Power State

Building the Victorian Hydrogen Industry

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Executive Summary

Hydrogen is an important new player in Australia's clean energy transition, which can help fuel a new era of economic prosperity and job creation, meet ongoing domestic energy needs of consumers and industry, and create a lucrative long-term, sustainable export market.

The State of Victoria is perfectly positioned to take advantage of hydrogen and associated technological applications, given its supply of renewable energy sources, existing scalable energy, industry infrastructure, established government policy agenda and skilled workforce. If the commonwealth and state government get the policy settings right, zero-emissions hydrogen technology can boost Victorian and Australian GDP growth, create a new sustainable job market while helping to shift Australia away from its reliance on fossil fuels, especially coal.

An integrated hydrogen sector will directly lead to the creation of thousands of high-skilled, high-tech, well-paid, and secure blue and white-collar jobs in the hydrogen industry. Downstream, it has unmatched potential as a clean energy fuel that can power heavy industry and manufacturing. Victoria could become a leading green steel producer, and Australian capital of hydrogen exports, in terms of actual production and related clean energy products but only with the right investment and regulatory framework. Producing the intellectual property that makes the hydrogen economy tick is an important way Victoria can contribute to and benefit from its development. In turn, given its interconnections with wind and solar, hydrogen is a missing part of renewables jigsaw. Its practical application runs the gamut of clean, green transport, both private or public, and more efficient household energy consumption.

This report outlines practical steps to fostering a large-scale hydrogen industry. Other nations – and other states – are moving quickly. For the sake of our economy, our jobs, and our environment, we do not have time to play catch up. A Victorian hydrogen industry represents a once in a lifetime opportunity if we get the investment and policy settings right, Victoria will play an integral role in shaping Australia's long-term economic recovery from COVID-19.

Key recommendations

Power State proposes six recommendations to build a viable Victorian hydrogen industry:

- ✓ The Victorian government should rapidly **establish a roadmap for the development of a hydrogen industry**. This roadmap should enunciate short, medium and long-term targets to build new infrastructure and upgrade existing energy infrastructure. The roadmap should outline supply side targets for hydrogen production, demand side targets for domestic and export use, and targets for developing skills and training and workplace safety.

- ✓ The Victorian roadmap should encourage private sector investment in new technology, by **making available subsidies and tax incentives for companies to purchase and/or develop hydrolysers** and facilitate firms using hydrogen as industrial feedstock.

- ✓ The Victorian Government should **identify and put in place appropriate hydrogen industry skills and training, planning, environmental and regulatory frameworks**, in consultation with industry, employees, unions and environmental groups.

- ✓ The government working with stakeholders needs to **cultivate consumer and industry demand for hydrogen** at levels necessary for production and export at scale.

- ✓ It is recommended that the Victorian government **make a significant financial investment in the Plumbing Industry Climate Action Centre at Brunswick so that it can permanently host a Victorian Hydrogen Excellence Centre**, providing a full suite of training in hydrogen production and use, including storage, transport, and residential operations.

- ✓ The government should **actively support the establishment of two to three practical demonstration projects as a first step towards making Victoria the hydrogen capital of Australia**. The demonstrations projects should include two hydrogen production facilities and one industrial feedstock project, for instance feeding into a steel manufacturing plant. It is recommended that of the production demonstration projects one be located in each of eastern and western regional Victoria, as a means of stimulating employment, proximity to ports and renewable energy supplies: for instance, the ex-Ford car manufacturing plant in Geelong, which is being transformed into a renewable energy hub, and a feedstock project in western Melbourne's manufacturing heartland.

Foreword

In my role as Secretary of the Plumbing Pipe Trades Employees Union and as a Director at Plumbing Industry Climate Action Centre, I am uniquely placed to observe how industries and governments around the world are approaching energy policy.

Almost all stakeholders agree that there is a global need to transition to clean technologies that can produce the energy we need for reliable household power without emitting the greenhouse gases that are changing the climate of our planet. Faced with that challenge, innovators in Japan, Germany, and across Scandinavia continue to embrace green, clean hydrogen gas technology. Australia, and especially Victoria, can and should follow their lead in making clean hydrogen the focal point of our state's energy transition by leveraging our existing gas infrastructure.

Clean hydrogen is exciting because it ticks all the boxes – low emissions and reliable household power. The key is to make it green. If making hydrogen is powered by renewables, we can produce the gas we need in our homes without harming our planet. Our showers will still run hot, our ovens will still cook a roast and living rooms will still be warm in winter, whether they're powered by natural gas, hydrogen gas, or a blend of the two.

The advantage of clean, green hydrogen production over other renewable technologies in terms of reliability is obvious. If you have solar hot water, and that's your only source of energy and heat, you might struggle for a hot shower if someone else runs overtime. But if that solar hot water is boosted by a hydrogen gas system, you're going to get a 'clean' hot shower every time. The clincher is that this transition can be gradual, making it so seamless that users won't even know it's happening. No blackouts. No down spots. No threat to baseload power. No major problems for our economy. Victoria is in the fortunate position of already having an extensive gas pipework and distribution network. Making use of these existing assets lowers costs to the state and eliminates the environmental impact of having to build infrastructure from scratch. As we slowly dial up the amount of clean hydrogen running through our pipes – from say, 10% to 20% and beyond – only minor works are needed.

For example, hydrogen can impact on steel, so household gas fittings and hot water installations need to be upgraded gradually to prevent corrosion. These adjustments have to be done safely, which is one of the major reasons Victoria is in poll position to lead the nation into a green hydrogen future. Most Victorian homes are plumbed for gas, which means the state's plumbers have been working with gas infrastructure their whole lives. They are ready to kick start this gradual transition, especially if we can improve training capacity.

Dr Meagher and Dr Dyrenfurth recommend that the Victorian government invest $20 million to develop Australia's first Hydrogen Centre of Excellence at the existing PICAC facility in Brunswick. A commitment of this scale would help to build a suitable curriculum taught by qualified teachers, which would in turn encourage people in our industry to enrol to upskill. The Hydrogen Centre for Excellence could also be built by apprentices, for apprentices. PICAC estimates suggest over 100 apprentices could be employed to undertake the Brunswick facility upgrade, a huge boost given our current economic situation.

As this report shows, Victoria's transition to clean hydrogen will not just benefit plumbers but businesses and families across our state as well. If Victoria leads, Australia can also follow, for the benefit of the planet and everyday consumers. It's a no-brainer.

Earl Setches
National and Victorian Secretary,
Plumbing and Pipe Trades Employees Union and
Board Member,
Plumbing Industry Climate Action Centre

Introduction

Hydrogen is an important new player in Australia's clean energy transition, which can help fuel a new era of economic prosperity and job creation, meet ongoing domestic energy needs of consumers and industry, and create a long-term, sustainable Asia-orientated export market.

If the commonwealth and state governments get the policy settings right, zero-emissions hydrogen technology can boost Victorian and Australian GDP growth, while helping to shift Australia away from its reliance on fossil fuels, especially coal. It will directly lead to the creation of thousands of high-skilled, high-tech, well-paid, and secure blue and white-collar jobs in the hydrogen industry but also downstream, being the clean energy fuel that can power heavy industry and manufacturing. In particular, exciting possibilities abound in terms of becoming a leading green steel producer, and Australia's capital of hydrogen exports, both in terms of the product itself and the intellectual property used throughout the supply chain. In turn, given its interconnections with wind and solar, hydrogen is a missing piece of the renewables-jigsaw. Its practical application runs the gamut of clean, green transport, industrial feedstock, meeting Victoria's baseload energy needs, and more efficient household energy consumption.

To make Victoria the hydrogen capital of Australia, to position the state to better service local baseload energy requirements and become a world-leading exporter, policymakers and governments need to begin rolling out new hydrogen technologies while upgrading existing 'like' infrastructure. Necessary investment conditions should be facilitated through carefully targeted tax support and subsidies. Victoria must also plan and deliver the necessary skills and training framework so that Victorian workers can take advantage of the opportunities of hydrogen, from production to storage, transport, and residential use. As the Chief Scientist Alan Finkel has outlined, policy makers need to help build industry-sustaining levels of demand. However, the emerging hydrogen industry also requires careful, strategic supply-side interventions, and the facilitating infrastructure investments, as well as providing a clear regulatory framework.

With the right policy settings, this cutting-edge, zero-emissions technology has limitless potential. If government lays out a clear roadmap for the development of a large-scale Victorian hydrogen industry by encouraging private sector investment in new technology; identifying and putting in place appropriate training, planning, environmental and regulatory frameworks; and cultivating consumer and industry demand for hydrogen, this industry will benefit all Victorians. A Victorian hydrogen industry represents a once in a lifetime investment opportunity, but we need to get it right, and quickly, and do it in coordination with all the relevant stakeholders.

Part One | What is hydrogen?

Something old, something new

There is a lot of buzz around hydrogen. A light, odourless, colourless gas, hydrogen is the most abundant element in the universe. Hydrogen energy can be made and used with minimal Greenhouse Gas (GHG) emissions. It is incredibly versatile: hydrogen can be stored and used as a gas or liquid fuel, and it can produce either heat, chemical, or electric energy: what we need to keep us warm and keep the lights on, run public and private transport and produce essential goods, from heavy manufacturing including the production of green steel, to fertilisers and consumer goods. Two simple facts explain much of the global interest in this technology:

1. Hydrogen can be produced using a simple process known as electrolysis. Water is a compound of hydrogen and oxygen. An electrical current is filtered through purified water and a membrane which separates the hydrogen from the water molecules. The hydrogen is captured and can then be stored as a source of energy.

2. Using hydrogen produces nothing but water and heat. Hydrogen reacts with oxygen, re-making water and producing heat that can be captured to do work.

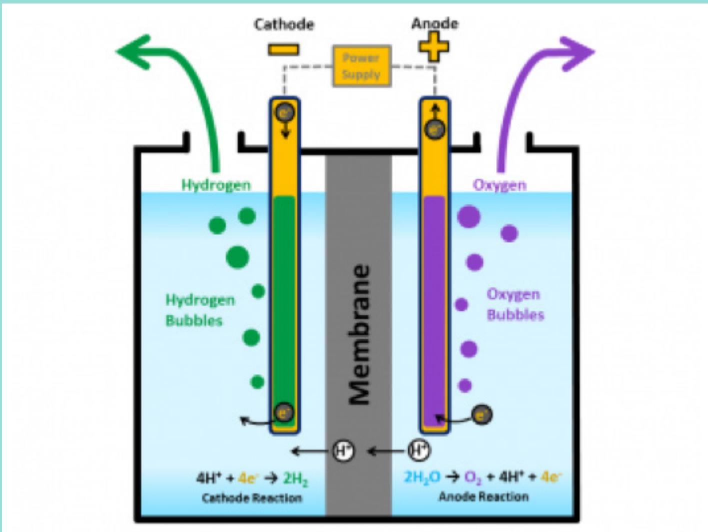
Of course, if the practical reality were as simple as this then hydrogen would have become our main energy source as soon as Nicolson and Carlisle (an English chemist and English surgeon) discovered the electrolysis process in 1800. Ensuring the hydrogen reacts with oxygen quickly and that the heat can be captured and can be used effectively requires detailed technical knowledge. One Australian system, HERO®, uses a catalyst to cause the chemical reaction, generating 700 degrees Celsius of heat in minutes without consuming the catalyst.

Making hydrogen

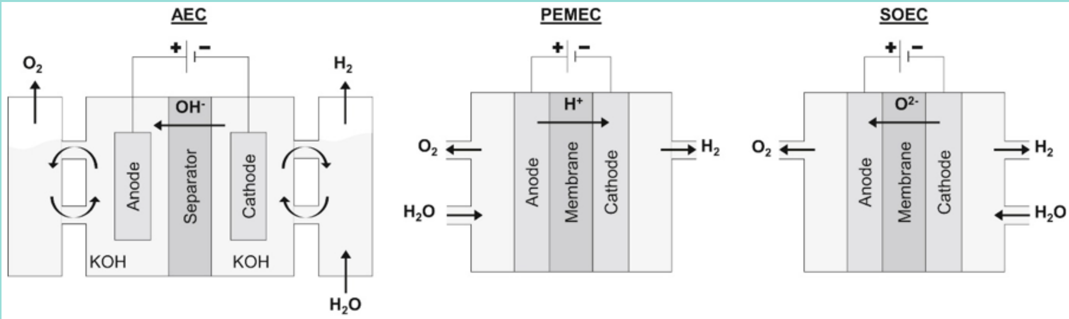
There are three ways of making hydrogen. Australia's National Hydrogen Strategy explains the first method: "Hydrogen can be produced from water in three main ways. One way is through a process known as electrolysis, which extracts hydrogen from water using electricity. If renewable electricity is used, this process produces no carbon emissions."[1] The other two methods are not emissions-free or considered 'green hydrogen' and are not part of this report's scope. Hydrogen is made by running electricity through water, but making, storing, and using an economically useful amount of hydrogen at a competitive price in a reasonable amount of time needs huge material inputs, a lot of technical knowledge, and a deep skilled workforce. Making and installing hydrogen electrolysers at scale is a major task, as is ensuring sufficient access to water. Distributing hydrogen to where it is needed is no small challenge. Finding catalysts to make the chemical reaction in electrolysis occur quickly is an ongoing focus of research scientists. The National Hydrogen Roadmap is a 20-year plan precisely because there is a lot of work to do.

To appreciate how technically sophisticated the hydrogen production process is, consider one of the most recent breakthroughs, which came from researchers at Singapore's Nanyang Technology University (NTU).[2] Other researchers had previously observed that a material (spinel oxides) worked relatively well to catalyse the electrolysis process, but without understanding why, there was no way to optimise the process. The team at NTU observed at the atomic level how spinel oxides were interacting with the water to hasten the creation of hydrogen. The NTU team found out why this type of material worked well as a catalyser. With that knowledge, they used machine learning processes to predict what specific type of spinel oxide would work best in the production process. Their model predicted that manganese-aluminium oxide would be ideal. They confirmed their prediction by making the optimal oxide and testing its ability to catalyse the hydrogen electrolysis. This is challenging enough, but for the process to be economically useful, it needs to be done on a massive scale at high speed and low cost. That means obtaining a huge amount of the precise manganese-aluminium oxide to use in making electrolysers (among other challenges). Making hydrogen from water and electricity is a simple concept but making enough to power the world at a low enough cost is a major challenge involving collective efforts to make and distribute the hydrogen. Even if it can be made and distributed at scale, we still need to alter many industrial or commercial components to make them suitable for hydrogen use. For instance, hydrogen can destroy steel, so household gas fittings and hot water installations may need to be altered to prevent corrosion. Hydrogen molecules are smaller, and lighter than natural gas, so preventing leaks in pipes full of hydrogen requires different specifications for most pipes and fittings. Training a workforce of plumbers with the skills and knowledge to maintain gas fittings to the right specifications is just one example of why the practical challenge is much greater than 'making hydrogen from water'. However, it is a challenge that Victoria can meet, and the rewards in terms of jobs, growth, and lower GHG emissions are worth it.

What is an electrolysis machine?[3]



At the most basic level, an electrolyser is a vat of water containing two electrical nodes (one being negative and the other positive), and a separate 'exit valve' near each node. Conducting an electric current from one node through the water to the other node causes a chemical reaction in the water. The water molecules (H2O) split into hydrogen and oxygen (H2 and O2). The hydrogen molecules attract toward the negative node and the oxygen molecules attract toward the positive node, meaning separate exit valves make it possible to collect just hydrogen.



More advanced electrolysers include carefully designed nodes to optimise the number of water molecules being exposed to an electric charge at any given moment and include catalysts to make the chemical reaction occur faster. The more hydrogen that can be made for a given amount of time, water, electricity, and steel (or other materials a container may be made from) the better.

As the technology involved in hydrogen electrolysis continues to be refined, the price of electrolysis machines, and therefore the end product of hydrogen, will inevitably fall. According to the International Energy Agency (IEA), the upfront capital cost of an electrolyser is approximately $700 to $2,000 per kW.[4] More precise and reliable estimates are scarce because electrolysers are still a relatively new product, so they are not yet commoditised. Additionally, the technology is advancing rapidly, so the price frontier is continuing to shift accordingly.

Alkaline electrolysers have been the most common type of electrolyser for producing hydrogen, mainly because its components are similar to those used for making other widely used products (chlorine and sodium hydroxide), and thus already available at scale. But PEM electrolysers have recently become more common. These are smaller devices that can be turned on and off faster, making them more suited to work with the variable electricity supply from renewable sources.

PEM electrolysers use a catalyst to split water into protons, which move through a membrane to bond with neutral hydrogen atoms, creating hydrogen gas. These systems are relatively small and modular, produce hydrogen faster than the old machines and operate at lower temperatures, however because they are relatively new technologies, they are also more expensive.

In 2018, CSIRO estimated the levelised cost of electricity (LCOE) for hydrogen produced by alkaline electrolysers in Australia was around AUD $4.80 to $5.80 per MWh, while hydrogen produced by PEM electrolysers produced hydrogen at a LCOE of around $6.10 to $7.40.[5] However, the cost of electrolysers is only one part of the cost of green hydrogen. The other major component is the cost of renewable electricity. Analysts are predicting green hydrogen made with wind and solar could become the cheapest 'transformative fuel' faster than expected, leapfrogging gas and coal as the most cost-effective energy before the end of the decade.[6]

Over the past decade, the cost of generating electricity from solar and wind has plummeted. New research from the Centre for Climate and Energy Policy at the Australian National University cites CSIRO estimates that in Australia, the LCOE for large scale solar PV installations in 2020 is between A$41-60/MWh and A$48-60/MWh for onshore wind. This is expected to continue falling over the next two decades, potentially reaching $33/MWh as early as 2030. The ANU scholars show that "the mean cost projection for 2030 across both PV and onshore wind is A$40/MWh, and the lowest estimate was A$25/MWh." The consequences for hydrogen usage are profound. They find that "green hydrogen production at or below A$3/kg will be possible soon or could already be possible, and green hydrogen production costs in the vicinity of A$2/kg may well come within reach in coming years."[7] At these prices, the domestic use of hydrogen becomes a live option, not a future dream. Victoria must be a first mover.

Because one of the main costs of clean hydrogen is the cost of renewable energy, it is intrinsically linked to renewables (especially solar, wind, and hydropower). Australia's abundance of these resources is one of the major reasons for the interest in developing an industry here. Besides renewable energy, the other major ingredient for green hydrogen is water, meaning locations with abundant water resources (such as coastal areas) are ideal. Since fresh water is relatively scarce in Australia, sea water can be used. This present a hurdle previously and continues to add somewhat to the cost relative to using fresh (clean) water, but given Australia's scarcity of fresh water, the use of salt-water is an important breakthrough for the industry in Australia.

Storing hydrogen

Hydrogen can be stored as a compressed gas in high-pressure tanks, and in pipelines, or as a liquid at below freezing temperatures. It can also be 'embodied' in products such as steel or ammonia that require a lot of heat to produce, however this is not 'storage' in the sense that the hydrogen itself remains available to use at a later date. Liquid hydrogen is by far the most expensive option since it needs to be kept at very close to absolute zero temperatures. This method is mainly considered an option for export markets, where the hydrogen would need to be transported over long distances. However, even in those cases, transporting hydrogen as a liquid is expected to approximately double the cost, so it is unlikely that liquid transport options will be among the early solutions deployed. Compressed gas in high pressure tanks are a good option with a variety of applications. For instance, remote locations could store hydrogen this way. It is well suited to longer-term storage and is ideal for transport by truck or rail. There are safety issues, but these are no different to those presented by natural gas storage. Storage tanks have an advantage in that they can be made at different sizes, ranging from home BBQ-sized cylinders to building sized tanks. In Victoria, however, the existing gas pipe infrastructure possess a significant advantage other states do not have. Victoria has 1,900km of gas transmission pipes in its Principal Transmission System (PTS), covering Melbourne and central Victoria. The PTS is owned by GasNet and operated by AEMO. This system connects more households to gas than any other state, with more than a third of gas consumption in Victoria being residential consumption (40% is industrial, 12% commercial, and 8% for power generation).[8] Large-scale existing integrated storage and distribution assets is a major advantage for Victoria's hydrogen industry. They can be upgraded with relatively low new capital expenditure or disruption to public infrastructure, and there is already a work force with skills that can be applied to hydrogen with only moderate additional training required.

Transporting hydrogen

Transporting hydrogen includes both long-distance 'transmission' and local 'distribution'. Distribution involves moving hydrogen to end-users, such as households or industry. The method of distribution is dependent upon how the end-user is equipped to receive hydrogen. Households will need to be fitted with gas piping, as most households in Victoria already are. Industrial users may have other needs, such as two-way connections if, for instance, a large steel maker that requires a sizeable amount of heat, has the potential ability to make hydrogen on-site and can make more hydrogen than they need. Transmission, however, involves moving hydrogen from market to market. Transmission is analogous to the large high-voltage AC power cables that make up the backbone of Australia's electricity grid. Conversely, distribution is analogous to the street-level power lines that connect directly to our houses and offices.

Transmitting hydrogen from market to market can be done in several ways. Shipping is the only real option for Australia to export hydrogen as a product in itself (as opposed to exporting 'hydrogen' embodied in manufactured commodities such as green steel).[9] Shipping hydrogen is not a developed industry. In December 2019, the world's first liquid hydrogen carrier, the Suiso Frontier, was unveiled in Kobe, Japan, made by Kawasaki Heavy Industries.[10] The name 'Suiso' is a romanisation of the Japanese word for hydrogen. The Suiso is expected to make its first trial shipment in 2021, carrying hydrogen to Japan from the Port of Hastings, in Victoria, where a consortium of Japanese and Australian firms (supported by the Victorian, Australian, and Japanese governments) is building a hydrogen liquification facility.[11] That first shipment will be hydrogen made with coal rather than renewables, but it establishes Australia as a confirmed exporter of hydrogen to Northeast Asia from the very beginnings of this industry. Australia and Japan have been collaborating on the project for a number of years already, securing safety approval for the project from the International Maritime Organisation in 2016. Australia and Japan are well in front of the rest of the world in developing the technology and regulations for open-water shipping of liquified hydrogen. It ensures that Australia's hydrogen industry begins as an export competitive industry, meaning we will never have to play global catch-up. The pilot facility at the Port of Hastings can liquify hydrogen at a rate of 0.25 tonne/day and store 41 cubic metres, while the Suiso can carry 1,250 cubic metres and will make 4 trips over the year-long pilot program in 2021.[12] Working closely with Japan to expand shipping capacity and upgrade port facilities will be part of Australia's clean energy export mission. The future of shipping liquid hydrogen still has questions to resolve, especially with respect to the cost relative to other ways of using hydrogen, but if the economics can be made to work, shipping will be a key part of the potential clean hydrogen supply chain linking Australia's abundant renewable resources to partners around the world. Developing this specialist ship building and port-upgrading industry is a project that Australia and Japan should continue to develop together. Significant opportunities exist for Australia and Victoria to reboot these neglected industries.

Not all transport will be conducted by international shipping, however. Pipelines are one way to transport hydrogen over long distances within and between Australian states and territories. This would likely be the most efficient way to transport massive quantities over very long distances (such as interstate, for instance) across Australia, but the upfront capital cost is large. Hydrogen pipes must be made from (or lined with) corrosion-resistant material. Steel does not suffice because the hydrogen embrittles the steel, causing breaks and leaks. High-purity stainless steel, or pipes lined with carbon fibre or polymers are required.[13] Existing infrastructure is expected to be reliable for carrying blends of gas with 10% hydrogen but moving beyond 10% is expected to require upgrades and retrofitting pipes and other fittings. According to Dr Dennis Van Puyvelde, the head of gas at Energy Networks Australia, much of the gas distribution network in Australia are made from plastics that can carry hydrogen. It may be possible to repurpose gas pipelines to carry hydrogen at less cost than transmitting the same amount of power in the form of electricity through transmission lines.[14] Determining the optimal parameters and estimating the ongoing hydrogen maintenance regimes is a subject of ongoing research, testing and investigation.

Trucking is a more economical option for smaller scale transmission of hydrogen. Trucks would need to carry compressed-gas tanks suitable for safely containing hydrogen at high pressures. These are largely the same as the LNG tanks that most Australians are likely already familiar with. The characteristics of trucking are advantageous in some contexts and disadvantageous in others. For instance, trucking is modular: you can have a single truck or an entire fleet, but you only need to expand on the scale of one truck at a time. That is distinct from trans-continental pipelines that need their entire maximum capacity to be constructed before they can be used at all. If needed, trucking can be made even more modular by using small cylinders, similar to a backyard BBQ LNG cylinder. Trucks also have the advantage that they use existing road infrastructure. And they can carry hydrogen to anywhere that roads go. They are not restricted in their destinations to only those places with suitable gas fittings connected to the gas network. Their main disadvantage is that the quantity of gas that can be moved over large distances by trucks is far less than the quantity that can be moved by pipeline. Trucks are likely to be one of the extremely important component of Victoria's hydrogen transport infrastructure.

For local distribution in Victoria, the existing infrastructure of natural gas pipelines provides a valuable, leverageable and transferable asset. It is generally expected that hydrogen can be blended directly into existing infrastructure up to a concentration of around 10%,[15] however this may need to be confirmed in certain settings or under certain conditions. For instance, many specific types of equipment that use large amounts of gas currently, such as gas boilers, may be affected by corrosion or embrittlement if the concentration of hydrogen in the gas supply is too high. According to Siemens, new gas turbines are able to use gas blends with up to 20% hydrogen, and the next generation of turbines are expected to be compatible with 100% hydrogen.[16] These technical specifications are details that need to be resolved, as are questions of who should carry the associated costs and risks and what regulatory changes are needed. Energy Safe Victoria regulates the safety of gas infrastructure in Victoria, operating under the Gas Safety Act 1997, Pipelines Act 2005 and Gas Industry Act 2001. These Acts will need to be updated to accommodate the use of hydrogen. Using existing institutions and workers with closely transferrable skills and expertise will help make the adoption of hydrogen as easy as possible. In its recommendation section, this report explores in detail how Victoria can upskill and (re) train a new generation of white and blue-collar workers engaged in the hydrogen industry.

Finally, there is another way in which hydrogen can be 'transported', and that is embodied in the products which use hydrogen. In this sense, it is not the hydrogen itself that is being transported, but the energy content of hydrogen, or even just its economic value. As a gas or liquid, hydrogen is a rich energy fuel, meaning it stores chemical energy that can be transformed into other forms of electricity without too much loss of the end product. Typically, the other forms of energy will be heat, electric, or chemical energy, but it may also be a different type of potential energy. Or the energy may be used to do the work itself. These forms of 'transporting' hydrogen (or at least, transporting its energy content or economic value) are discussed in the paper's next section, which specifically concerns the uses of hydrogen in various industrial processes.

Using hydrogen

One of the major sources of excitement about hydrogen is the versatile uses it may be put to, but this is also one of the constraints on developing the industry. Using hydrogen is a constraint, because there is a need to build up the demand-side (industrial and residential) of the industry in order to demonstrate the economic viability of investments in the supply-side (for instance, manufacturing, residential supply, and exports). Simply put, we cannot create demand when there isn't supply available to use. This is a market failure in the sense that there is no existing market (or at best, the existing market is very thin). Solving this dilemma is one of the main reasons why government leadership and action is required, with strategic interventions needed on supply and demand sides (as well as infrastructure and regulations) working with industry groups, employees and unions covering workers in hydrogen and related industries.

The National Hydrogen Strategy[17] distinguishes **five categories of use for hydrogen**:

1. Producing **electricity** for the grid
2. A **fuel** for transport (private and public)
3. **Heat**, either for industry or residential heating
4. **Chemical feedstock**, such as ammonia
5. Australian **exports**.

Electricity

Producing electricity for the grid is the most intuitive use of hydrogen. We can have our cake and eat it too. In this way, hydrogen acts in the same way as batteries or pumped hydro: we use the electricity produced from variable renewables (water, solar and wind) to make hydrogen when there is an over-supply of electricity generation, then we convert the hydrogen back into electricity when the direct renewable sources are under-supplied. Another way to think of this process is that we buy electricity to make hydrogen when the electricity price is low, and we use hydrogen to sell electricity when the electricity price is high. This process makes the entire electricity grid cleaner and more efficient and lowers the cost of electricity for everyone.

Transport

Hydrogen can also be deployed as a low-carbon fuel for transport, whether for private (including for commercial uses) and public use. As it stands, transport is the second largest source of GHG emissions in Victoria. Victoria's 2019 Greenhouse Gas Emissions Report notes that transport was responsible for 22.7 million tons of carbon equivalent GHG emissions (over 20% of Victoria's GHG emissions that year).[18] Transforming the way we move around is an essential task as we work to meet our commitments made to the 2016 Paris Climate Agreement.

One of the main technical challenges for hydrogen as a transport fuel is the need to keep it in liquid state. Hydrogen evaporates at an exceptionally low temperature: to keep it in liquid state, it has to be cooled to minus 253 degrees, which is almost absolute zero. This presents a technical and economic challenge. Because hydrogen is the smallest element, preventing leaks is challenging, and because it is highly combustible, preventing leaks is vitally important.

Japan is the leader in hydrogen technology for transport as it is applied to cars and trucks. Toyota, Honda, and Nissan have all invested heavily in hydrogen technology and infrastructure. A conglomerate of Japanese car and energy makers have established a joint venture, 'Japan H2 Mobility' to invest in building a network of hydrogen fuelling stations.[19] The 7-Eleven chain of retail stores has partnered with Toyota in Japan to introduce hydrogen-fuelled refrigerated delivery trucks for its distribution process (7-Eleven operate more than 20,000 stores in Japan).[20] Toyota has also invested in Victoria to establish the Toyota Ecopark Hydrogen Demonstration, which is a $7.37 million project based in Altona that began in March 2019 with $3.07 million funding from the Australian Renewable Energy Agency (ARENA). The project aims to demonstrate that green hydrogen can fuel vehicles and supply electricity through the use of a fuel cell. It also intends to demonstrate that a combination of on-site Solar Photovoltaic system (SPV), battery storage, and hydrogen production can provide reliable and continual power. The project includes a Hydrogen Education Centre, an Altona-based demonstration project showcasing hydrogen innovation and education to promote the technology to the public.[21]

Hydrogen as a transport fuel is not limited to cars and trucks. The world's first hydrogen-powered trains were deployed in the Lower Saxony region of Germany in September 2018. The initial two hydrogen trains had a 1000km range per tank, which is similar to the range of existing diesel trains and roughly the distance between Melbourne and Sydney.[22] The main advantages that trains fuelled by green hydrogen have relative to diesel is the lack of GHG emissions and the potential that hydrogen fuel becomes far cheaper than diesel once the industry is properly established. Significant synergies exist with the potential development of national fast rail.

Shipping is another form of transport where hydrogen is a potential game changer. A number of Norwegian firms are working to design and build hydrogen-fuelled ships. Among them is Viking Cruises, which announced plans in 2017 to introduce a liquid hydrogen fuel cell powered cruise ship. Japan is also developing technology for using hydrogen fuel in shipping. A consortium of shipping (NYK-Line) operators, oil and energy (Eneos) companies, and engineering (Kawasaki Heavy Industries and Toshiba Energy Systems & Solutions) firms launched a demonstration project in September 2020 aimed at making high-power hydrogen-fuelled cruise ships.[23] It is beyond the scope of this report, but the Victorian government should explore the downstream industrial and job creation possibilities involved in dedicated hydrogen shipbuilding.

Aviation is the last transport sector where the use of hydrogen is being explored. The CSIRO has partnered with Boeing to explore how clean hydrogen can reduce aviation emissions.[24] CSIRO and Boeing identified the earliest possibilities to be in transitioning airport ground vehicles. They envision some use of hydrogen in planes without requiring major changes to existing assets, which could be deployed over the medium term. But they consider transitioning away from conventional jet fuel as a near 30-year project.[25] The first stage in transitioning the aviation sector (airport ground vehicles) can begin in Victoria promptly. Melbourne Airport may be considered as a possible early customer to help underwrite demand for the technology.

Heat

Heat is one of the most important forms of energy for industrial use. The concept of 'clean steel' is one of the most exciting potential uses of hydrogen in Australia and is an area where Victoria can take advantage of well-developed existing capacities. For instance, BlueScope Steel's facility at Western Port in Hastings is a potential site to develop a major demonstration project of clean steel. The NSW government has recently identified Port Kembla as a hydrogen renewable energy zone.[26] If the Western Port site was similarly transitioned, the company may be able to return to the export market, after a decade of producing only for domestic consumption. The effects on jobs and local development could be substantial. BlueScope also has facilities in Brisbane and Adelaide: transitioning all four of their Australian facilities to hydrogen would be a major step toward making Australia the hydrogen superpower that Victoria has the potential to be.

Chemical

Ammonia is one of the main existing commercial uses for hydrogen. In 2019, just over half of all hydrogen was used to make ammonia,[27] producing about 230 million tonnes of ammonia.[28] It is the main form within which hydrogen is currently being used for export. The major companies producing ammonia in Australia are Yara International ASA, Orica, Incitec Pivot, and CSBP (Wesfarmers). CSBP explains that ammonia is "an important raw material for both industry and agriculture in Australia.
It's used in the production of ammonium nitrate, nitrogen-based fertilisers, sodium cyanide and in nickel processing."[29] Existing methods of making ammonia are based mainly on natural gas, which has significant GHG content. Ammonia production alone generates over 1% of global GHG emissions.[30] Transitioning the ammonia industry to a clean hydrogen basis is an important task and exciting economic opportunity. Indeed, it represents one of the main ways to reduce emissions from the agricultural sector in the short term. In 2017, Yara, the largest maker of ammonia globally, began a demonstration plant in the Pilbara region of Western Australia, to make ammonia from clean hydrogen. In 2018, ARENA funded a collaboration CSIRO project with Orica Australia to develop, in Victoria, an improved process for making ammonia from hydrogen. The existing process known as Haber-Bosch is about 75% efficient (meaning 25% of the energy used in the process is lost). The CSIRO project in Victoria aims to reduce this loss

of energy. Producing the intellectual property that makes the hydrogen economy tick is an important way Victoria can contribute to and benefit from its development.

Part Two | Mean, clean and green

Ultimately, the driving motivation behind the shift to hydrogen is that it is a technically and economically viable substitute for many critical processes that are currently very intensive in GHG emissions. The consequence of not restricting the amount of GHG in the upper atmosphere will be changes to the climate that make many of the ways we are used to doing things impossible: farms may need to be relocated, cities may find that their water supplies are no longer reliable, and mass migration could mean that where things have been built are no longer suitable. That would mean that the value of many major investments made in the old climate could turn out to be worth not nearly as much as we anticipated. The more we mitigate that process now, the less the cost to us will be in the future. There are, of course, other consequences, such as for the environment, human rights, migration, geopolitics, habitat destruction, and the risk of new pandemics as permafrost melts, exposing bacteria and viruses locked in ice for millennia and to which humanity have no immunity. Building a hydrogen industry is part of the process of stabilising the climate to avoid all those costs.

Hydrogen is the missing link

The hydrogen transition program will respond to unmet priorities identified by the Victorian Government's *Climate Change Act 2017*, which sets out a clear policy framework and a pathway to 2050 that is consistent with the Paris Agreement to keep the global temperature rise below 2 degrees Celsius above pre industrial levels. The Act sits alongside other key Victorian energy and climate change initiatives, including Victoria's Climate Change Framework, Victoria's Climate Change Adaptation Plan 2017-2020 and Victoria's Renewable Energy Action Plan.

Within the *Climate Change Act 2017* a well-planned, strategically focussed hydrogen transition program will directly address priorities connected to greenhouse gas emission reduction. The act sets a target of net zero greenhouse gas emissions by 2050: the proposed program involves delivering new infrastructure and renewing/replacing existing infrastructure to reduce Victoria's emissions footprint. (Further information on the Victorian Government's suite of climate change and renewables legislation, policies and initiatives is available on the Department of Environment, Land, Water and Planning's website at www.climatechange.vic.gov.au) The recent explosion of interest in hydrogen is a direct response to developments in the supply of electricity from renewables; principally solar and on-shore wind. Hydrogen and renewable electricity are, in many ways, co-dependent technologies. Hydrogen can only be economic if there is a supply of cheap, abundant sources of electricity. And it can only contribute to climate stability if that electricity comes from sources with very low GHG emissions intensities. Hydrogen is the missing link in the renewable energy economy. Produced from wind or solar generated electricity, it has a very low emissions intensity. As we have noted it is also highly versatile: hydrogen can replace either liquid or gas fuels and used for heat or electric power.

Integrating variable supply

Victoria and Australia do not have a clean energy problem, but rather a storage and demand problem. The intermittency of solar and wind creates several challenges. Power grids need to constantly balance supply and demand. If the supply of electricity is lower than demand, the power will not work. Conversely, if the supply of electricity is greater than the demand, it has nowhere to go and must be simply earthed, creating waste and potentially stressing the network. Granted, an electricity grid that relies mainly on solar and wind power will, by definition, deal with major natural variations in supply. The obvious example is solar power not generating at night, and wind tends to come and go. However, the variability of these renewable sources is more than just these obvious examples. There is also great variation across the country, with some places receiving far more wind over time than others. There is also variation over the course of the year, with summer months receiving far more sunlight than winter months, with additional geographical differences. Then there is variation from year to year, with some years simply being much hotter than others. These sources of variation must be accounted for.

Australia's grid, run by the Australian Energy Market Operator (AEMO), is currently stressed because it was not designed to accommodate the current degree of variation in supply. AEMO is regularly forced to curtail the supply of electricity from wind or solar farms, in turn making these businesses less viable, and creating asset stress. It is also forced to regulate some of the major users of electricity, dictating when they can operate and how much they electricity they can use. These existing arrangements are highly wasteful and inefficient. There are a number of solutions available to the problem of intermittency, but the best approach is a comprehensive nationally-driven strategy that draws on multiple methods and complementary technologies at once.

For instance, we can distribute resources over wide areas so that the national grid as a whole is supplied by the average sun and wind resources across several states and territories instead of just the local resources at any one time. While the wind may not always be blowing where you built your first wind turbine, if you have hundreds of them spread across the entire country, the chances that a certain percentage of them will be turning at any given time is actually quite high. Conversely, the chance that all of them might be active at any given moment is quite low. By averaging out over a large area, we can reduce the variability somewhat. Building a widely distributed network of generators can contribute to that smoothing process.

'Big batteries' have proven to be incredibly useful at smoothing fluctuations over very short time intervals. The Hornsdale Power Reserve, Tesla's big battery in South Australia, responds in microseconds to charge itself when the supply of electricity is too high and to discharge when the supply is too low. By doing this, the battery automatically buys electricity when the price is low and sells it when the price is high, making significant profits and adding even more value to the Australian power grid. It has been estimated that the battery has cut more than $150 million in costs to consumers since it was built in late 2017.[31] Yet making batteries is expensive and not without concern. Mining lithium and other 'rare earth' materials that are required for batteries degrades the environment in significant ways. This can be managed at moderate levels (certainly at levels far higher than where we are now), but it does not scale infinitely. The Hornsdale battery had a 100MW capacity when it was built, and that has now been expanded to 150MW. Furthermore, batteries have a finite life: eventually they degrade, stop holding their charge, and need to be replaced. This produces waste that is currently difficult to recycle. These are not insurmountable challenges, and batteries are an important part of the renewable economy, but not the whole story. The magnitude of the storage task demands a role for hydrogen.

We can complement batteries with pumped hydro. This is a form of battery that 'charges' by pumping water from a low-lying reservoir up to a higher reservoir. Then it discharges by letting the water flow back downhill, turning turbines on the way down. In essence, pumped hydro converts electricity into potential gravitational energy when the price of electricity is low (because there is too much of it), then converts that potential gravitational energy back into electricity when the price of electricity is high (because there is not enough). Pumped hydro has some advantages and other disadvantages relative to batteries. For instance, it doesn't require lots of rare-earth elements and doesn't produce difficult-to-recycle waste products. But pumped hydro doesn't have the same degree of near instant responsiveness as batteries. It falls in an intermediate zone of being less easy to turn on and off than batteries, but easier than gas, which in turn is easier than coal. Relative to batteries, pumped hydro is also constrained by location: it takes a lot of space and needs significant elevation. Pumped hydro has the advantage of potential very low cost at scale, able to store very large quantities of power, and having very long system lifespans. Pumped hydro does not degrade the way batteries do (though it does require ongoing maintenance). Snowy Hydro 2.0 is the highest profile example of a pumped hydro system.

Hydrogen adds another variable storage option to the grid that makes it easier to synchronise supply and demand of electricity over both time and location. It's why AEMO, the CSIRO, Chief Scientist Alan Finkel and others are turning to hydrogen to solve Australia's clean energy storage challenge. Hydrogen has some unique features that differentiate it from both batteries and pumped hydro: it is more modular than hydro, meaning it can be deployed at smaller scales, but it can potentially be deployed at much larger scales than batteries. Hydrogen generation can be turned on and off within seconds, not as quickly as batteries but faster than other options.

As the share of our electricity that comes from variable renewable sources increases, the importance of smoothing features increases. That's because the more we move away from the old model of 'base-load plus peaking' the less commercially viable it is for any of those baseload suppliers to continue operating, and the more extreme our peaks and troughs possibly become. A power network that has 100% renewable supply is subject to considerable variation.

Hydrogen also makes possible one other method of integrating variable renewable power supplies: over-building. Over-building means that rather than supplying 100% of our power needs from renewables, we could instead generate 300% or 700% or more. At that point, even the lowest troughs of supply may be greater than actually required. To make this strategy commercially viable, we need a way of exporting the surplus. There are two ways hydrogen can help export renewable energy. First, it can be sold directly as gas or liquid. Australia and Japan are leading the world in developing technology to do this, with a partnership to run a year-long pilot exporting liquid hydrogen from the Port of Hastings in Victoria beginning in 2021 (as discussed in part one). Australia also has an MOU with South Korea to explore this option, and in September 2020 the Australian and German governments agreed to begin a joint feasibility study into the potential for exporting liquid hydrogen to Germany.[32] Australia is seen as a potential supplier of the vast quantities of hydrogen needed to decarbonise Germany's heavy industry in order to meet the Paris accord and achieve its goal of net zero emissions by 2050.[33] Hydrogen can also help facilitate an over-build model of renewables is to embody the hydrogen in other exportable commodities: that is, to use it as a low-GHG industrial input that can drive energy-intensive processes like steel production. Steel made from low-emissions hydrogen can be shipped more easily than liquid hydrogen. We discuss green steel later in this report.

Over a third of Australia's coal-reliant power stations have closed in the past seven years. More are scheduled to close over the next five years, but there are signs that many, even most, will be forced to close ahead of their current timetable. That is largely due to coal-fired stations not being economically viable when they can only operate less than half the time, which is the prospect many operators are now faced with. The closure of these power plants ahead of schedule creates an urgent imperative for Australia to successfully integrate renewables into our national grid and ensure that our power infrastructure is stable, cheap, and clean. Australia will need other sources of electricity production ready to be substituted into the national grid. That means we need to continue increasing our investment in large-scale renewables, firmed with batteries, pumped hydro, network optimisation, and of course, hydrogen production.

What are the barriers?

What is preventing hydrogen stepping up? Hydrogen is an emerging industry: the world is currently in the process of testing the technology, developing standards and environmental guidelines, discovering how hydrogen can be effectively applied, underwriting demand, building supply, designing the financial models that extract the most value from our efforts, and training and upskilling workforces. All this is happening at the same time. None of these steps can move too quickly ahead of the others. Coordination is major challenge. Strategic intervention partnering government with industry and employees is thus required to ensure the potential uses of hydrogen are successfully developed and implemented. The same logic applies to ensuring that the technology and investments required to make hydrogen are developed and implemented. These need to happen at the same time, since neither can be viable without the other.

Alongside the technological development and investment in capacities on both supply and demand side, new regulatory frameworks need to be developed. Critically, our workforce needs to develop new skills: we need to properly understand what those skills are to integrate hydrogen into power networks across the economy, and we need training centres to ensure the workforce is able to safely and efficiently install and maintain equipment across Victoria and Australia, as well as in the export and shipping process. Much work has begun, and there is much to do. The next section reviews recent developments in advancing hydrogen globally and in Australia.

Part Three | Recent developments

Hydrogen has attracted a lot of attention in Australia in recent years, but international enthusiasm for hydrogen is not new, and our competitors are moving ahead at full speed.

The global picture

International developments have seen several developed countries take major steps in building a hydrogen economy. Notable leaders in developing production capacity include Germany, Japan, Norway, and France, with countries in our region, South Korea, and Singapore, among the most enthusiastic on the demand side. Germany's Federal Minister for Economic Affairs and Energy Peter Altmaier is on the record saying that hydrogen will have a key role in his nation's carbon-free energy system.[34] Germany's National Hydrogen Strategy, released in June 2020, includes plans to build 5GW of hydrogen capacity by 2030, requiring 20TWh of new renewable energy generation.[35] For a sense of scale, Australia produced 50TWh of electricity from renewables in 2018 (about 20% of our total electricity production).[36] Hastening the transition to hydrogen as a major player has been the need for economic recovery in the wake of Covid-19. As part of its €130 billion economic stimulus plan, Germany announced €9 billion in funding dedicated to hydrogen, making up almost a quarter of the climate-related spending in the government's stimulus package.[37] Germany also recognises Australia's huge potential in the hydrogen economy, with the Federation of German Industries describing Australia as a "future hydrogen giant".[38] Leading German experts have identified Australia and Japan as pioneering hydrogen nations in the Asia Pacific region. They see Australian LNG export terminals and the infrastructure and capacity to convert gas to liquids for export as major comparative advantages, but still describe Australia as a "sleeping giant" owing to our as-yet meagre renewable energy production.[39]

Australia and Germany have partnered to establish the Australian German Energy Transition Hub: a collaborative venture supported by our Department of Foreign Affairs and Trade and Germany's Ministry of Education and Research. The hub brings together a large number of university-based researchers and industry partners to focus on technical and policy aspects of energy transition. It has produced a huge amount of impactful research which could be leveraged and extended by dedicated commonwealth and state government hydrogen excellence centres.

America

The United States Department of Energy published a 'National Vision of America's Transition to a Hydrogen Economy' in 2002.[40] More recently, in 2020, a consortium of 20 private sector firms (mainly car makers and oil and gas firms) released a 'Roadmap to a US Hydrogen Economy'.[41] Currently the US uses over 11 million tons of hydrogen, valued at almost US$18 billion per year. Almost all of the hydrogen used in the US currently is either for making ammonia and methanal or for refining.[42] In the US., the transport and oil and gas sectors are driving interest in hydrogen. There are almost 5 million km of gas mainline and other pipelines in the US that can be repurposed for hydrogen. The US has not had much leadership from government in the hydrogen sector over recent years, meaning it is mainly at the early stages of addressing problems that Australia and some countries in Europe and Asia have already made significant progress on. However, the US has many very large private sector firms that can innovate at scale very well. There is little doubt that the US will catch up quickly.

Europe

In 2019, the CSIRO Hydrogen Roadmap, in discussing hydrogen export opportunities, specifically highlights HYBRIT, a Swedish joint venture of SSAB, LKAB, and Vattanfall, major makers of steel, iron ore, and electricity, who are aiming to convert to a clean steel process using electric arc furnaces powered by clean hydrogen. The joint venture was formed in 2016 with the aim of revolutionising steelmaking by replacing coking coal with hydrogen. The pilot phase of the project was estimated to cost SEK1.4 billion (about AUD $220 million).[43] On 31 August 2020, HYBRIT began operations. They have shifted their original goal of putting carbon free steel to market by 2035; their goal is now to achieve that by 2025. To achieve that goal, they are rebuilding factories and testing processes. A Stockholm Environment Institute working paper for the HYBRIT project explains that "the product from the H-DR process is called direct reduced iron (DRI), or "sponge iron", which is fed into an electric arc furnace (EAF), blended with suitable shares of scrap, and further processed into steel."[44] In May, a second Swedish steel maker began trialling clean steel. Ovako specializes in making 'engineering steel' and has worked with Linde Gas to make clean steel using hydrogen at their Hofors rolling mill. They recently announced the first successful trial in the world to heat steel using clean hydrogen using existing production facilities.[45] The HYBRIT project's spokesperson has remarked of these developments: "We have been working on furnace modernisation for a long time, to make our furnaces as productive and energy efficient as possible. It is exciting that we now have proof that it is possible to use hydrogen in heating without affecting the quality of the steel."[46]

Germany has emerged as the world's leading country in terms of developing most efficient hydrogen electrolysis machines, with Siemens being one of the leading firms in this space. The German government has announced €9 billion in funding to support new projects and aims to have 5GW of hydrogen electrolysis capacity by 2030. One of the major investments in this plan is at the Heide oil refinery near Hamburg. The WESTKUESTE 100 project will build a 30MW hydrogen electrolyser and has attracted €60 million in private investment and another €30 million in co-funding from the federal government. While €90 million is not a revolutionary scale financial investment, 30MW is a major advancement in producing large scale hydrogen facilities.[47] In November 2020, Siemens Gas and Power announced another new project to build a 2.2MW PEM hydrogen electrolysis plant powered by 30MW of wind turbines. The Salzgitter Wind Hydrogen project is expected to be completed in 2020 and the hydrogen is intended for use in clean steelmaking.[48] Germany has ambitions to be the leading hydrogen maker in Europe but lack the domestic renewable energy resources. The recently announced feasibility study with Australia to explore the hydrogen supply chain is a step toward resolving that dilemma.[49]

And in Norway, power utility firm Statkraft has announced an agreement with a steel manufacturer (CELSA) and an industrial park (Mo) to develop green hydrogen for industrial use in high-temperature metal processes: the most advanced 'green steel' project to date.[50]

When clean steel begins to supply global markets, it will have major consequences for legacy processes of steel making and their suppliers, including Australia's exports of iron ore and coking coal. To avoid the risk of being cut out of the global steel making supply chain, Australia will need to certify to European standards that our iron ore is GHG free. The consequences for China's imports of iron ore are not yet clear, but they are likely to follow the European lead without major lag time. This raises major questions about the future of coking coal, but it also raises the tantalising prospect of Australia beginning to make certified clean steel here for export to global markets, rather than export iron ore and coking coal for the steel to be made elsewhere. Ultimately that could mean a larger share of the value chain is captured by Australians in Australia, and more skilled blue-collar jobs. International developments mean that Australia has a huge opportunity to transform our iron ore, coking coal, and steel making industries, but it also means that if we fail to do that, some of our major exports could be at risk within a decade.

Asia

In our immediate region, industrialised countries such as Japan, South Korea, and Singapore are taking major strides, especially on the demand side, to build hydrogen-based economies. Australian exports to Asia are estimated to be worth $8.4bn and create 16,000 jobs by 2040.

Japan

Japan has had a highly strategic focus on energy for many decades owing to its scarce supply of natural resources relative to the size of its economy. Following the twin oil crises in the 1970s, Japan elevated energy security to one of its top policy priorities. It put enormous effort into reducing energy consumption (especially in industry) and into guaranteeing reliable energy supplies.[51] Later, when Japan's focus shifted to reducing GHG emissions, it introduced significant supplies of nuclear power. However, Japan's willingness to rely on nuclear power largely ended after the Fukashima disaster. To avoid a return to a carbon-based power system, Japan has become highly interested in ways to effectively import renewable energy, and Australia is central to those plans. In particular, Australia can export major energy intensive commodities to Japan, including ammonia and steel. We can work with Japan to develop the technology to transition their transport industry to accommodate hydrogen. Eventually hydrogen will be exported directly, though the economics of shipping hydrogen mean some commercial-viability questions remain open. Japan developed its Basic Hydrogen Strategy in 2017: the first country to have a dedicated hydrogen plan at the national level.[52] Japan's focus is on ensuring green hydrogen is cost-competitive as a fuel for transport, heating, and electricity production. Japan's car manufacturers have a particular interest in using hydrogen as a transport fuel, with companies such as Toyota, Honda, and Nissan investing heavily in hydrogen technology and infrastructure. A conglomerate of Japanese car and energy makers have established a joint venture, 'Japan H2 Mobility' as a means of investing in building a network of hydrogen fuelling stations.[53] Japan's energy market is estimated to be worth $136bn and is attracting major investment interest.[54]

South Korea

Like Japan, South Korea is a major industrial powerhouse with very limited renewable energy resources but a strong appetite for experimenting with new technologies. South Korea sees hydrogen as central to its economic development and its plan to transition to a GHG emission free economy. It has told the World Economic Forum that it is "vying to win the race to create the first hydrogen-powered society. It wants to build three hydrogen-powered cities by 2022 as it positions itself as a leader in the green technology."[55] In 2018, Australia exported over $17 billion of coal, iron ore, and gas to South Korea. As South Korea changes its energy settings, we will need to change with it or lose this valuable market.[56] The transport sector is central to South Korea's national hydrogen plans. In August 2020, Hyundai announced a collaboration with Jemena (a gas utility firm) to trial a hydrogen refuelling station at their headquarters in Macquarie Park in Western Sydney.[57] They plan to supply infrastructure for clean hydrogen cars in Australia to help build demand for the technology they intend to use in their car making industry.

Singapore

Singapore is exploring options to become a 'hydrogen society'. The Australia-ASEAN Power Link project in Darwin (discussed below) is a major component of those plans. For Singapore, the major opportunities for hydrogen are in the supply of electricity, and in fuel for ships, especially since Singapore is a major trading hub. A consortium of firms in Singapore including PSA, Jurong Port, City Gas, Sembcorp Industries and Singapore LNG, are collaborating with Japanese companies Mitsubishi and Chiyoda, with a view to developing new technologies for importing, transporting, and storing hydrogen. They are experimenting with the transport of liquid hydrogen, using Chiyoda's 'SPERA Hydrogen' technology (an organic chemical process for storing and transporting hydrogen).[58] If their efforts are successful, this technology could hasten significant export opportunities for Australia and Victoria's hydrogen industry.

Australia

Australia's path to a hydrogen economy was first seriously appraised in 2005. Global concern about climate change had reached scientific consensus, but only just beginning to filter into the consciousness of the public. In that year, the commonwealth government released the first Australian Hydrogen Activity Report.[59] The report summarised Australia's research efforts in the field and explained technologies for hydrogen production, distribution, storage, and use. In the few years following, Australia was an active participant in the International Partnership for the Hydrogen Economy (IPHE), supported the International Energy Agency's (IEA's) Hydrogen Implementation Agreement, hosted the World Hydrogen Energy Conference (2008), and created the National Hydrogen Materials Alliance (NHMA), an R&D cluster supported by the CSIRO to coordinate hydrogen research among twelve university and public research groups.[60]

In 2008 the second Australian Hydrogen Activity Report was released.[61] By 2008 climate change was a top public concern in Australia, with the Garnaut Review informing the national strategy.[62] COP15 in Copenhagen had focused hopes on a possible international agreement to limit emissions and allocate a global carbon budget to nations on a basis of converging emissions per-capita. COP15 infamously failed to meet those high expectations, but the failure was not absolute: all over the world, people had been made aware of the expected consequences of our continuing emissions of massive quantities of greenhouse gasses. The singularly important role of our energy systems as producers of GHG emissions became household knowledge.

As part of the broader development of clean and renewable energy technologies, the commonwealth government sought to encourage research and development in hydrogen and fuel cells, which it viewed as having the potentially important role in meeting the demand for clean and secure energy supplies. Yet a hydrogen economy remained a distant vision for future energy security. Holding us back was a number of technical steps needed to build connecting infrastructure, but more importantly, hydrogen was still not economically competitive as an energy carrier. It is the economic competitiveness of hydrogen that has changed drastically over the past decade or so. Since 2008, the price of solar and wind power has collapsed. It has fallen so rapidly and so far that solar and wind are now the cheapest way to produce new supplies of electricity in Australia.[63] In South Australia, it has become common for more than half of the electricity supply to come from renewables, while in Tasmania it is common for 100% of electricity to be generated by renewables on a given day, and in the ACT, 100% of electricity was from renewables for the entire year in 2019.[64] This radical shift has altered the economic fundamentals determining the viability of a potential hydrogen economy. Because of this change, interest in hydrogen has exploded in the past few years, both in Australia and globally.

In 2016 Australia ratified the Paris Agreement on Climate Change, committing us to reduce GHG emissions by 26-28% from their 2005 level by 2030.[65] The Paris Agreement has ensured that the world is continuing to invest in stabilising the climate. That means continued rapid transformation of energy systems, which can best be done with hydrogen energy playing a significant role. The world is racing toward a hydrogen economy, and Australia is right there with the pack of global leaders. For instance, an Australian firm, Star Scientific, recently developed a technology, Hydrogen Energy Release Optimiser (HERO®), which is at the forefront of using hydrogen to produce heat energy used in industrial processes. Major projects are under way in almost every state or territory (discussed in this section below) – some are beyond audacious.

The past three years have been especially promising for hydrogen in Australia, with COAG, and the CSIRO providing national leadership by developing a number of high-level planning documents to provide a framework that each state and territory has acted within to produce their own hydrogen plans and strategies. The COAG Energy Council and Chief Scientist took leading roles, with COAG's Hydrogen Strategy Group producing a 2018 briefing titled 'Hydrogen for Australia's Energy Future', which laid the groundwork for proposing a National Hydrogen Strategy and COAG agreeing to establish a dedicated Hydrogen Working Group.[66] Chaired by the Chief Scientist, the group is tasked with developing a clean, innovative and competitive hydrogen industry by 2030.[67] In 2019, four major reports were released: COAG's National Hydrogen Strategy,[68] CSIRO's National Hydrogen Roadmap,[69] and their Hydrogen Priorities and Opportunities report,[70] and AEMO's Integrated System Plan of the Electricity Market.[71] These four documents form the national framework for coordinating government and private efforts to develop a hydrogen economy in Australia. They are the intellectual product of an enormous amount of work by many people over several years and indicate that Australia is in the midst of one of the fastest energy system transitions that any country has every embarked upon.

Finally, in September the Morrison government outlined its technology investment roadmap backing what it describes as new energy-efficient power sources to reduce emissions, albeit without a date to achieve net zero emissions. The energy blueprint outlines Australia's lower-emissions technology priorities, ends ARENA's strict rules on funding only wind and solar projects, which requires changes to legislative and regulatory frameworks. The government's slimmed down list of five priority emissions technologies are: clean hydrogen; energy storage; green steel and aluminium; as well as more contentious Carbon Capture and Storage; and soil carbon projects. Government investment in low-emissions technologies through to 2030 is estimated to run to $18bn, and an expected $50bn will flow from private sector co-investment and other levels of government. This comes on top of the federal government's technology investment roadmap discussion paper released in May which set a long-term goal for hydrogen production of under $2/kg where it becomes competitive in applications including ammonia, transport fuel and firming electricity, and $570m in funding to establish an Australian hydrogen industry, including $70.2m announced in September for a regional export hub.[72]

Notably, the technology road map aims to create clean energy industry that can ship hydrogen to customers such as Japan and South Korea, building a new export industry to replace gas.[73] The plan includes both green hydrogen produced from renewables and blue hydrogen produced from gas (with carbon capture to bury the emissions), as part of the government's plan to increase new gas supplies and construction of a new gas-fired power station in the Hunter Valley if AGL does not replace its Liddell coal-fired power station.[74] The first shipments of hydrogen to Japan will be made from coal. However, this means Australia has gets a technological head start, sending a strong demand signal, and making it easier to invest in more solar and wind in the future. While the cost of Australia's decarbonisation will be higher than need be (due to nearly a decade of inaction), investments moving Australia in the right direction are welcomed.

It is not only the commonwealth that has been actively planning for a hydrogen future. Each Australian state and territory have embarked on some type of hydrogen-building agenda.

New South Wales

Until 7 September 2020, the main policy vehicle for the development of hydrogen in NSW was its electricity strategy, which established a number of 'renewable energy hubs' in the state.[75] However, in September 2020 the NSW Chief Scientist and Engineer released a report commissioned by the Energy Minister, 'Opportunities for prosperity in a decarbonised and resilient NSW: Decarbonisation Innovation Study'.[76] This study has a more ambitious view of the role of hydrogen in NSW, especially for use in industry. It notes hydrogen's potential to "increase industrial productivity while also decarbonising industrial processes that cannot be electrified." It envisions hydrogen being used in the production of steel, ammonia, and industrial heating. The plan builds on the National Hydrogen Strategy to develop 'hydrogen hubs.'

The value of establishing hydrogen or renewable energy hubs was explored in a technical study for the COAG Energy Council in 2019, titled 'Australian Hydrogen Hubs Study'.[77] The report explains the benefits of agglomeration, sector coupling and co-location. This means taking advantage of having a lot of contributors to the supply chain located near each other (including science and research centres). The report also recommended that such hubs themselves be located near required resources, which include the potential to produce renewable electricity, appropriate infrastructure for distribution, and if possible, major users or export terminals.

The NSW plan identifies the cities of Newcastle and Port Kembla as potential hubs based on their existing industry capacity and port facilities. Moreover, it calls for developing and commercialising hydrogen technologies in the specialised hubs, where production, storage and use are concentrated alongside infrastructure for transport, industry, water, and renewables.

Queensland

Queensland released its Hydrogen Industry Strategy in 2019, declaring that "the Queensland Government is committed to developing a sustainable hydrogen industry".[78] It aims to supply hydrogen to other states in Australia as well as to export markets in Asia by 2030. The strategy focuses on supporting innovation, facilitating private sector investment, ensuring an effective policy framework for sustainable development, building community awareness and confidence, and facilitating skills development for new technology. Queensland perceives its main competitive advantages for a hydrogen industry as being the state's proximity to Asian markets, established relevant infrastructure, existing manufacturing capabilities and significant renewable energy potential. In September 2020, the Queensland government announced $500 million to create three new 'renewable energy zones' in the state, significantly stepping up the previous $145 million commitment it allocated to develop an initial three renewable energy zones.[79]

Western Australia

The West Australian Renewable Hydrogen Strategy[80] was released in July 2019. In September 2019, the Western Australian Government launched a $10 million Renewable Hydrogen Fund to drive development of the industry and take advantage of Western Australia's abundant renewable energy resources.[81] Central to the development of hydrogen in Western Australia is the Asian Renewable Energy Hub on the lands of the Nyangumarta People in the Pilbara region, which is the biggest single renewables project in Australia. The project has attracted more than $22 billion of investment and is anticipated to install over 15GW of wind and solar capacity with 3GW designated for the Pilbara region itself, and more than 12GW directed to renewable hydrogen production.[82] The AREH brings together a consortium of global energy leaders, including InterContinental Energy, CWP Energy Asia, Vestas, Pathways Investment and the Energy Change Institute of the ANU. The Nyangumarta People are recognised as critical project partners. The project passed a significant stage in May 2020, being recommended by the Western Australian Environmental Protection Agency. It also has the backing of the Pilbara Development Commission. Another major hydrogen investment in WA is the Arrowsmith Hydrogen Project, developed by Infinite Blue Energy. Their $300 million project near Dongara (300km north of Perth) is expected to produce 25 tonnes of green hydrogen each day, powered by 75MW of wind and 85MW of solar. It is expected to begin production in 2022. The same firm already has plans for other green hydrogen projects in WA to produce up to 75 tonnes of hydrogen per day.[83]

Aside from these major projects, in August 2020 the government announced a further $22 million to be invested in renewable hydrogen projects as part of the Western Australian Recovery Plan. The plan includes projects on expanding the Renewable Hydrogen Unit in the Department of Jobs, Tourism, Science and Innovation, identifying suitable locations for storage, developing a detailed supply chain model that promotes hydrogen and identifies bottlenecks and limitations affecting the hydrogen export industry, as well a study on the technical, economic and regulatory implications of blending hydrogen in the Western Australian gas network.

Three capital works projects were announced in August 2020, including $1 million for a hydrogen metro transport refueler station project with ACTO Gas Australia, $2 million for a remote transport project: the Christmas Creek Renewable Hydrogen Mobility Project with Fortescue Hydrogen, and $1 million for a remote hydrogen power demonstration project, namely the Denham Hydrogen Microgrid Demonstration Project with Horizon Power. The state government also announced 7 feasibility studies, including a 10 MW electrolysis hydrogen production plant, two studies looking at blending hydrogen and natural gas in transmission pipelines, and three looking at the use of hydrogen in remote, isolated microgrids, including one focused on developing 100% renewable power systems in Indigenous communities.[84]

South Australia

South Australia's Hydrogen Action Plan released in September 2019 identifies a number of key projects that the state government is supporting across five 'action themes':

1. Facilitate investments in hydrogen infrastructure;
2. Establish a world-class regulatory framework;
3. Deepen trade relationships and supply capabilities;
4. Foster innovation and workforce development; and
5. Integrate hydrogen into our energy system.[85]

The South Australian government has identified its key challenge as producing at sufficient scale to facilitate hydrogen exports. To overcome this, the government has co-invested over $40 million in hydrogen infrastructure projects. To help develop its regularly framework, the government has partnered with the International Association for Hydrogen Safety where it advocates for harmonised international standards, has established a Hydrogen Regulatory Working Group as a cross-government agency, has developed a certification for South Australian Renewable Hydrogen (to distinguish it from non-renewable hydrogen, especially for the purposes of measuring GHG emissions embodied in exports).[86] It also has a number of key projects, such as a hydrogen and ammonia supply chain demonstration project at Port Lincoln in cooperation with The Hydrogen Utility (H2U).[87] The government also supports $500 million renewable energy project 'hydrogen super hub' at the Crystal Brook Energy Park, which houses a 275MW renewable energy production facility and 130MW of battery storage. The project includes a 50MW hydrogen facility with the potential to produce 25 tons of green hydrogen per day.[88] They also highlight an $8.7 million collaboration with UniSA's Mawson Lakes campus to test solar power, flow batteries, a hydrogen fuel cell stack and thermal energy storage. The project is supported by a $3.6 million grant from the South Australian government.[89] Last November, British billionaire Sanjeev Gupta's GFG Alliance announced it would create a green steel facility at the Whyalla steelworks in South Australia. Work has begun on replacing the ageing blast furnace with a $1 billion-plus electric arc furnace capable of the process. At first the facility will use gas before making a shift to hydrogen, which it believes Australia should be focusing on using onshore and for safety reasons exporting green steel instead.[90]

Tasmania

In Tasmania, the Department of State Growth is the responsible body for the Tasmanian Renewable Hydrogen Action Plan. A key element of the plan is the $50 million Tasmanian Renewable Hydrogen Industry Development Funding Program, which has allocated $20 million to the Tasmanian Renewable Hydrogen Fund, $10 million for support services including financial assistance for renewable electricity supply, and $20 million in concessional loans. The program is currently assessing 23 proposed projects.[91] Tasmania sees its competitive advantages in hydrogen as deriving from its high contribution of renewable energy from hydropower and wind, its abundant fresh water supplies, and its industrial precincts with access to land and high-quality infrastructure. Within four years, Tasmania aims to be producing and using hydrogen at scale, and almost ready to export hydrogen both to other states in Australia and globally.

Tasmania's hydro power is a major asset. It has an installed capacity of around 2.3GW of hydro power from 30 power stations and over 50 dams and expects to become fully self-sufficient from renewable energy by 2022.[92] It has ambitious plans to become the 'battery of the nation' by exporting stored renewable power. As it stands, Tasmania has more electricity production than it can use or transfer to the rest of Australia. It is constrained by the limits of the single 500 MW high voltage direct current (HVDC) cable, Basslink. Hydro Tasmania has proposed more interconnection between it and the rest of the National Electricity Market (NEM).[93] The project would make better use of Tasmania's abundant power storage assets and could help hasten the transition to a more stable power system with abundant production of hydrogen.

Northern Territory

The Northern Territory Renewable Hydrogen Strategy,[94] released in July 2020, identifies hydrogen as particularly suitable to support renewable energy generation in remote area power systems where it could displace high cost liquid fuels such as diesel. They note a particular export opportunity due to the challenge that many countries in our region will face in meeting their Paris Climate commitments, despite lacking the natural solar and wind resources to produce their own renewable energy at the necessary scale. In contrast, the Northern Territory government considers that it has "extensive renewable energy resources, enabling infrastructure, and expertise developing a world-scale energy production and export industry, the Territory is well positioned to capitalise on emerging hydrogen opportunities". The Northern Territory's hydrogen strategy also notes the jurisdiction's proximity to lucrative international export markets, making it 'the shortest and quickest route from Australia to potential hydrogen markets throughout Asia'.

The Northern Territory is home to an ambitious project to produce 20% of Singapore's energy supply by connecting the world's largest solar farm to energy consumers in Singapore via a 3,000km undersea cable. The Australia-ASEAN Power Link project is run by Sun Cable, and aims to produce renewable energy for Australia, Singapore, and Indonesia. Both the Commonwealth and NT Governments have designated the project with 'Major Project Status', ensuring the backing of the Major Projects Facilitation Agency. It has already attracted significantly more than $25 billion from investors. While the project does not itself aim to produce hydrogen, it will include 10GW of solar power and 22GWh of battery storage and has indicated a willingness to sell its output to hydrogen developers.[95] Proximity to that much solar generation will certainly be highly attractive to the development of a hydrogen industry. The Northern Territory also has considerable experience in the gas industry, with INPEX's Ichthys LNG project being one of the largest gas projects ever built. Many of the skills and technology needed by the LNG industry overlap substantially with the requirements of hydrogen.

Each state and territory have developed either a specific hydrogen investment strategy or identified hydrogen as a major component of a broader development plan. The remainder of this report discusses the opportunities for Victoria to extend its Hydrogen Investment Program.[96]

Part Four | Hydro 3.0? Towards a Victorian Hydrogen Industry

Australia and Victoria have a golden but time sensitive opportunity to become regional leaders in clean energy, clean heavy industry, make components for the hydrogen supply chain, and to finance its growth. No state is better positioned than Victoria. Victoria can use the hydrogen industry to fill energy needs and fuel local manufacturing, export surplus of the raw commodity overseas, as well as export IP and training, and parts of the manufactured supply chain. It is predicted that a hydrogen industry can create 16,000 jobs by 2040 and $8.4 billion in revenue.[97]

Building upon Victoria's competitive advantage

Victoria has some major advantages in renewables and clean, green heavy manufacturing. Building on the Victorian government's track-record in the renewables and climate policy, a deep hydrogen industry is the next logical step, and can be part of the solution to the state's energy challenges. With the moratorium on gas exploration, Victoria's long-term gas exports are limited. Of Australia's states, Victoria is the main gas user (almost every house is plumbed for gas) and a huge number of industries there are dependent on gas supplies. One major head start that Victoria has in building a hydrogen industry is its existing extensive gas distribution pipeline infrastructure. Victoria's gas pipeline network is the most extensive in Australia: Victorians are amongst the most gas-connected people in the world. Repurposing existing infrastructure is far cheaper than building entirely new infrastructure. An opportunity exists to replace natural gas to guarantee domestic supply rather than buy gas from Queensland. The infrastructure exists but needs to be updated. This can be done by setting up major hydrogen plants in specific areas, building on existing demand for hydrogen in ammonia, food processing and transport.
Along with the existing physical infrastructure, Victoria has one of the largest workforces with existing skills in safely installing, using, and maintaining gas. These skills can be re-allocated to hydrogen with relatively low disruption to workers and low cost. The other major inputs for making hydrogen are also available in abundance in Victoria: water and renewable electricity. Victoria has many advantages on the demand side, as well. It is at the global forefront of developing the technology to export hydrogen by ship. It is home to a significant industrial base, including steel-maker BlueScope. And much of its under-used industry capacity can potentially be revitalised with hydrogen providing a cheap, clean fuel source. Victoria has a demand for new shovel-ready projects that can provide or facilitate significant employment: transitioning to a hydrogen economy is a task that meets many of Victoria's priorities and can begin quickly.

What needs to be done?

Developing a hydrogen economy in Australia is a 20-year project, but there is a lot to do now, and the Victorian government can take an important leading role. Government interventions in support of hydrogen are needed on both the supply side and demand side of the industry.

Demand side interventions

Because the market for hydrogen is still in its infancy, government intervention is needed to stimulate demand. As discussed previously, the main uses for hydrogen include electricity, transport, heat-intensive industry feedstock such as steel making, residential heating, chemical products such as ammonia, and overseas exports. Each of these major uses of clean hydrogen needs to be developed with strategic assistance including from the Victorian government.

Electricity production

The Victorian government should work with AEMO to ensure that ongoing upgrades to the NEM which are part of their Integrated System Plan (ISP) (the 20-year plan for developing Australia's electricity network) can facilitate electricity supply from hydrogen production as soon as practicable. Some baseload sites may be more able, or have more need to, integrate new supplies sooner than others, and the Victorian government should work with AEMO to ensure that these relatively easier to integrate or more urgent baseload sites are developed sooner.

Residential heating

More houses are fitted for gas in Victoria than in any other state, so residential heating has enormous potential to become one of the major uses of hydrogen. The Victorian government should work with Victorian gas suppliers to ensure households can begin receiving gas with up to 10% hydrogen blend in the near term. To facilitate a complete transition to hydrogen from natural gas, the Victorian government should work with relevant stakeholders to determine the necessary upgrades to existing gas fittings, pipes, and other infrastructure, and develop a roadmap for converting households to 100% hydrogen over the next decade or so.

Clean steel

The Victorian government should explore the potential for steel making in Victoria as a major local user of hydrogen, building on its existing work in this field with local steelmakers.

Steel

Steel is the one of the most used commodities in the world. In 2018, 1.8 billion tonnes were produced world-wide.[98] Australian iron ore and Australian coking coal (carbon) are two of the main ingredients for a large portion of the world's steel. World-wide, iron and steel produce 7-9% of the GHG emissions from the manufacturing industry.[99] Australian iron ore and Australian coking coal (carbon) are two of the main ingredients for a large portion of the world's steel. Steel is an alloy, meaning a combination of a metallic element and other elements. There are many variations of steel that can be made by adding various elements. Ordinary steel is a combination of mostly iron and a little carbon. Stainless steel requires the addition of chromium. Adding other elements can affect properties like hardness, brittleness, malleability, propensity to corrode, or reactiveness to other elements (such as oxygen – i.e.: to rust). One element that affects steel is hydrogen: the hydrogen molecules seep into the grain of the steel and form bubbles. The result is that the steel becomes brittle and unable to bear loads well.[100] At high temperatures, hydrogen that has seeped into the grains of ordinary steel can react with the steel to produce methane, which can form white bubbles on the surface of the steel and cause cracks.[101] A great deal of the work involved in making steel from processes using hydrogen is ensuring that nothing goes wrong and the quality of the steel is not affected. To make iron, iron ore, coke, and some 'flux' material (often limestone) are fed into a blast furnace. Extremely hot air (about 1200°C) is blown into the bottom of the furnace. The coke burns, producing carbon monoxide which reacts with the iron ore, separating the iron from other elements that become slag.[102] The iron is then made into steel by blasting hot air through the molten iron, reducing the carbon content and creating steel. To make steel without producing GHG emissions, the process needs to be done without coking coal or heating coal. Thyssenkrupp Steel, in Duisburg, Germany, has demonstrated successfully using hydrogen as the reducing agent in a blast furnace instead of coking coal.[103] Instead of producing GHG emissions as a by-product, the process makes water vapour. HYBRIT, from Sweden, is also developing steel from clean hydrogen to almost eliminate GHG emissions completely from the steel production process.[104]

Transport

Victoria has a long and proud history of vehicle manufacturing. While this industry has suffered greatly in recent times, hydrogen offers an opportunity to revive the industry, making use of assets and skills that still exist, many of which have not yet been re-deployed. The Victorian government should engage the manufacturing industry, in collaboration especially with Japan and South Korea where car makers are investing heavily in hydrogen technology, to ensure local industry is part of the long-term future of that sector. The government should also develop an investment case for installing a network of hydrogen refuelling stations across Victoria. This may initially be done in collaboration with other states through COAG, assuming that interstate trucking and buses are likely to be early adopters of hydrogen in the transport sector.

The government should also work with Melbourne and Tullamarine airports to begin transitioning their ground vehicles to hydrogen fuel. These sites have the advantage of not requiring entire networks of refuelling stations, since they operate only on one location, their operators are highly trained, so any challenges in the transition process are manageable, and fuel is a major cost, so the business case will be relatively easy to make. Finding major customers such as these, who have the ability and interest to move ahead of the rest of the market, makes it financially possible to underwrite investment on the supply side and for infrastructure.

Ammonia

The Victorian government should encourage the use of clean hydrogen, through more efficient processes, to make ammonia, shifting away from making ammonia based on natural gas, offering incentives to the agricultural industries which make use of the end product. This serves two purposes: reducing the GHG emissions of the agricultural industry, and (as discussed below) becoming a key component of Victoria's emerging exports of hydrogen and related products.

Exports

To help stimulate the export potential of hydrogen, the Victorian government should examine the feasibility of eventually shipping hydrogen from Victoria to Japan and South Korea. If shipping is proven viable, then port infrastructure needs to be upgraded to facilitate loading of hydrogen onto ships. This should be done in partnership with the major developers of hydrogen-capable ships, which include Japan, South Korea, and Denmark. Partnering with those countries will ensure that the infrastructure developed in Victoria is compatible with the technologies being developed for ships, and the equivalent infrastructure at ports in importing countries. The Victorian government should also work with COAG to develop a clean steel certification process to ensure that as our major iron ore and coking coal export markets increasingly require GHG-free steel, Australia is able to continue meeting their needs.

Supply side interventions

The CSIRO has identified "lowering costs, improving production efficiency and enhancing safety and sustainability to support a range of end-uses" as the main areas where improvements in hydrogen supply are needed.[105] Achieving those priorities will require a combination of primary research, industry demonstration projects, and testing the integration of hydrogen with Australia's existing infrastructure and other facilities. The most immediate supply side interventions include support for specific demonstration projects, investment in basic science, development of standards and polices, and support for the skills development and training needed to ensure hydrogen can be produced, stored, distributed, and used safely. The Victorian government should consider a number of interventions on the supply-side of hydrogen production, including infrastructure needs, demonstration sites, and skills training. Victoria has an opportunity to establish itself as a national, regional, and global leader in retrofitting existing industry to hydrogen. Cambridge Econometrics value this market at US$1T to $4T globally.[106]

Hydrogen production

Geosciences Australia has identified a huge number of potential sites for the production of clean hydrogen.[107] The main requirements for making clean hydrogen are:

1. access to a supply of renewables-generated electricity (mainly solar or wind powered),
2. access to a significant supply of water, and
3. either the ability to supply electricity to the NEM or the ability to supply hydrogen to Victoria's existing gas pipeline infrastructure.

The old Ford vehicle manufacturing site located at Geelong is well positioned to be retrofitted as a new hydrogen facility. It also boasts a locational advantage: excess rooftop PV and other energy sources that can provide the electricity required to drive hydrogen process, large supplies of recycled (grey) water nearby that are currently unused, and ready access to existing gas transmission pipelines. There are plans to install around 100 MW of solar power on the site, so there is a significant supply of clean electricity. The Ford plant has more roof space for solar power than that the plant could use. It used to use 30-100MW but will require much less in the future. It cannot feasibly sell that energy because the network is unable to receive it. Using that excess power to power a hydrolyzer instead of wasting it is efficient and can drive hydrogen production. Critically, the solar is being built anyway: it is going to power the facility underneath, so it makes sense to store some in a battery, and for use in hydrolyses. Furthermore, major gas pipelines are already installed, meaning the site can readily demonstrate the potential to blend hydrogen directly into the gas network. The Victorian government should provide support to install a large-scale hydrogen electrolyser at the site, pursue a refit of wind turbine technology, and upgrade the water and gas facilities to ensure provide a demonstration at scale for the production and integration of clean hydrogen with Victoria's electricity and gas networks.

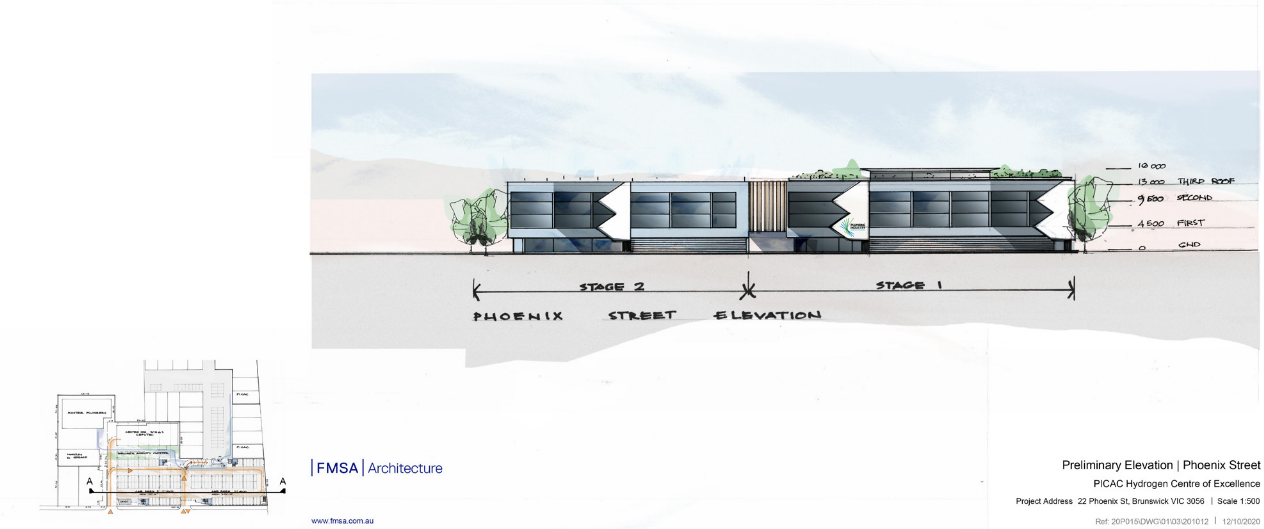
Skills training

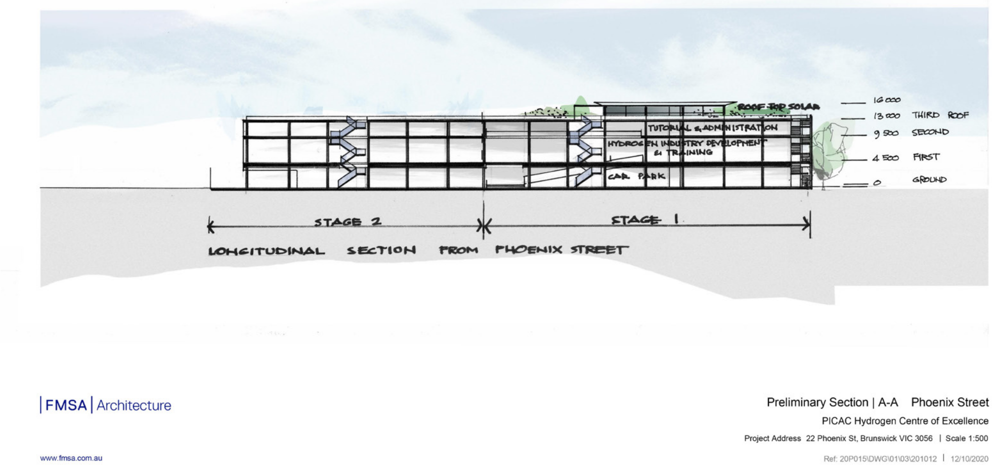
Installing and maintaining pipes and fittings to move and use hydrogen at an economy-wide scale requires a large skilled workforce. To develop a safe and effective hydrogen industry, we will need to up-skill Victorian workers with the highly specific skills that hydrogen use requires. It is imperative the transition to hydrogen energy is undertaken safely and by persons trained and qualified in the use of hazardous materials. This is particularly important when the gas fitting involves interaction with members of the public. Fortunately, Victoria already has a workforce of plumbers and gas fitters with most of the appropriate skills and training since natural gas is a familiar fuel. However, hydrogen and natural gas are not the same: there are different safety protocols that need to be developed, different fittings protocols to prevent leakage and maintain pressure, and many other differences. Victoria needs a centre of excellence for training and maintaining the skills its workforce needs to deploy hydrogen infrastructure and equipment. This is an area that has not received attention from the other states and countries working to transition to hydrogen, and it is an area that Victoria has more advantages in than any other region. Victorian households are more gas-connected than any other part of Australia, meaning the state's plumbers are more familiar with fitting gas appliances and infrastructure. Moreover, Victoria has existing training centres. The Victorian government should make a significant financial investment to establish a Victorian Hydrogen Excellence Centre, providing a full suite of training in hydrogen production, storage, transport, and residential operations.

The centre should be located at the Plumbing Industry Climate Action Centre in Brunswick, with training costs covered by businesses that intend to provide the installation and maintenance of hydrogen-based equipment. The Hydrogen Centre of Excellence at PICAC Brunswick could up-skill gas plumbing professionals to enable the workforce to begin the transition to a clean hydrogen industry. This training facility would provide real-world insights on safety to help inform policymakers on best-practice regulation to protect the community, particularly around standards, practices, and licensing. To broaden the industry and public awareness of the potential of hydrogen, we recommend the development of an electrolyser demonstration plant at PICAC's existing state-of-the-art research and training facility in Narre Warren.

This demonstration plant could play an introductory role in the development of a hydrogen industry in East Victoria.

To address the current apprenticeship crisis, we recommend that the Hydrogen Centre of Excellence in Brunswick be built by apprentices, for apprentices. This will provide significant economic benefits to the local community and the Victorian economy by generating employment and continuing development of vital trade skills, at a time when investment is critical for addressing supply and demand-side shocks caused by COVID-19, especially for young Victorians. Our estimates suggest that at least 100 apprentices could be directly employed during the construction phase of an upgrade to the PICAC Brunswick Training Facility.





Part Five | Recommendations

Developing a hydrogen economy in Australia is a 20-year project, but there is a lot to do now, and the Victorian government should take an important leading role. Government interventions in support of hydrogen are needed on both the supply side and demand side of the industry. If it moves quickly Victoria can become a major technological, energy and education expert. Power State proposes six recommendations to build a strong, viable Victorian hydrogen industry:

- ✓ **Develop a comprehensive Victoria Hydrogen Strategy.** The Victorian government should establish a roadmap for the development of a Victorian hydrogen industry with clearly enunciated short, medium, and long-term targets around building new infrastructure and upgrading existing energy infrastructure, hydrogen production targets, domestic demand, exports, and skills training. This work will build upon and complement the government's existing climate and renewables policies.

- ✓ The Victorian roadmap should **encourage private sector investment in new technology**, making available subsidies and tax incentives for companies to purchase and/or develop hydrolysers and facilitate firms using hydrogen as industrial feedstock. An EOI process should begin for parties interested in participating in hydrogen-retrofitting at demonstration sites (see below), aimed at industry, universities, and TAFE. Here, Tasmania provides an example of an effective, timely EOI hydrogen process.

- ✓ The Victorian government working with industry needs to **cultivate consumer and industry demand for hydrogen** necessary for production and export at scale. The Victorian government should facilitate the coordination of potential consumers and provide incentives for industry consumers to take risks with a new technology.

- ✓ The Victorian Government should identify and **put in place appropriate hydrogen industry skills and training, planning, environmental and regulatory frameworks**, in consultation with industry, employees, unions and environmental groups.

- ✓ To assist industry to address the hydrogen trade skills shortage we recommended that **the Plumbing Industry Climate Action Centre be upgraded to permanently host the Victorian Hydrogen Excellence Centre**, providing a suite of training in hydrogen production, storage, transport, and residential operations. We recommend a $20 million investment to redevelop the existing PICAC Brunswick Training Facility.

- ✓ The government should actively **support the establishment of two to three practical demonstration projects** as a first step towards making Victoria the hydrogen capital of Australia. The demonstrations projects should include two hydrogen production facilities and one industrial feedstock project, for instance feeding into a steel manufacturing plant. It is recommended that of the production demonstration projects one be located in each of eastern and western regional Victoria, for instance the ex-Ford car manufacturing plant in Geelong, which is being transformed into a renewable energy hub, and a feedstock project in western Melbourne's manufacturing heartland. The government should invite EOI for parties interested in retrofitting sites (specifically inviting industry groups, universities, TAFE, and Australia-German Energy Transition Hub). Government should also consider subsidising the retrofit in exchange for deliberate learning, feedback, and hydrogen industry demonstration.

This report recommends the following specific asset investments:

1. **Demonstration green hydrogen electrolyser – Ford Geelong**

   The Victorian government should support large-scale hydrogen demonstration, specifically a clean energy production project at the former Ford Geelong plant. The power generated by that much solar cannot feasibly be sold on the grid because the network currently is not able to receive it. Using the excess power to make hydrogen (instead of simply wasting it) is efficient and can drive early hydrogen production in Victoria. Critically, the solar power is already being built, so the only missing link is the hydrolysis and hydrogen distribution. Existing refineries near Geelong can help with distribution directly into major gas pipelines, meaning a hydrogen facility at this site can demonstrate the potential to blend hydrogen directly into the gas network. Moreover, the Victorian government should designate Geelong as a 'Hydrogen Innovation Zone', based upon NSW proposals. NSW has had significant success with Renewable Energy Zones, and this should contribute to informing Victoria's strategy. Specifically, the government should seek to defray costs, upgrade public infrastructure assets, and seek to 'white label' the Geelong zone from a regulatory point of view, and thus take a clear national regulatory leadership role. Designating a hydrogen development zone in Geelong reduces risk to investors by signalling an intent to work collaboratively, "white labelling" the zone from a regulatory perspective (meaning environment, planning, safety and other regulations should be negotiable for demonstration projects in the zone), will help in levelling the energy playing field. This does not mean "less" commitment to environment, safety, and other considerations, but instead commits a higher degree of attention, signalling that decisions will be made through consultation on a case-by-case basis rather than the simple application of rigid pre-existing rules.

The Victorian government should also begin discussions with the Tasmanian government for Geelong to receive Tasmanian-produced hydrogen. The cost of shipping for export is significant, and the export of liquid hydrogen may be one of the last market segments developed. Conversely, the local use of hydrogen by industry and for electricity supply optimisation are likely to be relatively early developments that have significant local effects. An agreement underwriting demand of Tasmanian hydrogen to be used in Victorian industry has the potential to accelerate the development of the industry in both states, with mutually positive externalities.

The Geelong retrofitting should be modelled on the recent Tasmanian process for the Bell Bay sites and pipeline networks, but with lessons learned. As with the Tasmanian process, government should establish a portal for interested parties to obtain technical details required to develop their bid. However, the Victorian government should be willing to share some risk with industry, and not seek to obtain party's IP. One risk is that overly involved processes can inadvertently favour the largest potential parties (e.g. major gas firms) that have the capacity to commit significant resources to an EOI at the expense of smaller firms with specific technical innovations. Most importantly, government should accept that the task is to develop a new industry, which necessarily involves some learning-by-doing and frequent responses to the rapid changing technical frontier. It should not be overly prescriptive in its requirements.

i. **Asset enhancements**

The Ford project integrates directly with existing gas distribution infrastructure. This allows testing of pipes, fittings, and end-use equipment to determine how much asset enhancement will potentially be required, and how much hydrogen those existing assets can accommodate. The first target milestone is to include a 10% mix of hydrogen into the existing gas services and 10% represents a threshold widely seen as compatible with pre-existing energy assets. Additionally, utilising water from the Western Treatment Plant at Werribee Farm near Geelong provides an opportunity for the Geelong demonstration project to further bolster its renewable capacity.

Retrofitting gas pipe and distribution infrastructure

The government should provide support to install a large-scale hydrogen electrolyser at the site and upgrade the water and gas facilities to ensure provide a demonstration at scale for the production and integration of hydrogen with Victoria's electricity and gas networks.

ii. **Integrating waste water**

The Victorian government should explore the feasibility of utilising waste water sourced from the Western Treatment Plant at Werribee Farm which is relatively near the Geelong project.

2. **Monsanto Chemical site, Summerville Road, West Footscray**

This site has significant gas reticulation, and next door is a waste station with 30 years of gas use. This has the potential to locate hydrogen storage in the industrial west of Melbourne, next to heavy industry manufacturing, transforming an industrial chemical site into clean energy.

3. **Green steel demonstration**

BlueScope's facility at Western Port in Hastings is a potential site for a 'green steel' demonstration project given existing work on clean hydrogen at the plant. The government should invite an EOI from heavy industry to agree on an MOU for using hydrogen in industrial processes. This may include underwriting or providing tax incentives for investments in upgrading or retrofitting existing assets, support for the development of relevant skills and knowledge, or encouraging collaboration with countries that are leading the world in demonstrating heavy industry applications of hydrogen: Germany and Sweden.

Victorian Hydrogen Excellence Centre

The government should invest $20 million to develop a training facility and upgrade the existing PICAC Brunswick Training Facility, including the creation of a Hydrogen Centre of Excellence for hydrogen-specific trade skills. Importantly, this "shovel ready" project should include:

1. Expanding facilities and training equipment;
2. Developing suitable curriculum;
3. Training technologically literate teachers in world's best practice hydrogen skills, tools, equipment, and techniques;
4. Providing continuous feedback from real-world insights on health and safety to inform policymakers on best-practice regulation, standards, practices, equipment, and licensing to protect the community.
5. Building an electrolyser demonstration plant at PICAC's existing state-of-the-art research and training facility in Brunswick.
6. To help address the apprenticeship crisis, the Brunswick Hydrogen Centre of Excellence should be built by apprentices, for apprentices.

PICAC estimates that at least 100 apprentices could be employed during the construction phase of an upgrade to the Brunswick facility.

7. Immediately encourage industry to enrol plumbers in certified hydrogen safety and skills training and involvement in demonstration projects.

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