Getting H2 right

Success factors for Australia's hydrogen export industry

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The green hydrogen opportunity is here, now

Green hydrogen will be an exciting part of a net zero emissions future – driving change through the simple 'magic' of splitting water into hydrogen and oxygen.

With abundant land and high-capacity-factor renewable energy, Australia has the building blocks to produce globally competitive clean hydrogen to service growing domestic and international markets. It is also an opportunity to create new future-focused jobs and invigorate regional Australia.

For nations that want to reduce emissions but do not have the renewable energy capacity domestically to meet those needs, importing green hydrogen is an increasingly attractive opportunity. Japan and South Korea are already key markets for Australian energy exports and have signed hydrogen partnership agreements at government-to-government and private sector levels. Other energy-rich, export-oriented nations are racing to capture this opportunity, so there's no time to waste.

Placing Australia at the forefront of the hydrogen export industry will need rapid action both from government and industry. Government must develop a timely yet robust regulatory framework and ensure a competitive business framework. At the same time, industry should move quickly to develop the necessary infrastructure and export pathways. Together, these actions will boost confidence and build reputation.

These are exciting times, but new technologies also raise new questions, uncertainties and risks. Developers and investors are seeking confidence and certainty.

We've identified four critical success factors for getting hydrogen right, regardless of its form or destination:

- getting the price right
- establishing infrastructure and supply chain
- navigating policy and regulation
- making it bankable through partnerships.

Getting the price right

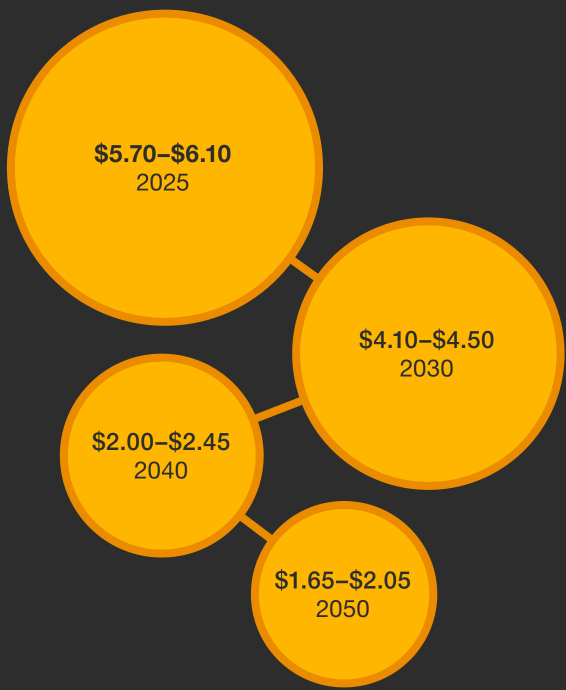
According to the Clean Energy Finance Corporation (CEFC), hydrogen produced by renewable energy is forecast to become cost-competitive with grey hydrogen between 2030 and 2040, leaving an economic gap to be bridged for projects over the next decade.

To drive down the cost of hydrogen production, the industry must focus on overcoming the cost of large-scale electrolysers whilst continuing to drive down the price of our internationally competitive renewable energy.

Developers will need to think innovatively about how they can best configure their project, including the sizing of the electrolyser, the choice of technologies, and where best to locate the project – for ongoing access and proximity to a secure water source, low-cost renewable energy and export infrastructure. They should also consider the most appropriate use case for their production based on project specific factors.

PwC's Future of Energy Hub has released a global hydrogen analysis tool, forecasting hydrogen production costs internationally and demonstrating Australia's opportunity to be a leader in production and export. The table below shows Australia's forecast green hydrogen production costs over time, declining rapidly by 2040 to the joint-lowest cost globally, on par with key export competitors.

Australia's forecast green hydrogen production cost (AUD/kg)



PwC analysis of bottom-up cost estimates to produce green hydrogen

Reductions in the cost of large-scale electrolysers

Green hydrogen projects reaching scale will provide confidence to global equipment providers to finance improved electrolyser manufacturing facilities with increased automation. Bringing down the cost of electrolysers will largely be driven by global developments, such as increased spending on research and development, availability of components, and manufacturing at Gigawatt scale.

The CEFC's 2021 report forecasts that current capital costs of electrolysers of around A$1.1 million per megawatt will fall rapidly to around A$0.5 million per megawatt by 2050, fully installed. Several market analysts and manufacturers forecast an even more aggressive reduction in capital costs over a shorter time frame. We have seen this before with other low emissions technologies that have benefited from economies of scale and learning effects.

Increasing efficiency of electrolysers – requiring less energy for production of hydrogen

Innovation in electrocatalysts, fuel cells, conversion to hydrogen carriers and overall electrolyser efficiency is occurring rapidly. These advances will reduce energy requirements and increase the overall capacity factor of the system. Industry will benefit from efficiency gains in the hydrogen production process once this R&D graduates from university research institutions (including many in Australia) and is able to harness increasingly available private funding.

Growing the domestic manufacturing capability – avoiding supply-chain bottlenecks in the move to GW scale

No major electrolyser manufacturing facilities are currently based in Australia. Domestic manufacturing would provide security of supply to Australia's large-scale projects and present an opportunity to revitalise our onshore manufacturing and export of intellectual property. For example, Fortescue Future Industries has announced a 2 GW electrolyser manufacturing facility in Queensland, which is set to capitalise on this opportunity for Fortescue's own green hydrogen projects and to service a growing customer base for electrolysis projects.

Sustained low-cost renewable electricity in Australia – available for the production of H2

Electricity supply represents 50–70% of the production cost of green hydrogen, depending on system size and electrolyser technology. The sustained roll-out of low-cost solar and wind generation is key to cheaper hydrogen production, as is continued decarbonisation of the grid, including the roll-out of renewable energy zones (REZs).

Increased renewables in the electricity network can also be complemented by hydrogen production. Hydrogen can provide a storage mechanism for excess renewable capacity as well as another pathway for firming generation. These services are expected to be increasingly valuable as the grid accelerates its transition to variable renewable energy and may attract payments for capacity or system stability benefits. This effect may allow for further integration of renewables into the National Electricity Market (NEM) with improved demand response from the grid.

Establishing infrastructure and supply chains

Australia's critical infrastructure and hydrogen supply chain will require parallel development as pilot projects progress towards industrial-scale production targeting both the domestic and export markets over the coming decade.

For project developers, some of the critical questions will be:

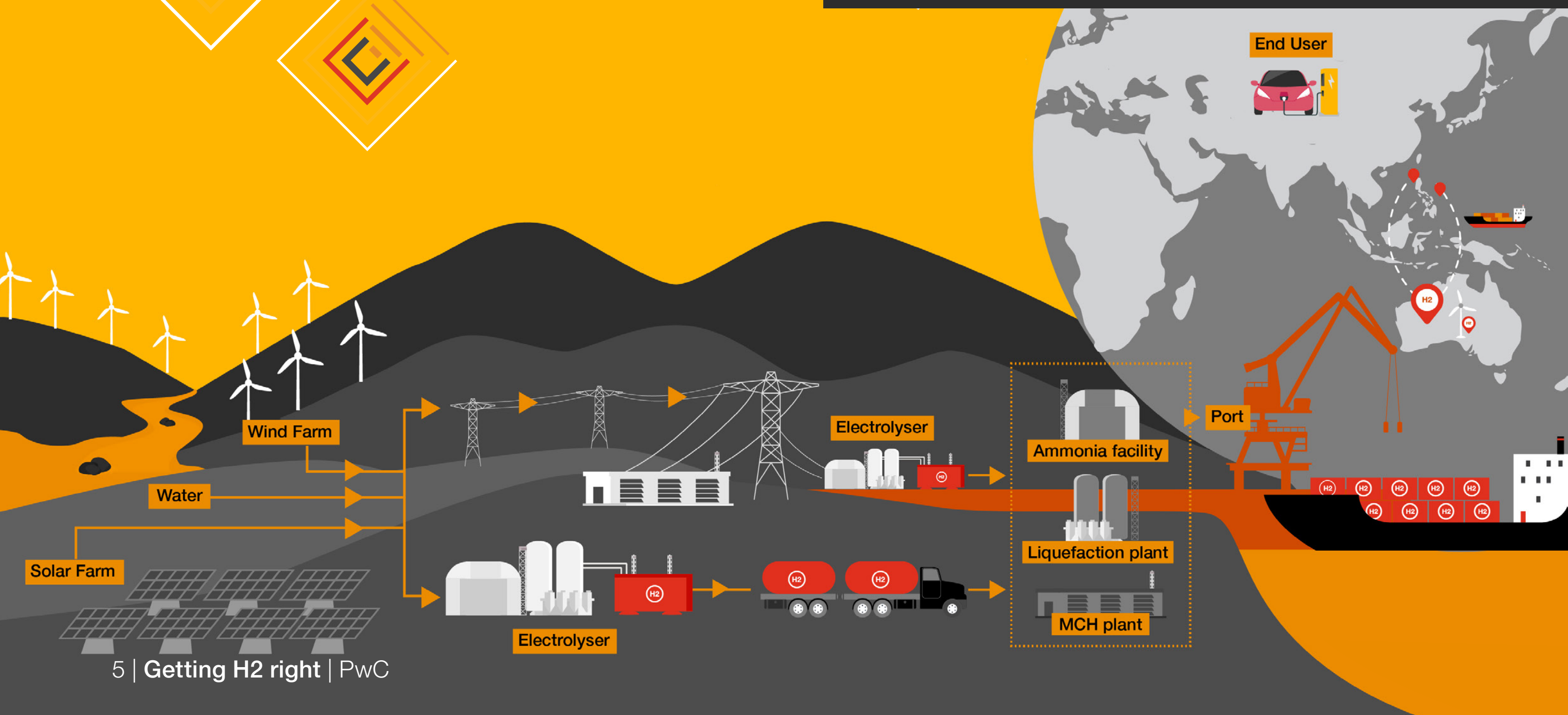
- where to locate the hydrogen project
- how to safely, efficiently and cost-effectively transport hydrogen molecules
- availability of the required infrastructure at Australia's ports
- what form the product should take to satisfy customer demand.

Transport costs from project to port can outweigh location benefits

For many export-focused inland hydrogen production projects, transporting the hydrogen to a port can incur high costs and offset other cost advantages that the project may otherwise have had, including access to low-cost, behind-the-meter renewable energy generation. Selecting the optimal method of land-based transport requires consideration of the volumes being transported, distance to port, available infrastructure, and downstream demand profile.

Australia must invest in the infrastructure that will support hydrogen export

Although there are additional technical hurdles to be overcome for hydrogen, most of Australia's bulk commodity ports are capable of accommodating hydrogen export infrastructure. The Australian Government's seven priority regional hydrogen hubs all have direct access to deepwater port infrastructure but will require coordination to create hub infrastructure that is fit for purpose and to maximise value-for-money (notwithstanding existing port capacity and coordination with existing port users).



Common methods for land-based transport

Transmission pipelines

Transmission pipelines generally represent the most efficient method of moving large volumes of gaseous hydrogen over vast areas of land (>1000 km). Constructing new 'hydrogen-ready' pipelines or converting existing gas pipelines to safely transport and store hydrogen will generally have high upfront costs but lower operational expenditure, and will allow for long-term scalability of the project.

Operators can use the pipeline's storage function and generate revenue by supporting other nearby projects or supplying to domestic customers. Central coordination among stakeholders will be needed to successfully navigate land rights and permitting, as well as uphold ongoing safety measures.

Electron movement

Portside projects rely on a strong transmission network that enables renewable electricity to be transported to an electrolyser located closer to the point of export. Network charges will be incurred for connecting to the electricity grid, but this cost can be partly overcome by incentive schemes, such as the NSW Hydrogen Strategy, which exempts electrolysis projects from 90% of network charges.

Compressed hydrogen gas trucking

Hydrogen can be transported over land by trucks containing gas tubes pressurised between 200–700 bar. This is a cost-efficient mode of transport for small-scale projects and is already commonly demonstrated, with a single high-pressure tube trailer storing approximately 600 kg of hydrogen. Hydrogen storage tanks will be required at either end of the transport route.

Liquid hydrogen trucking

For longer distances, trucking liquid hydrogen is more economical than trucking gaseous hydrogen. To maintain adequate pressure inside the insulated vessels, hydrogen must be vented at times as the liquid turns to gas, which can result in losses of up to 5% per day, which is considerably higher than for LNG. The benefit of trucking liquid hydrogen compared to trucking hydrogen gas is a seven times greater throughput, reducing daily truck movements, cost and operational emissions. This is a relatively new trucking methodology but is rapidly progressing towards commercial scale.

With strong strategic alignment across the supply chain and Australia's state and federal governments focused on developing hydrogen-ready export infrastructure across the country, one area of differentiation is the form of export for the hydrogen as it leaves Australian shores.

Three potential export forms are emerging as leaders among the 18 export-focused hydrogen production projects listed on HyResource.

Form of export	Pros	Cons	Leading proponents in Australian H2 projects
Liquified hydrogen (LH2) Hydrogen cooled to –253°C and transported in specially designed ships	No conversion back to a hydrogen molecule is required at the export destination	Capital-intensive infrastructure required New technology needed for bulk transportation Hydrogen boil-off occurs during shipping	Kawasaki Heavy Industries Iwatani Corporation Origin Energy
Ammonia Hydrogen combined with nitrogen using industry-standard processes	Simpler cooling and storage requirements Transported using existing ammonia infrastructure and technology Carrier density of hydrogen twice that of LH2	Significant energy and chemical processing are required to extract hydrogen from ammonia at destination	IHI Corporation Origin Energy Mitsui & Co BP
Methylcyclohexane (MCH) Formed by adding hydrogen to the hydrocarbon toluene, and serves as a liquid organic hydrogen carrier	Transported as a liquid at ambient temperature and pressure Can use existing petrochemical storage and transport infrastructure Toluene can be captured at destination and reused	Significant energy and chemical processing are required to extract hydrogen from MCH at destination	ENEOS

There are also new and emerging technologies including compressed hydrogen tankers, which allow for reduced capital costs of both the ship and the loading infrastructure, and reduce efficiency losses from boil-off. Further, metal hydride technology – the process whereby hydrogen can be reversibly absorbed into the physical composition of an alloy – may be a strong competitor once initial technical hurdles are overcome.

The challenges of exporting hydrogen in molecular form may also be surmounted by realigning the value chain of emerging green-hydrogen-dependent products, including through the production of green steel, green aluminium and green methanol. The rising willingness of manufacturing companies to pay a green premium for sustainable materials gives Australia a chance to compete in global green products markets, particularly if bold action is taken in the short term to improve onshore capability.

Navigating policy and regulation

Beyond the physical infrastructure required across the renewable hydrogen value chain, it is the 'soft' infrastructure – the regulatory and social infrastructure – that is the binding ingredient to accelerate the uptake and growth of green hydrogen in Australia.

The following actions will underpin an effective, competitive, safe and sustainable transition.

1. Setting formal emissions targets to drive demand signals and attract investment

In the Australian Government's updated Nationally Determined Contribution (NDC) submission to the United Nations Framework Convention on Climate Change (UNFCCC), Australia committed to seven stretch goals for low-emissions technology, two of which relate to hydrogen.

In addition to the recent announcement of successful projects in ARENA's Renewable Hydrogen Deployment Funding Round, the NDC priority stretch goals further affirm the government's commitment to playing an enabling role in the renewable hydrogen transition.

Beyond national commitments and goals, setting specific targets in the early stages of an emerging technology may offer greater certainty to manufacturers and investors. If Australia implemented similar transport emissions targets as global leaders such as Japan, the European Union (EU) and the UK, momentum would grow, which would help to attract more private sector investment into the hydrogen economy.

Priority stretch goal	Potential pathway	Expected timeframe for achievement
Clean hydrogen production under $2/kg	Steam methane reforming with carbon capture and storage	2025–30
	Renewable electrolysis	2028–35
Low-emissions steel production under $700/t (based on the long-run marginal cost)	New-build direct iron reduction plant using hydrogen	2030–40

2. Developing a Guarantee of Origin scheme to provide transparency and consistency

The National Hydrogen Strategy identified the establishment of a hydrogen Guarantee of Origin (GO) scheme as a priority action. A GO scheme will support Australia's emergence as a leading hydrogen exporter by enabling different hydrogen products to be compared accurately. This will provide transparency and consistency to investors and customers, and creating a competitive advantage. The Department of Industry, Science, Energy and Resources (DISER) is developing a scheme for Australia (see discussion paper), which is anticipated to be formally released in 2022.

3. Implementing safety standards to boost community confidence and social licence

Although hydrogen is a well-established energy carrier and has been safely used in Australia for many decades, its use in transport has been less common. A safe hydrogen industry will need local standards and regulations that integrate with international standards and are deployed and embedded effectively across the industry. Standards Australia's technical committee, ME-093 Hydrogen Technologies, is developing regulations and standards that set out specifications, procedures and guidelines for working with hydrogen.

4. Establishing a skilled and capable workforce for the hydrogen transition

As the hydrogen industry scales up, its potential will expand to include advanced applications, such as combined heat and power and long-distance passenger transportation. To realise the opportunities, Australia will require a workforce that is adequately skilled to work effectively and safely with hydrogen.

In a recent PwC analysis, more than 40 roles needed to support the Australian hydrogen economy in the next five years were identified across six 'occupational clusters':

engineers	• chemical engineer • mechanical engineer
technicians & tradespersons	• electrician • welder • heavy vehicle technician • refuelling technician
safety & quality control	• process safety technician • gas inspector
specialists	• ship-to-shore loadmaster • integration specialist
logistics	• tube trailer driver • mooring operations personnel
managers	• operations manager • maintenance manager

Some of these occupational clusters present opportunities to reskill segments of the existing workforce. Other clusters are likely to require new, highly specialised roles. Locating these opportunities in regional areas will drive local economic growth and provide an avenue to reduce emissions of FIFO workforces.

Governments, industry, educational institutions and registered training organisations will need to work together to develop and deliver quality education and training that takes into account domestic and international standards relating to the production, handling, transport and use of hydrogen.

Making it bankable through partnerships

The Hydrogen Council estimates global investments of US$540 billion will be required by 2030 to remain on track to meet its 2050 global net-zero goal, whereby 22% of the world's energy demand will be met by hydrogen. The investment required in Australia will only represent a portion of this, but it will require large amounts of capital to be deployed.

For investors, hydrogen projects present more challenges than traditional infrastructure assets due to complex supply chain considerations. Traditional private sector energy and infrastructure projects source only 20–40% of total financing from equity, which can make optimising debt finance key to a project's capital structure. Many hydrogen export projects under development in 2021 have formed consortia bringing together the requisite industry knowledge, skill sets and delivery capability.

Forming project consortia reduces three primary risks

1. **Construction risk (deliverability)**
   Hydrogen projects represent a new form of construction risk for many financiers in the sector. Lenders will need to get comfortable with EPC guarantees and equipment warranties relating to first-of-a-kind projects. Some comfort may be taken by EPC (engineer, procure, construct) and OEM (original equipment manufacturers) parties having a direct equity stake in projects.

2. **Technology risk**
   Financiers will focus on the performance of electrolysers and will rely heavily on the opinion of technical advisers and the ability to stress-test key technical assumptions such as efficiency, losses and degradation.

3. **Market and offtake risk**
   The commercial structure surrounding offtake is critical to ensuring guaranteed revenue. An offtaker can underwrite some or all of the hydrogen produced at a fixed or pegged price for a significant period of an asset's economic life. It is likely that debt financing will be sized on these parameters if gearing of >50% is to be achievable.

Partnering with a credible export party improves investor confidence

Ideal export partners have strong creditworthiness with existing knowledge and skills in related industries. This positions them well to guarantee their component of project delivery and operational efficiency, bolstering investors' confidence. In some cases, the export partner may be the offtake party or may develop a 'back-to-back' offtake arrangement with a trading partner or industrial user in the export country.

Offtake parties provide financiers with assurance over revenue

At present, hydrogen has multiple uses and no liquid traded market. With no merchant market, projects will require a bankable offtake arrangement to be financeable. To give confidence of the returns the project is likely to achieve, a project will need clear end-use markets and customers, and certainty of volume and price.

Strategic partners add value across the construction phase

A variety of additional strategic partners should be considered by project developers, depending on size, location and government stakeholders. These may include EPC partners and renewable energy providers; port authorities and operators; water authorities; local, state and federal government bodies; traditional land owners and the applicable land councils.

We have looked at Australia's path to building a competitive hydrogen industry, from getting the price right, and establishing a hydrogen-ready supply chain, through to navigating policy and regulation and engaging partners and offtakers. These success factors will need to be considered by project developers, investors and policy-makers as projects progress towards construction and operation.

The factors remain essential for both individual projects looking to secure financing, and for the development of the wider hydrogen economy.

Over the longer term, there is great potential for Australia to play a leading role in a globally traded hydrogen market – but this is not a time to watch and wait. The success factors we have explored in this report will not occur by chance. Australia must put the green hydrogen future at the forefront or risk innovation and investment being deployed elsewhere.

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