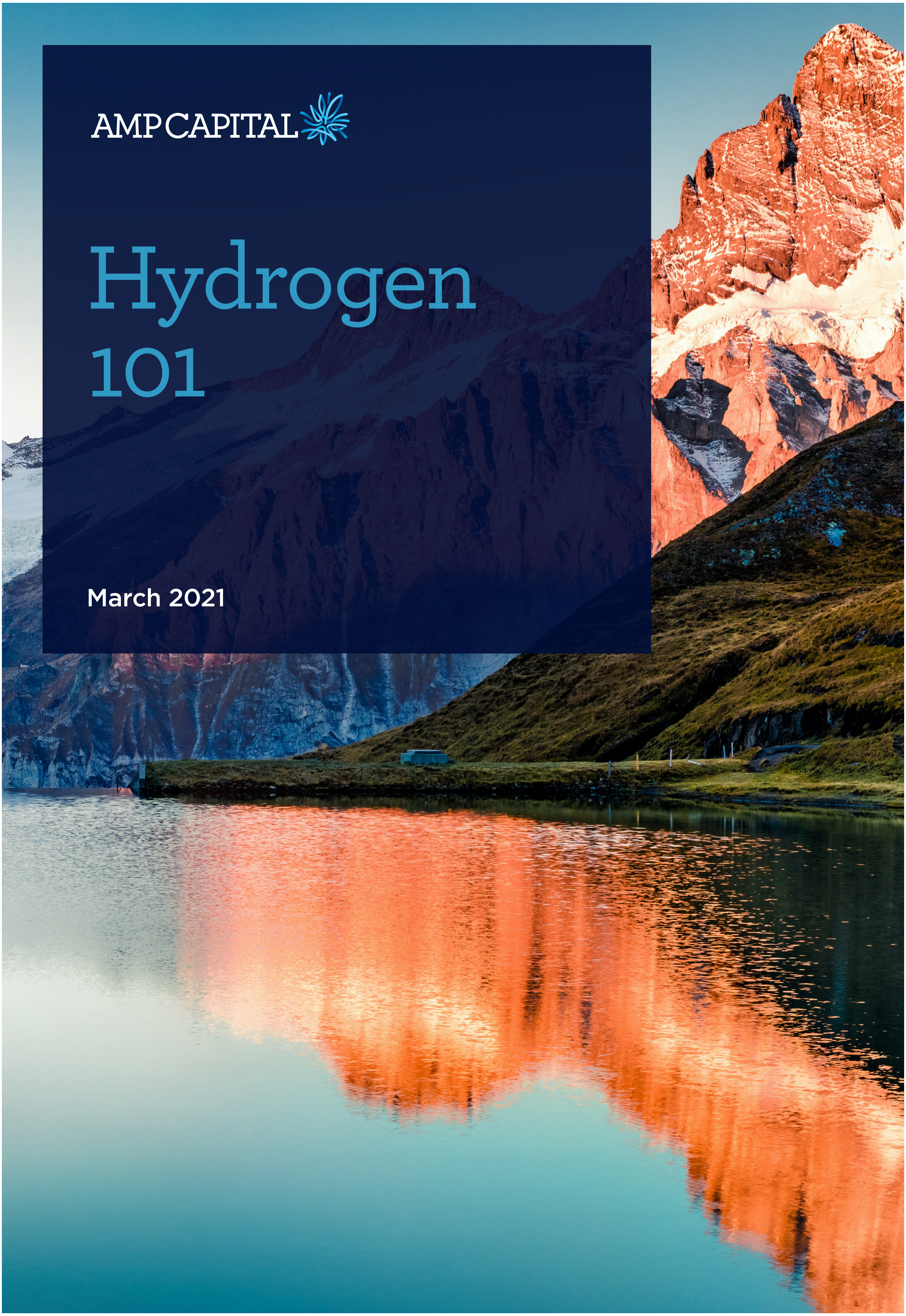
AMP CAPITAL

Hydrogen 101

March 2021



Executive summary

Can renewable hydrogen reduce emissions and help solve climate change? As the dangers associated with climate change become more widely understood and accepted, the fight to save the planet and its people has intensified. As investors, we believe that stopping climate change will aid economic growth – as such we strive to understand how the companies we invest in can not only manage these risks but also how they can be part of the solution. Renewable hydrogen has been touted as a simple, cost-effective solution to the climate crisis.

In this article, AMP Capital provides a Hydrogen 101, looks at the role Australia could play, and suggests questions investors can ask companies about how hydrogen fits into their emissions reduction strategy.

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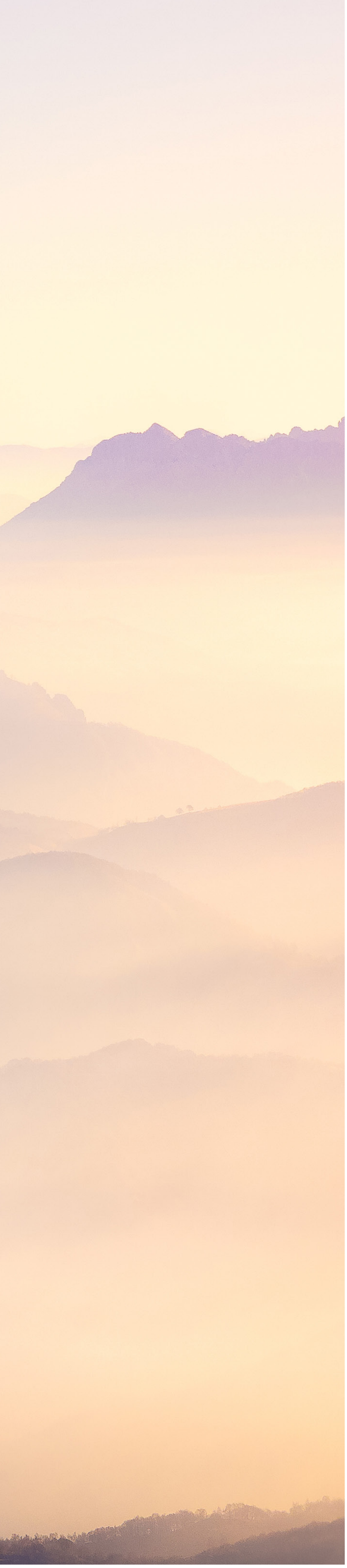


Hydrogen 101

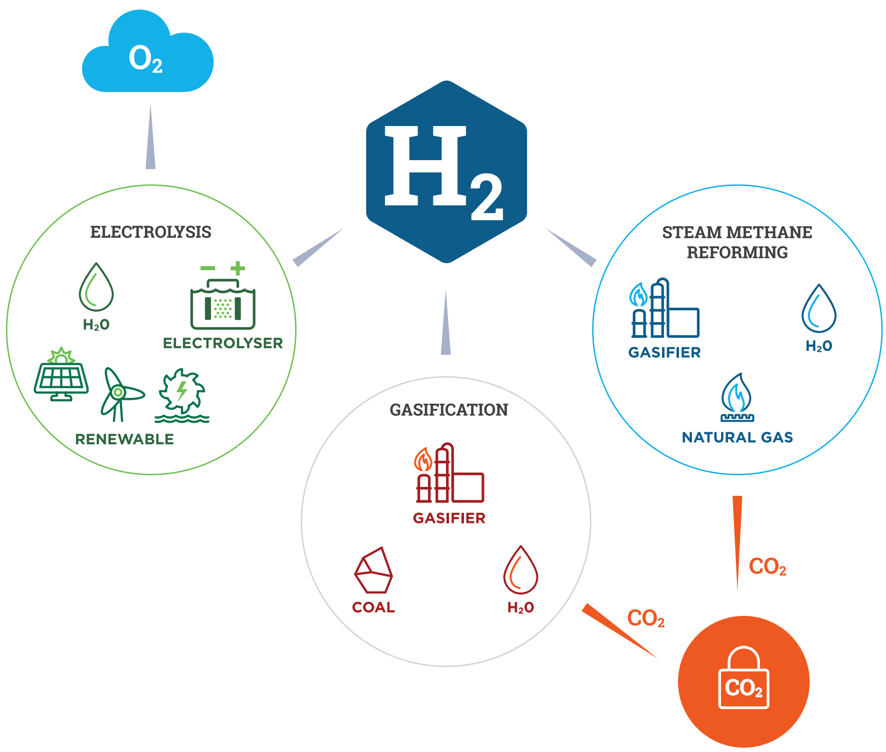
Production → Storage and transport → Application

The science of hydrogen

Hydrogen, a colourless, odorless, tasteless, flammable gaseous substance, can be produced several ways, depending on whether you start with methane, coal, or water. The three most prominent methods to produce hydrogen are through steam methane reforming (SMR), coal gasification and electrolysis.

- **Steam methane reforming:** As the name suggests, SMR is the process whereby methane (CH_4) reacts with high-pressure steam to produce hydrogen, carbon monoxide and carbon dioxide.
- **Coal gasification:** This is the process of reacting coal with oxygen and steam ($CH + O_2 + H_2O$) under high pressures and temperatures to form synthesis gas, a mixture consisting primarily of carbon monoxide and hydrogen. After the impurities are removed from the synthesis gas, the carbon monoxide in the gas mixture is reacted with steam through the water-gas shift reaction to produce additional hydrogen and carbon dioxide.
- **Electrolysis:** Electrolysis is the process of using electricity to split water (H_2O) into hydrogen and oxygen, using an electrolyser. There are two main types of electrolysis: alkaline electrolysis and polymer electrolyte membrane (PEM). The most widely adopted and mature technology is alkaline electrolysis, characterised by relatively low electrolyser capital cost and uses a hydroxide solution to create the hydrogen. In comparison, PEM electrolysis requires the use of expensive electrode catalyst materials (e.g. platinum or iridium) but overcomes some of the issues associated with hydroxide solutions.

Figure 1: Production pathways for hydrogen



Source: Australia's National Hydrogen Strategy

What makes hydrogen grey, blue or green?

The environmental impact of making hydrogen depends on how it is produced, and it is assigned different colour-codes to represent the environmental impacts of each production process.

Grey/brown hydrogen

Grey and brown hydrogen, the most carbon-intensive forms, are based on the production of hydrogen from steam methane reforming and coal gasification, respectively. These are currently the most common types of hydrogen, constituting over 98% of total hydrogen production globally[1]. The costs of grey and brown hydrogen are very competitive with alternative energy sources, but their production processes emit CO_2 into the atmosphere.

In the remainder of this paper, “grey hydrogen” refers to both grey and brown hydrogen.

Blue hydrogen

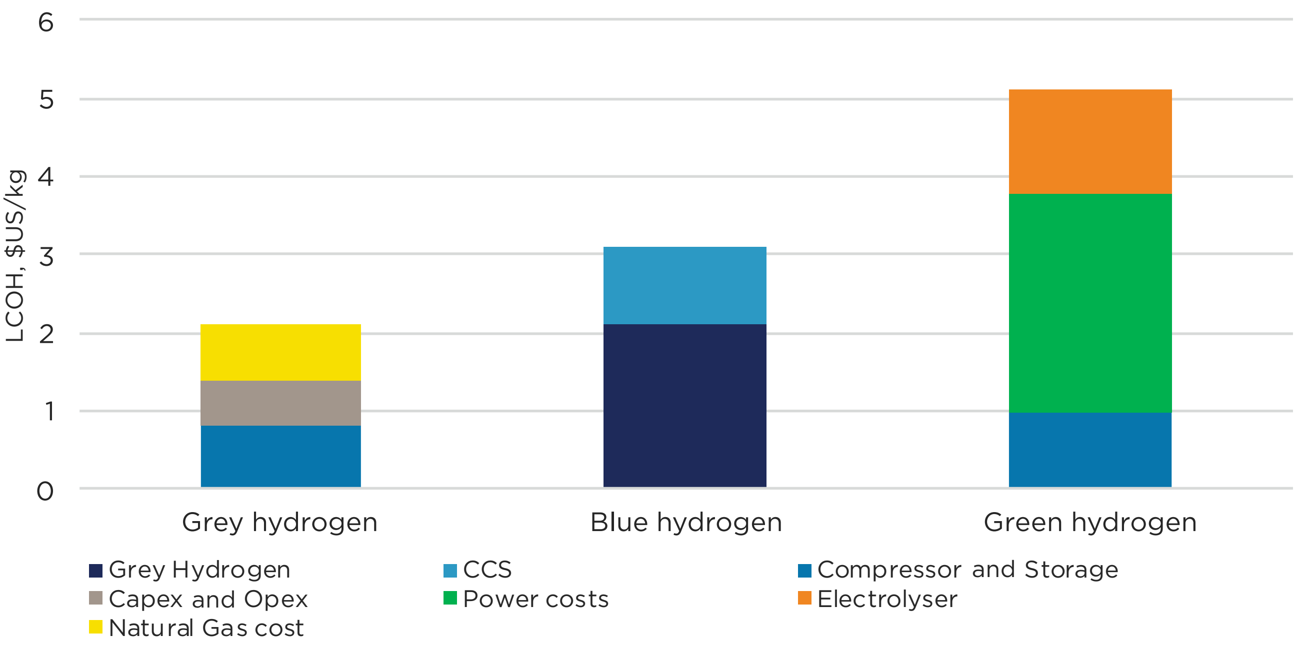
When the carbon dioxide (CO_2) waste that emerges as a result of producing grey hydrogen is captured, the remaining hydrogen is re-categorised as is blue hydrogen. Blue hydrogen combines grey hydrogen with carbon capture and storage (CCS), the process of capturing waste carbon dioxide (CO_2), transporting it to a storage site, and storing it where it will not enter the atmosphere. The reason blue hydrogen is not as common as grey hydrogen is due to the cost and lack of scale of CCS. The scale-up of blue hydrogen is reliant on the wider adoption and integration of carbon capture and storage technologies. but could reach cost parity with grey hydrogen through the introduction of a carbon price, as CCS avoids the cost of a carbon price.

Green hydrogen

Green hydrogen is produced when renewable energy is used to power water electrolysis, to create hydrogen and oxygen. Theoretically this process generates zero carbon emissions and is what many consider the ideal path for hydrogen development. Currently the cost of green hydrogen is more than double the cost of grey hydrogen due to the cost of electrolysers and renewable energy. However, these costs are expected to decrease as the technology evolves.

Below is a graph depicting the costs of each form of hydrogen, showing the significant premium currently paid for green and blue hydrogen. A commonly used cost target for green and blue hydrogen is H2 < US$2/kg, which would result in competitiveness compared to grey hydrogen.

Figure 2: Levellised Cost of Hydrogen (LCOH) Model



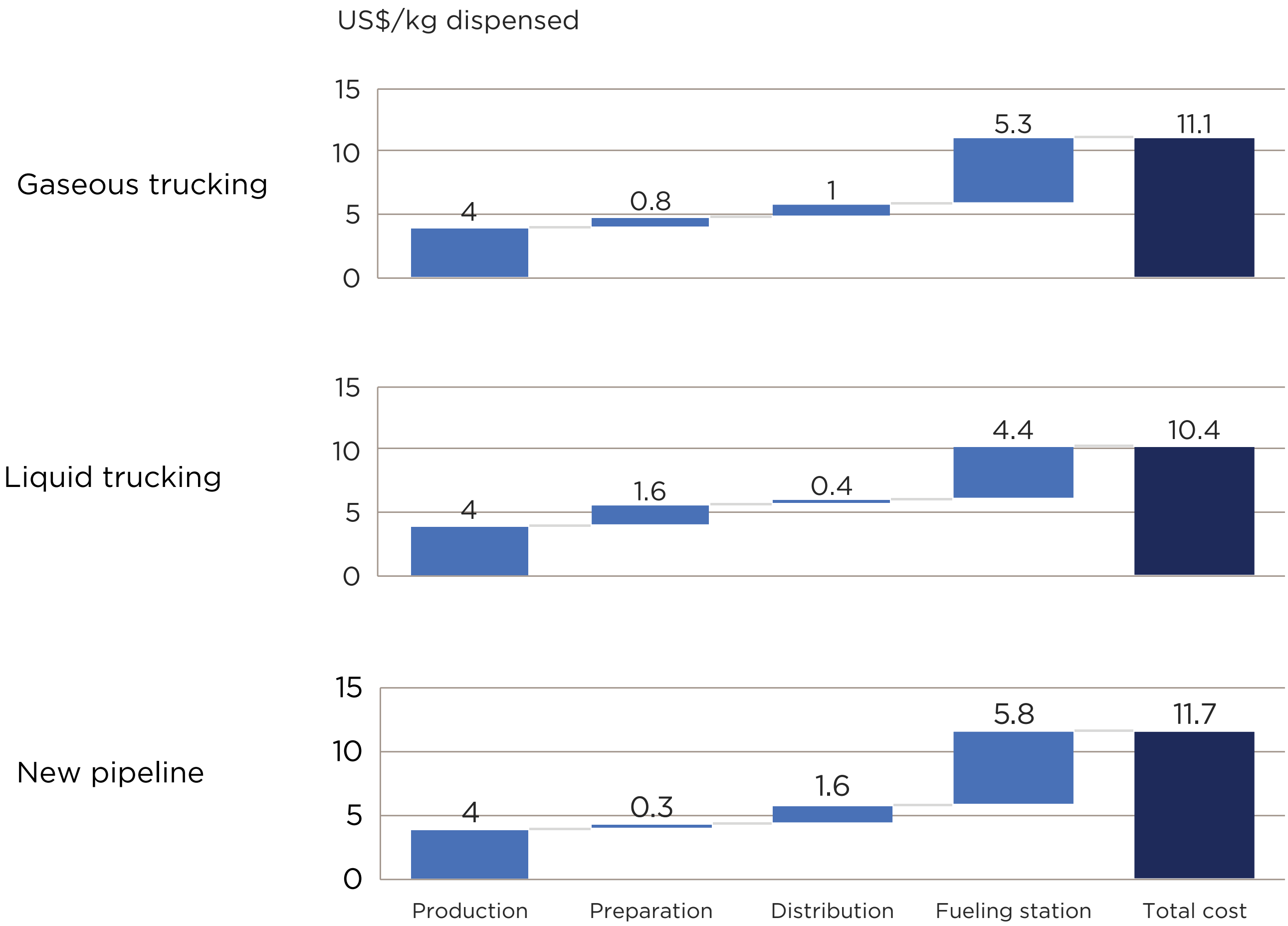
Source: Credit Suisse Equity Research, Hydrogen: A new frontier, December 2020

1 Credit Suisse Equity Research, Hydrogen: A new frontier , December 2020

Hydrogen is difficult to store and transport due to its low volumetric energy density, meaning that it is problematic to convert to high density as it occupies three times more volume than gasoline. It is typically stored either in a gas or liquid form in large high-pressure tanks and currently, there are three main ways to transport hydrogen, each of which has unique issues:

- **Gaseous trucking:** Transporting hydrogen in compressed gas tanks is typically used for small deliveries that are close to the hydrogen production plant. Due to the smaller quantities, costs are higher for the distribution and processing at fuelling station, as shown below.
- **Liquid trucking:** Hydrogen is converted from gas to liquid, then injected into liquid hydrogen tanks. This is the most economical method for longer distances (over 300-400 kilometres) because a liquid hydrogen tank can hold substantially more hydrogen than a pressurised gas tank. However, the cost of liquefaction is high and energy intensive if renewable energy is not used.
- **Pipelines:** Transporting compressed gaseous hydrogen by pipelines is the optimal solution for large-scale transportation. However, there is a large initial investment to build the pipeline. Mixing hydrogen with natural gas transferred through the existing gas pipeline has been proposed as a more efficient transportation solution. However, the durability and integrity of the existing gas pipeline could present a risk as hydrogen can significantly reduce the mechanical performance of steel by making it more brittle. Companies and government can use the existing pipeline infrastructure built to transport resources such as natural gas to transport hydrogen in the future. Recently, the NSW government established their infrastructure roadmap, including a plan to target up to 10% blending on hydrogen in gas pipelines by 2030[2].

Figure 3: Composition of total hydrogen distribution cost (assuming production cost of H_2 at US$4/kg)



Source: Hydrogen Council: Path to hydrogen competitiveness – A cost perspective, 2020; McKinsey Hydrogen Supply Model, 2019

2 NSW Electricity Infrastructure Roadmap, 2020: https://energy.nsw.gov.au/media/2271

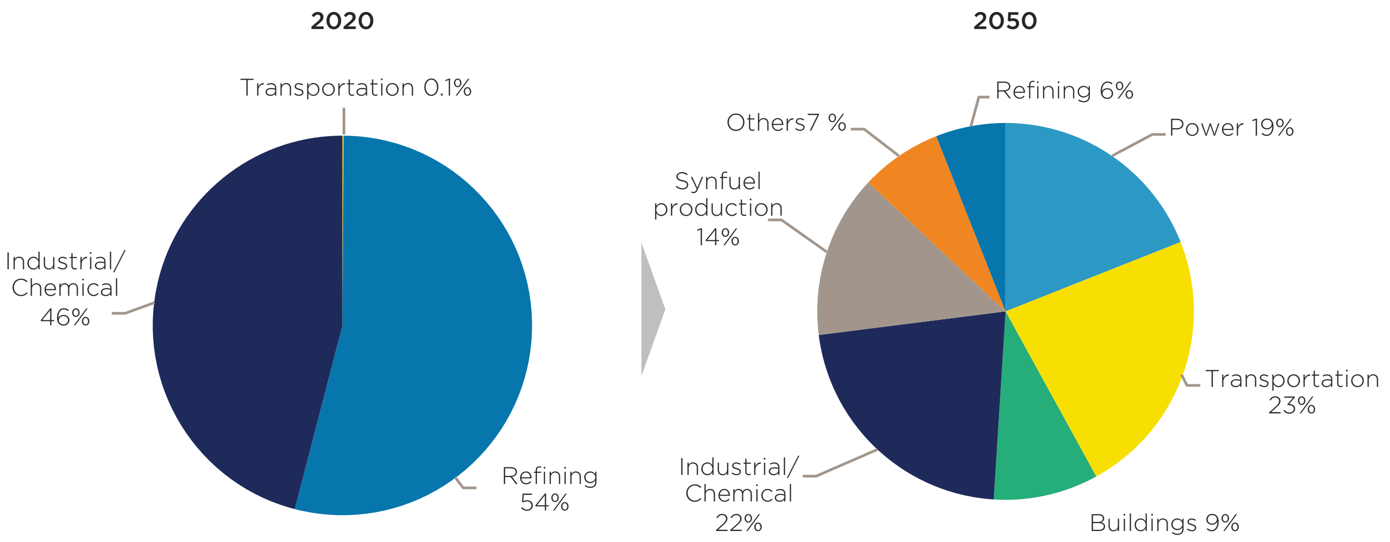
Hydrogen application can be broken up into the current and future hydrogen end-use applications.

Current state: 2020

Currently, there are two main uses of hydrogen, both of which utilise grey hydrogen:

- **Refining:** As per Figure 4 below, refining accounts for 54% of the global hydrogen demand. There are two main purposes for hydrogen in refining: (1) to lower the sulphur content in oil production; and (2) to upgrade heavy products to lighter distillates (such as oil to jet fuel).
- **Chemical production:** Accounting for the other 46% of global demand, hydrogen is used in producing ammonia (to make input fertilisers) and methanol (used to make adhesives, foams and plywood).

Figure 4: Global hydrogen demand by end-use sector: 2020 vs 2050 (under IEA's Sustainable Development Scenario)



Source: IEA: The Future of Hydrogen, 2019; Credit Suisse, 2020

Future state: 2050 and beyond

As the production of green and blue hydrogen increases, it will likely uncover new opportunities in numerous different industries in the future:

- **Transportation:** Hydrogen has multiple potential applications in the mobility sector. Most notably in Australia, car manufacturers are looking to develop cars and hydrogen refuelling stations in partnership with the Commonwealth Scientific and Industrial Research Organisation (CSIRO). However, this is a chicken-and-egg situation - it is unlikely that consumers will buy a hydrogen car without a strong supply of refuelling stations, but it is not commercially viable to build a refuelling station without enough demand from cars. Another issue surrounding hydrogen cars, often referred to as fuel-cell electric vehicles (FCEVs), is the competition from lithium-ion battery electric vehicles (EVs). It is widely predicted that FCEVs will not be as efficient as EVs for passenger vehicles, as a hydrogen fuel cell requires two-three times more energy to drive the same distance. FCEVs currently have a 54% conversion efficiency rate of converting hydrogen to electricity, whereas EVs can capture 80% of the energy[3]. However, hydrogen vehicles are likely to dominate with heavy trucks, as hydrogen fuel cells are more economically viable than EVs primarily due to the shorter amount of time it takes to refuel a FCEV compared with the time it takes to charge an EV (3-8 minutes for FCEV vs 8 hours for EV[4]).
- **Grid electricity (referred to as power in chart):** Hydrogen provides a long-term and large-scale storage option to balance seasonal variations in electricity demand and generation from renewables. There are two scenarios where

3, 4 Comparison of hydrogen and battery electric trucks: Transport & Environment, June 2020. https://www.transportenvironment.org/sites/te/files/publications/2020_06_TE_comparison_hydrogen_battery_electric_trucks_methodology.pdf hydrogen can assist in balancing the variation in renewable energy demand and supply: (1) If there is excess electricity supplied to the grid from renewable energy, hydrogen can be produced using electrolysis to store this excess energy as gas and help mitigate curtailment; (2) By storing additional power in the form of hydrogen, it would provide critical peaking support to the power grids, as power grids' growing exposure to intermittent renewable power would require more energy-storage facilities to help stabilise the power supply. Hydrogen systems could theoretically enable the transformation of electricity into gas and vice versa (due to fuel cells), combining scenario (1) and; (2), thus providing more flexibility to both the electricity and gas sectors. This requires power stations to be compatible with hydrogen, to convert it back to electricity.

- **Steel (referred to in building):** Steel is one of the hardest-to-abate sectors when it comes to reducing carbon emissions. It is also likely to have one of the longest timelines in implementing hydrogen technologies due to the very long capex cycles required to replace current manufacturing processes. Currently, the production of steel causes a large amount of carbon emissions and is produced via two main processes: either using an integrated blast furnace (BF) or an electric arc furnace (EAF). For EAF, scrap steel is melted using heat from electrical currents. If the electricity used in EAF is from renewable energy, this would produce "green" steel. However, the main challenge lies within the coal-dependent BF process. This requires a substantial amount of coal (specifically coke) to melt the iron ore, thus emitting large amounts of CO_2. To replace the BF process, steel manufacturers could instead use the production method of direct reduced iron ore (DRI), which uses natural gas (instead of coal) to produce steel. In theory, the DRI method can substitute hydrogen for natural gas, meaning it could be the key to enabling the production of high purity steel grades in the future without the emission of carbon dioxide, however it is still yet to work at a mass scale.

Australia and hydrogen

COAG Energy Council published Australia's National Hydrogen Strategy in November 2019[5], which outlines the vision for a clean, innovative, safe and competitive hydrogen industry. Part of this strategy paper presents the following timeline and Australia's ambition to become one of the top three exporters of hydrogen to Asian markets.

Timeline

The long-term vision of the hydrogen economy will take several decades to achieve. Initially, governments are likely to play a key role in conducting the R&D to achieve the "technology readiness" needed to allow industry to make decisions on commercialisation. As such, the timeline into hydrogen is often broken up into pre and post 2025.

Pre-2025

There are several initiatives required to prepare both the supply and demand sides of the hydrogen industry.

- **Demonstration hydrogen hubs:** A key element of Australia's approach will be the development of hydrogen hubs – where various uses of hydrogen across industrial, transport and energy markets are co-located. Hubs are pivotal in providing use cases for corporations to see the future economic viability of how renewable hydrogen can integrate into their operations.
- **Development of supply chains for hydrogen hubs:** There is significant research being conducted into how hydrogen can be incorporated into the existing supply chain for natural gas and other materials. These supply chains refer to both the production of hydrogen as well as the necessary infrastructure to export it.
- **Government and corporations' R&D investment**

Post-2025

To capitalise on this potential market activation, Australia could look to bolster the following initiatives:

- **Scaling export potential:** With Australia's large export potential, it will be paramount to build and maintain robust and sustainable export markets for hydrogen.
- **Expanding supply chains:** Building on the supply chains put in place with the hydrogen hubs, Australia will need to ensure a nationwide supply chain is in place to accommodate the increase in demand.

Australia's export potential

The global interest in clean hydrogen presents a major opportunity for Australia. There are three distinct advantages Australia has in fulfilling this potential market demand:

- **Renewable energy:** Australia has some of the world's best renewable energy in wind, solar and hydroelectric resources. Based on the quality of wind, solar and hydro resources alone, Geoscience Australia estimates about 11% of Australia (872,000 square kilometres) could be highly suitable for

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

renewable hydrogen production[6]. However, producing hydrogen also requires water. Therefore, the most ideal sites for production facilities will have access to both renewable electricity and fresh water supplies.

- **Track record in building large-scale energy industries:** Australia has useful expertise in building new large-scale industries, notably the LNG export industry and the renewable energy sector. Furthermore, there is world-class industrial and export infrastructure that can accommodate a hydrogen industry[5].
- **Reputation as a proven partner to Asia's biggest energy importers:** Australia has grown to become the world's largest exporter of LNG, overtaking Qatar at the end of 2020[7]. Furthermore, Australia has become a world leader in renewable energy deployment. Key export markets for Australia are Japan, Korea, China and Singapore.

There have been several significant events that have taken place in the last few months which accelerate the need for Australia to invest further in hydrogen, and could as such present both long-term risks and opportunities for our investee companies.

- **China, Japan and South Korea's commitment to net zero:** This year, China, Japan and South Korea pledged to become net zero emission economies by 2050 (2060 for China)[8]. For these countries to meet this goal, renewable hydrogen is likely to play a significant part.
    - **China:** The hydrogen strategy[9] outlines ambitious targets for increased roll-out of FCEVs, aiming to have over 1 million on the road by 2030, accompanied by 1,000 hydrogen refuelling stations (HRSs).
    - **Japan:** A new plan released by Prime Minister Suga in October 2020 outlined the role that hydrogen FCEV will play in their transition to a net zero economy, with the likes of Toyota leading the development of this technology[8].
    - **South Korea:** South Korea's strategy is focused on hydrogen imports. In June 2019, South Korea signed a memorandum of understanding with Norway on shipbuilding for liquefied hydrogen transportation[10]. South Korea also recently signed a letter of intent with Australia to identify and promote a mutually beneficial hydrogen import and export partnership.
- **Biden presidency:** The Biden-Harris agenda[11] includes a US$2 trillion economic recovery plan focused on clean energy investments and the creation of green jobs. It is expected that the US (under President-elect Biden) will re-join the Paris agreement to reduce greenhouse gas emissions. Furthermore, in Biden's clean energy plan, he states that the market can access green hydrogen at the same cost as grey hydrogen within a decade.
- These two events should catalyse Australia to lift their hydrogen investment and ambitions, to help meet the expected demand of hydrogen importers. Net zero emissions by 2050 is now the global benchmark against which to judge the credibility of long-term commitments to address climate change, according to the UN Secretary General[12]. In November 2021, the United Nations Climate Change Conference, also known as COP26, will take place. Each country will re-examine and look to improve their 2030 emissions targets. However, further inaction by Australia is a key risk and will increasingly be seen as an outlier if they do not align with their allies on the emission target upgrades.

"So what?"

While there is justified excitement about the potential of renewable hydrogen to help countries and companies meet their emissions reduction targets, there are still significant challenges ahead:

- **Cost:** Green and blue hydrogen are currently significantly more expensive than grey hydrogen due to the costs of the electrolysers, renewable electricity and CCS technology.
- **Low density:** Hydrogen (in its ambient form as a gas) is the lightest element and so has a low energy density per unit of volume, making long-distance transportation and storage complex and costly.
- **Water usage:** Roughly 9 litres of water are needed to produce 1 kilogram of green hydrogen. It is too often assumed that the scarcity of fresh water is not a problem, however, our view is that this is not the case.
- **Government policy:** There is currently a lack of committed government funding in Australia to incentivise hydrogen and CCS development, lagging other countries (notably European countries).

Despite significant obstacles, the opportunity set for green hydrogen is substantial given that hydrogen has the potential to become a large export for Australia. It is important that investors are asking companies the right questions and holding them to account on the related risks and opportunities, as it is apparent that some companies are passively leaning on hydrogen as the silver bullet in aiding them to reach their emissions reduction targets.

6 Geoscience Australia: Prospective Hydrogen Production Regions of Australia, 2019
7 Energy Magazine: LNG exports reach record output for 2020, 2020: https://www.energymagazine.com.au/lng-exports-reach-record-output-for-2020/
8 FT: South Korea follows Japan and China in carbon neutral pledge, 2020; Greenpeace: China, Japan, and Korea promised carbon neutrality, 2020
9 IEA: Hydrogen, more efforts needed, 2020: https://www.iea.org/reports/hydrogen
10 South Korea's Hydrogen Strategy, 2020: https://www.ifri.org/en/publications/editoriaux-de-lifri/edito-energie/south-koreas-hydrogen-strategy-and-industrial
11 Biden-Harris: Clean Energy: https://joebiden.com/clean-energy/
12 United Nations, 2020: https://www.un.org/press/en/2020/sgsm20411.doc.htm

Below we outline two key questions we ask our investee companies during engagements, in order to properly assess how they are approaching renewable hydrogen.

Question 1:

Where does the responsibility lie between government and corporations for hydrogen research? Have you had any interaction with state/federal government on different funding programs available?

- There are a number of funding programs currently available. For example, the Clean Energy Finance Corporation (CEFC) announced a $300 million Advancing Hydrogen Fund in May 2020.

If a company is not investing enough in hydrogen

- **Question:** How do you see climate risk impacting the long-term value of your assets and how are you managing this risk if you are not investing in the future of hydrogen?
- **Purpose:** As the energy transition continues to gain momentum, companies who continue to re-invest in carbon-intensive assets face two key risks:
    1. Missing out on the opportunity to invest in assets that will contribute to a net zero economy;
    2. Contributing to the climate crisis and facing backlash from key stakeholders, such as shareholders, communities, and government.

As alluded to during the section on steel, resource intense industries face very long capex cycles required to replace current manufacturing processes. Management can sometimes be short-sighted in nature, just focusing on meeting short-term financial obligations to shareholders. However, it is also important for management to fully consider how the energy transition will impact their assets in the long-term. To mitigate this short-sighted financial lens of management, it is important to align the company's emissions target with remuneration, an issue we typically place a lot of importance on.

If a company is investing too much in hydrogen

- **Question:** Given that renewable hydrogen is currently very expensive compared to other alternatives, why do you believe it to be a good use of shareholder funds compared to other forms of emissions mitigation?
- **Purpose:** While it is hard to quantitatively assess how much is 'too much', it is important to gauge how the company is thinking about the return on investment of their shareholder capital. The level of investment will also depend on the size of company and what sector they operate in. For example, it is likely that a car manufacturer can incorporate hydrogen into their product suite before a steel manufacturer can replace their manufacturing process. Similarly, large companies with bigger R&D budgets are expected to spend larger amounts of capital on researching new technologies.

Question 2:

When the commercial viability of green and blue hydrogen becomes apparent, where do you see [insert company]'s greatest potential in being involved?

Purpose: As the technology and regulation continues to evolve, green and blue hydrogen will become closer to reaching cost parity with grey hydrogen. When this commercial viability materialises, shareholders should expect the alignment of company strategy to this hydrogen technology. From an ESG point of view, some of the considerations we look for are:

- **Corporate governance:** Management short-term and long-term incentives (STI/LTIs) should accurately reflect the direction the board is setting, and there should be appropriate oversight and expertise in climate matters at both the board and management levels.
- **Environment:** Companies should update their glide-paths to Net Zero in sustainability reports, breaking down the incremental benefit from each activity being used to assist them reach their targets.
- **Social:** Companies should ensure they have adequate human resources trained to help transition the necessary parts of the business to the use of hydrogen.

Conclusion

While we are quietly optimistic about renewable hydrogen's potential to help companies and governments meet their emissions reduction targets, we are also very conscious of organisations who are taking for granted that human ingenuity will get us there in the necessary time frame. As investors, it is important to probe relevant companies about their reliance on renewable hydrogen, as well as ensuring they have a diversified approach to meet their emissions reduction commitments.

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