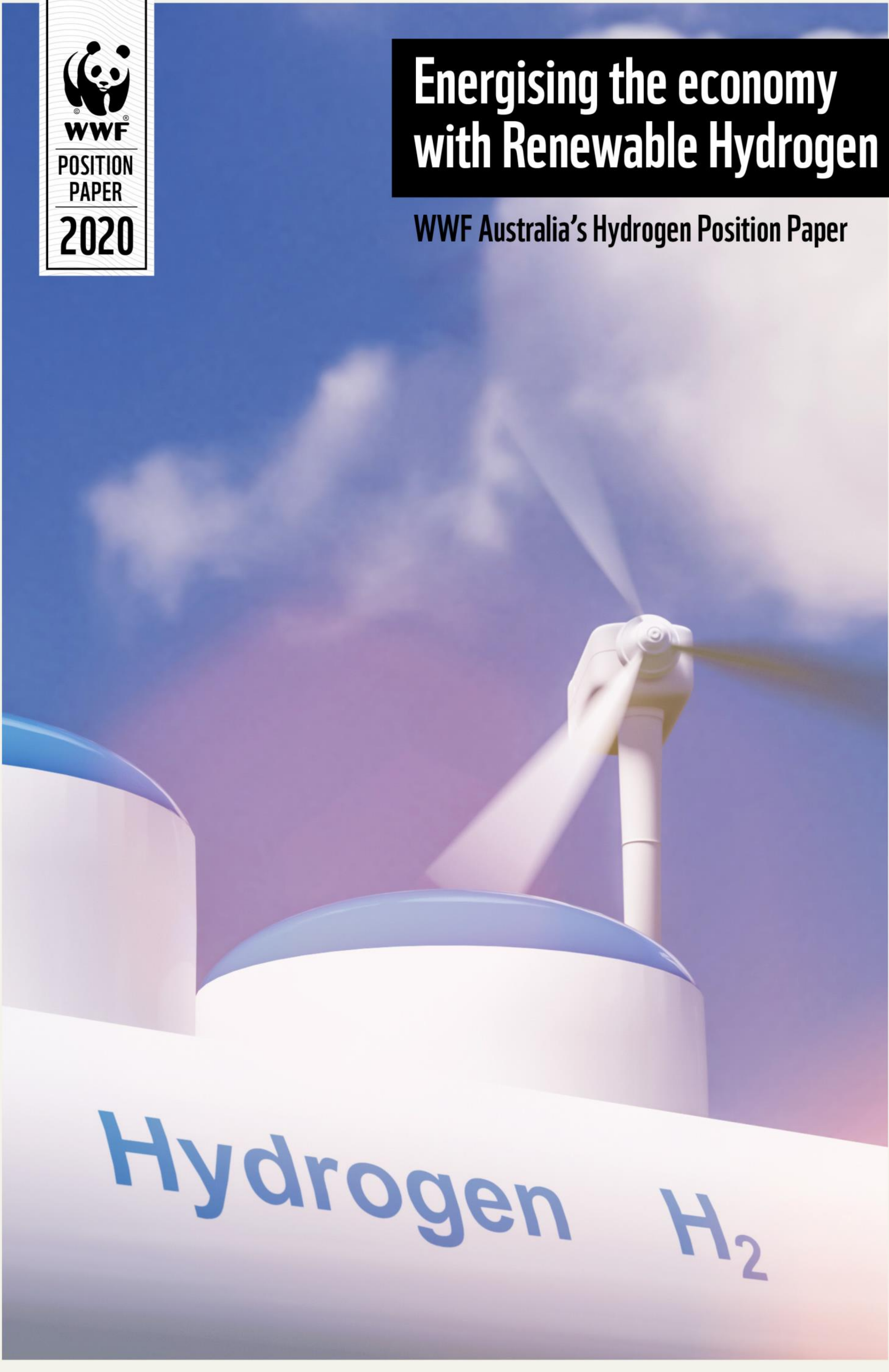
Energising the economy with Renewable Hydrogen

WWF Australia's Hydrogen Position Paper

WWF POSITION PAPER 2020



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1. Introduction

In 2019, WWF Australia launched its Renewable Powerhouse Campaign that seeks to make Australia the world's leading renewable exporter by 2030. The generation of cost-competitive renewable hydrogen is critical to several of Australia's renewable export pathways, including:

- The direct export of renewable hydrogen
- The creation and export of derivative chemical products such as ammonia and
- The manufacture and export of green steel and green cement.

It is essential that Australia benefits domestically and by growing domestic applications of renewable hydrogen to develop expertise in 'learning by doing'. This will, in turn, allow us to create cost-competitive export capabilities.

In November 2019, the Council of Australian Governments (COAG) Energy Council endorsed a National Hydrogen Strategy. However, there is a lot of hype about hydrogen, much of it is warranted, some of it is not.

WWF Australia's position on hydrogen, the opportunities, issues, and interventions needed in advocating for this critical industry are outlined in this paper. It will be the first in a series, outlining WWF's position on renewable export opportunities that arise from planned renewable exports.

2. WWF-Australia's position

WWF-Australia believes renewable hydrogen is essential to the full decarbonisation of the global economy and ought to be supported, subject to:

1. **Being renewable only.** Renewable hydrogen is the only hydrogen production method that is zero carbon. Hydrogen from coal and gas contributes to climate change and distract from renewable hydrogen-based industries that are essential to the decarbonisation of the global economy.

2. **Being traceable**. If we are to ensure that only renewable hydrogen is supported, guarantee of origin schemes must be put in place.

3. **Stringent public, worker and environmental safety practices being adopted**. Hydrogen is highly combustible, and in many cases its derivatives are toxic; as such, safety measures must be instituted throughout the supply chain.

4. **Being developed following sustainability principles.** Renewable hydrogen and the associated infrastructure, like all forms of energy production, are not free from environmental or social impacts. We must reduce negative environmental and social externalities and maximise the biodiversity and social co-benefits with hydrogen projects and industrial development.

5. **Being pursued as a complementary strategy to electrification.** For some applications and sectors, directly powering them with renewable electricity is easier, more efficient, and cost-effective than with hydrogen. A complementary strategy provides a pathway to decarbonisation. However, Australia lags much of the OECD in electrification. Hydrogen, as an option, must not be used to delay or come at the expense of electrification opportunities.

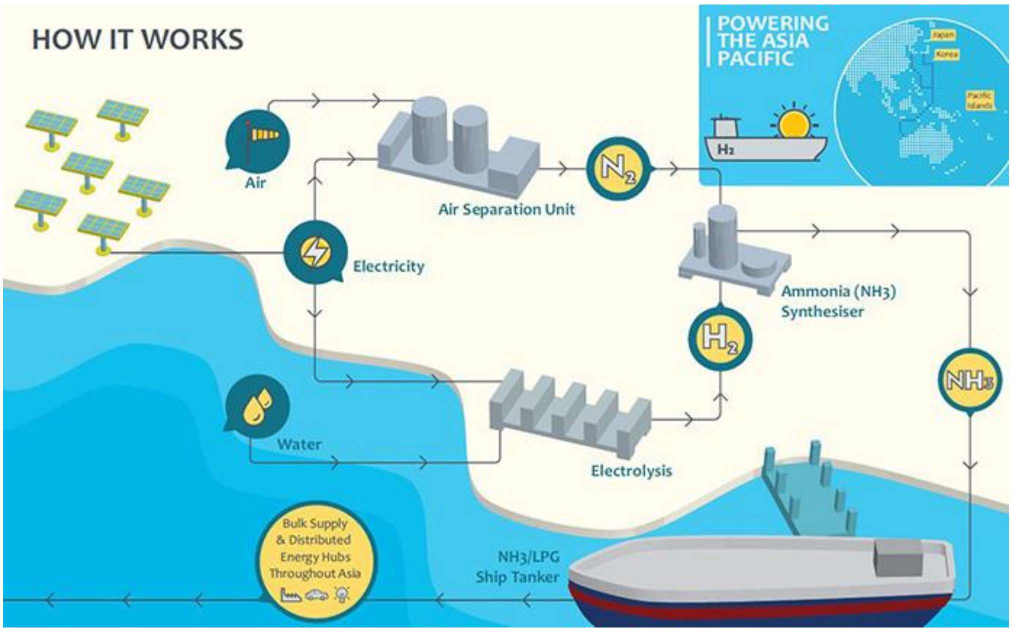
6. **The industry is structured to lower energy costs to Australian consumers.** Previously, the pursuit of fossil fuel energy exports has been at the expense of Australian consumers; WWF wants to ensure that the development of a renewable hydrogen industry benefits Australians.

3. What is hydrogen?

Hydrogen is the smallest molecule in the universe and is the most common chemical element. While not naturally occurring on its own on Earth, it can be produced as a gas. When hydrogen gas is burnt, it does so cleanly, producing water vapour and no greenhouse gas emissions.

Renewable hydrogen is produced when renewable electricity powers an electrolyser, which splits water molecules into its constituent parts – hydrogen and oxygen. Renewable hydrogen is captured and used in a range of applications.

Figure 1: How is renewable hydrogen made? (Source: Renewable Hydrogen 2017)



Hydrogen can be produced using several chemical processes, including steam reforming of methane and gasification of coal; both of these processes produce greenhouse gas emissions.

Hydrogen can be thought of like electricity - it doesn't occur naturally on Earth, and it has to be created. Just like electricity, it can be made in ways that are highly polluting, or it can be made in ways that are zero carbon. As such, like electricity, hydrogen is not inherently polluting or clean – it depends primarily on how it is made.

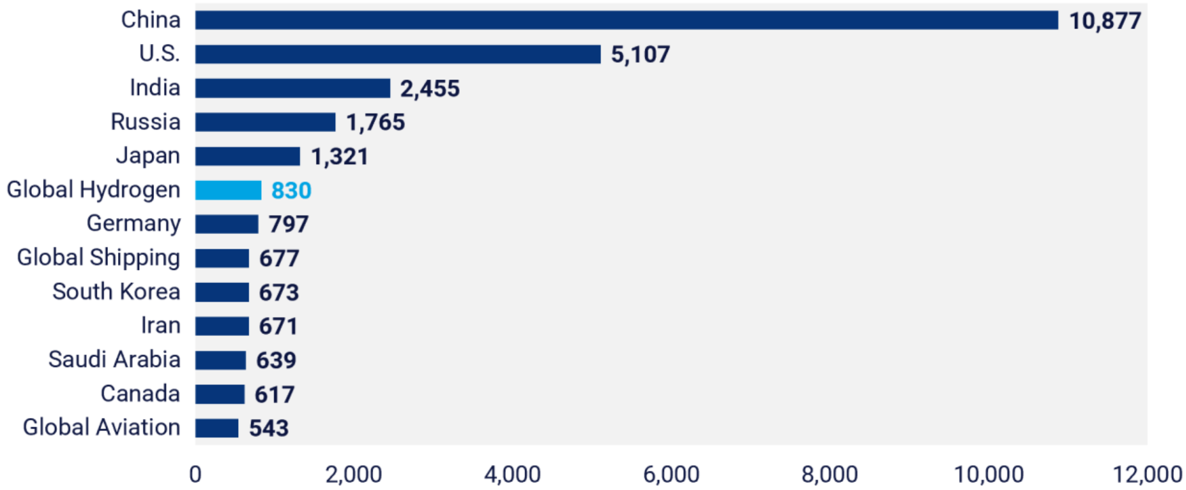
4. The current global hydrogen industry

While hydrogen is touted as a new opportunity, the hydrogen industry is a large and important global industry. Unfortunately, it is a highly polluting industry.

Currently, 99% of global hydrogen is produced from fossil gas and coal and accounts for approximately 1% of global greenhouse gas emissions[1]– see Figure 2.

Hydrogen is currently used as a fundamental building block in the chemical industry for the manufacture of ammonia and methanol. Ammonia is one of the world's most globally traded commodities and is used to make fertilisers that are essential to global agriculture and food production.

Figure 2: 2017 CO2 emission by country and sector (Mt CO2 /year) (Source: Wood Mackenzie, 2019)



Refineries, where hydrogen is used for the processing of intermediate oil products, are another area of use.[2] *Table 1* outlines what current hydrogen production globally and is used for in Australia. The International Energy Agency (IEA) estimates current global hydrogen production is 70millon tonnes per annum.[3]

Table 1: Global and Australian uses of hydrogen (Source: Hydrogen Europe, 2019 and ANT Energy Solutions, 2020)

Hydrogen Use	Global Percentage	Australian Percentage
Ammonia Synthesis	55%	65%
Refineries	25%	33%
Methanol Production	10%	0%
Other	10%	~1%

According to chemical company Incitec Pivot,[4] Australia produces 550,000 to 600,000 tonnes of hydrogen per annum, more than 98% of which is used in the chemical industry for oil refining and to produce explosives and fertilisers. All of Australia's current hydrogen production is made via steam reforming of methane which is an emissions-intensive process.

5. The role of hydrogen in global climate action

Currently, the world is at 1°C of warming and impacts from bushfires, to droughts, to floods are devastating to both human life and the precious ecosystems on which life depends.

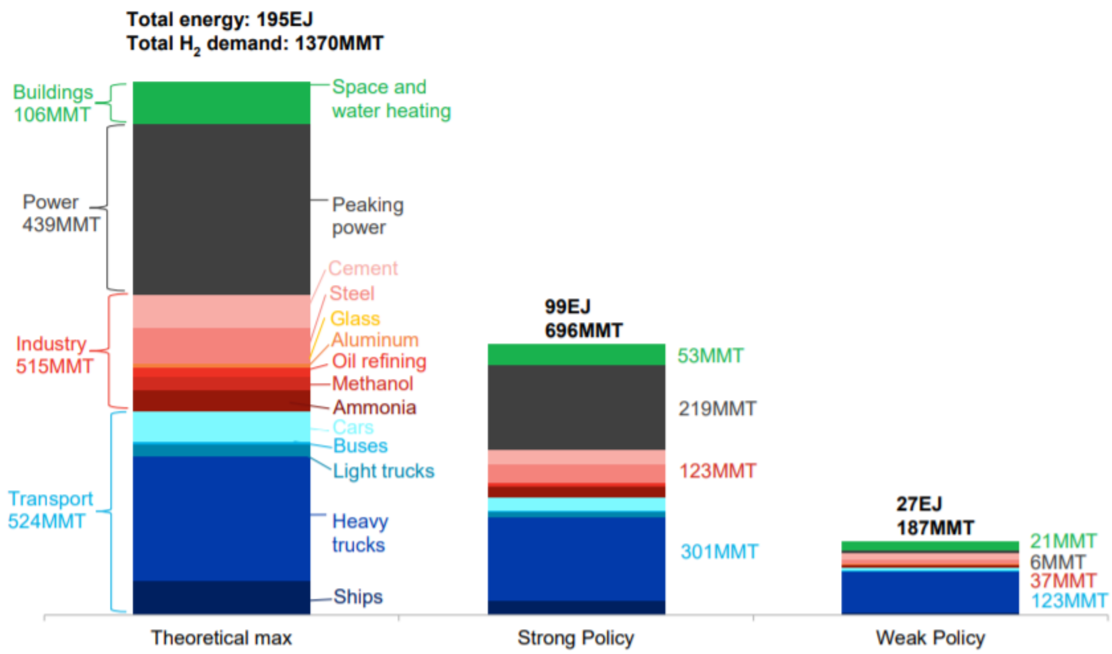
The climate science says that the world must achieve net-zero emissions of greenhouse gases before 2050 if the world hopes to stay below 2°C of global heating and must decarbonise even more rapidly to stay below 1.5°C.

All sectors of the economy need zero-emissions options and technologies to achieve net-zero emissions. Historically, several economic sectors are both emissions-intensive and have been considered "hard to decarbonise." These sectors include the manufacture of steel, aluminium and cement, the chemical industry, shipping, and other heavy transport.

These sectors are considered hard to decarbonise. This is because they cannot easily be directly powered, or their emissions removed using renewable electricity by electrification or fuel-switching.

Recent research has focused on the creation of a global renewable hydrogen industry. The research found that there is a great opportunity to decarbonise these "hard to decarbonise" sectors. Indeed, research and development is currently underway to create hydrogen alternatives to fossil fuels in all these sectors.

Figure 3: Potential demand for hydrogen in different scenarios, 2050 (Source: BNEF, 2020)



Source: BloombergNEF. Note: Aluminum demand is for alumina production and aluminum recycling only. Cement demand is for process heat only. Oil refining demand is for hydrogen use only. Road transport and heating demand that is unlikely to be met by electrification only: assumed to be 50% of space and water heating, 25% of light-duty vehicles, 50% of medium-duty trucks, 30% of buses and 75% of heavy-duty trucks.

Renewable hydrogen may also play a role in providing seasonal storage and peaking power to the electricity sector and some role in other transport and heating applications where direct electrification is not possible. See Appendix A for a full list of critical hydrogen applications for global decarbonisation.

Figure 4: Global Hydrogen Momentum 2013- July 2020 (Source: Adapted from Queensland Government, 2019)[1] [5]

[1] This image highlights some recent hydrogen policies or policy positions both in Australia and globally, it is not an exhaustive list.

A recent report by Bloomberg New Energy Finance[6] found that if the world is to keep warming to below 1.5°C, renewable hydrogen will be needed to meet between 7% (under the weak policy scenario in Figure 3) and 24% of global energy needs by 2050 (under the strong policy scenario in Figure 3). This percentage could be higher if all the 'unlikely to electrify' sectors in the economy substitute fossil fuels with renewable hydrogen (theoretical maximum scenario in Figure 3).

Under the strong policy scenario (middle column in Figure 3), an additional 11TWhs of wind and solar capacity will also be required just for hydrogen production over the next 30 years, to generate 31,320TWh. To put this in perspective, this is more electricity than is generated globally from all sources for all applications. If we are to unlock this opportunity, BNEF projects US$11 trillion in hydrogen production, storage and transport infrastructure investment will be required.

Australia is not the only country to have understood both the need and opportunity for renewable hydrogen, as Figure 4 shows.

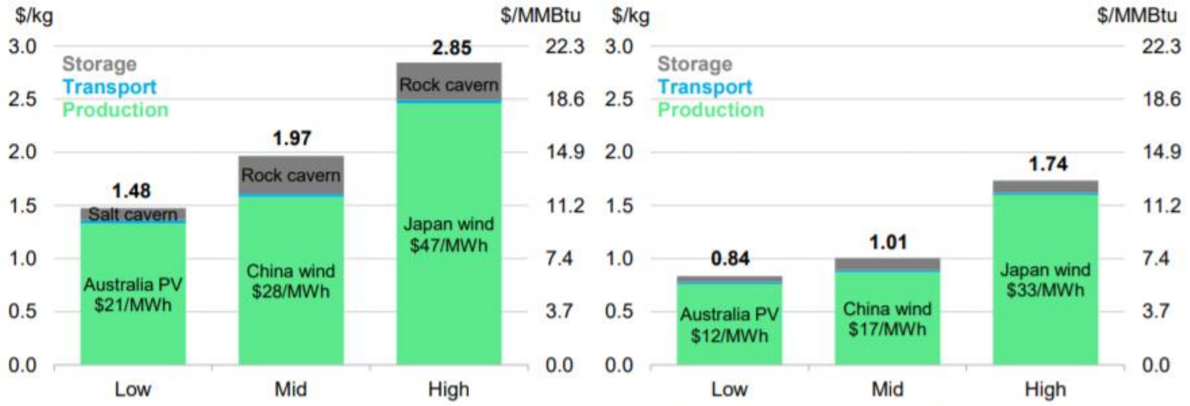
6. Opportunities for Australia

Why Australia?

Few places in the world are as well endowed with the resources needed to position themselves as a global leader in renewable hydrogen as Australia. Australia has a large land area and some of the best solar and wind resources in the world. It also has the world's fourth-largest capital market, which is more than capable of cost-effectively funding this infrastructure development at the scale required. Through water recycling and desalination of seawater, we have abundant water resources.

We have the expertise, trust, a stable democracy, and strong existing trade relationships. This means that Australia has the potential to produce some of the cheapest renewable hydrogen in the world (see *Figure 5*).

Figure 5: Estimated delivered renewable hydrogen costs to large-scale industrial users in 2030 (left) & 2050 (right) (Source: BNEF, 2020)



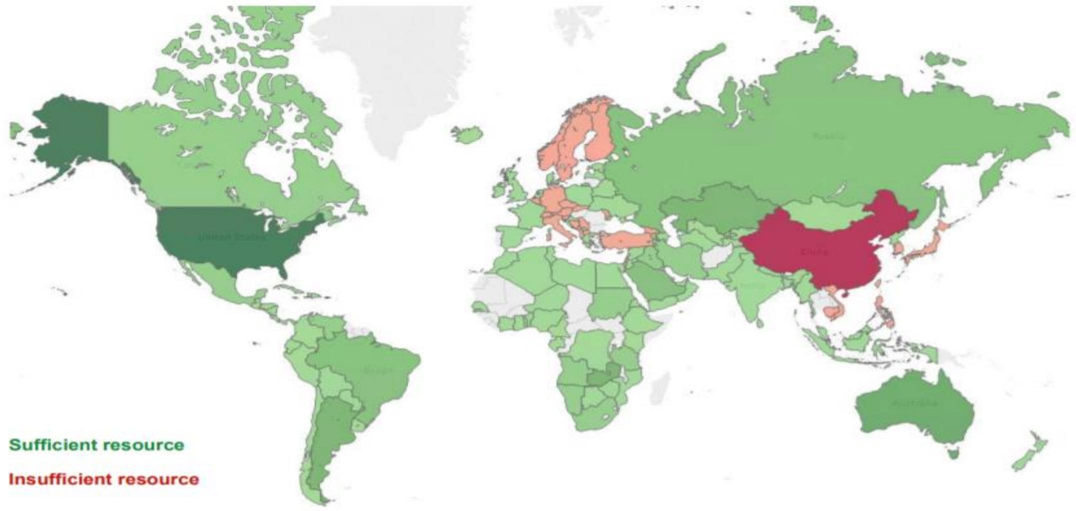
Source: BloombergNEF. Note: Power costs depicted are the LCOE used for electrolysis, and are lower than the BNEF's standard LCOE projections in 2050 due to savings from integrated design of the electrolyzer and generator, and anticipated additional learning from increased renewable deployment for hydrogen production. Production costs are based on a large-scale alkaline electrolyzer with capex of $135/kW in 2030 and $98/kW in 2050. Storage costs assume 50% of total hydrogen demand passes through storage. Transport costs are for a 50km transmission pipeline movement. Compression and conversion costs are included in storage. Low estimate assumes a salt cavern, mid and high estimate a rock cavern for both 2030 and 2050.

Meanwhile, some of our biggest trading partners such as Japan, South Korea, Singapore and even countries in Europe face significant challenges decarbonising their energy sectors (see *Figure 6*). They have higher populations, less land, and a lot less sunshine. BNEF concludes that some places around the world will not have enough wind or solar resources to produce sufficient renewable electricity for direct domestic use in the power, transport and industry sectors. They would not have enough renewable capacity to produce hydrogen for the remaining applications, at the same time.

As such, Australia has the opportunity to capture a significant share of what BNEF projects could become a $700 billion per year global industry, sufficient to offset the inevitable technology-driven progressive decline in our LNG (A$49 billion in 2019/20) and thermal coal exports (A$21 billion[7]).

By aggressively developing a renewable hydrogen industry, we can help our neighbours and key trading partners decarbonise while underpinning the economic competitiveness of Australia's manufacturing, resources, and agricultural sectors in a low-carbon world. We can also use Australia's abundant renewable resources and cost-competitive renewable hydrogen to attracting new industries to the Australian economy.

Figure 6: Indicative estimate of the ability for major countries to generate 50% of electricity and 100% of hydrogen from wind and solar PV in a 1.5-°C scenario (Source: BNEF, 2020)[8]



Source: BloombergNEF, Baruch-Mordo et. al, 2019. Note: Green = Country has sufficient estimated solar and wind resources and Red = Country has insufficient resources to generate 50% of electricity and 100% of hydrogen by 2050. The methodology used to estimate potential renewable generation is conservative, and may underrepresent achievable generation in specific locations. In some countries the estimate for potential generation is below current levels. These countries are not given a sufficiency rating.

Early market opportunities

While there are many possible markets for renewable hydrogen, WWF-Australia believes the following three represent the greatest short-term opportunities or "use-cases" for Australia to grow domestic demand for renewable hydrogen at scale. In the process, Australia could create a cost-competitive renewable hydrogen sector, positioning ourselves as a global leader in this emerging green industry.

Decarbonising the ammonia and fertiliser industry

The global fertiliser industry is currently the largest end-user of hydrogen. Hydrogen is used to create ammonia – a nitrogen-rich chemical, which in turn is used to make nitrogen-based fertilisers.

Compared to other potential hydrogen applications, it is a relatively simple process to replace fossil-fuel-based hydrogen progressively with renewable hydrogen to create ammonia. This is because the fertiliser industry already relies on hydrogen production at scale, while other potential hydrogen applications would be replacing different feedstocks or fuels such as gas.

Around the world we are seeing many feasibility studies and renewable ammonia pilot projects for the fertiliser industry, including in Western Australia.

While one of Australia's seven ammonia facilities supplies approximately 5% of the global market,[9] Australia is a net importer of ammonia for fertiliser and explosives. As such, by investing in renewable ammonia production and the creation of a renewable fertiliser industry, Australia could go from net importer to net exporter of ammonia and fertiliser and help decarbonise this global industry in the process.

ANT Energy Solutions (2020) agrees, identifying the replacement of current hydrogen production, particularly for ammonia with renewable hydrogen as the greatest hydrogen market opportunity in Australia by scale between 2020-2025. Ammonia is far more stable and compact than hydrogen, making export transportation significantly more cost-competitive today.

Heavy Vehicle Transport

Conversations with investors investigating hydrogen opportunities in Australia suggests that renewable hydrogen production in places with excellent wind and solar resources is likely to be cost-competitive or nearly cost-competitive with expensive imported diesel for trucks at remote mine sites. Indeed, Aurecon Australasia[10] recommends focusing on back-to-base transport fleets and transitioning bulk handling in the mining and heavy industry sectors for early investment in hydrogen for transport.

Already, Anglo American is developing a hybrid mining dump truck powered by both electricity and hydrogen fuel, which will be tested at their mining operations in South Africa towards the end of 2020.[11] Meanwhile, Bosch, Kenworth/Toyota and a Canadian consortium AZETEC (Alberta Zero-Emissions Truck Electrification Collaboration) are all working on long-range fuel cell electric trucks to be powered with hydrogen.

Australian fuel consumption, including diesel, is highly reliant on imports[12]. The country also has high-quality renewable resources and many remote mines and communities. There is an opportunity to increase energy security by growing a commercial renewable hydrogen trucking industry in Australia, starting with mining trucks. In the longer-term, hydrogen fuel cells for long-haul trucks represents a significant market opportunity.

WWF does not see the same opportunity for hydrogen fuel cell passenger and light vehicles in Australia, as it does for trucks. The evidence suggests that electric vehicles are a more efficient and cost-effective zero-carbon solution. They are being deployed at an increasing scale today (see Appendix A).

Gas injection

Injecting renewable hydrogen directly into the gas grid is another area where we are seeing a significant number of pilot projects globally and in Australia, including in South Australia and NSW. Injecting renewable hydrogen into the gas grid has the potential to create both early demand at scale for renewable hydrogen, and also build broad industry experience in creating and using hydrogen.

However, there are limits to this application. Depending on the age of the gas infrastructure and the materials it is made of, the limits to injecting hydrogen into existing gas infrastructure range from 5% to 20%, with most industry experts suggesting 10% is the average limit. Beyond these limits, both the gas grid and end-use equipment (stoves in households to gas boilers) will require significant upgrades and often wholesale replacement.

It is likely that in many domestic and industrial applications directly converting to renewable electricity (electrify/fuel switch) rather than upgrade to renewable hydrogen will be a more cost-effective way to decarbonise. Indeed, analysis by Renew found that it was much more cost-effective for new homes to go all-electric with solar, rather than connecting to the gas grid. Indeed, the savings are above $10,000 per household over 10 years.[13] Meanwhile, Beyond Zero Emissions has identified electrification options for almost all industrial uses of gas, particularly many low and medium temperature industry processes.[14]

There are concerns that a renewable hydrogen gas injection strategy will be used to extend the life of the gas industry and justify opening new gas reserves. As such, WWF only supports renewable hydrogen gas injection if jurisdictions are also pursuing renewable electrification strategies for households, commercial buildings, and industry.

Longer-term opportunities

Some of the largest renewable hydrogen opportunities are in sectors where hydrogen applications are still in the research, development, and early deployment stages. However, if Australia wants to ensure it captures these likely future hydrogen markets, it is essential that it is involved in the early stages of the industries development, given the global technology race that is already well underway. Of the many potential applications for renewable hydrogen, WWF-Australia has currently identified the following three as the most promising use-cases for an Australian domestic and export hydrogen industry.

Green building materials

Steel, aluminium and cement are critical materials for the construction of most buildings and infrastructure globally. Manufacturing of steel and cement represents about 14% of global emissions. In Australia, we are globally significant exporters of iron ore (37% of global production) and bauxite (28% of global production) - the raw materials used to manufacture steel and aluminium.[15] We also produce steel, cement, and aluminium domestically.

The use of renewable hydrogen as both a heat source and reductant has been identified as the most promising decarbonisation pathway for these difficult-to-decarbonise industries. These three sectors represent significant economic opportunities for Australia. For example, the Energy Transition Hub found that by converting just 18% of the iron ore that Australia exports annually into green steel, using renewable hydrogen, would almost double Australia's current iron ore and steel export revenue.[16] Further, the Grattan Institute has found that value-adding our domestic resource industries and creating a new green steel industry in Central Queensland and the Hunter Valley could replace the coal mining jobs in these regions.[17]

Internationally, we are seeing renewable hydrogen pilot projects, particularly in the steel industry in Europe. Australia is yet to follow suit, although the Liberty Steel Group project in Whyalla could be the first example.[18] If Australia wants to capture a significant global share of the renewable hydrogen industry for green building materials, Australia must invest in research and development to modernise our steel, cement, and aluminium industries. It is also important to grow local demand for zero carbon building materials domestically.

Decarbonising shipping

Green ammonia presents one of the most promising pathways to decarbonise the deep-ocean shipping industry. If Australia pursues the development of a green ammonia industry, we will be well placed to help supply the global shipping industry. However, to position Australia as a green ammonia supply country of choice, it will be important to play a role in shipping demonstration projects fuelled by green ammonia. It will also be important to develop strategic bilateral collaborations with countries like Singapore, which are currently global shipping and oil bunkering hubs and work with the International Maritime Organization.

Exporting to other countries

While producing goods and commodities with renewable hydrogen onshore is likely to be a greater medium-term opportunity for Australia, several of our key trading partners have flagged the intention to import renewable hydrogen or ammonia from Australia.

However, BNEF warns that shipping hydrogen is the least efficient or cost-effective approach to renewable hydrogen distribution (well behind direct use locally and pipes). Nevertheless, they agree that due to renewable resource availability in import countries as well as geopolitical considerations, some renewable hydrogen is likely to be shipped globally. Continuing to build strategic bi-lateral and multi-lateral agreements and partnerships with likely renewable hydrogen import nations will be critical. Nations, such as Japan, Singapore and South Korea, are already key energy trade partners for Australia and will be key.

Where will the Australian hydrogen industry be located?

Australia's existing hydrogen industry is located in coastal, urban industrial centres such as Gladstone, Newcastle and Kwinana in Perth. Early indications suggest that these locations and other similar industrial centres such as Bell Bay in Tasmania and Whyalla in South Australia are likely to be the main locations for renewable hydrogen production in Australia. However, given that Australia's best renewable resources are inland, this will require additional investment in transmission infrastructure.

One opportunity would be to use renewable hydrogen pilot projects and hubs to help foster broader renewable industry precincts, which could jointly benefit from the infrastructure required to service multiple low-carbon industries, including:

- Transmission lines to transport renewable electricity for direct industrial use and hydrogen production,
- Hydrogen pipelines,
- Water infrastructure for hydrogen production (see Section 0),
- A port where both hydrogen and other green commodities can be exported, and
- A skilled workforce.

Additional benefits – lower-cost electricity

As Australia moves to ever higher penetrations of renewable energy, particularly solar and wind, there will be an increase in periods when electricity supply could exceed demand. This phenomenon is called the "duck curve." One solution to the duck-curve is "flexible demand" – these are electricity-using processes that can turn on when electricity prices are low. There is excess generation, and turn off when prices are high. If incentivised through targeted tariffs, electrolysers creating renewable hydrogen could be an excellent use for excess electricity generation. According to Wood Mackenzie, electrolysers "used for green hydrogen production can operate dynamically, requiring only seconds to be able to operate at maximum capacity. As such, they can be easily paired with renewable assets that are frequently curtailed for either a long or short duration."[19]

Incentivising electrolysers to act flexibly on-demand would, in turn, enable "overbuilding" of renewables and the long-overdue grid modernisation investments now required. Analysis by ClimateWorks suggests that taking an overbuilding renewable energy to 200% capacity – double what the country needs – "could be more cost-effective than building to 100% and would spark new clean export opportunities",[20] such as hydrogen.

Also, this increased demand for electricity could help cover more of the fixed costs of transmission and other electricity system upgrades, lowering network and system costs for all electricity users.[21]

This co-benefit is an example of 'sector coupling' whereby building shared infrastructure and allowing optimisation not just within sectors, but across sectors, lowers the cost of decarbonisation for all sectors. That is, the hydrogen production that, for example, is needed by the steel sector helps lower the cost of renewable energy integration for the power sector.

However, if incentivised inefficiently, electrolyser use could drive up electricity demand at peak times. This would exacerbate the duck-curve and drive up electricity prices for consumers. This would prioritise export hydrogen customers over domestic energy customers, which is what has occurred in the LNG industry on the east coast and should be avoided.

7. Issues to be addressed

Renewable energy and other zero-emission technology solutions, including renewable hydrogen, are clear solutions to climate change, helping countries and industries move away from carbon polluting alternatives. However, that does not mean these technologies and associated infrastructure come without other environmental and social impacts. It is essential that as we transition to clean energy, new clean industries, including hydrogen, are developed sustainably. We need to make all efforts to reduce or eliminate negative environmental, social, health and safety impacts and externalities. Opportunities for co-benefits and net-positive sustainability outcomes should be actively pursued.

Concerning hydrogen, there are three major issues that WWF-Australia believe must urgently be addressed that are outlined in more detail below.

Fossil fuel hydrogen

Currently, the fossil fuel industry is promoting hydrogen from fossil gas and coal, both with and without carbon capture and storage (CCS) technology. They argue that it is important to establish a fossil hydrogen industry now, on the basis that a renewable hydrogen industry will develop later.

As the Australia Institute argues "this approach is likely to lock in high carbon infrastructure and undermine the green hydrogen opportunity. For example, hydrogen made from fossil fuel methods and electrolysis use different processes and require different infrastructure. Furthermore, fossil fuel-based hydrogen requires proximity to fossil fuel sources and carbon storage sites where renewable hydrogen requires proximity to water and renewable energy sources".[22]

From a carbon pollution perspective, as Table 2 outlines, the only form of zero-emission hydrogen production is renewable hydrogen, through the electrolysis of water using renewable electricity. The alternative proposed is to apply CCS measures to gas and coal-based hydrogen. Internationally, there is only one project – Quest that does this at scale. However, the application of CCS currently only reduces the project's emissions by 24%.

Despite the first CCS project starting operation in 1972, globally there are just 19 large-scale operating CCS projects across all applications – coal power, oil and gas extraction and industrial emissions.[23] The majority of these projects use the captured CO_2 for enhanced oil recovery, which further contributes to climate change through the combustion of oil products and in some cases freeing up natural gas to be burnt as well.

In Australia, the Gorgon LNG project is the only operational large-scale CCS project. The project, which received a $60million grant from the Federal Government, and ran three years behind schedule,[24] at best hopes to capture 40% of the carbon dioxide released when the natural gas is extracted and processed into LNG (Scope 1).[25] This means that to become a low-carbon project, the application of CCS technology is also required at the end-use stage, whether that be the combustion of natural gas or steam reforming it to create hydrogen. Indeed, analysis suggests that the Gorgon CCS project will only have a CO_2 capture rate of 3.3% when Scope 3 emissions are considered.[26] To date, the Australian Commonwealth Government has invested $1.3 billion in government funds in CCS technology, with very little to show for it.[27]

Even, if coal and gas hydrogen were to achieve the maximum theoretical CO_2 capture rates of 85-95%[28] , which are significantly higher than any currently operating project globally, they will not be zero-emissions projects.

Table 2: Emissions and % Reduction in Emissions of Different Hydrogen Production Technology in Australia (Source: COAG, 2019[29])

Production technology	Emissions (kg CO2-e/kg hydrogen)	% reduction in emissions (relative to SMR without CCS)
Electrolysis – NEM average electricity	54.6	-542% (increase in emissions)
Coal gasification, no CCS	12.7 – 16.8	-49% — -98% (increase in emissions)
Quest project, Canada (SMR, partial CCS)	6.5	24%
Steam methane reforming (SMR), no CCS	8.5	--
CertifHy threshold for 'low-emissions'	4.4	48%[vi]
SMR + CCS – best case	0.76	91%
Coal gasification + CCS – best case	0.71	92%
Electrolysis – 100% renewable electricity	0	100%

Bloomberg New Energy Finance project that by 2030 renewable hydrogen will be cheaper to produce than hydrogen from gas or coal with CCS, particularly in countries like Australia where there are abundant, low cost and high-quality renewable resources.[30] As such, there is a high risk that investments in new coal and gas to hydrogen infrastructure will become stranded assets.

The International Renewable Energy Agency (IRENA) also suggests that investment in fossil fuel hydrogen may divert limited capital away from renewable energy deployment back to fossil fuels.

Given the significant increase in renewable energy deployment required to meet emission reduction targets, this would be a backwards step that would lock in emissions.[31]

As such, supporting the expansion of hydrogen from coal and gas is synonymous with supporting the expansion of the fossil fuel industry, which is incompatible with a safe climate and the need to decarbonise our economy. If CCS is required for global decarbonisation, for example, for industrial emissions capture, it should be limited to sectors where there are no renewable alternatives. This is not the case in the hydrogen sector.

Water

Water is a critical input for the hydrogen industry, with around 9 L of water needed to produce 1 kg of hydrogen through the electrolysis process.[32]

According to the National Hydrogen Strategy, producing "enough hydrogen to satisfy Japan's projected annual imports in 2030 would require less than 1% of the water now used by Australia's mining industry each year".[33]

Nevertheless, as a dry country regularly faced with drought, water is a significant consideration in the development of a renewable hydrogen industry in Australia. Indeed, the renewable hydrogen industry should look for ways that renewable hydrogen could reduce the energy industry's use of water currently used for households and farming or even open new water sources.

A study by global consultancy Jacobs, into water use in the hydrogen industry, found that using recycled water for hydrogen production could be beneficial due to its availability throughout the year. This would eliminate drinking water supply issues and creating additional opportunities for water businesses.[34]

Recycled water could come from wastewater facilities across Australia. Given that wastewater facilities are often located close to urban centres, hydrogen production facilities could be located near these wastewater facilities and reduce distribution costs. Furthermore, the use of recycled water would reduce the water quality impacts of discharging recycled water to waterways and oceans, resulting in an additional environmental benefit.[35]

The potential for renewable hydrogen to help grow the recycled water in Australia showcases the circular economy opportunities associated with this emerging industry if it is done correctly from the beginning.

Desalination is another potential water source for the hydrogen industry. While this would reduce competition for existing potable water sources, there are potential negative ecological consequences associated with highly saline water and scaling chemicals being released into marine ecosystems. Best practice environmental management and looking for opportunities to use this saline by-product (circular economy and industrial ecology options) will be essential for the development of a sustainable renewable hydrogen industry, should desalination be required.

Safety

Hydrogen is highly flammable, so storing, transporting, and using it safely is a significant concern. Its flammability is mitigated by high buoyancy and diffusivity, which causes it to disperse quickly.

Ammonia production using hydrogen as a feedstock also presents risks to humans as well as marine life if leakages occur, as it is a highly toxic chemical. It is also a potential source of nitrogen oxide emissions if combustion is not perfectly optimised.[36]

The renewable hydrogen industry and its derivatives must be developed safely for workers, consumers, the community at large and the environment. These standards and practices should be as stringent or more so than Australia's existing hydrogen and ammonia industry.

We support the efforts by Australian Governments to put safety, environmental sustainability, and benefits to Australians at the forefront, as identified in the National Hydrogen Strategy. Furthermore, we support the role of governments to coordinate reviews of legal frameworks, where practical, in the development of technical safety standards for the hydrogen industry.

8. Policy and market initiatives

To grow a renewable hydrogen industry of the scale required to help limit climate change to 1.5°C, government policy and support are essential. Wind, solar PV and battery technology, like hydrogen, were identified as essential to a safe climate and as such have enjoyed public policy support in countries around the world. This public policy support has been essential to driving wind, solar and battery technologies down the cost curve to the point where they are the cheapest new-build electricity generation options in most jurisdictions globally.

Similar levels of policy support will be required to unlock the potential of renewable hydrogen. If Australia wants to capture a significant market share, governments and industry must play a more proactive role than they have in the past. If Australia is to thrive in a low-carbon world, we cannot repeat the mistakes that occurred due to not fully commercialising our world-leading solar PV technology.

Given the importance of government policy, it will be important that WWF and other organisations advocate for a range of policies and market-shaping initiatives that ensure renewable hydrogen is developed efficiently, safely and at the speed required by the ongoing climate crisis.

The following section outlines key areas for action that will inform WWF-Australia's hydrogen advocacy.

Reducing the cost of renewable hydrogen

Currently, renewable hydrogen costs \$3.40-\$7.45/kg to produce[37] , which is more expensive than the \$1-2/kg it costs to produce hydrogen from coal and gas.[38] The National Hydrogen Strategy, ARENA and BNEF all suggest that a target of \$2/kg for renewable hydrogen would put it within reach of commercial applications in many industries, particularly when combined with a carbon price. As such, it will be essential to work to halve the cost of renewable hydrogen within the next decade.

Three key outcome areas could be targeted to bring down the cost of renewable hydrogen:

1. Lowering the cost of renewable electricity, as the largest cost driver of renewable hydrogen.
2. Lowering the cost of electrolysers through
    a. increasing production scale and
    b. through innovation in the electrolysis process (making it more efficient).
3. Creating the infrastructure, equipment, regulatory environment, and workforce able to implement renewable hydrogen projects safely and efficiently.

To achieve these outcomes, governments and industry will need to:

1. Invest in early-stage research, development and deployment (RD&D) in the local context for more efficient renewable hydrogen production processes and essential hydrogen equipment (such as containment, pipes, or valves).

2. Continue to implement policies that drive demand for renewable electricity.

3. Fund pilot projects that prove applications and help establish supply chains and infrastructure.

4. Stimulate demand for renewable hydrogen by incentivising and mandating the use of renewable hydrogen in the most promising short-term applications (see Section 0 and Appendix A).

5. Put in place standards and regulations for renewable hydrogen that include traceability and certification options.

6. Invest in academic and workforce training programs, that both reskill the existing workforce and train the workers of the future.

Scaling hydrogen for the long-term

As most of these critical renewable hydrogen applications are not currently commercial, it will take time and pilot investments to build these industries of the future (as has been a feature of ARENA's new $70m investment program[39]). To achieve the scale of decarbonisation needed to reduce the risk of dangerous climate change and put Australia in a position to capture significant market share, governments and industry could:

1. Legislate climate policy, including net-zero emissions targets by 2050 at the latest. A global renewable hydrogen industry is only going to grow if countries and companies around the world are committed to acting on climate change. Without the climate imperative, there is little need to replace fossil fuels in steel, shipping, and other sectors with renewable hydrogen.

2. Develop plans for transport and industry sectors to unlock electrification and renewable hydrogen-based decarbonisation. These plans should be accompanied by:

    a. Research, development, and commercialisation funding, including for pilot projects which help develop supply chains.

    b. Targets, mandates and investment policies that stimulate demand for decarbonised transport, products and commodities such as those outlined in Section 0 (also see Appendix A). This will likely include the need for a carbon pricing mechanism to ensure renewable hydrogen is used over the emissions-intensive alternatives.

    c. Standards and regulatory development.

3. Develop and implement a Renewable Exports Strategy to accompany the National Hydrogen Strategy, with a focus on unlocking renewable export options, including renewable hydrogen. This strategy and early-stage activity should focus on growing demand internationally for renewable hydrogen and renewable hydrogen-based products and commodities with key trading partners, key industries, and industry leaders.

Ensuring hydrogen is a climate solution – traceability

It is important to have schemes in place to verify the origin and trace the source of hydrogen and the associated environmental impacts to provide chain-of-custody assurances. Specifically, greenhouse gas emissions and other impacts such as water use could also be considered. The National Hydrogen Strategy proposes to establish a guarantee of origin scheme. This scheme could be used to comply with regulatory measures designed to reduce emissions, demonstrate corporate commitment to climate change mitigation, or to go beyond compliance towards best practice emissions management. Also, it may be that blockchain technology, which is already being used for traceability purposes across other global supply chains, could be used in the hydrogen industry.

WWF advocates that the guarantee of origin verification stipulates the production technology and the lifecycle emissions (scope 1, 2, 3 emissions and disposal) to ensure that fugitive emissions from CCS are included.

Appendix A: Critical Hydrogen Applications in a Zero Carbon Economy

Potential applications of hydrogen

Hydrogen is versatile and has the potential to be used in many applications:

- Hydrogen can be used as fuel and replace petrol, diesel and LNG in transport either through direct combustion, creation and combustion of ammonia, or a hydrogen fuel cell.

- Hydrogen can be burnt creating heat, replacing the use of coal, oil and gas in manufacturing processes, domestic and commercial heating.

- Hydrogen can be combined with a range of catalysts. It will then act as a reductant within chemical processes, such as in the manufacture of steel.

- Hydrogen is an existing chemical feedstock, and as such, renewable hydrogen can replace hydrogen made from coal and gas in this industry.

Hydrogen has not been used much beyond the applications outlined in *Table 1* in this report. It is not as energy-dense, nor as easily manufactured, transported or stored as fossil fuel alternatives. Since it is a clean-burning, renewable hydrogen presents a zero-carbon alternative to the use of coal, oil and gas. Given that the climate imperative is to move away from carbon-intensive fossil fuels, wide-scale R&D is starting to address these challenges. According to IRENA, in the most suitable locations, renewable hydrogen will become competitive with fossil fuels[40] in applications during the next 3-5 years. It is an area of interest for companies and governments that wish to address the Paris Agreement. It also follows the wishes of global investors to implement the Taskforce for Climate Related Disclosures (TCFD) and provides a pathway to net-zero by 2050, or sooner.

Prioritising applications of hydrogen

While hydrogen has the potential to be used in many applications, some applications are more promising and critical for decarbonisation than others. WWF identifies promising short and long-term uses of renewable hydrogen. These applications were chosen based on industry analysis of the following factors:

1. Is the renewable hydrogen technology available for this use-case soon (short-term), or is it likely to be available (long-term)?

2. Is an alternative zero-carbon pathway likely to be more cost-effective, functional, and have less negative externalities?

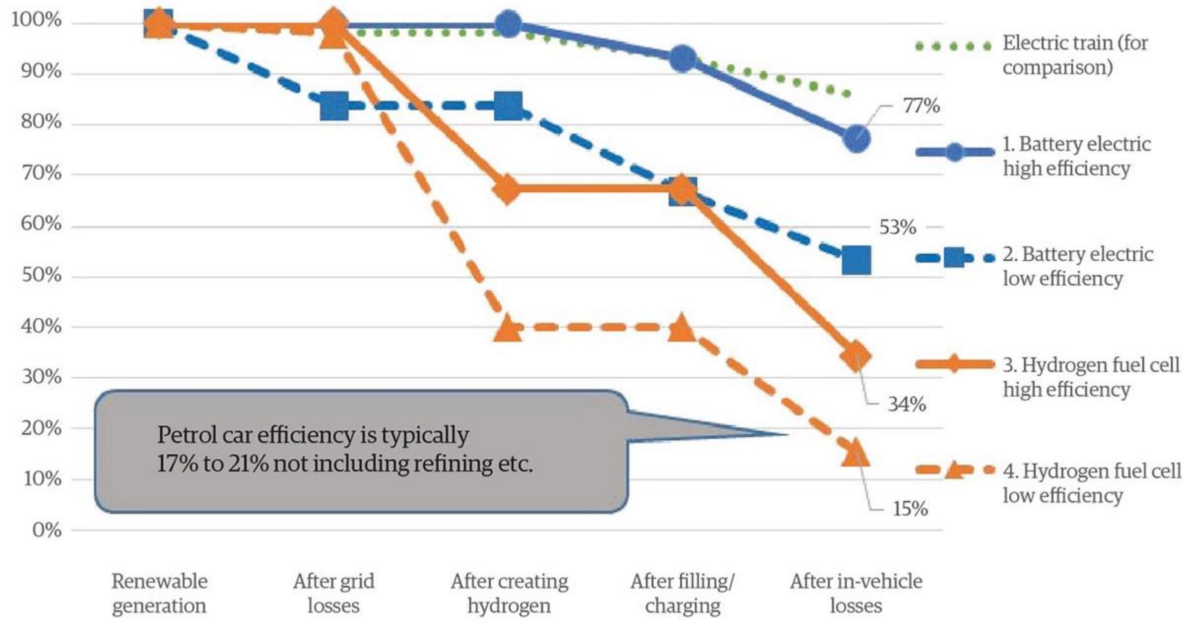
Two potential applications – light vehicles and shipping – are examined to illustrate the considerations associated with this second factor.

Light vehicles

Every energy technology and application has efficiency losses along the supply chain. Coal power, for example, is typically only 37% efficient[41] when we use it to light or heat our homes. There are significant concerns about the efficiency of renewable hydrogen when compared to renewable electrification options. Light vehicles are perhaps the best example of this. Analysis by Renew of renewable hydrogen fuel-cell cars compared to renewable-powered electric cars (EVs) found that they are significantly less efficient (see *Figure 7*).

A lower efficiency typically means that hydrogen vehicles are and will continue to be more costly than EV alternatives. As such, priority should be given to supporting the uptake of EVs over hydrogen fuel-cell cars.

Figure 7: Efficiency of hydrogen fuel cell vehicles compared to electric vehicles (Source: Renew, 2019)



Global shipping

The Global Maritime Forum, a body working to shift the global shipping industry towards zero-carbon energy sources, identifies renewable ammonia as one of the most promising pathways.[42] While battery-powered ships and ferries are likely to be feasible for short routes (like this one in China), internal industry analysis suggests that for longer trading routes, the number of batteries required would take up much of the available shipping volume.

One consideration as to whether WWF would support the use of renewable ammonia as a fuel for any application, including shipping, is whether the production of NOx – an air pollutant and greenhouse gas – will be within current IMO and WHO limits. Shipping engine manufacturers suggest that this is possible, but it is an area one which WWF must keep a watching brief.

List of critical hydrogen applications for a zero-carbon economy

Based on a high-level analysis undertaken across multiple sectors, WWF-Australia has identified the following five applications of renewable hydrogen likely to be critical for decarbonisation.

Table 3: List of critical hydrogen applications for a zero-carbon economy

Hydrogen application	Rational compared to other zero-carbon pathways	Technology availability
1. Chemical feedstock for ammonia and methanol production	There are no current zero-carbon alternatives	Available, but not commercial.
2. Reductant and heat source for the harder-to-decarbonise industry sectors such as steel,	Due to the chemical reactions that occur during the reduction of ores like iron into industrial products like steel, conventional thinking is that a combustion-based approach is	Not yet available. Demonstration projects are underway in Germany and Sweden into hydrogen use in the

alumina, and cement	required. As such, while electric arc furnaces and similar electrification technologies will likely play a much larger role in the refinement of metals, it is likely hydrogen combustion combined with specific catalysts will be needed for at least some of the process.	manufacture of steel.
3. Fuel in heavy transport such as mining trucks, long-haul trucking and shipping.	Batteries will likely be too heavy and occupy too much space for them to be a functional alternative to renewable hydrogen. Biofuels also have significant environmental and carbon concerns.	Prototype technology exists for trucking. Demonstration projects are being undertaken, particularly in trucking, and shipping pilots are in development.
4. Seasonal storage for the electricity sector	The necessity of hydrogen for seasonal storage depends on the need for such storage (greater in places with short daylight hours in winter) and the availability and relative cost of other storage and firm renewables options, such as sustainable bioenergy and pumped hydro. Remote grids for communities and mines may likely require higher levels of seasonal storage, and as such, hydrogen could play a critical role.	Technology exists. Pilot projects are being undertaken.
5. Multiple energy applications (transport, electricity and industry) in places that are unlikely to have enough land/renewable resources to electrify domestically.	Some countries (see *Figure 6*) are unlikely to have sufficient renewable resources to directly electrify their transport, electricity, heating and industrial sectors and as such, importing renewable hydrogen may present one of the only alternative zero-carbon solutions.	Direct hydrogen import is not yet available; ammonia import technology is commercial. Countries like Japan have developed hydrogen import strategies.

Endnotes

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