testing and prototyping facilities and shared office space – that can facilitate growth through reducing barriers to market for emerging technologies.

4.3.6 Regulation

The regulatory framework for the hydrogen sector can be seen as the foundation for all industry development. It is policy made legal.

Regulations obviously create compliance obligations in operations – this is traditional regulation to avoid or prevent harm. Regulations of this type fall into the following general categories:

- Safety regulation, such as workplace health and safety and hazardous/dangerous goods handling.
- Environmental regulation, such as exclusion zones in planning, access and use of water, waste disposal and asset decommissioning.
- Economic regulation, such as revenue caps on what electricity and gas networks can bill from customers, and access regimes for common use infrastructure.
- Competition and consumer regulation, such as rules to support competition and protect consumers from misinformation.

Regulations can also be market making; rules can set the parameters now for what is investable, such as regulations for acceptable carbon emissions in hydrogen production, or targets that force users to switch fuels and so create demand. The point of these regulations is to prevent harm as well, but a more long-term and diffuse version of harm is intended here, where the harm could be argued to eventuate if policy objectives weren't met.

Clearly future regulation might also address such matters as domestic reservation policies and royalties. These could be justified on broader public interest grounds.

Figure 22 shows the various topics and types of regulation. One can assess the entire regulatory landscape through the lens of any one topic. While this list is not exhaustive, it provides an illustration of the many issues for hydrogen projects, across different regulation types and jurisdictions.

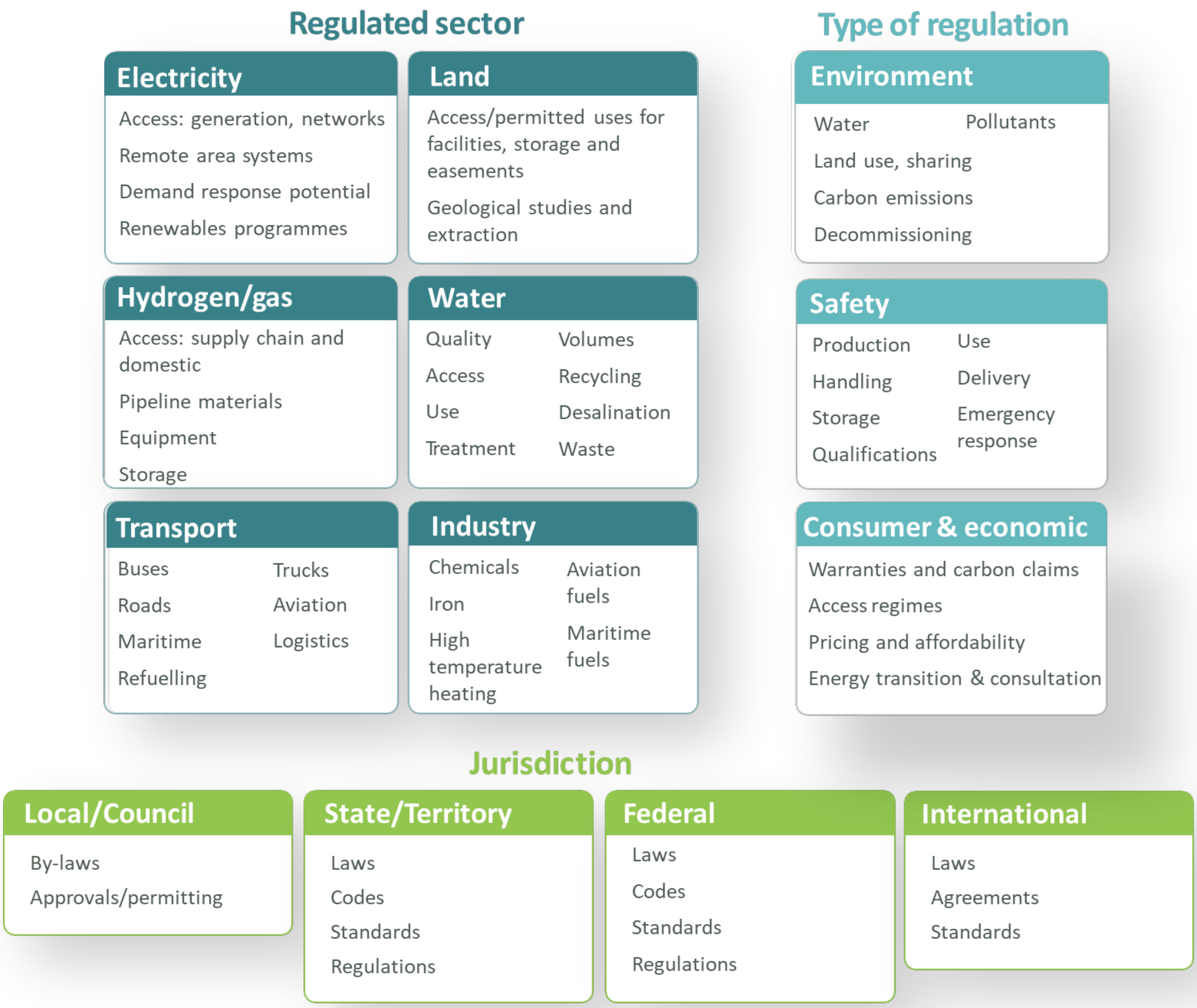


Figure 22: Categories and topics for regulation.

Regulation to prevent harm

The Australian Government has compiled federal information about regulations that can affect hydrogen projects,[192] and has also provided an overview of issues identified late in 2022.[193] This material is of some use, but only as a checklist at the highest level, and obviously not for state and territories.

We note the proposed work that will proceed in the coming months to develop National Hydrogen Codes of Best Practice in the following areas:

- Hydrogen Production
- Ammonia Production
- Hydrogen Refuelling
- Hydrogen Appliances, Plant and Equipment
- Ammonia Appliances, Plant and Equipment.

We understand that these codes of best practice will address existing regulations, rather than write new rules to fill gaps. While we welcome the work, it is not clear (yet) why these topics were chosen as the basis for codes of practice, what coverage is likely for safety, environmental, economic or competition/consumer matters, or the likely detail (particularly for those topics other than refuelling).

Overall, regulatory harmonisation remains the ideal across sectors. We note the NHS v1 Agreement 29 related to coordinated regulatory reviews, but the delays in this work programme have led to jurisdictions following their own paths. (On this, we also note that the ongoing separate state consultations plus the federal consultation are creating stakeholder consultation fatigue. This is particularly problematic given the industry is pre-commercial and there are not generally specialist staff in industry who can commit to participating. There is a need for a much stronger commitment to coordination and harmonisation if industry is to provide meaningful contributions to the process.)

There is no (public) gap analysis that can help direct attention and efforts to necessary regulatory reform, or to at least provide transparency to stakeholders on the work undertaken to date. It is also not clear how any regulatory gaps are likely to be filled.

From AHC's observation, the key regulatory gap issues that have arisen to date include:

- **Regulatory barriers for vehicle adoption in heavy transport:** Australia imports over 90 per cent of its medium trucks from Japan, and around two thirds of heavy trucks from Japan or Europe. However, Australian design standards are different from all overseas markets: Australian trucks cannot be wider than 2.5m, which is misaligned with Europe (2.55m) and North America (2.6m). Vehicles based on EU or US market designs are around 60 per cent of new heavy trucks, and the cost to redesign for our market is estimated at A$15-$30 million a year.[194] Future battery electric vehicles and FCEV trucks will be even more costly/difficult to redesign. We recognise the work that the Australian Government has been undertaking to

[192] Department of Climate Change, Energy, the Environment and Water (2023a).
[193] Department of Climate Change, Energy, the Environment and Water (2022).
[194] Department of Infrastructure, Transport, Regional Development and Communications (2021), page 5.

address the international harmonisation of the Australian design rules (ADRs) and urge that these standards be further reviewed to lessen the regulatory barriers, within reason and while upholding safety.

Additionally, steer axle mass concessions should be considered for heavy ZLEVs. ZLEV technology is generally heavier than an ICE, meaning that this weight cuts into the mass capacity that would be allocated to payload.[195] As a short-term incentive to combat this deterrent, the Australian Government should implement an axle mass concession for commercial heavy ZLEVs, so as to allow for technical non-compliance for vehicles currently in operation. [196] This is a mechanism that has been utilised in comparable overseas jurisdictions, such as the EU and California.

Heavy vehicles already operate at a range of dimensions and weights, including through individual road access permit approvals and the Performance Based Standards scheme. However, this approach has a high regulatory burden which disincentivises use of these vehicles. Incentivising a large-scale shift to heavy ZLEVs will require these vehicles to become widely available and without a payload or regulatory penalty, which can be achieved with an axle mass concession.

- **Industrial processes hydrogen handling**: Stakeholders have reported a lack of clarity on a range of hydrogen handling rules for new uses, particularly how hydrogen should be handled as a fuel in industrial plants, how to plan for environmental matters such as water use, and what might be acceptable NOx emissions thresholds when using hydrogen as a fuel source. These matters at the least indicate a need for industry outreach on these issues but are probably also a matter for regulatory gap analyses and risk management.
- **'Hydrogen ready' definitions**: We note that the NHS v1 included an agreement to "develop and incorporate 'hydrogen-ready' capabilities into planning and regulatory approvals mechanisms where required" (Agreement 31). This has not been progressed to our knowledge. The issue is gaining attention: we are hearing concern from high temperature process businesses on this matter, where they are asking for a precise and unambiguous definition of 'hydrogen-ready' for boilers and burners. This definition will eliminate any uncertainty for end-users who purchase the equipment, ensuring that they understand precisely what steps are required to enable the equipment to burn hydrogen with full efficacy.

  There is also a precedent recently reported in the UK of 'hydrogen-ready' statements being misused and misunderstood by small to medium gas customers.[197]
- **Cost recovery from consumers for major upgrades to regulated assets**: We have already suggested in Recommendation 20 that energy policy is amended so that policy initiatives to grow the hydrogen industry are not funded from small consumers on their energy and gas bills. This currently relates more to special cases of government policy but in the future will also be about infrastructure cost recovery for both electricity and gas assets. This relates to

[195] Lee et al. (2023), page 6.
[196] See Electric Vehicle Council and Australian Trucking Association (2021), page 14, and Terrill, Burfurd and Fox (2022), page 30.
[197] Competition Markets Authority (2023), page 6.

the fitness-for-purpose of the AER regulatory reviews for the changing gas and electricity assets in the transition. The current five-year regulatory resets are based on a view that assets are required, maintained indefinitely, and they even grow. This reflects an incremental approach to change and regulation, with increments only in a forward direction. The regulations operate on the basis that end use customers are the recipients of value and that assets are essential services.

Several of these basic premises are being questioned now, such as the accelerated move toward electrification and how to responsibly manage and recover costs for gas network assets that may be underutilised.[198] As the AER has noted: "In the longer term, it may be that the gas access arrangement review process is not enough, or not the best avenue, to deal with the … safety and equity issues that may arise" from a transition away from natural gas.[199]

While these are not specifically hydrogen matters, hydrogen has a role in the future of each set of assets (and new hydrogen pipelines may or may not be regulated assets). As discussed in section 1.4, there has been little public discussion about who pays for new assets and how costs are recovered to pay for existing sunk assets so they aren't stranded. The assumption appears to be that energy bills will continue to reflect major connected electricity and gas infrastructure builds.

Recommendation 42: Undertake and publish a regulatory gap analysis and programme of reform.

The Net Zero Economy Agency should task and resource DCCEEW and the jurisdictions to identify regulatory gaps and reform opportunities and lead a programme of reform to meet the refreshed NHS targets and milestones. Further engagement with international jurisdictions is encouraged.

Recommendation 43: Harmonise Australian heavy vehicle regulation with international standards.

The Net Zero Economy Agency should task and resource DCCEEW to work with the Department of Infrastructure, Transport, Regional Development, Communications and the Arts and jurisdictional bodies to support lessening the regulatory and administrative burden for ZLEVs, especially concerning width and axle mass, through the harmonisation of standards with international markets and a ZLEV axle mass concession.

Recommendation 44: Develop harm prevention regulations to support industrial sectors.

The Net Zero Economy Agency should task and resource DCCEEW and the Department of Industry, Science and Resources to consult with priority industrial sectors to understand the different regulatory needs across the following dimensions of harm reduction, and lead national rule-making as far as possible:

- Safety, such as how hydrogen should be handled as a fuel in industrial plants.
- Planning and environment, such as use of water from environmental flows for hydrogen production, or acceptable NOx emissions thresholds when using hydrogen as a fuel source.
- Economic, such as possible future shared pipelines and the ease and cost of access.

[198] For example, see Wood, Reeve and Suckling (2023).
[199] Australian Energy Regulator (2023), page 8.

- Competition and consumer regulations, such as establishing a definition of 'hydrogen-ready' for boilers and burners.

Recommendation 45: Work with AEMC and AER on cost and price models to ensure affordable energy bills.

DCCEEW should coordinate activity with the AEMC and AER not only on maintaining a separation of new hydrogen policy initiatives from small customer energy bills, but also to maintain visibility over key future assets required for hydrogen and the effect of hydrogen on electricity and gas asset values, maintenance and growth.

Regulation to make markets

The Australian Government has undertaken significant stakeholder consultation on the development of a carbon certification mechanism. The AHC is broadly supportive of this process, given its alignment with the key principles of ensuring that investment in new renewable energy generation is sustained (and increased) as well as enabling the price signals for the domestic and international sale of hydrogen and other products.

The AHC also welcomes the budget announcement for the Clean Energy Regulator to develop the implementation guidelines for the Guarantee of Origin (GO scheme)[200] and the inclusion of an assessment criterion on compliance with the GO scheme in the Hydrogen Headstart proposed funding guidelines.[201] The AHC is supportive of the Australian Government's engagement to date, and its lead role in the negotiations of global standards at the IHPE.

However, we are concerned that there is little clarity about the process for the GO scheme to be implemented, which affects how businesses plan for future compliance.

There is also limited information on Australia's overall carbon accounting approach. There will be a GO scheme, but Australia lacks initiatives such as CBAMs and other climate supportive tax measures. Other countries are developing these measures, and global policy and legislative trends indicate that the remit of carbon border adjustment schemes will increase to cover a range of products beyond fossil fuels or their replacements such as hydrogen, ammonia and methanol.

For example, the first phase of the EU's CBAM (from October 2023) covers cement, iron and steel, aluminium, fertiliser, electricity and hydrogen. The *Prove It* Act in the US, should it be passed, would require the Department of Energy (DOE) to study and compare the carbon emissions of products that are produced in the United States vs. other countries. Within two years, the DOE will publish a study comparing the carbon output of U.S. goods, like aluminium, cement, crude oil, fertilizer, iron, steel and plastic, to goods made elsewhere, paving the way to a CBAM.

The Australian Government has a role to play in ensuring that the international standards for CO_2 reporting and monitoring that are likely to apply to all traded goods at some point in the future are developed in a timely manner to provide clarity to producers and manufacturers, as well as to agree on the oversight bodies and independent auditors of these global schemes.

There is also a need to clarify process and timing to align with accelerating global demand for low carbon fuels across diverse sectors. For example, since 2018, large ships over 5,000 gross tonnage

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[200] Department of Climate Change, Energy, the Environment and Water (2023b).
[201] Department of Climate Change, Energy, the Environment and Water (2023c).

loading or unloading cargo or passengers at ports in the European Economic Area (EEA) have been expected to monitor and report their related CO_2 emissions and other relevant information:

> To ensure that the maritime transport sector contributes to the EU's increased climate ambition, the Commission is proposing to extend the scope of the EU's Emissions Trading System to cover CO_2 emissions from large ships (above 5000 gross tonnage), regardless of the flag they fly. The extension will include all emissions from ships calling at an EU port for voyages within the EU (intra-EU) as well as 50 per cent of the emissions from voyages starting or ending outside of the EU (extra-EU voyages), and all emissions that occur when ships are at berth in EU ports.[202]

As of 2024, shipping companies will need to pay for the emissions they have reported in the previous year. The EU legislation has developed a phased approach: in 2025, they will pay for 40 per cent of the emissions reported in 2024; in 2026, they will pay for 70 per cent of their 2025 emissions, and from 2027 onwards, they will pay for 100 per cent of their reported emissions, the intention being to create a price signal and incentive for decarbonisation.

In July 2023, the EU passed regulations to mandate at least 1 per cent 'renewable-energy derived fuels' by 2034. The regulations also set emissions reduction targets on the shipping sector as a whole, including expectations of a 2 per cent reduction on 2020 levels by 2025, ramping up to 80 per cent reduction by 2050.[203]

Should Australian producers of methanol and ammonia wish to trade and supply marine operators looking to reduce their emissions (and therefore also their liabilities under this scheme) they have no mechanism for compliance. The methodology developed in Australia should be released in a timely manner to enable Australian producers to take advantage of this opportunity.

An additional consideration relates to the use of hydrogen for the decarbonisation of particularly hard to abate industries locally. As the transition of the power sector gathers pace, by the early 2030s, industry will become the largest source of domestic emissions, marking a generational shift and it is critical that policy development not only aid this transition but also speeds it up.

There is an opportunity for Australian governments to not only shore up manufacturing sovereignty, but also create a demand pool for clean products from the hard to decarbonise industries such as urea, ammonia, steel, aluminium and concrete, which for the foreseeable future will be confronted by a green premium.

Subsidising and incentivising the domestic purchase and utilisation of these products (for example, mandating the use of clean concrete in government-funded construction projects, green steel in offshore wind, clean urea to displace imports for agriculture) will strengthen not only these industries, but also enable downstream users of the materials (particularly trade exposed industries) to begin to decarbonise their supply chains. We can see this goes beyond hydrogen, and there is also international precedent. For example, the US General Services Administration has announced a pilot of new requirements for the procurement of substantially lower embodied carbon construction materials in GSA projects funded by the Inflation Reduction Act.[204]

[202] European Commission (n.d.).
[203] Parkes (2023).
[204] US General Services Administration (2023).

Recommendation 46: Clarify the next steps and fast-track the process to implement the GO scheme.

DCCEEW should implement the GO scheme as a matter of priority, or at a minimum, communicate a clear timeline for development and release. This should be aligned with international requirements wherever possible.

Recommendation 47: Support Australian-made clean products in hard-to-abate industries, supported by government procurement.

The Australian Government should create a dedicated subsidy scheme for Australian-made clean products in hard-to-abate industries, which will serve to increase uptake by the private sector. This can be supported by government procurement of these products to be used in any government funded projects.

Domestic reservation policies and future royalties

This type of policy thinking can also apply to the development of a domestic reservation policy, particularly for the purpose of ensuring the availability of clean hydrogen for use by priority industries (as described above). Such a scheme can be reviewed and extended if required, once the production of hydrogen has scaled and international trade of hydrogen and derivatives takes place in the absence of significant subsidy (likely to be late 2040s and beyond).

Whilst there are many reports prepared by consultants and thinktanks arguing that the sector will become competitive and profitable within ten years, in the absence of a very significant increase in the pricing of carbon in the very short term, this is highly unlikely. For context, although we have seen a significant uptick in the level of investment in renewable energy generation, the fossil fuels' share of global energy use was 86 per cent in the year 2000 and 82 per cent in 2022. This therefore means that in the medium term, governments globally (particularly in the developed world) will need to provide significant subsidies for clean fuel production to hasten the displacement of fossil fuels.

As a final point, while the NHS v1 decided to not change revenue arrangements for hydrogen at the time, a clearer signal may be needed now. In our view it is far too soon to be considering future royalties – particularly as the industry remains dependent on subsidy. However, government may want to start setting expectations soon to settle any perceptions of sovereign risk.

5 No regrets market development and support

The previous chapters addressed the ecosystem for large scale hydrogen production and use for key sectors but did not discuss market creation mechanisms or further demand case investigations that may be required.

This chapter fills that gap, and discusses the matters of road transport, industrial use, shipping, aviation and electricity as shown in green below.

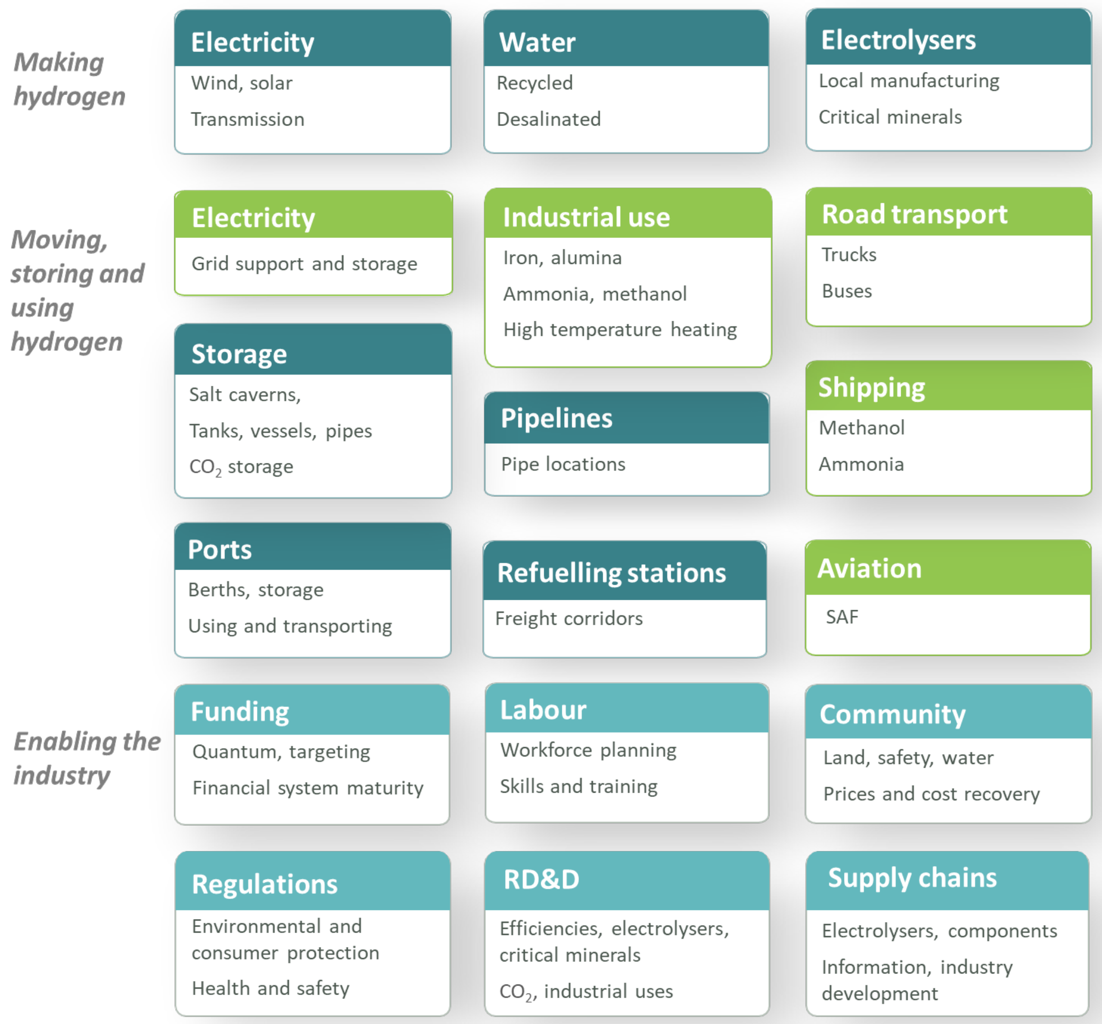

Figure 23: Areas for government policy and support for the emerging hydrogen industry.

5.1 Heavy road transport

As discussed in section 4.2.7, the NHIA and NZAu studies have shown the fundamental role of transport use of hydrogen for future hydrogen demand. Hydrogen is particularly useful for buses and trucks that must travel long distances, or where battery weight compromises effective payload. It is also suitable for commercial use, where effective range and recharging/refuelling times affect the bottom line.[205]

The problem is that Australia does not have a strategy or policy to support the adoption of zero to low emission vehicles (ZLEVs).

5.1.1 A national ZLEV strategy for heavy vehicles

In response to the National Electric Vehicle Strategy, a report by Adiona Tech[206] used the latest ABS vehicle data to illustrate why heavy vehicles warrant the focus of transport decarbonisation. While passenger cars represent a higher proportion of the Australian landscape, both in terms of volume and emissions total, at 75 per cent and 52 per cent respectfully, heavy vehicles are much less fuel efficient. To illustrate, articulated trucks represent only one per cent of the vehicles on Australian roads but make up 15 per cent of transport emissions. Furthermore, articulated trucks travel vast distances; 600 per cent more kilometres per year than the average passenger vehicle. Adiona Tech's conservative estimate suggests that transitioning one delivery truck is equivalent to almost six passenger ZLEVs. The benefit of decarbonising Australia's heavy vehicles is on a steeper scale and indicates an opportunity not yet recognised towards our net zero ambitions.

In order to take advantage of this prospect, Australia must first realise some of the factors that impact heavy vehicle transition.

The primary factor is that the heavy transport transition in Australia is naturally much slower than the transition for lighter transport. Australian trucks remain in use significantly longer than other countries, with an average age of 10-15 years. [207] The Grattan Institute[208] notes that approximately 14 per cent of Australian trucks on the road were built before 1996, when Australia had not yet implemented a pollution standard, and a further 12 per cent (1996-2002) were only required to fulfil the Euro I. This means that Australia's heavy transport topography holds an unbalanced proportion of outdated and heavily polluting vehicles that do not meet current standards, let alone ambitious targets. Australia therefore requires an array of support mechanisms to bring down the average age and consequently emissions of heavy vehicles.

However, when these older vehicles are up for replacement and Australia looks to decarbonise, unfortunately the supply of ZLEV technology for heavy vehicles also lags. The Truck Industry Council[209] estimates that truck technology is approximately five years behind passenger vehicles and there isn't yet a viable, commercially available ZLEV technology for freight on an ICE replacement

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[205] California Fuel Cell Partnership (2021), page 9.
[206] Adiona Tech (2023). This report is based on the most recent data from the Australian Bureau of Statistics - ABS (2020), *Survey of Motor Vehicle Use, Australia*, https://www.abs.gov.au/statistics/industry/tourism-and-transport/survey-motor-vehicle-use-australia/latest-release).
[207] Electric Vehicle Council and Australian Trucking Association (2021).
[208] Terrill, Burfurd and Fox (2022).
[209] Truck Industry Council (2022).

basis. This is where a fuel efficiency standard or ZLEV sales target for heavy vehicles could play a pivotal role in signalling Australia's appetite for heavy vehicle transition, incentivising the supply and affordability of ZLEVs.

Furthermore, heavy vehicles are generally a commercial asset and, more so than passenger vehicles, require a strong business case for the full lifecycle of the vehicle and recognition of risk. Approximately 80 per cent of truck businesses have five or less vehicles, therefore, the risk of transitioning even a single truck is a significant share of the business' operational capabilities. [210] In this case, the uncertainty concerning total cost of ownership and insufficient infrastructure is compounded, requiring substantial indicators and enablers to incentivise transition. There is an important role for the Australian Government to support these businesses in their transition, facilitating confidence and alleviating overheads through mechanisms such as subsidies, tax breaks and scrapping import duties for heavy ZLEVs.

The heavy vehicle industry needs a market signal to provide confidence and certainty of investment. The fundamental priorities refer to regulatory barriers and infrastructure, but as these are recognised, ambitious policy will be required to also drive down the costs and encourage supply of heavy ZLEVs.

5.1.2 Standards and targets

We note that heavy vehicles have been excluded from the proposed fuel efficiency standard and largely from the National Electric Vehicle Strategy. We are concerned that this is a lost opportunity, and we strongly recommend that the Australian Government considers extending the coverage to heavy vehicles (buses and trucks) as part of conducting a comprehensive heavy vehicle strategy. We are not suggesting any delay for light vehicle implementation but do require some indication that heavy vehicle fleet decarbonisation is a priority.

The fuel efficiency standard for light vehicles could be extended for heavy vehicles; however, with separate targets to other vehicle categories. This mechanism has been utilised in similar jurisdictions, such as in Europe, and is generally a holistic albeit more complicated mechanism. An alternative is a sales target for heavy ZLEVs, which is a key element of the Global Memorandum of Understanding on Zero-Emission Medium and Heavy-Duty Vehicles which was a COP26 pledge that has currently been signed by 27 countries. This MoU includes a sales goal for zero emission new truck and bus sales of 30 per cent by 2030 and 100 per cent by 2040. Similarly, in the 2022 Grattan Truck Plan report,[211] it recommends starting an Australian zero emissions sales target for rigid trucks at 2 per cent for a 2024 implementation, ramping up to 30 per cent by 2030 and 100 per cent by 2040.

Either way, this mechanism will play a key role in a comprehensive national heavy ZLEV strategy, which should also incorporate additional enablers such as investment in refuelling infrastructure and further FCEV trials, as well as tax breaks or instant asset write-off on the purchase of heavy FCEVs. The Grattan Institute[212] recommended a purchase price incentive to bridge the cost gap for businesses while the heavy ZLEV technology matures, ultimately accelerating the transition. This

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[210] Ibid.

[211] Terrill, Burfurd and Fox (2022).

[212] Ibid.

included a mechanism referencing the California Hybrid and Zero Emission Truck and Bus Voucher Incentive Project (HVIP), in which the Australian Government could offer vouchers to businesses at the point of purchase for 50 per cent of the gap,[213] which would shrink as heavy ZLEVs reach price parity with diesel.

There are also non-financial mechanisms that could be employed now to enable the supply of commercial ZLEVs, including the adoption of clean truck zones/exemptions from urban truck curfews, signing the Global Memorandum of Understanding on Zero-Emission Medium and Heavy-Duty Vehicles, removing import duties on ZLEVs, the review of Australian Design Rules to align with international standards, and implementing axle mass concessions for ZLEV trucks to counteract the payload capacity lost to heavy ZLEV technology.

5.1.3 Total cost of ownership certainty for FCEVs

A significant factor in the uptake of heavy FCEVs is the uncertainty of total cost of ownership (TCO). While there is significant work being produced to assist in this calculation, including from AHC members, the Australian Government can also play an additional role in facilitating heavy vehicle trials. These knowledge gaps due to the immaturity of the technology within the Australian context affect the investment gap. As noted by Advisian,[214] manufacturers need to provide supply to create fleet sizes that justify the (unclear) potential infrastructure spend, and purchasers need proof of fuel consumption and operational cost benefits over the life of a vehicle (also currently unclear). Until commercial pilots can provide commercial operations with strong validation of a fully commercial product and business model, heavy ZLEVs will experience slow adoption.

In its work for the NHS v1 in 2019, Aurecon[215] recommended that for FCEV trials to be considered effective with substantial evidence and learnings across a sufficient fleet size, investment would need to be between A$20-$100 million for each trial. AHC notes the significant work and funding that the federal and state governments have invested in FCEV bus and truck trials, however almost four years on, the State of Hydrogen report[216] illustrates that only the investment in the Hume Hydrogen Highway initiative has reached this financial threshold, and at the lowest end.

The Hume Hydrogen Highway is an integral and welcome initiative, in which we look forward to the next stages when proponents are announced and the proposed extension to Queensland for the East Coast Renewable Hydrogen Refuelling Network is committed. Provided how long is required to design, consult, tender and execute on such projects, it is paramount that sufficient planning and funding is allocated for each individual freight corridor to ensure that TCO is further clarified and lessons learned are coordinated.

We also note that all indications are that the funding envelope available for the Hume Hydrogen Highway is insufficient. While the Australian Government has apparently committed A$20m in matched funding, the mechanism for delivering this is unclear and the scale is still well below what is required.

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[213] Although we note that this implies the other 50 per cent can be provided by consumers or TCO savings, which is not assured.
[214] Advisian (2021).
[215] Aurecon (2019).
[216] Australian Government (2023a).

If we combine refuelling and fleet vehicles, the figures are closer to what we advocated for in our White Paper[217] as below:

- At least two heavy vehicle trials of large fleets, at a minimum of A$200 million each, focussed on heavily-trafficked truck routes.
- At least three larger trials for lighter trucks for logistics near hydrogen centres, at A$25 million each.
- At least two larger trials for bus routes near hydrogen centres, at A$45 million each for 40 buses (or a combination of smaller and larger, at A$12 million per small trial for 10 buses).

Recommendation 48: Support hydrogen in heavy road transport with a national ZLEV strategy, fleet trials, transition funds, and either a heavy vehicle fuel efficiency standard or sales target.

In line with the revised NHS objectives and targets, DCCEEW should develop a national ZLEV strategy for heavy vehicles with both financial and non-financial incentives, including:

- Funding further heavy FCEV trials to aid total cost of ownership certainty. This should include separate trials for heavily-trafficked truck routes (at least two trials of heavy fleets at minimum of A$200 million each), lighter logistics trucks (at least three trials at A$25 million each), and for bus routes near hydrogen centres (at least two larger trials at A$45 million each for 40 buses).
- Financial support for transitioning heavy vehicle fleet and associated infrastructure, which could align with support under Recommendations 49 and 50.
- Developing a heavy vehicle fuel efficiency standard or sales target for the Australian context.

5.2 Priority industrial processes

The processes that appear to hold the greatest benefits for more immediate ‘no regrets’ planning and investment include iron, ammonia, methanol and alumina. This is because each of these sectors is more dependent on hydrogen for decarbonisation and can also drive large sources of demand. These are scalable markets and support both direct and indirect growth in jobs.

We have already discussed the opportunities for iron to make steel throughout this paper, and covered how ammonia holds great promise because we have an existing industry to decarbonise, ammonia is a vector for hydrogen export, and there is also a new export opportunity because Japan and Korea anticipate using clean ammonia in power stations (see discussion in section 3.1.4). Unlike hydrogen, ammonia has been traded globally for decades and has well developed technologies for large scale storage and transport.

Both ammonia and methanol are considered logical replacements for the bunker fuel used for shipping, as discussed in section 5.3. Researchers from the Grattan Institute[218] state that if Australia was to produce 6.5 per cent of the world’s ammonia with green hydrogen by 2050, there would be a further 5,000 ongoing jobs. This number rises by a further 15,000 jobs if global shipping moved exclusively to ammonia and Australia maintained 6.5 per cent market share.

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[217] Australian Hydrogen Council (2021).
[218] Wood, Dundas and Ha (2020), page 36.

Hydrogen is used for both fuel and feedstock to make methanol, and clean hydrogen is a good prospect to decarbonise the sector's high temperature processes. There is an established global market, with extensive experience in handling.

For industrial heating, experts consider that electrification will be more cost effective than hydrogen and other alternatives to decarbonise many heating applications. However, technological constraints make electrification challenging for processes requiring more than 800ºC. We discuss these processes in more detail in our White Paper,[219] and have also recently completed a report with Australian Alliance for Energy Productivity (A2EP) on decarbonisation options for different high temperature heating applications.

Alumina will likely require hydrogen to decarbonise the calcination process. Australia is the second largest producer of alumina in the world, and the largest exporter. Primary aluminium is made from bauxite, which is refined to make alumina before being smelted to make aluminium. Refining bauxite to produce alumina has four stages: digestion, clarification, precipitation, and calcination. Digestion takes place at 150-270°C and calcination at temperatures above 1000°C.

There are also large-scale opportunities in other high temperature processes, such as in cement and bricks. Achieving scale in hydrogen production for these sectors can then pave the way for relatively smaller scale industries, such as food and meat processing.[220]

As discussed by the Grattan Institute, new clean energy industries can "plausibly create new jobs at a scale comparable to existing carbon-intensive industries".[221] Many of these new and replacement jobs are likely to be located in carbon-intensive locations, because these locations have key infrastructure such as ports and electricity transmission, as well as access to natural gas networks. Such jobs are also likely to be created in other regional areas where renewable energy resources are most favourable.

5.2.1 Transition finance

The barriers faced by parties seeking to integrate hydrogen into their heating and chemical processes are largely the same as for transport and any other use; that is, the significant cost required to convert assets, and the uncertainty about the total asset life costs of doing so given lack of current experience. For industrial processes there is also the complication of hydrogen being more expensive than the natural gas it is (often) replacing.

If we look at steel for example, a modern blast furnace can have a lifecycle of 50 years or more, with major overhauls or 'relines' every 15-20 years to stay operational. The capital cost for a 4.0 Mt/year integrated steelmaking facility is around US$4 billion, compared with relining a blast furnace at between US$50 million and US$200 million, depending on the jurisdiction.[222]

[219] Australian Hydrogen Council (2021).
[220] While there are many more food processing plants than refineries, the scale is much smaller. For example, a large alumina refinery uses around 30,000 to 40,000TJ/year, and a modest sized factory in the food sector might use 20TJ/year. See ITP (2019), page xiv.
[221] Wood, Dundas and Ha (2020), page 26.
[222] BHP (2020).

Long-lived industrial assets like blast furnaces need long term planning for major renewals. This planning needs to occur in the environment of changing social acceptance and uncertain technological choices, where the asset owner needs to maintain production while not locking in choices that in the future might be found to be poor. And the risk is particularly high with companies (and sectors) with few facilities, such as steel and ammonia.

Regarding ammonia, Advisian advises: "A large portion of Australia's ammonia manufacturing capacity is beyond the initial design life of the facility and survives through judicious asset management and favourable domestic gas pricing".[223] Where there isn't the option to further sweat assets or take assets offline, companies may need to consider closures (with associated job losses), or it could mean "a like-for-like replacement of an old facility, or shift to a proven but still relatively emissions-intensive process, locking in emissions for another 30 years or more".[224] This is all the more likely while producers cannot recover the additional costs of greener technology via green premium prices.

Recommendation 49: Attract private investment for hard-to-abate industrial processes.

Noting the need for funding to align with analyses addressed in Recommendations 3-5 and any targets set, the Australian Government should:

- Fund a hydrogen readiness programme of at least A$1 billion for capital expenditure on industrial processes that cannot readily be electrified, including (and not exclusively) for the production of steel, ammonia, methanol, and alumina/aluminium.
- Continue to use ARENA (and CEFC where possible) to underwrite demand through a revenue support mechanism (such as contract for difference) intended to incentivise domestic production of critical chemicals and metals, including (and not exclusively) for the production of steel, ammonia, methanol, and alumina/aluminium. Funding should be aligned with funding from state/territory governments.

Funding should be prioritised for projects that protect or create local jobs and have a detailed plan for skilling and re-skilling. Applicants should be required to share non-commercially sensitive information to support industry knowledge development – this could be assisted by engaging with industry associations to support delivery.

To mitigate and reduce the costs associated with project development (such as transmission costs), the Australian and state governments could collaborate to further incentivise co-location of chemical production within Hydrogen Economic Zones, and within proximity to other industrial infrastructure such as ports.

5.2.2 Support for smaller industrial players

With hydrogen industry development still in a nascent stage, end users are understandably cautious.

Even for the sectors more likely to need hydrogen as replacement fuel, the high cost and long life of industrial processes – such as alumina refineries, cement kilns, brick kilns, and large boiler rooms –

[223] Advisian (2021), page 77.
[224] Wood, Reeve and Ha (2021), page 37.

require this cautious approach given that investments within this decade can determine carbon footprint of those applications for decades to come.

Hydrogen also has different heating characteristics from natural gas, requiring more hydrogen to have the same heat outcome, and a change to equipment to manage matters such as flame speed. In work undertaken for AHC by A2EP,[225] study participants noted that blending hydrogen into natural gas is an option, but the impact of any inconsistent gas ratios on burner performance must be understood and managed. The current lack of regulations relating to burning pure hydrogen fuel was also considered to be a risk. We address the other regulatory issues raised in section 4.3.6.

There is a need for government support for early adopters of decarbonised industrial heat so they can start to develop business cases for change and manage financial and/or technology risks.

Recommendation 50: Develop bespoke packages for other early adopters in high temperature process heating.

Target government support packages for early adopters who need to switch to hydrogen for high temperature heating but cannot access support under Recommendation 49. This should include:

- Financial support through tax and/or targeted market mechanisms.
- Increased ARENA funding for trials and demonstrations.

5.3 Shipping

The challenges facing international shipping are, in many ways, a microcosm of the issues we have described throughout this paper:

- Technological solutions are required (engines, turbines etc) that can operate effectively with new fuels. These solutions are not readily able to be retrofitted on existing costs, meaning that change is slower than ideal as a result of sunk costs in existing assets and the high costs associated with new build vessels.
- Supply chains for the secure, at scale, supply of the new fuels are undeveloped and the prices for offtake are uncompetitive with existing, incumbent fuels.
- Workers all along the supply chain as well as on the vessels are unprepared for working with the new fuels and globally accredited training is not yet available. Unions and the broader citizenry are unsure about the new fuels and bulk storage at ports close to residential centres.
- Infrastructure to meet future shipping needs is undeveloped, including ports with space for additional storage capacity and safety buffer zones, as well as any specialised delivery systems and trained workforce. Shipyards must have capacity for retrofits and new builds.

Globally, the shipping industry is a significant emitter, accounting for between 3 per cent and 4 per cent of total CO_2 emissions; equivalent to the Japanese or German economies. Global trade – and therefore prosperity – is intrinsically tied to shipping.

225 This paper will be provided separately.

According to analysis of United Nations Conference on Trade and Development (UNCTAD) data, approximately 40 per cent of current global cargos are natural gas, petrochemicals and coal.[226] Whilst some analysts have predicted that the transition away from fossil fuels is likely to also see a significant reduction in global shipping, others have noted that the size and scale of the renewable energy buildout is likely to ensure that reductions are not significant.

The shift to clean fuels for shipping presents opportunities as well as challenges. Whilst as a whole the industry uses a significant volume of fuel, no one company or port will have sufficient enough offtake to enable the construction of at-scale future fuel production. Therefore, shipping companies are increasingly looking to manage risk by investing upstream to secure supply of fuels. For example, MOL Clean Energy, a subsidiary of Mitsui O.S.K. Lines, is now a joint venture (JV) shareholder of a proposed clean hydrogen-ammonia production and export facility in Louisiana,[227] and A.P. Moller – Maersk has partnered with REintegrate and European Energy on a clean methanol facility in Denmark.[228]

It is important to note that, in the context of global shipping, LNG is seen as an alternative fuel moving away from petroleum-based fuels.

A recent analysis undertaken by DNV in the UK[229] found that ammonia would have a 35 per cent share of marine fuels in 2050, the largest of any type of fuel, while e-fuels (that is, methanol) would likely contribute 14 per cent. This also links back to how we think about clean methanol and accessing clean carbon, such as through DAC.

Linked to Recommendations 24-26, Australia can engage with first movers across energy and maritime to collaborate on commercial-scale demonstration projects. The Energy Transitions Committee[230] sees this as vital, with a high priority for the shipping industry to:

> choose pilot locations that offer privileged access to low-cost renewable electricity and hydrogen, opting for regions with large renewable energy potential, preferential prices and tax exemptions for major industrial electricity consumers, and industrial clusters where several transport and industry sectors will share energy infrastructure costs.

While it is perhaps too early to set market stimulation measures for hydrogen as a feedstock for shipping fuel, the industrial process recommendations for ammonia and methanol discussed in 5.2 should be sufficient for now. Instead, there is more to be done to understand the options and opportunities for Australia.

Recommendation 51: Develop a national assessment of shipping routes and refuelling requirements.

The Australian Government should engage with shipping companies operating in Australia and peak bodies to analyse and report back on:

- Current shipping routes.

[226] Subramanian (2022).
[227] Mitsui O.S.K. Lines (2023).
[228] Maersk (2021).
[229] DNV (2023a), page 10.
[230] Energy Transitions Committee (2020), page 19.

- Shipping companies' views on fuels in which they are investing, the relative energy densities of options, and requirements to refuel (that is, the maximum journey length without bunkering requirements).
- Bunkering in Australia, to understand if products (including fuels) are to be transported from southern Australia, what the impact is on key matters such as the total journey length and requirement to refuel.
- Opportunities for demonstration projects at suitable ports.

5.4 Electricity

In principle, hydrogen can provide net benefit to electricity system security through the use of electrolysers as flexible load.

The issue of the 'duck curve' has become prominent in electricity system planning,[231] where there is a dip in demand from the grid during the day as consumers meet their own energy demands through solar power. Prices can even go negative, meaning that sellers need to pay buyers in the spot market. While sellers can protect themselves ahead of time contractually, the fact of very low to negative prices in some regions is already having a chilling effect on the ability for project developers to bring new renewables projects online. Given Australia's extraordinary need to build significant renewable generation capacity for the transition, this is extremely concerning.

Very low demand from the grid also gives rise to another issue for system operation: ensuring minimum demand. Demand drops can cause problems in managing transmission network voltages, and minimal generating units are also required to provide security services such as system strength, inertia, and frequency control. There are also a range of other possible negative effects in the event of a need to restart the system or if a region loses its connection to the larger grid.

Hydrogen can be part of the solution to both problems. Electrolysers draw considerable power from the grid, meaning they can flatten out peak and trough periods of supply and demand, provided there are the right incentives to do so. Increasing demand in the day can provide the investment case for much needed new investment in renewables while still ramping down during peak demand periods, releasing renewable supply to market to support reliability.

Highly controllable electrolyser load could provide other essential power system services, such as frequency control ancillary services.[232] Further, electrolysis facilities can provide highly controllable load that may be suitable for system restart purposes.

While batteries can also act as a load, they do not produce a new product like hydrogen production does; this is a new primary revenue stream that does not rely on the energy market. For a future energy market with renewable capacity beyond 100 per cent of current energy needs, flexible loads that are capable of floating between traditional demand and variable renewable supply will be critical, perhaps more so than short to medium duration storage.

[231] The graph of this use has a dip like a duck's belly, in contrast to pre-solar years of a reasonably constant curve during the day.
[232] Carter et al. (2020).

However, the National Electricity Market (NEM) and other Australian energy markets are not well equipped to leverage the opportunities these new assets will bring. In a marginal price energy market, demand response often supports positive consumer price effects that are not captured by a spot price. For loads with primary markets outside the energy market, this becomes a difficult trade off to manage when not properly incentivised.

A grid and energy market impact analysis is an important step to take, particularly as load flexibility has a value not captured by current market structures, with the Australian Energy Market Commission noting that:

> studies exploring the opportunity and benefits of load flexibility have found that controllable and flexible demand offers significant economic value (up to the order of $8-18 billion in savings), providing enormous potential to offset the need for new-build large-scale generation assets if appropriately integrated.[233]

What this could mean is that by using electrolysers in the way described, renewable electricity assets that would need to be built to decarbonise the grid, *but aren't*, might now be built to support both hydrogen and the grid. And hydrogen has a further market, or series of markets.

Recommendation 52: Undertake a full energy market and grid impact analysis for wide scale adoption of electrolysers as flexible load in the electricity grid.

The Australian Government should task AEMO and AEMC with undertaking a full energy market and grid impact analysis for wide scale adoption of electrolysers as flexible load in the electricity grid. This work can then inform energy and hydrogen policy.

5.5 Aviation

Using hydrogen for aviation is further away than the other applications,[234] with the discussions about a scale replacement of jet fuel focussing on the production of Sustainable Aviation Fuels (SAF) that rely on biofuels as input.

Most analysts agree that hydrogen will play a role in SAF in the future, primarily because there will be a natural constraint on how much biofuel will be available. However, there does not seem to be consensus yet on what the opportunities are, or the next steps.

There is progress in addressing SAF in Australia,[235] as well as limited use of hydrogen for smaller aircraft.[236] The announcement of the Australian Jet Zero Council by the Department of Infrastructure, Transport Regional Development, Communications and the Arts (DITRDCA), and the Department's proposed Aviation White Paper[237] appear to provide an opportunity to develop next steps.

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[233] Australian Energy Market Operator (2023), page 62.
[234] International Energy Agency (2023), International Renewable Energy Agency (2021).
[235] See Peacock (2022), Virgin Australia (2023), Queensland Government (2023).
[236] Dowling (2022).
[237] See Department of Infrastructure, Transport Regional Development, Communications and the Arts (2023a, 2023b).

A study by CSIRO Futures and Boeing is also instructive, with modelling that should inform the revision of the NHS. The study looked at the commercial opportunity for SAF in Australia by 2050, projecting that hydrogen will be required to produce SAF from around 2035. The authors recommend the following next steps:

IMMEDIATE TERM (2023-2025)

- Establish a PtL [Power to Liquid] demonstrator (100 L/day) to integrate with local renewables and hydrogen production.
- Research public tolerance for point source and biogenic CO2.
- Conduct an assessment to identify the optimal location for the first large PtL plant considering the locations of potential hydrogen hubs.
- Develop Roadmap aimed at a PtL industry in Australia, considering the evolution of CO2 sources, the hydrogen industry, and renewable energy requirements.
- Fund development of less mature hydrogen technologies such as high temperature electrolysis.

MEDIUM TERM (2025-2035)

- Build consortium and initiate planning for large-scale plant
- Guarantee supply of hydrogen and CO2.
- Implement pilot-scale projects for DAC technologies.
- Industry involvement in demonstration projects for mature green hydrogen technologies to overcome 'first of kind' risk.

LONG TERM (2035+)

- Build the first large-scale PTL plant.
- Focus on improving plant efficiencies and asset life.[238]

Recommendation 53: Work with the Department of Infrastructure, Transport, Regional Development, Communications and the Arts and its Jet Zero Council to consider the next steps for hydrogen for SAF production, using the CSIRO Futures report.

DCCEEW should work with the Department of Infrastructure, Transport Regional Development, Communications and the Arts, the Jet Zero Council and related stakeholders to assess future SAF needs for Australia and how they can be met, using the CSIRO Futures study. This should lead to planning and target setting for scaling up hydrogen production as required.

[238] Temminghoff et al. (2023).

6 Recommendations

Chapter 2: The required approach to the refreshed NHS

Recommendation 1: Commit to significant market making and ecosystem building in the public interest.

The Australian Government should commit to the following for the emerging hydrogen industry:

- **Priorities, planning and coordination**: Match the refreshed NHS to broader climate targets and align with other policy for cross government approach. Commit to nationwide planning for critical energy, including hydrogen infrastructure. See Recommendations 6-10.
- **Targeted and ambitious international engagement**: To secure the investment required, support 'Team Australia', and provide clarity on objectives and communication channels for our trade partners. See Recommendations 11-14.
- **Investment in infrastructure**: Commit to investments in key infrastructure that meet public interest tests for common user infrastructure and prioritise investment and sequencing of government-funded projects to seek investors and partners. See Recommendations 15-47.
- **No regrets market development and support**: Commit to further revenue support mechanisms and target setting for industries that are most likely to rely on hydrogen to decarbonise, and undertake further analysis as needed. See Recommendations 48-53.

This work must embed the refreshed NHS within the Australian Government's broader programme of work for reaching net zero.

Recommendation 2: Task the Net Zero Economy Agency with overseeing the implementation of the refreshed NHS.

The Australian Government should task the Net Zero Economy Agency with overseeing the implementation of the refreshed NHS, with ultimate reporting responsibility to Cabinet.

The Net Zero Economy Agency should work with a cross-departmental group of senior leaders from central agencies and line areas to advise on the refreshed NHS as part of the overall net zero project. This should be via a formal steering group, supported by a secretariat, with quarterly reporting to the group on implementation of the refreshed NHS actions. The steering group should be supported by a technical advisory panel and an investor panel (local and international).

Recommendation 3: Task the Net Zero Economy Agency to oversee a rolling programme of industry analysis to support ecosystem planning.

The Net Zero Economy Agency should oversee a rolling programme of industry analysis to support ecosystem planning in line with broader net zero targets and the refreshed NHS. This needs to be a sector by sector, commodity by commodity analysis to assess relative strengthens and identify gaps to inform development of infrastructure and project investment propositions. This could be undertaken in phases to match industry priorities and may overlap with the sectoral decarbonisation plans.

This work should seek to stimulate the right programmes of investigation, connect different bodies, and encourage discussions about different forms of the future to serve policy and planning.

Recommendation 4: Task the Net Zero Economy Agency to oversee an assessment of cost and clarify investment needs from the public and private sectors.

Connecting with the analysis recommended above, the Net Zero Economy Agency should oversee an assessment of the cost of the energy transition as a whole, and the capital reallocation required, and then a matching of public funding to de-risk qualified projects.

Within this, the Net Zero Economy Agency should oversee a review and schedule for the effective lives of key assets (as per application priorities) that may require fuel switching to hydrogen, and set policy to support replacement options and investment cycles.

Recommendation 5: Extend and re-run the NHIA analysis to support decision-making for the refreshed NHS.

The Australian Government should undertake the NHIA again in 2023 for the refreshed NHS to account for the changed assumptions and inputs since 2020.

The NHIA should then be repeated every two years, up to industry establishment (that is, over the next two decades). Updates should also align with other energy planning and infrastructure implementation planning such as the AEMO ISP (Integrated System Plan) and broader federal and jurisdictional energy planning and infrastructure planning pipelines (e.g., the Infrastructure Australia priority infrastructure list). This work should also support and inform the analysis in Recommendation 4, particularly regarding major asset lives and replacement schedules.

Recommendation 6: Prioritise hard-to-abate and scalable domestic demand sources.

The Australian Government should prioritise growing demand for hydrogen in the applications that are more likely to require clean hydrogen to decarbonise, and more likely to achieve large scale. Ideally these should demonstrate an ability to open the market to other applications, through knowledge/technology sharing, geographic proximity, and/or cost reduction. Current evidence supports these industries as being:

- Chemicals, particularly ammonia and methanol
- Low emissions metals, particularly iron and alumina
- Heavy road transport
- High temperature process heating
- Marine and aviation, where hydrogen is a feedstock for future fuel
- Seasonal storage for the electricity market.

Recommendation 7: Support hydrogen for export as an energy vector and for value added products such as green iron.

In the absence of extraordinary evidence to the contrary, the Australian Government should continue to build an export market for hydrogen (and its derivatives) as an energy vector.

There is also a need to prioritise and plan for domestic use of hydrogen to build Australia's processing and manufacturing capabilities, which will provide new long-term value for the economy. The design of the funding support mechanism and guidelines for the Hydrogen Headstart program provide an opportunity to incorporate this thinking and set these priorities.

Recommendation 8: Assess Australia's hydrogen supply chain risks and opportunities.

The Australian Government should assess the supply chains needed to match the objectives and priorities of the revised NHS, noting the need to assess both the risks to industry growth and the opportunities to seed and support Australian innovation.

Recommendation 9: Set hydrogen targets for 2030 and 2040, with a range for 2050.

Based on modelling undertaken by/for the Net Zero Economy Agency and the revised NHIA, the Australian Government should decide and announce domestic and export targets for hydrogen production for 2030 and 2040. Consideration should be given to industry specific targets, for example dedicated hydrogen production to support green steel production. Given the uncertainty about 2050 capability, any target for 2050 could be a range or guide. These targets should be set out in the refreshed NHS and also drive further financial packages and investment attraction activities, to match goals and delivery mechanisms in direction, volume and timing.

Recommendation 10: Support the refreshed NHS with public implementation plans and stakeholder engagement.

The Australian Government should ensure the refreshed NHS is supplemented by actions to meet targets and milestones, with responsibility clearly allocated. Detailed implementation plans may need to be by sector or ecosystem element.

Chapter 3: International engagement

Recommendation 11: Support the refreshed NHS through a clear investment proposition.

The Net Zero Economy Agency should use the modelling and cost analysis from Recommendation 4 and the targets from Recommendation 9 to engage with DFAT, Austrade and the jurisdictional trade and investment offices to create an investment proposition to take to international markets. This work will need to be sufficiently funded and will also require clear coordination across posts, with reporting lines through to the Net Zero Economy Agency.

Recommendation 12: Develop joint support packages between Australia and its trading partners to support trade in hydrogen and hydrogen derivatives.

The Australian Government should develop bespoke joint support packages between Australia and its trading partners that underwrite trade and support necessary infrastructure.

These should also cover multilateral agreements to incentivise investment and collaboration, for example, between Australia as a producing country, Singapore as a key intermediary for shipping and the nations of North Asia as key customers for hydrogen, its derivatives and also products produced using hydrogen.

Recommendation 13: Explicitly locate hydrogen production and use within the current international agreements on critical minerals.

The Australian Government should seek to explicitly locate hydrogen production and use within the current international agreements on critical minerals and the need for both diverse minerals supply and for diverse minerals processing.

The proposed Australia-US Taskforce on Critical Minerals presents an opportunity for Australian policymakers to present a coherent value proposition for investment in whole-of-supply chain development, and to ensure that we negotiate favourable investment terms for processing and downstream manufacturing to also occur in Australia.

Recommendation 14: Actively seek risk and information sharing opportunities with like-minded international partners.

The Australian Government should closely review the US and other key trading and investment partners' hydrogen strategies and roadmaps to guide the revised NHS on the topics and timing of industry evolutionary steps and favourably position Australia's policy and funding priorities.

Chapter 4: Building the ecosystem

Physical infrastructure

Recommendation 15: Create Hydrogen Economic Zones to support regional hydrogen initiatives and connect the relevant supply, demand, infrastructure and workforce.

The Net Zero Economy Agency should oversee the development of Hydrogen Economic Zones that link hydrogen production targets to locations via hydrogen economic zones that incorporate REZs and ports, as well as likely requirements for hydrogen storage, CCS, refuelling, pipelines, and workforce.

This work should adopt work already undertaken by the jurisdictions.

Recommendation 16: Support a nationally connected and coordinated regional network facilitated by the Australian Hydrogen Council.

The Australian Government should fund the Australian Hydrogen Council to seed the development of a Regional Collaboration Lead that works across state borders and into regions to maximise the efforts of industry funding to share lessons and best practice.

Recommendation 17: Support Business Renewables Centre Australia to expand its remit and create hydrogen specific modules.

The Australian Government should encourage the BCRA – an existing, independent organisation with expertise, funding streams and governance arrangements – to expand its remit to offer an increasingly needed service covering hydrogen.

Recommendation 18: Support the development of domestic electrolyser production and assembly through a domestic manufacturing package.

The Australian Government should lead a partnership with jurisdictional governments to attract and retain investors to establish electrolysis manufacturing and assembly in Australia. The governments should underwrite risk through long term local electrolyser targets, aligned with a package that could include funding, taxation relief, and streamlined approvals.

Recommendation 19: Secure supplies of raw materials (e.g., nickel and platinum group metals) and other key components.

The Australian Government should partner with industry to leverage the critical minerals reserves that are required in electrolysers, as has been the case with lithium for batteries.

Recommendation 20: Develop consistent energy planning scenarios and cost recovery mechanisms by connecting AEMO, AEMC and energy regulators with the Net Zero Economy Agency and the refreshed NHS.

The Net Zero Economy Agency should engage closely with energy bodies to coordinate energy transition scenario assessments and regulatory practice. Priorities include:

- Linking AEMO's ISP with the Australian Government net zero programme (which includes Hydrogen Economic Zones) and with REZ jurisdictional planning.
- Connecting discussions on grid stability and long-term storage with hydrogen storage policy.
- Linking AEMC rulemaking and regulators' compliance enforcement with net zero policy to ensure infrastructure can be paid for, and via the right mechanisms. Importantly, the Australian Government should set policy that ensures initiatives to build the market (both capital and operational) are not passed through to small energy users via bills for essential services. See Recommendation 45.
- Encouraging jurisdictional governments to provide exemptions on TUoS charges for hydrogen projects, and concessions on state schemes that add cost.

Recommendation 21: Remain open to blue hydrogen for regions that can support it without unnecessarily delaying renewable hydrogen developments.

The Australian Government should remain open to blue hydrogen projects for regions that can support it without unnecessarily delaying renewable/green hydrogen developments.

In practice, the issue is not one of colour but of emissions intensity, supported by robust measurement and reporting.

Recommendation 22: Develop a national assessment of hydrogen industry water needs and required planning to meet the revised NHS objectives and support long-term water security.

DCCEEW should engage across the hydrogen and water divisions and with water utilities and state/territory jurisdictions to analyse and report back on:

- Total water availability, mapping across Hydrogen Economic Zones.
- The role of the hydrogen industry in maintaining Australia's water balance.
- A national plan with water utilities that specifically addresses likely needs and timeframes for manufactured water and water infrastructure for hydrogen.

Hydrogen policy settings should be incorporated into the revised National Water Initiative.

Recommendation 23: Develop a national assessment of hydrogen pipeline corridors, easements and route alignment.

DCCEEW should engage with pipeline companies, AEMO and the AER to analyse and report back on:

- The location of easements, and particularly as they relate to Hydrogen Economic Zones
- The fitness for purpose of the easements from a regulatory, safety and community acceptance perspective, and any unnecessary regulatory barriers that should be addressed.
- If more easements are required, where and by when.

This work should be able to address the refreshed NHS targets and policy priorities, and it should inform further policy on necessary coordination, co-funding and regulation.

Recommendation 24: Develop a national assessment of port capability to meet the revised NHS objectives and targets.

DCCEEW should engage with port corporations and peak bodies to analyse and report back on port capability for future exports, in line with the objectives and targets set by the revised NHS and connected with Hydrogen Economic Zones.

This should lead to an understanding of how ports can collaborate without triggering unforeseen regulatory hurdles and future government support for common use infrastructure.

Recommendation 25: Select and support ports with existing industry connections to be demonstration ports.

Australian governments should work with ports to identify appropriate demonstration sites for hydrogen development. To mirror international developments this could include ports that have existing industrial connections.

Recommendation 26: Commit to a funding envelope for ports.

The Australian Government should undertake to support port redevelopments to 2045. The national assessment will clarify what is required, but this is expected to be around A$20-$30 billion.

Recommendation 27: Develop a national assessment of hydrogen storage needs for different purposes, timeframes and locations.

DCCEEW should engage with pipeline and gas storage companies, AEMO, Geoscience Australia and the AER to analyse and report back on:

- The economic benefit of hydrogen storage, including in supporting the electricity system.
- The need for different types of storage for hydrogen, at what scale/volume and in what timeframe.
- The fitness for purpose of existing storage measures, including current and new salt caverns, depleted gas reservoirs, line packing in pipes, and above-ground solutions.
- If more storage is required, the next steps to develop this as needed, including cost recovery mechanisms as required for users.

This work should be able to address the refreshed NHS targets and policy priorities.

Recommendation 28: Commit to a funding envelope for common user storage.

The Australian Government should undertake to support common user storage developments to 2045. There is a particular need to fund demonstration and pilot projects for large-scale underground hydrogen storage.

Recommendation 29: Ensure a refreshed NHIA addresses refuelling infrastructure.

Building on Recommendation 5, the NHIA analysis should address refuelling needs for hydrogen in heavy transport. If the NHIA is not rerun, this requires separate analysis and reporting.

This should lead to an understanding of future government support for refuelling infrastructure, which then needs to be costed for different options.

Recommendation 30: Commit to a funding envelope for refuelling infrastructure.

The Australian Government should undertake to support refuelling station development until the uptake of FCEVs reaches a level sufficient to sustain the expansion and infill of a national hydrogen refuelling station network. The NHIA and cost analysis will clarify what is required. This funding may be provided as the infrastructure element of a combined refueller and vehicle trial, as discussed in Recommendation 48. Funding could be matched by states and territories for key projects and split so that one funding stream defrays capital costs and the other provides long term underwriting for contracts.

Social and institutional support

Recommendation 31: Boost Australian Government ability to attract and deploy private capital.

Building on Recommendations 4 and 11, build capacity within the Australian Government to work more closely with the financial sector to better anticipate and manage roadblocks to deploying and re-allocating private capital, and to develop investment and value propositions that work to secure private capital interests and meet the Australian governments' aims for the hydrogen industry.

See also Recommendation 38.

Recommendation 32: Support a new programme of work on community water values and hydrogen awareness.

The Australian Government should either lead a cross-sector engagement forum, or support one led by water and hydrogen peak bodies, that seeks to connect hydrogen and water organisations in community engagement regarding water values and planning.

This would naturally lead from analyses and planning from Recommendation 22.

Recommendation 33: Develop messages and communications support for the refreshed NHS to roll out to all governments and industry.

The Australian Government should support government and industry communications on the refreshed NHS by developing clear messages about hydrogen, with links to industrial decarbonisation objectives and achieving net zero for the economy.

The strategic approach should be based on the existing AHC-drafted communications model, and outcomes should inform changes to HyLearning.

Recommendation 34: Undertake capacity gap analyses to support regional development.

As part of the analyses recommended above for sectors and regions within Hydrogen Economic Zones, the Net Zero Economy Agency should oversee workforce capacity gap analyses of regional areas in which hydrogen infrastructure is being proposed.

Recommendation 35: Drive coordination of competency standards and training packages for hydrogen.

The Australian Government should coordinate jurisdictional training package development, collaborate with education institutions, and connect with regulators. This work should build on outcomes from the Clean Energy Capacity Study, and the hydrogen workforce modelling of the SA and NSW governments.

Recommendation 36: Support a lessons learned repository through CSIRO's Knowledge Hub.

The Australian Government should expand the remit of CSIRO's Knowledge Hub to collect lessons learned and provide key messages to a public audience in a digestible and consistent way. This will need to align with the intent and values of the refreshed NHS, and current and future ARENA information collection practices and format.

Recommendation 37: Support the Australian Hydrogen Council to expand the scope of HyCapability.

The Australian Government should work with, and co-fund, AHC to align the development of HyCapability to help deliver on the objectives of the refreshed NHS through becoming a globally leading platform to highlight Australian capability and enable business connections domestically and internationally.

Recommendation 38: Create a 'one stop shop' and case management to assist with funding and permissions.

The Australian Government should establish a 'one stop shop' approach to permitting support and packaging financial options for hydrogen and related low emissions infrastructure.

This should include a case manager within government to assist project developers and funders to tie all potential sources of support together, as well as assist in the coordination of planning and approvals.

Recommendation 39: Develop and articulate RD&D priorities for hydrogen.

The Net Zero Economy Agency should work with CSIRO and the Office of the Chief Scientist to develop RD&D priorities in line with broader revised NHS priorities, and based on commercial opportunities, with a view to make the emerging industry resilient to supply chain issues. Priorities should include:

- Novel and emerging electrolyser and fuel cell technologies, addressing asset lifetimes, efficiency and cost.
- Storage, particularly salt caverns, depleted gas reservoirs and MCH.
- Industrial processing to support iron, alumina, steel and cement production.
- Forms of sustainable/clean carbon capture for the production of e-fuels, including direct air capture.
- Opportunities and capacity to develop natural hydrogen resources.

Recommendation 40: Work with CSIRO, the Chief Scientist and other RD&D leaders to deliver hydrogen RD&D priorities and knowledge sharing.

Based on hydrogen priorities established in Recommendation 39, and in collaboration with CSIRO, the Net Zero Economy Agency to task and resource the Office of the Chief Scientist to lead a hydrogen RD&D work programme that:

- Quantifies required Australian public investment in hydrogen RD&D to 2040.
- Establishes timeframes and milestones for delivery.
- Establishes and manages a knowledge sharing approach with key international parties, such as the US DOE National Laboratories and the German Fraunhofer Institute.
- Aligns with other support for Australian innovation such as that provided through the Commercialisation Action Plan and National Reconstruction Fund, as well as include dedicated funding for attraction of cleantech scale ups looking to expand to Australia, particularly from the Asia Pacific region.
- Establishes annual public reporting on each of the above.

Recommendation 41: Establish common testing and prototyping infrastructure.

The Australian Government should consider the creation of soft common user infrastructure – such as testing and prototyping facilities and shared office space – that can facilitate growth through reducing barriers to market for emerging technologies.

Recommendation 42: Undertake and publish a regulatory gap analysis and programme of reform.

The Net Zero Economy Agency should task and resource DCCEEW and the jurisdictions to identify regulatory gaps and reform opportunities and lead a programme of reform to meet the refreshed NHS targets and milestones. Further engagement with international jurisdictions is encouraged.

Recommendation 43: Harmonise Australian heavy vehicle regulation with international standards.

The Net Zero Economy Agency should task and resource DCCEEW to work with the Department of Infrastructure, Transport, Regional Development, Communications and the Arts and jurisdictional bodies to support lessening the regulatory and administrative burden for ZLEVs, especially concerning width and axle mass, through the harmonisation of standards with international markets and a ZLEV axle mass concession.

Recommendation 44: Develop harm prevention regulations to support industrial sectors.

The Net Zero Economy Agency should task and resource DCCEEW and the Department of Industry, Science and Resources to consult with priority industrial sectors to understand the different regulatory needs across the following dimensions of harm reduction, and lead national rule-making as far as possible:

- Safety, such as how hydrogen should be handled as a fuel in industrial plants.

- Planning and environment, such as use of water from environmental flows for hydrogen production, or acceptable NOx emissions thresholds when using hydrogen as a fuel source.
- Economic, such as possible future shared pipelines and the ease and cost of access.
- Competition and consumer regulations, such as establishing a definition of 'hydrogen-ready' for boilers and burners.

Recommendation 45: Work with AEMC and AER on cost and price models to ensure affordable energy bills.

DCCEEW should coordinate activity with the AEMC and AER not only on maintaining a separation of new hydrogen policy initiatives from small customer energy bills, but also to maintain visibility over key future assets required for hydrogen and the effect of hydrogen on electricity and gas asset values, maintenance and growth.

Recommendation 46: Clarify the next steps and fast-track the process to implement the GO scheme.

DCCEEW should implement the GO scheme as a matter of priority, or at a minimum, communicate a clear timeline for development and release. This should be aligned with international requirements wherever possible.

Recommendation 47: Support Australian-made clean products in hard-to-abate industries, supported by government procurement.

The Australian Government should create a dedicated subsidy scheme for Australian-made clean products in hard-to-abate industries, which will serve to increase uptake by the private sector. This can be supported by government procurement of these products to be used in any government funded projects.

Chapter 5: No regrets market development and support

Heavy road transport

Recommendation 48: Support hydrogen in heavy road transport with a national ZLEV strategy, fleet trials, transition funds, and either a heavy vehicle fuel efficiency standard or sales target.

In line with the revised NHS objectives and targets, DCCEEW should develop a national ZLEV strategy for heavy vehicles with both financial and non-financial incentives, including:

- Funding further heavy FCEV trials to aid total cost of ownership certainty. This should include separate trials for heavily-trafficked truck routes (at least two trials of heavy fleets at minimum of A$200 million each), lighter logistics trucks (at least three trials at A$25 million each), and for bus routes near hydrogen centres (at least two larger trials at A$45 million each for 40 buses).

- Financial support for transitioning heavy vehicle fleet and associated infrastructure, which could align with support under Recommendations 49 and 50.
- Developing a heavy vehicle fuel efficiency standard or sales target for the Australian context.

Funding could be matched by states and territories for key projects and split so that one funding stream defrays capital costs and the other provides long term underwriting for contracts.

Industrial processes

Recommendation 49: Attract private investment for hard-to-abate industrial processes.

Noting the need for funding to align with analyses addressed in Recommendations 3-5 and any targets set, the Australian Government should:

- Fund a hydrogen readiness programme of at least A$1 billion for capital expenditure on industrial processes that cannot readily be electrified, including (and not exclusively) for the production of steel, ammonia, methanol, and alumina/aluminium.
- Continue to use ARENA (and CEFC where possible) to underwrite demand through a revenue support mechanism (such as contract for difference) intended to incentivise domestic production of critical chemicals and metals, including (and not exclusively) for the production of steel, ammonia, methanol, and alumina/aluminium. Funding should be aligned with funding from state/territory governments.

Funding should be prioritised for projects that protect or create local jobs and have a detailed plan for skilling and re-skilling. Applicants should be required to share non-commercially sensitive information to support industry knowledge development – this could be assisted by engaging with industry associations to support delivery.

To mitigate and reduce the costs associated with project development (such as transmission costs), the Australian and state governments could collaborate to further incentivise co-location of chemical production within Hydrogen Economic Zones, and within proximity to other industrial infrastructure such as ports.

Recommendation 50: Develop bespoke packages for other early adopters in high temperature process heating.

Target government support packages for early adopters who need to switch to hydrogen for high temperature heating but cannot access support under Recommendation 49. This should include:

- Financial support through tax and/or targeted market mechanisms.
- Increased ARENA funding for trials and demonstrations.

Shipping

Recommendation 51: Develop a national assessment of shipping routes and refuelling requirements.

The Australian Government should engage with shipping companies operating in Australia and peak bodies to analyse and report back on:

- Current shipping routes.
- Shipping companies' views on fuels in which they are investing, the relative energy densities of options, and requirements to refuel (that is, the maximum journey length without bunkering requirements).
- Bunkering in Australia, to understand if products (including fuels) are to be transported from southern Australia, what the impact is on key matters such as the total journey length and requirement to refuel.
- Opportunities for demonstration projects at suitable ports.

Electricity

Recommendation 52: Undertake a full energy market and grid impact analysis for wide scale adoption of electrolysers as flexible load in the electricity grid.

The Australian Government should task AEMO and AEMC with undertaking a full energy market and grid impact analysis for wide scale adoption of electrolysers as flexible load in the electricity grid. This work can then inform energy and hydrogen policy.

Aviation

Recommendation 53: Work with the Department of Infrastructure, Transport, Regional Development, Communications and the Arts and its Jet Zero Council to consider the next steps for hydrogen for SAF production, using the CSIRO Futures report.

DCCEEW should work with the Department of Infrastructure, Transport Regional Development, Communications and the Arts, the Jet Zero Council and related stakeholders to assess future SAF needs for Australia and how they can be met, using the CSIRO Futures study. This should lead to planning and target setting for scaling up hydrogen production as required.

References

Adiona Tech (2023), *Connected Thinking: An Adiona Tech report on Australian transport electrification priorities*, https://www.adionatech.com/resources/connected-thinking-report.

Advisian (2021) *Australian hydrogen market study: Sector analysis summary*, 24 May, for the Clean Energy Finance Corporation, https://www.cefc.com.au/media/nhnhwlxu/australian-hydrogen-market-study.pdf.

AGIG (2020) *Five year plan for the Dampier to Bunbury Natural Gas Pipeline*, January, https://www.agig.com.au/-/media/files/agig/stakeholder-engagement/agig-dbngp-final-plan-2021-2025.pdf.

Arup (2022) *Water for Hydrogen Technical Paper*, prepared for Department of Climate Change, Energy, the Environment and Water Australian Hydrogen Council, reference: 286739-00-RPT-001, 14 November, https://h2council.com.au/wp-content/uploads/2023/02/221114-Arup-Technical-paper-Water-for-Hydrogen-report-FINAL.pdf.

Arup (2023a) *Powering Up: Seizing Australia's Hydrogen Opportunity by 2040*, report for NERA, https://www.nera.org.au/Publications-and-insights/HETS-Study.

Arup (2023b) *National Hydrogen Infrastructure Assessment: Final Report*, prepared for the Department of Climate Change, Energy, the Environment and Water, April, https://www.dcceew.gov.au/energy/publications/national-hydrogen-infrastructure-assessment.

Arup (2023c) *National Hydrogen Infrastructure Assessment, Final Report – Appendix E*, for the Department of Climate Change, Energy, the Environment and Water, Reference: Rev 2, 23 December 2022.

Aurecon (2019), *Hydrogen for Transport: Prospective Australian Use Cases*, October, https://www.dcceew.gov.au/sites/default/files/documents/nhs-hydrogen-for-transport-report-2019.pdf.

Australian Energy Market Operator (2023) *Rule change request – Scheduled Lite Mechanism in the National Electricity Market (NEM)*, submission from Violette Mouchaileh, https://www.aemc.gov.au/sites/default/files/2023-01/ERC0352_Rule%20Change%20Request_Scheduled%20Lite%20-%20including%20Appendix.pdf.

Australian Energy Regulator (2023) *Final decision – AGN (Victoria & Albury) Access Arrangement 2023–28*, AER reference 212593, 2 June, https://www.aer.gov.au/networks-pipelines/determinations-access-arrangements/australian-gas-networks-victoria-and-albury-access-arrangement-2023–28.

Australian Government (2022) *Korean hydrogen market update*, South Korea, Australian Trade and Investment Commission, June, https://www.intralinkgroup.com/getmedia/8ba563f7-08f6-43de-ab4a-4467c7e8b3bd/Austrade-Korean-Hydrogen-Market_Report#:~:text=According per cent20to per cent20the per cent20Ministry per cent20of per cent20Trade per cent2C per cent20Industry per cent20and,1.96 per cent20million per cent20tonnes per cent2Fyear per cent20of per cent20clean per cent20hydrogen per cent20from per cent20abroad.

Australian Government (2023a) *State of Hydrogen 2022*, Australian Government Department of Climate Change, Energy, the Environment and Water, April, https://www.dcceew.gov.au/energy/publications/state-of-hydrogen-2022.

Australian Government (2023b) *A new national Net Zero Authority*, media release, Department of the Prime Minister and Cabinet, 5 May, https://www.pmc.gov.au/news/new-national-net-zero-authority.

Australian Government (2023c) 'Quad Statement of Principles on Clean Energy Supply Chains in the Indo-Pacific', Department of the Prime Minister and Cabinet, 20 May, https://www.pmc.gov.au/resources/quad-statement-principles-clean-energy-supply-chains-indo-pacific.

Australian Government (2023d) 'Community consultation key to developing renewable energy infrastructure', media release from the Minister for Energy Chris Bowen, 4 July.

Australian Hydrogen Council (2021), *Unlocking Australia's hydrogen opportunity*, September, https://h2council.com.au/wp-content/uploads/2022/10/AHC_White_Paper_FINAL_28-Sep-21_2021-09-30-012757.pdf.

Australian Hydrogen Council (2023a) *Consultation on the design of Hydrogen Headstart program*, 3 August, https://h2council.com.au/wp-content/uploads/2023/08/AHC-submission_Hydrogen-Headstart_03082023.pdf.

Australian Hydrogen Council (2023b) *Securing Australia's hydrogen future*, 1 March, https://h2council.com.au/wp-content/uploads/2023/02/230301-AHC-Policy-Paper-Securing-Australias-hydrogen-future.pdf.

BHP (2020) 'Pathways to decarbonisation episode two: steelmaking technology', 5 November 2020, https://www.bhp.com/media-and-insights/prospects/2020/11/pathways-to-decarbonisation-episode-two-steelmaking-technology/.

BlueScope Steel (2021) *BlueScope submission to the Standing Committee on State Development's Inquiry into the development of a hydrogen industry in NSW*, 26 February, https://www.parliament.nsw.gov.au/committees/inquiries/Pages/inquiry-details.aspx?pk=2643#tab-submissions.

Bocobza, J. and M. Tanabe (2023) 'Japan Hydrogen Basic Strategy', White &Case website, 26 June, https://www.whitecase.com/insight-alert/japan-hydrogen-basic-strategy.

Bowen, C. (2023) *Address to Clean Energy Council*, speech, 18 July, https://minister.dcceew.gov.au/bowen/speeches/address-clean-energy-council.

Briggs, C., Gill, J., Atherton, A., Langdon, R., Jazbec, M., Walker, T., Youren, M., Tjondro, M., Rutovitz, J., Cunningham, R., Wright, S. and Nagrath, K., (2022) *Employment, Skills and Supply Chains: Renewable Energy in NSW – Final Report*, University of Technology Sydney and SGS Economics and Planning, https://www.energy.nsw.gov.au/sites/default/files/2022-09/employment-skills-and-supply-chains-renewable-energy-in-nsw-final-report.pdf.

Bruce, S., Temminghoff, M., Hayward, J., Schmidt, E., Munnings, C., Palfreyman, D., and P. Hartley (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.

California Fuel Cell Partnership (2021), *Fuel cell electric trucks: A vision for freight movement in California – and beyond*, July, https://app.greenrope.com/content/Fuel-Cell-Electric-Trucks-Vision-CaFCP.pdf.

Carter, N., O'Sullivan, T., Nolan, T, and E. Saba (2020) *Flexibility of hydrogen electrolysers: Opportunities in the Australian National Electricity Market*, Macquarie, https://www.macquarie.com/assets/macq/perspectives/Flexibility-of-Hydrogen-Electrolysers-Interactive.pdf.

Clean Energy Council (n.d) *Best Practice Charter for Renewable Energy Projects*, https://www.cleanenergycouncil.org.au/advocacy-initiatives/community-engagement/best-practice-charter.

Climateworks Centre and Climate-KIC Australia (2023) *Pathways to industrial decarbonisation: Positioning Australian industry to prosper in a net zero global economy*, Australian Industry Energy Transitions Initiative, Phase 3, February, https://www.energy-transitions.org/publications/pathways-to-industrial-decarbonisation/.

COAG Energy Council (2019) *Australia's national hydrogen strategy*, November, https://www.dcceew.gov.au/energy/publications/australias-national-hydrogen-strategy.

Collins, L. (2023) 'Germany to sanction the use of blue, turquoise and orange hydrogen 'to a limited extent'', *Hydrogen Insight*, 26 July, https://www.hydrogeninsight.com/policy/germany-to-sanction-the-use-of-blue-turquoise-and-orange-hydrogen-to-a-limited-extent/2-1-1491786.

Competition Markets Authority (2023) *Consumer protection in the green heating and insulation sector*, Call for information: findings report, 31 May, https://assets.publishing.service.gov.uk/media/6475f1685f7bb7000c7fa176/Consumer_protection_in_the_green_heating_and_insulation_sector_-_Final_report.pdf.

Construction Skills Queensland (2022) *Queensland's Renewable Future: investment, jobs and skills*, CSQ, Brisbane, Australia, August, https://www.csq.org.au/wp-content/uploads/2022/08/CSQ-Queenslands-Renewable-Future-full-report.pdf.

Craen, S. (2023) *Financing a world scale hydrogen export project*, Oxford Institute for Energy Studies, January, https://www.oxfordenergy.org/wpcms/wp-content/uploads/2023/01/Financing-a-world-scale-hydrogen-export-project-ET-21.pdf.

Cranston, M. (2023) 'How the US could soon invest millions in Aussie companies', *Australian Financial Review*, 23 May, https://www.afr.com/world/north-america/why-the-us-could-soon-invest-millions-in-aussie-companies-20230523-p5dafo.

CSIRO (2023) *Australia's critical hydrogen research questions*, derived from the 2023 Australian Hydrogen Research Conference, ANU, Canberra, 8-10 February 2023. See https://ahrn.org.au/wp-content/uploads/2023/06/Australias-critical-hydrogen-research-questions-FINAL.pdf.

Davis, D., Pascale, A., Vecchi, A., Bharadwaj, B., Jones, R., Strawhorn, T., Tabatabaei, M., Lopez Peralta, M., Zhang, Y., Beiraghi, J., Kiri, U., Vosshage, Finch, B., Batterham, R., Bolt, R., Brear, M., Cullen, B., Domansky, K., Eckard, R., Greig, C., Keenan, R., and S. Smart (2023) 'Modelling Summary Report', *Net Zero Australia*, ISBN 978 0 7340 5704 4, https://www.netzeroaustralia.net.au/wp-content/uploads/2023/04/Net-Zero-Australia-Modelling-Summary-Report.pdf.

Delaval, B., Rapson, T., Sharma, R., Hugh-Jones, W., McClure, E., Temminghoff, M. and V. Srinivasan (2022) *Hydrogen RD&D Collaboration Opportunities*: Global Report, CSIRO, Australia. See http://mission-innovation.net/wp-content/uploads/2022/09/H2RDD-Global-FINAL.pdf.

Deloitte (2019) *Australian and global hydrogen demand growth scenario analysis*; COAG Energy Council – National Hydrogen Strategy Taskforce, November, https://www.dcceew.gov.au/energy/publications/australias-national-hydrogen-strategy/reports-to-support-the-strategy.

Deloitte (2022) *A Roadmap for Decarbonising Australian Alumina Refining In collaboration with the Australian Renewable Energy Agency, and in consultation with participants Alcoa, Rio Tinto and South32*, for ARENA, November, https://arena.gov.au/knowledge-bank/a-roadmap-for-decarbonising-australian-alumina-refining/.

Deloitte Access Economics (2021) *Australia remade: A country fit for the age of disruption*, https://www2.deloitte.com/au/en/pages/building-lucky-country/articles/australia-remade.html.

Deloitte Access Economics (2022) *All systems go: Transforming Australia's economy to grow*, for NAB, July, https://news.nab.com.au/news/opportunity-in-low-emissions-world/.

Deloitte Access Economics (2023) *Australia's Hydrogen Tipping Point – The urgent case to support renewable hydrogen production*, February, https://www2.deloitte.com/au/en/pages/about-deloitte/articles/australia-hydrogen-tipping-point.html.

Denis-Ryan, A. and Gordon, J. (2023) *Australia needs 1.5°C aligned national energy pathways*, Institute for Energy Economics and Financial Analysis, June, https://ieefa.org/resources/australia-needs-15degc-aligned-national-energy-pathways-0.

Department of Climate Change, Energy, the Environment and Water (2022) *Review of Hydrogen Regulation: Hydrogen Industry Consultation*, Australian Government, https://consult.dcceew.gov.au/review-of-hydrogen-regulation.

Department of Climate Change, Energy, the Environment and Water (2023a) *Commonwealth Hydrogen Regulation*, Australian Government, https://consult.dcceew.gov.au/review-of-hydrogen-regulation.

Department of Climate Change, Energy, the Environment and Water (2023b) *Guarantee of Origin scheme*, Australian Government, https://www.dcceew.gov.au/energy/renewable/guarantee-of-origin-scheme.

Department of Climate Change, Energy, the Environment and Water (2023c) *Hydrogen Headstart: Consultation Paper*, Australian Government, Australian Renewable Energy Agency, July, https://consult.dcceew.gov.au/hydrogen-headstart-program-consultation.

Department of Foreign Affairs and Trade (2023) *Singapore-Australia Green Economy Agreement Progress on Implementation: June 2023*, Australian Government, https://www.dfat.gov.au/geo/singapore/singapore-australia-green-economy-agreement/singapore-australia-green-economy-agreement-progress-implementation-june-2023.

Department of Infrastructure, Transport, Regional Development and Communications (2021) *Discussion Paper: Safer freight vehicles*, Australian Government, https://www.nhvr.gov.au/files/media/document/257/202306-1359-discussion-paper-implementation-of-safer-freight-vehicle-reforms.pdf.

Department of Infrastructure, Transport, Regional Development, Communications and the Arts (2023a) *Australian Jet Zero Council*, 21 June, https://www.infrastructure.gov.au/infrastructure-transport-vehicles/aviation/australian-jet-zero-council.

Department of Infrastructure, Transport, Regional Development, Communications and the Arts (2023b) *Aviation White Paper*, https://www.infrastructure.gov.au/infrastructure-transport-vehicles/aviation/aviation-white-paper.

Department of Planning, Industry and Environment (2021) *Net Zero Industry and Innovation Program: Driving a clean industrial revolution*, March, https://www.energysaver.nsw.gov.au/sites/default/files/2021-07/NetZero-Industry-Innovation-Program_FINAL_24-March-21_webaccessible.pdf.

DNV (2023a) *The Role of Hydrogen and Batteries in Delivering Net Zero in the UK by 2050*, prepared for the Faraday Institution, Report No. L2C231476-UKLON-R-01, Rev F, 21 April, https://www.faraday.ac.uk/wp-content/uploads/2023/04/L2C231476-UKLON-R-01-F_Market-and-Technology-Assessment_FaradayInst_24Apr2023.pdf.

DNV (2023b) *Ammonia Bunkering Pilot Safety Study*, Global Centre for Maritime Decarbonisation, Surbana Jurong, Singapore Maritime Academy, April, https://www.gcformd.org/ammoniabunkeringreportdownload.

Dougherty, R. (2023) 'Australia lined up as domestic source for US Defense Production Act', Defence Connect, 22 May, https://www.defenceconnect.com.au/land-amphibious/12006-australia-lined-up-as-domestic-source-for-us-defense-production-act.

Dowling, H. (2022) 'Rex to trial electric planes on short routes in 2024', *Australian Aviation*, 28 July, https://australianaviation.com.au/2022/07/rex-to-trial-electric-planes-on-short-routes-in-2024/.

Electric Vehicle Council and Australian Trucking Association (2021) *Electric trucks: Keeping shelves stocked in a net zero world*, https://electricvehiclecouncil.com.au/wp-content/uploads/2022/01/ATA-EVC-Electric-trucks_Keeping-shelves-stocked-in-a-net-zero-world-2.pdf.

Energy Market Authority & Maritime and Port Authority of Singapore (2022) *Expression of interest (EOI) to develop an end-to-end low or zero-caron ammonia power generation and bunkering solution ("project") in Singapore*, media release, 5 December, https://www.mpa.gov.sg/docs/mpalibraries/media-releases/older/expression-of-interest-for-ammonia-project-(final).

Energy Ministers (2022) 'National Energy Transformation Partnership', August, https://www.energy.gov.au/sites/default/files/2022-08/National%20Energy%20Transformation%20Partnership.pdf.

Energy Transitions Commission (2021) *Making the Hydrogen Economy Possible – Accelerating Clean Hydrogen in an Electrified Economy*, the Making Mission Possible Series, April, version 1.1, https://www.energy-transitions.org/publications/making-clean-hydrogen-possible/.

European Commission (n.d.) 'Reducing emissions from the shipping sector,' https://climate.ec.europa.eu/eu-action/transport-emissions/reducing-emissions-shipping-sector_en.

Geoscience Australia (n.d.) *Australia's Future Energy Resources*, Australian Government, https://www.eftf.ga.gov.au/australias-future-energy-resources.

German Government (2023) *Energy from climate-friendly gas*, media release, 26 July, https://www.bundesregierung.de/breg-de/schwerpunkte/klimaschutz/hydrogen-technology-2204238.

Green Hydrogen Organisation (2022) *Green Hydrogen Contracting Guidance: Financing green hydrogen projects*, Contracting brief, December, https://gh2.org/sites/default/files/2022-12/GH2_Contracting%20Guidance_Financing%20Green%20Hydrogen%20Projects_2022.pdf.

Groenenberg, R. (2023) *Large-scale hydrogen storage*, Session 3, world energy storage 2023, 10 May 2023, Rotterdam, TNO, The Netherlands.

Hydrogen TCP-Task 42 (2023) *Underground Hydrogen Storage: Technology Monitor Report*, see https://www.ieahydrogen.org/task/task-42-underground-hydrogen-storage/.

HyResource (2023) *Republic of Korea (South Korea)*, https://research.csiro.au/hyresource/policy/international/republic-of-korea-south-korea/, accessed 12 July 2023.

International Energy Agency (2021a) *Net Zero by 2050: A Roadmap for the Global Energy Sector*, May, https://www.iea.org/reports/net-zero-by-2050.

International Energy Agency (2021b) *Global Hydrogen Review 2021*, revised version, November, https://www.iea.org/reports/global-hydrogen-review-2021.

International Energy Agency (2022) *Direct Air Capture: A key technology for net zero*, https://iea.blob.core.windows.net/assets/78633715-15c0-44e1-81df-41123c556d57/DirectAirCapture_Akeytechnologyfornetzero.pdf.

International Energy Agency (2023) *Aviation*, https://www.iea.org/energy-system/transport/aviation.

International Renewable Energy Agency (2019) *A New World: The Geopolitics of the Energy Transformation*, the Global Commission on the Geopolitics of Energy Transformation, https://irena.org/publications/2019/Jan/A-New-World-The-Geopolitics-of-the-Energy-Transformation.

International Renewable Energy Agency (2021) *Reaching Zero with Renewables: Biojet fuels*, https://www.irena.org/-

/media/Files/IRENA/Agency/Publication/2021/Jul/IRENA_Reaching_Zero_Biojet_Fuels_2021.pdf.

International Renewable Energy Agency (2022) *Geopolitics of the energy transformation: the hydrogen factor*, International Renewable Energy Agency, January, Abu Dhabi, see https://www.irena.org/publications/2022/Jan/Geopolitics-of-the-Energy-Transformation-Hydrogen.

International Renewable Energy Agency (2023), *Low-cost finance for the energy transition*, International Renewable Energy Agency, Abu Dhabi, https://www.irena.org/Publications/2023/May/Low-cost-finance-for-the-energy-transition.

ITP Thermal (2019) *Renewable Energy Options for Industrial Process Heat*, prepared for Australian Renewable Energy Agency, August, https://arena.gov.au/assets/2019/11/renewable-energy-options-for-industrial-process-heat.pdf.

Jung, M-H (2022) 'POSCO Group to Invest US$40bn in Australia by 2040', *Business Korea*, 2 December, https://www.businesskorea.co.kr/news/articleView.html?idxno=105269.

Keppel Corporation (2022) 'Keppel to develop Singapore's first hydrogen-ready power plant, with construction undertaken by Mitsubishi Power Asia Pacific and Jurong Engineering consortium', media release, 30 August, https://www.kepcorp.com/en/media/media-releases-sgx-filings/keppel-to-develop-singapores-first-hydrogen-ready-power-plant/.

Kinch, D. (2022) 'Direct-reduced iron becomes steel decarbonization winner', S&P Global Commodity Insights, 22 June, https://www.spglobal.com/commodityinsights/en/market-insights/blogs/metals/062222-dri-steel-decarbonization-direct-reduced-iron.

Kissin, E. (2023) 'The Five Eyes set their sights on critical minerals', *FDI Intelligence*, 2 March, https://www.fdiintelligence.com/content/feature/the-five-eyes-set-their-sights-on-critical-minerals-82006.

Komachi, H., Neilson, S., and M. Voss (2023) 'Japan unveils green subsidy programme – can it compete with the U.S. Inflation Reduction Act?', Allen & Overy website, 11 April, https://www.allenovery.com/en-gb/global/news-and-insights/publications/japan-unveils-green-subsidy-programme-can-it-compete-with-the-us-inflation-reduction-act#who-qualifies.

Kurmayer, N.J. (2023) 'Germany commits to 'blue hydrogen' in updated national strategy', *Euractiv*, 27 July, https://www.euractiv.com/section/energy-environment/news/germanys-updated-hydrogen-strategy-new-commitment-to-fossil-based-hydrogen/.

Lee, B., Gordon, J., Sutton, K. and A. Kushwah (2023), *Roadmap to Fuel Cell Electric Truck Commercialization California Market Assessment*, CALSTART, March, https://calstart.org/wp-content/uploads/2023/03/Roadmap-to-FCET-Commercialization.pdf.

Ludlow, M. (2023) 'Stuck in the slow lane to net zero', *AFR Weekend*, Saturday 24th June, page 17.

Ma, Y., Wung Bae, J., Kim, S-H., Jovičević-Klug, M., Li, K., Vogel, D., Ponge, D., Rohwerder, M., Gault, B., and D. Raabe (2023) 'Reducing Iron Oxide with Ammonia: A Sustainable Path to Green Steel', *Advanced Science*, vol. 10, issue 13, 2 June, first published 30 March 2023, https://onlinelibrary.wiley.com/doi/10.1002/advs.202300111.

Maersk (2021) 'Maersk secures green e-methanol for the world's first container vessel operating on carbon neutral fuel', media release, 19 August, https://www.maersk.com/news/articles/2021/08/18/maersk-secures-green-e-methanol.

Mallett, A., and P. Prosanto (2022) 'Green transformation in the iron and steel industry in India: Rethinking patterns of innovation', Energy Strategy Reviews, vol. 44, 22 November, https://www.sciencedirect.com/science/article/pii/S2211467X22001626#bib25.

Maritime and Port Authority of Singapore (2022) *Joint Media Release: Call for Expression of Interest to Develop Low or Zero-Carbon Power Generation and Bunkering Solutions*, 5 December, https://www.mpa.gov.sg/media-centre/details/joint-media-release-call-for-expression-of-interest-to-develop-low-or-zero-carbon-power-generation-and-bunkering-solutions.

McCoy, J., Davis, D., Mayfield, E., and M. Brear (2023) 'Downscaling – Employment impacts', *Net Zero Australia*, 19 April, https://www.netzeroaustralia.net.au/wp-content/uploads/2023/04/Downscaling-Employment-impacts.pdf.

McDonagh, N. (2023) '"Friend-Shoring": From Rhetoric to Reality and Options for Australia', *Institute for Economic Affairs*, 31 March, https://www.internationalaffairs.org.au/australianoutlook/friend-shoring-from-rhetoric-to-reality-and-options-for-australia/.

McKinsey & Company (2022) *Sustainable infrastructure: The best ideas from the 2022 GII Summit*, Global Infrastructure Initiative, https://www.mckinsey.com/capabilities/operations/our-insights/global-infrastructure-initiative/summit/sustainable-infrastructure-the-best-ideas-from-the-2022-gii-summit.

Meti (2023) 'Five-Point Plan for Critical Minerals Security', *Annex to the Climate, Energy and Environment Ministers' Communiqué,* https://www.meti.go.jp/information/g7hirosima/energy/pdf/Annex005.pdf.

Milne (2021) 'Yara plans massive Pilbara green ammonia plant by 2030', 30 June, *Boiling Cold*, https://www.boilingcold.com.au/yara-plans-massive-pilbara-green-ammonia-plant-by-2030/.

Mining Technology (2022) 'ArcelorMittal-Nippon Steel JV begins $7.2bn India plant expansion', *Mining Technology*, 31 October, https://www.mining-technology.com/news/arcelormittal-nippon-india-expansion/.

Mission Possible Partnership (2022), *Making Zero-Emissions Trucking Possible: Trucking Transition Strategy*, July, https://missionpossiblepartnership.org/wp-content/uploads/2022/11/Making-Zero-Emissions-Trucking-Possible.pdf.

Mitsui O.S.K. Lines (2023) *Mitsui O.S.K. Lines, Ltd. (MOL) makes strategic investment in Ascension Clean Energy: Leading global shipping company latest shareholder in planned Louisiana clean hydrogen-ammonia production facility*, media release, 15 June, https://www.mol.co.jp/en/pr/2023/23080.html.

Muller, F., Saddler, H., and H. Melville-Rea (2021) *Carbon Border Adjustments, What are they and how will they impact Australia*, The Australia Institute, https://australiainstitute.org.au/wp-content/uploads/2021/06/P1031-Carbon-Border-AdjustmentsWEB.pdf.

Nakano, J. and Majkut, J. (2022) 'Energy and critical minerals', *Growing challenges, Rising Ambitions: Ausmin 2022 And Expanding U.S. – Australia Cooperation*, Centre for Strategic and International Studies, eds. C. Edel and L. Tran, December, https://www.csis.org/analysis/growing-challenges-rising-ambitions-ausmin-2022-and-expanding-us-australia-cooperation.

Net Zero Australia (2023) *How to make net zero happen: Mobilisation report*, University of Melbourne, University of Queensland, Princeton University and Nous, 12 July, https://www.netzeroaustralia.net.au/wp-content/uploads/2023/07/Net-Zero-Australia-Mobilisation-How-to-make-net-zero-happen-12-July-23.pdf.

Neuwirth, M., Fleiter, T., Manz, P., and R. Hofman (2022) 'The future potential hydrogen demand in energy-intensive industries - a site-specific approach applied to Germany', *Energy Conversion and Management*, 252 (2022) 115052, https://www.sciencedirect.com/science/article/pii/S0196890421012280?via%3Dihub.

New Energy and Industrial Technology Development Organization (n.d.) *Overview of the Green Innovation Fund Projects*, https://green-innovation.nedo.go.jp/en/about/.

Nippon Export and Investment Insurance (2023) *NEXI signs MOU with JOGMEC*, media release, 30 March, https://www.nexi.go.jp/en/topics/newsrelease/2023032802.html.

NSW Ports (2023) *2063: Our 40-year master plan for sustainable growth*, report, https://www.nswports.com.au/file-download/download/public/2368.

Parkes, J. (2023) 'European Parliament signs off new rules on hydrogen filling stations and H2-based shipping fuels', *Hydrogen Insight*, 12 July, https://www.hydrogeninsight.com/policy/european-parliament-signs-off-new-rules-on-hydrogen-filling-stations-and-h2-based-shipping-fuels/2-1-1484863.

Pascale, A., Tabatabaei, M., and S. Smart (2023), 'Downscaling – Hydrogen and synthetic fuel production, transmission and storage', *Net Zero Australia*, https://www.netzeroaustralia.net.au.

Peacock, B. (2022) 'Qantas partners with Airbus on sustainable fuels, Aviation H2 acquires hydrogen test engines', *PV Magazine*, 22 June, https://www.pv-magazine-australia.com/2022/06/22/qantas-partners-with-airbus-on-sustainable-fuels-aviation-h2-acquires-hydrogen-test-engines/.

Port of Townsville (2023) *Channel upgrade*, site updated 29 March 2023, https://www.townsville-port.com.au/projects-development/channel-upgrade/.

Queensland Government (2023) *Qld's green jet fuel industry set to soar with Qantas partnership*, media release, 23 May, https://statements.qld.gov.au/statements/97770.

Reid, S. and Cann, G. (2016) *The good, the bad and the ugly: The changing face of Australia's LNG production*, Deloitte, https://www2.deloitte.com/us/en/pages/energy-and-resources/articles/gx-australian-lng-production.html.

Rutovitz, J., Langdon, R., Mey, F., Briggs, C. (2023) *The Australian Electricity Workforce for the 2022 Integrated System Plan: Projections to 2050*, Revision 1, prepared by the Institute for Sustainable Futures for RACE for 2030, January, https://www.uts.edu.au/isf/explore-research/projects/australian-electricity-workforce-2022-integrated-system-plan-projections-2050.

Srinivasan, V., Delaval, B., Dollman, R., Towns, A., Charnock, S., Palfreyman, D., Hayward, J., Graham, P., Foster, J., Reedman, L and D. Tourbier (2023) *Renewable Energy Storage Roadmap*, CSIRO, https://www.csiro.au/en/work-with-us/services/consultancy-strategic-advice-services/CSIRO-futures/Energy-and-Resources/Renewable-Energy-Storage-Roadmap.

Stanwell (2023) *CQ-H2: Central Queensland Renewable Hydrogen Project*, https://www.stanwell.com/energy-assets/new-energy-initiatives/stanwell-hydrogen-project/stanwell-hydrogen-project/.

Subramanian, S. (2022) 'Forty percent of all shipping cargo consists of fossil fuels', *Quartz*, 14 January, https://qz.com/2113243/forty-percent-of-all-shipping-cargo-consists-of-fossil-fuels.

Tam, S. (2023) 'South Korea opens hydrogen power bidding market, *Argus*, 9 June, https://www.argusmedia.com/en/news/2457898-south-korea-opens-hydrogen-power-bidding-market.

Tan, S-L (2022) 'Yellen says the U.S. and its allies should use 'friend-shoring' to give supply chains a boost', *CNBC*, 19 July, https://www.cnbc.com/2022/07/19/us-treasury-secretary-on-supply-chain-resilience-use-friend-shoring.html.

Temminghoff, M., Kuen, M., Cohen, J., Duong, P., Deverell, J., Palfreyman, D., Livitsanis, A., Clark, J., Patel, J. and A. Moore (2023) *Sustainable Aviation Fuel Roadmap*, CSIRO, Canberra, https://www.csiro.au/safroadmap.

Terrill, M., Burfurd, I. and Fox, L. (2022) *The Grattan truck plan: Practical policies for cleaner freight*, Grattan Institute, report, August, https://grattan.edu.au/wp-content/uploads/2022/08/Grattan-Truck-Plan-Report.pdf.

Truck Industry Council (2022), *Truck Industry Council's submission to the Commonwealth of Australia's National Electric Vehicle Strategy Consultation Paper – September 2022*, https://consult.dcceew.gov.au/national-electric-vehicle-strategy/submission/view/457.

UK Government (2023) *Mobilising Green Investment: 2023 Green Finance Strategy*, HM Government, March 2023, see https://www.gov.uk/government/publications/green-finance-strategy/mobilising-green-investment-2023-green-finance-strategy.

US Department of Commerce (2023) *Joint Statement – Second Annual Australia-U.S. Strategic Commercial Dialogue*, media release, 26 May, https://www.commerce.gov/news/press-releases/2023/05/joint-statement-second-annual-australia-us-strategic-commercial.

US Department of Energy (2023a) *Pathways to Commercial Liftoff: Clean Hydrogen*, March, https://liftoff.energy.gov/wp-content/uploads/2023/05/20230523-Pathways-to-Commercial-Liftoff-Clean-Hydrogen.pdf.

US Department of Energy (2023b), *U.S. National Clean Hydrogen Strategy and Roadmap*, 6 June, https://www.hydrogen.energy.gov/clean-hydrogen-strategy-roadmap.html.

US General Services Administration (2023) *GSA pilots Buy Clean Inflation Reduction Act Requirements for low embodied carbon construction materials*, media release, 16 May, https://www.gsa.gov/about-us/newsroom/news-releases/gsa-pilots-buy-clean-inflation-reduction-act-requirements-for-low-embodied-carbon-construction-materials-05162023.

Virgin Australia (2023) *Virgin Australia and Boeing join forces on sustainability*, media release, 29 June, https://newsroom.virginaustralia.com/release/virgin-australia-and-boeing-join-forces-sustainability.

Water Services Association of Australia (2020) *All options on the table: Urban water supply options for Australia*, https://www.wsaa.asn.au/publication/all-options-table-urban-water-supply-options-australia.

Wettengel, J. (2023), 'Germany aims to accelerate hydrogen market ramp-up with strategy update', *Clean Energy Wire*, 26 July, https://www.cleanenergywire.org/news/germany-also-support-hydrogen-made-co2-capturing-under-upcoming-strategy-update-media.

The White House (2021) *Building resilient supply chains, revitalizing American manufacturing, and fostering broad-based growth*, 100-Day Reviews under Executive Order 14017, Washington, June, https://www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf.

The White House (2023) *G7 Hiroshima Leaders' Communiqué*, 20 May, https://www.whitehouse.gov/briefing-room/statements-releases/2023/05/20/g7-hiroshima-leaders-communique/.

Wood, T., Dundas, G., and J. Ha (2020) *Start with steel: A practical plan to support carbon workers and cut emissions*, Grattan Institute, Report No. 2020-06, May, https://grattan.edu.au/wp-content/uploads/2020/05/2020-06-Start-with-steel.pdf.

Wood, T., Reeve, A., and J. Ha (2021) *Towards net zero: Practical policies to reduce industrial emissions*, Grattan Institute, Report No. 2021-10, August, https://grattan.edu.au/report/towards-net-zero-practical-policies-to-reduce-industrial-emissions/.

Wood, T., Reeve, A., and Suckling, E. (2023) *Getting off gas: why, how, and who should pay?*, Grattan Institute, Report No. 2023-08, June, https://grattan.edu.au/wp-content/uploads/2023/06/Getting-off-gas-why-how-and-who-should-pay.pdf.