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HYDROGEN

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Hydrogen is an essential building block in the transition to a net-zero-emissions world economy. It can be produced from zero-emissions electricity and thereby can be used to store and ship clean energy, usually from renewables such as wind and solar. In this way it can replace fossil fuels in many applications that are otherwise difficult to decarbonise.

Hydrogen will be crucial for the carbon-neutral production of some energy-intensive goods that currently account for large amounts of greenhouse gas emissions, and which are difficult or impossible to convert to electricity – so called 'hard to abate' processes. It is an alternative to fossil carbon in reducing oxide ores to metals – for Australia, most importantly for reducing iron ore to iron in the first stage of steelmaking. It is the chemical foundation for producing many industrial products – for example, ammonia for nitrogenous fertilisers and explosives. It will help decarbonise heavy transport.

Australia is perfectly positioned to be a large producer and user of 'clean' hydrogen, including for energy-intensive commodities for export, because of Australia's practically unlimited potential to supply low-cost power from the sun and the wind. Rates of production of hydrogen from electricity through electrolysis can be varied considerably without technical difficulties, so its production fits neatly into use of intermittent renewable energy such as wind and solar.

In a decarbonising world economy, large-scale plants in remote areas of Australia could produce hydrogen for energy export to energy-importing countries that are constrained in their renewable energy potential relative to population and industrial production. These include countries in northern Europe and East Asia. Shipping hydrogen is costly, so exports on tankers will be economical only where the options to produce hydrogen locally are constrained. This is the case, for example, in Germany, which is pushing to shed its dependence on Russian gas while moving towards a low-emissions economy and keeping its energy-intensive industries going. Hydrogen trade opportunities are becoming more realistic, and from European importers' perspective more urgent, as a result of Russia's war in Ukraine.

An even larger prize for Australia than shipping hydrogen as a fuel would be new resource-processing industries in Australia that use hydrogen as an energy input or reductant. Potentially the biggest industry that could emerge is iron and steel: in a decarbonised world economy, primary steel would no longer use the traditional steelmaking process that relies on coking coal as its reductant but new methods that rely on hydrogen and electricity. For Australia, as the world's largest iron ore producer and exporter, this opens a tantalising possibility of processing some of the ore into iron – or even into steel through the use of more renewable electricity. This would mean potentially extremely large value added in the commodity supply chain, and export revenue. Fertiliser production is another potential hydrogen-based export industry.

Whether large-scale zero-carbon hydrogen-based industrial exports become a reality for Australia depends on many factors, from technological aspects to relative costs in different locations, global supply chain considerations and geopolitics. Where large-scale hydrogen production becomes a reality, it will be crucial to design and implement these projects in ways that accommodate Indigenous communities' needs and preferences, that minimise adverse local environmental impacts and that maximise gain to the broader community, including through taxation revenue.

Hydrogen will also have a role in Australia's domestic energy use. It is well suited to the production of various commodities for the domestic market, for heavy transport, and to augment supply in some remote applications. Most of the existing pilot projects focus on blending small amounts of hydrogen into gas networks or are hydrogen refuelling stations, but these are not the kinds of uses that will be transformative economically or in the climate transition.

Uses, attractions and difficulties of hydrogen

Hydrogen's fundamental advantages include that it can be turned into usable energy without creating any pollution at the point of use, and that it can be produced by splitting water into oxygen and hydrogen with the input of electricity, in a process called electrolysis. The only global warming impact of hydrogen use is if it leaks into the atmosphere. Hydrogen production can be clean depending on the energy sources and process used.

If the electricity is generated from renewable energy, the resulting 'green' hydrogen is a zero-carbon fuel that can be transported and stored in large volumes and for long periods of time. Zero-emissions hydrogen can also be produced using nuclear power where this is feasible and affordable. The main production method to date is by processing gas or coal, which leaves residual carbon dioxide emissions (see further below).

Hydrogen is versatile. Its greatest uses today are as a feedstock in chemical industrial processes, mostly to make ammonia, including for fertiliser production; in oil-refining; and in some other industrial uses.[1]

It can be used as a reduction agent in iron-and steelmaking, in processes that replace coking coal with hydrogen and electricity. Using green hydrogen in steel production could result in a meaningful reduction in future global greenhouse gas emissions; this could become one of the main uses of hydrogen in the long term – and a major industrial opportunity for Australia.

Hydrogen can also be burned for heat and in turbines, for power generation or thrust. It can be used in electricity-producing fuel cells to produce electricity cleanly at any scale, powering anything from small telecommunications equipment to ships, although fuel cells to date are very uncommon.

The benefits of hydrogen as an energy carrier and storage medium have been known for a long time and the advent of a global 'hydrogen economy' has been predicted many times since the 1970s. Yet today, hydrogen still accounts for only a tiny share of global energy use. It is mostly used in the chemical industry, including refining and production of ammonia.

Given its desirable properties, why is the world not already using very large amounts of hydrogen, and what might be different this time?

The main obstacle to hydrogen as a mainstream fuel is that much energy gets wasted in the production and compression and storage of hydrogen, as well as its conversion back to energy. The round trip from electricity to compressed hydrogen and back to electricity via a fuel cell has an efficiency cost of around 70 per cent of the total energy, so only about 30 per cent remains as usable electricity.[2] Where hydrogen from electrolysis is used as a fuel or feedstock, about two-thirds of the input energy is available. When powering vehicles, the energy losses from primary energy to the wheel are greater with hydrogen than for battery-powered vehicles, but hydrogen vehicles do better in overall energy efficiency than conventional diesel or petrol vehicles.

The conversion losses mean that producing hydrogen from fossil fuels intrinsically makes most sense where a particular activity relies on hydrogen, such as for chemical processes, which to date are the largest global use of hydrogen; and for replacing diesel in heavy transport and machinery.

Another set of difficulties lies in storing and transporting hydrogen. Transporting hydrogen in large volumes requires combinations of extremely high pressures and extremely low temperatures, or immersion in chemical mediums. Transporting hydrogen in pipelines requires special materials.

The cost of shipping hydrogen from Australia to Europe is expected to be over US$2 per kilogram of hydrogen, in the absence of further technological advances. This is similar to expected future production costs of hydrogen, so shipped hydrogen is at a large cost disadvantage compared to locally produced hydrogen.[3] Storing hydrogen in chemicals for transport is cheaper, but the required chemicals are toxic and pose a risk in transport. Conversion of hydrogen to ammonia allows much cheaper transport, but the uses of ammonia are more limited than hydrogen, unless it is reconverted, which once again adds cost.

The potential game changer is the push for net-zero emissions, which will require decarbonisation of global energy and industrial systems. If most energy uses need to be zero-emissions or very low in emissions, large opportunities emerge for hydrogen. This is what will drive the likely push to hydrogen.

In a world that moves to net-zero emissions, a premium will be paid for clean fuels, and industrial processes will tend to use cleanly produced hydrogen rather than gas or coal. Falling costs of renewable energy generation and hydrogen production technologies mean that the cost of green hydrogen will fall.

Estimating the size of the future global market for green hydrogen at this point is guesswork, because it is unclear to what extent hydrogen will displace fossil fuels in different applications, or to what extent direct electrification will obviate the need for hydrogen and hydrogen-based fuels. The International Energy Agency's scenario for a transition to net-zero emissions has global low-carbon hydrogen production at 17 EJ (exajoules) in 2030 and 60 EJ in 2050, assumed to be two-thirds green and one-third blue. In comparison, total final energy consumption is around 420 EJ per year today, and in the IEA net-zero scenario it is assumed to gradually fall in future to 390 EJ in 2030 and 330 EJ in 2050.

Scenarios that do not assume that the world achieves net-zero emissions in the energy sector by mid-century have much less hydrogen production. For example, IEA modelling of currently announced climate pledges has future hydrogen use at less than half compared to the net-zero scenario.

Such projections need to be taken with a large grain of salt as they depend on assumptions about the future costs of different energy sources, the costs of producing and shipping hydrogen, technologies for fuel substitution, government policies and more.

Grey, blue or green: How clean is hydrogen?

Different production methods for hydrogen have vastly different emissions footprints. It can be made as a clean fuel, by producing it through electrolysis, splitting water by means of an electrical flow. If the electricity used is generated from renewable energy sources such as wind and solar power – or nuclear power – then there are no greenhouse gas emissions involved in its production and use.[4] Hydrogen made through electrolysis using renewable energy is termed ‘green’ hydrogen. Green hydrogen is, in effect, carbon-free electricity stored in molecular form.

Hydrogen can also be produced from fossil fuels. It can be made from gas through a process called steam methane reforming, or from coal. The production processes releases carbon dioxide, and if this is released into the atmosphere, the benefits of zero emissions at the point of use are negated. Producing hydrogen from gas without capturing the carbon dioxide results in what is called ‘grey’ hydrogen – and from coal, ‘black’ or ‘brown’ hydrogen.

In 2020, over 99 per cent of the world’s hydrogen was produced from gas or coal.[5] It has been cheaper to use these processes than to produce hydrogen through electrolysis.

But hydrogen from fossil fuels is among the most emissions-intensive of all fuels. This is because the energy losses in the conversion mean that more fossil fuel is used than from burning gas or coal directly. Grey or black/brown hydrogen is typically 30 to 60 per cent higher in greenhouse gas emissions intensity, measured as the amount of greenhouse gas emissions per unit of energy, than direct combustion of gas or coal. The carbon dioxide emissions intensity of grey, black and brown hydrogen are around 74, 157 and 170 $kgCO_2$ per EJ of energy respectively, or around 9, 19 and 20 $kgCO_2$ per kg of hydrogen.[6] In addition, oftentimes sizeable emissions of methane are produced during the extraction, processing and transport of gas and coal.

Therefore, conventional hydrogen production chains are out of the question in a world that cuts emissions to address climate change.

The emissions intensity of fossil-fuel-based hydrogen can be lowered by capturing the carbon dioxide released in the processing of gas or coal to hydrogen and pumping it to underground storage reservoirs. The resulting product, hydrogen from fossil fuels with carbon capture and storage (CCS), is termed ‘blue hydrogen’.

In Australia, blue hydrogen is often called ‘clean’ hydrogen, with little regard to the actual emissions intensity of the production system.[7] Blue hydrogen cannot be zero emissions. It is technically impossible to capture all the carbon dioxide in the production process, and processes geared to capture 90 per cent or more do not always perform to this standard in practice. Methane emissions during the fossil-fuel extraction and processing stage are not addressed through CCS.

Even with very high rates of carbon capture and storage, the remaining emissions in the production chains of coal-and gas-based hydrogen are large. At carbon dioxide capture rates of 90 per cent, the hydrogen produced may have a greenhouse gas emissions intensity of between a quarter and half, and sometimes more, of the underlying fuel. In part this is because of methane emissions in the fossil-fuel supply chain.[8]

Consequently, blue hydrogen is not the long-term answer for a decarbonised world energy and industrial system.

Blue hydrogen is often seen as a necessary step in the evolution of a global hydrogen supply chain, as today it is typically cheaper to produce than green hydrogen, assuming fossil fuel prices at longer-term averages. Many countries' hydrogen strategies assume that the hydrogen systems of the future will start with blue or even grey, black or brown hydrogen, and move to zero-carbon hydrogen gradually over time. In 2021, an analysis of twenty-eight national hydrogen strategies found that twenty-four of these followed a 'scale first, clean later' approach.[9]

It is easy to see why many consumers of hydrogen do not place appropriate importance on the greenhouse gas intensity of hydrogen production. The emissions arise and are accounted for at the production level, while for the consumer it is a perfectly clean fuel with zero accounted emissions (aside from hydrogen leakage, which is not currently captured in emissions accounting), no matter how dirty the production process. Where hydrogen is traded between countries, the emissions are reflected only in the exporting country.

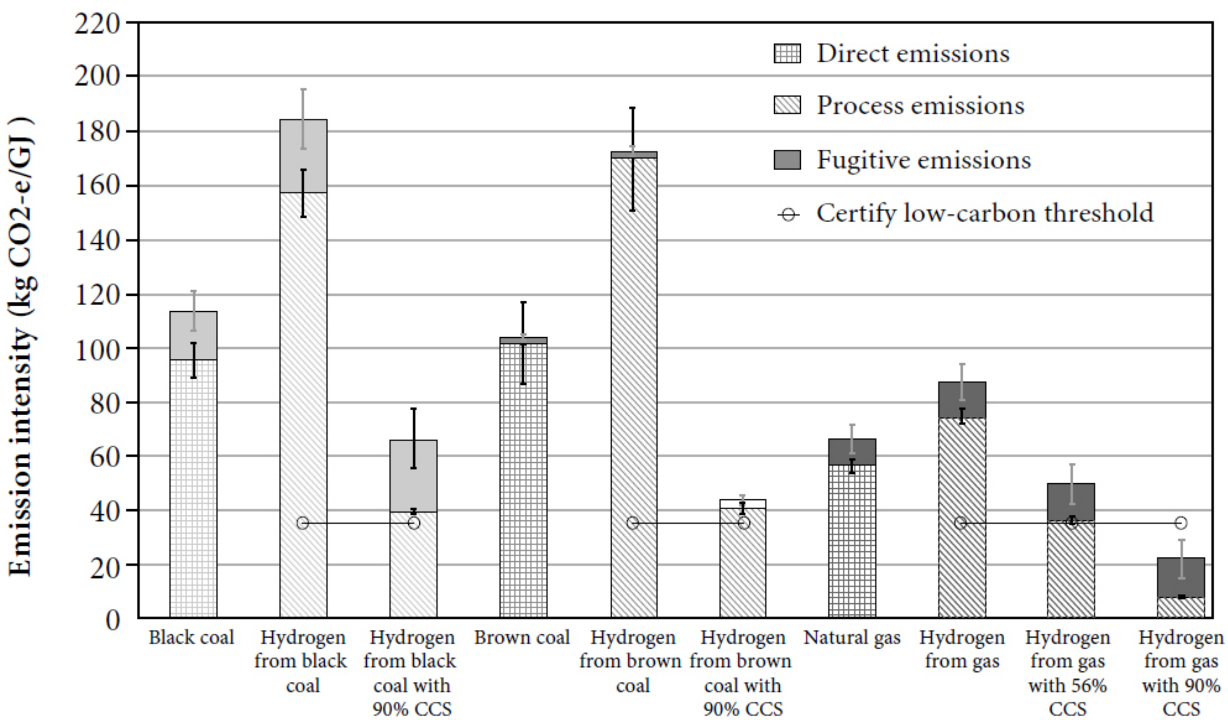
For Australia, as a potential large-scale exporter of hydrogen, establishing a hydrogen industry that uses gas or coal as the feedstock would result in sizeable additional emissions. It would make it harder to achieve any national emissions reductions target.

Australia's 2019 National Hydrogen Strategy is premised on blue hydrogen providing the bulk of Australia's future hydrogen production. In fact, the idea of turning gas into hydrogen was wrapped up with the Morrison government's political rhetoric of a 'gas-led recovery' from the economic downturn resulting from the COVID-19 pandemic.

A blue hydrogen industry would lumber Australia with a potentially large additional source of emissions. And once established, such an industry would be likely to persist, as its capital costs would be sunk and it might be able to exert pressure on governments, for example for exemptions from future penalties on emissions. If they were closed before the end of their technical lifetime, blue hydrogen production facilities would become stranded assets or partially wasted investments.

The answer, therefore, is green hydrogen. The future of hydrogen is for electrolysis driven by renewable energy, typically wind and solar power. This reality is dawning on many corporations and governments.

Figure 5.1 The emissions intensity of different fuels and hydrogen from different production methods.



Source: T. Longden, F.J. Beck, F. Jotzo, R. Andrews & M. Prasad, '"Clean" hydrogen? Comparing the emissions and costs of fossil fuel versus renewable electricity-based hydrogen', *Applied Energy*, 306, 2022, pp. 118–45.

The European Union, currently considered the largest source of hydrogen import demand in the medium term, is planning to put in place a regulation that would set a ceiling for the emissions intensity of imported hydrogen, which in practice would allow only green hydrogen. The EU 'REPowerEU' initiative explicitly supports 'renewable' hydrogen, with a target import of

10 million tonnes of green hydrogen by 2030, alongside the same quantity produced in the EU. Other hydrogen-importing countries could follow suit.

Hydrogen production costs

Estimates of the total production costs for blue hydrogen from gas in large-scale production systems range between US$1 and US$3 per kilogram of hydrogen for gas-based hydrogen, with a median from a sample of studies of just over US$2 per kg.[10] Production costs are somewhat higher for coal-based hydrogen. They are obviously higher if a carbon penalty is imposed on residual emissions, and carbon prices even at low levels tip the cost balance in favour of blue over grey, black or brown hydrogen.

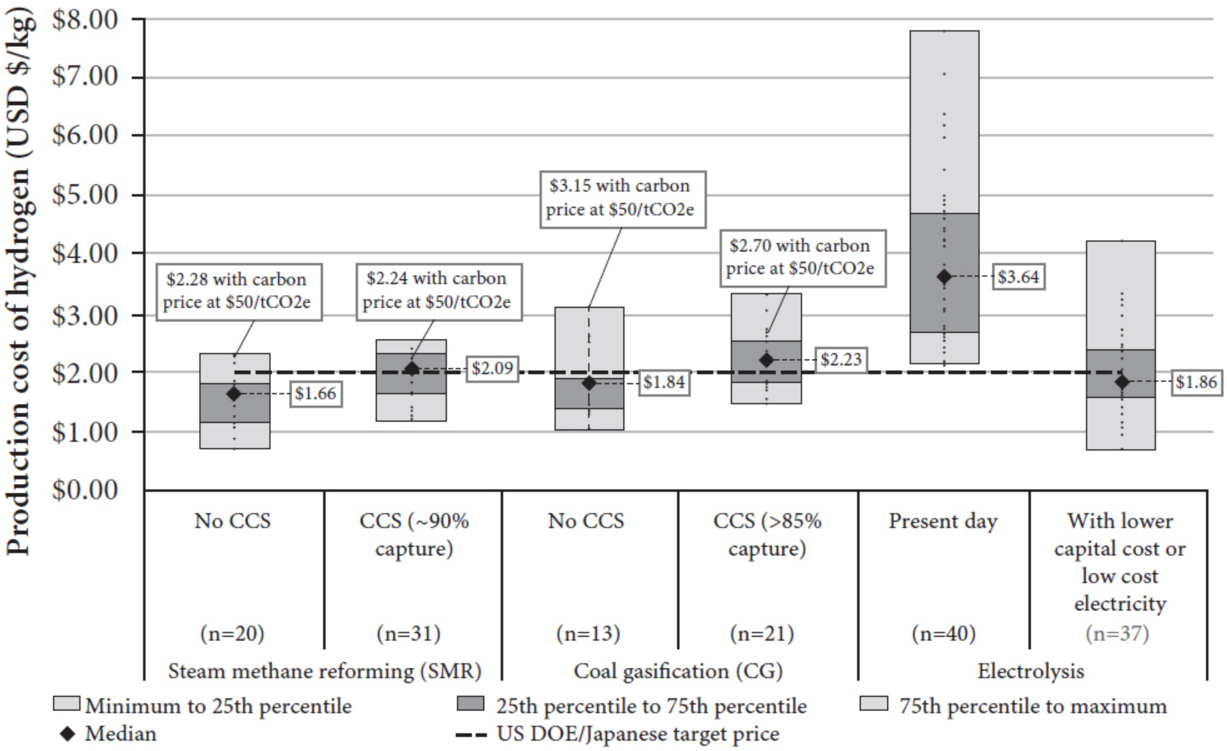
The spread in cost estimates is to a large extent due to different assumptions about fuel prices. At the time of writing, gas and coal prices are far above historical averages, which would result in much higher production costs for fossil-fuel-based hydrogen. For example, an increase of $10 per GJ in the gas price would add around $1.70 per kg to the cost of producing blue hydrogen with 90 per cent CCS. Wholesale gas prices in southeastern Australia were on average around $6 per GJ over the decade from 2011 to 2021; spot prices increased dramatically in the first half of 2022.

Green hydrogen is estimated to have median production costs in the order of US$3 to US$4 per kg under present-day conditions, with many studies arriving at higher or lower costs. It is lower in locations with access to low-cost renewable energy.

A higher carbon price will benefit green hydrogen in the cost comparison, but the larger effect will be from reductions over time in the cost of electricity from renewable energy, and the cost of electrolysers. These are the main cost factors for green hydrogen, and both are on a declining long-term trajectory.

The cost of both solar panels and wind turbines has fallen dramatically with the scaling-up of global production volumes and technical improvements. The supply chain pressures that the world is experiencing in 2022 are putting upward pressure on equipment and construction costs, but continuation of cost reductions is likely in the medium to long term. The scale effect of very large renewable energy installations will further drive down costs, for example through novel technologies for automated installation of solar panels.

Figure 5.2 The production cost of different fuels and hydrogen from different production methods.



Source: T. Longden, F.J. Beck, F. Jotzo, R. Andrews & M. Prasad, '"Clean" hydrogen? Comparing the emissions and costs of fossil fuel versus renewable electricity-based hydrogen', *Applied Energy*, 306, 2022, pp. 118–45.

Electrolysers are set for a major drop in prices. To date, they are used in niche applications and produced in small quantities. Mass production will allow much lower production costs, through larger scale of units, process improvements and greater competition between producers.

Taking these factors into account, the costs of producing green hydrogen are likely to rapidly fall below those of blue hydrogen in locations where renewable energy can be produced at low cost.

Where will green hydrogen be made?

The physical prerequisites for cost-effective large-scale hydrogen production are straightforward: a large-scale supply of low-cost renewable energy, which typically means a great deal of sunshine and good wind speeds (preferably in combination); available land to build large arrays of electrolysers and the energy supply to run them; and access to industrial ports or a geography that allows the building of suitable ports.

Water supply is also needed, but the required quantities make its contribution to costs small relative to energy, making it for example feasible to desalinate seawater if fresh water is unavailable.

There can be variations on the energy supply. It could be hydropower, offshore wind or floating solar panels. However, the lowest-cost energy supply at very large scale will usually be from solar and wind on land.

Large areas of Australia perfectly meet these conditions, including the Pilbara region and coastal areas in southwestern Australia, central Queensland and South Australia.

Australia is of course not alone in boasting such potential. Similar geographies are found in northern and southwest Africa, Chile and the Middle East. Many of these locations are also closer to European markets, where much of the early demand for green hydrogen is likely to be.

Still, Australia is in pole position to become a location for green hydrogen production for export, because it marries the physical comparative advantage with institutional and economic advantages. Australia has a cost advantage over developing countries in capital-intensive industries because the required interest rate (the cost of capital) is substantially lower in Australia. Investments in Australia carry lower risks because of its relatively stable political, investment and trade framework.

Australia also has a track record of successfully building large resource projects, including in the energy sector. The closest comparison with future hydrogen industries are the liquefied natural gas processing and export terminals. This gives Australia the required local expertise in engineering, project implementation, financing, regulatory approval, and physical and human capital infrastructure. These factors provide investors with confidence, which is especially important in a new industry where there are unavoidable project risks.

These risks are greatly amplified in countries where state institutions are weaker and where the industrial-technological system is not as deep. This is the case for most of Australia's main potential competitors. The risks are amplified in cases where major new infrastructure including ports needs to be built. Such infrastructure typically has long lead times, with risks of delays or non-completion. Political instability deters investors in some of the locations that may compete with Australia.

In a world of fracturing geopolitics, large-scale future trade relations will once again depend to a greater extent on political relations and shared norms, traditions and belief systems. For potential hydrogen-importing countries in Europe, Australia is an attractive option in this light also.

These factors beyond production cost matter more for hydrogen than for many other commodities because of a somewhat symbiotic relationship between producers (exporters) and consumers (importers), at least in the early stages of a hydrogen system. Building up a hydrogen use system, for example in Europe's chemical industry, demands reliable supplies. Importers will want to lock in supply contracts with reliable partners. Likewise, to commit to investment, producers and their suppliers of finance need confidence that purchase contracts will be honoured.

These factors suggest that hydrogen trade will likely be built up based on long-term contractual arrangements between trusted partners. They may see active involvement of the importing country in setting up supply chains, for example in the form of companies that are technology leaders in electrolysis-delivering equipment. They may involve foreign direct investment in, or joint ownership of, production facilities. They may even involve direct government involvement of various forms.

Australia is therefore well positioned. The most likely early partners at scale would be European countries including Germany: they are under pressure to diversify from Russian gas; they are strongly committed to decarbonisation, which translates to a strong preference for green hydrogen; and there is limited opportunity for cost-effective hydrogen production in Europe.

Likely features of large-scale green hydrogen projects

The specific form that large green hydrogen production systems take will vary with local conditions, but there are some shared features that are likely to prevail across Australia.

Typical large-scale green hydrogen production systems on mainland Australia would contain co-located solar photovoltaic and wind power, powering electrolysers located close to an industrial port. The hydrogen is prepared at the port, through liquefaction under pressure, immersion in a chemical carrier agent, or conversion into ammonia. The electricity generation may be adjacent to the coastal processing plant, or some distance away (as in central and north Queensland locations). In Tasmania, green hydrogen systems might be powered exclusively by wind backed by hydroelectric power.

Electricity supply for electrolysis may be standalone. It could be augmented by energy storage, for example through pumped-hydro power, where this is justified by cost saving from more intense utilisation of the electrolyser capital.

Hydrogen supply systems could also be connected to the electricity grid, saving costs in both. The two-way integration can increase utilisation rates for the electrolysers and reduce the need for energy storage and peaking capacity on the grid, because the grid can draw on the power supply built for the hydrogen system.

Grid connection of hydrogen production systems raises some complex questions for the sharing of costs and benefits, and for pricing. The transmission line and connection equipment can be a major cost factor. Whether and in what proportion the cost is borne by the hydrogen development or the grid should depend on expected benefits to each, rather than on regulatory rules established for different circumstances.

Grid connections of electrolysers present challenges for certification as ‘green’ hydrogen, which is essential for exports to high-value markets. Accounting and certification systems need to attain high levels of sophistication. There is a risk that overly strict or simplistic requirements on hydrogen imports, as are for example under development by the European Commission, could preclude efficiencies from grid connection of hydrogen production systems.

Hydrogen production systems require immense amounts of land for solar panels and wind turbines, and large areas for electrolyser banks and hydrogen processing and storage facilities near the coast.

Facilities will typically be located in areas where the opportunity cost of land is low. Electricity generation and electrolysis do not produce pollution, and water supply will usually be adequate.

But projects of this scale will generally have adverse effects on local environments, including biodiversity. These effects come about from construction, including the building of access roads and changes to local conditions for fauna and flora that arise, for example, from shading from solar panels over very large areas. The keys are to choose sites not only for minimisation of production costs but also minimisation of environmental footprint, and to design installations to take account of local environmental conditions.

In addition, some forms of processing for shipping of hydrogen and derivative products can involve local pollution or the risk of accidents with toxic materials.

Much of the land required will be subject to differing strengths of First Nations rights and interests, including through native title and land rights legislation. Benefits for First Nations will be more likely if Traditional Owner groups are engaged early and are well-resourced and well-informed so they can meaningfully engage in development including through agreement-making processes.

Economic benefits need to be fairly shared with local communities, including and especially First Nations people.

Using hydrogen in Australia: Another export story

Hydrogen is also likely to be used in Australia. Scale depends on whether an export industry for using hydrogen for energy-intensive processing of commodities emerges. The main candidates are iron metal and steel (see Chapter 6), synthetic fuels and fertiliser production.

Hydrogen is likely to be used in some transport applications in Australia. Hydrogen is likely also to be used to a small extent in the power system, as an energy storage medium in specific cases where this is cheaper than energy storage in batteries or pumped-hydro facilities. These uses are small compared to the potential for export industries.

Hydrogen can also be mixed in with the general gas supply. This is limited to a small share for technical reasons and would constitute a low-value use of hydrogen. For energy use by households and general businesses, decarbonisation is better achieved through direct electrification.

Decarbonisation of transport can be achieved through electrification through batteries, electrified rail and zero-emissions onboard fuels. Battery electric vehicle technology is set to win a lion's share of the market for clean on-road transport. It is shaping up as the technology of choice for cars and for at least part of the truck and bus fleet, owing to the rapidly falling cost of batteries, higher overall energy conversion efficiency and lower capital requirements for refuelling. Hydrogen may become the fuel of choice for long-distance and point-to-point heavy goods transport, including in heavy trucks and on rail lines that are not electrified. Hydrogen-powered flights may also become possible. It may also become competitive for transport and some stationary energy uses such as mining in remote locations, where onsite renewable energy generation is preferable to shipping fuels over long distances. Whether hydrogen or batteries are the cheaper storage option depends on the specific circumstances.

In shipping, ammonia (which can be produced from green hydrogen) is likely to be part of decarbonisation. Ammonia can be burned in ship engines. Australia can supply a large international cargo shipping market.

Hydrogen could also be used as an intermediate step in the production of synthetic liquid fuels to replace diesel and aviation kerosene. Synthetic zero-emissions fuels, or e-fuels, using electricity as the energy input could become a very large industry for Australia; for domestic and international transport with fuelling in Australia; and as an export commodity.

Ammonia is the critical input in the production of nitrogenous fertilisers and some other chemical processes. It can be produced from green hydrogen with zero emissions, rather than natural gas with high emissions. One of the world's first renewable ammonia production plants is in preparation in the Pilbara. The value of the global ammonia market is in the order of $100 billion per year. That will grow massively with progress towards the zero-emissions global economy. Australia could achieve a sizeable share of the global market.

The largest prize for hydrogen is likely in iron and steel production ('green steel'). Primary steel is made by combining iron ore and additives with coking coal in blast furnaces. Steel production is responsible for 7 to 9 per cent of global greenhouse gas emissions, and this will need to be removed as the world pushes to net zero emissions. Part of the answer is to reduce steel use. Part is to increase the share of steel recycling, which uses electricity, not coal. But the world will continue to need large amounts of primary steel, made from iron ore. This requires new processes, and currently the most economical ones use a combination of hydrogen and electricity to reduce the iron ore to iron and produce steel. These processes are in the early stages of commercialisation.

For Australia, a tantalising prospect is that part of the expansion of the world's future iron processing and steel production could be located in Australia. Australia is the world's largest producer of iron ore (37 per cent of global production) and the largest exporter of metallurgical coal. It produces only a tiny amount of steel. Most iron ore and coking coal are exported, with most of the exported iron ore going to China.

Australia has obvious potential to be a location for a future green iron industry, because it can produce practically unlimited amounts of hydrogen at comparatively low cost. The same goes for renewable electricity for steelmaking. Iron-ore mining is concentrated in areas (including the Pilbara in Western Australia) which are also highly suitable for large-scale green hydrogen production.

Some arithmetic illustrates possible magnitudes:[11] if all iron ore exported from Australia (in 2019) were processed in Australia, this would produce around 540 million tonnes of steel per year, requiring 2100 TWh of electricity per year to make 33 MT of hydrogen per year. This is more than seven times the current total annual electricity generation in Australia. About 1000 GW capacity of wind and solar power would be required. The investments would be in the order of trillions of dollars. Most value would be added in Australia. The value of Australia's iron-ore exports is in the order of $100 to $150 billion per year depending on prices; the value of the steel produced from it is several times larger, if exported in its simplest form, crude steel. The value added from processing would dwarf the value of current coking coal exports. One option for this might be to produce an intermediate product, such as pig iron, in Australia, for export and processing into steel in traditional steel-producing locations in the industrial heartlands of East Asia, Europe and America.

Processing a quarter or half of Australian exports of iron ore into metal would build an immense industry.

The world has ample capacity in traditional blast furnace steel plants, and a green steel industry requiring large upfront investment will compete with existing plants for which only running costs is a factor. This will tend to slow the transition to green steel. However, it is likely that demand for green steel will arise and drive the establishment of a green steel supply industry. Some car manufacturers are already planning to produce some vehicle types using green steel, as a 'greener' product. In other industries, green steel might become the choice as a result of policies, for example regulation of the maximum amount of embedded emissions in the construction of buildings.

The role of governments

What can and should governments do to foster the emergence of a hydrogen industry?

The single most important aspect is policies to penalise greenhouse gas emissions and incentivise the uptake of zero-emissions alternatives, in particular carbon pricing as well as emissions standards for fuels.

For potential hydrogen-exporting countries such as Australia, the policies of energy-importing countries matter greatly. The European Union's emissions trading system now imposes a sizeable price on greenhouse gas emissions, providing incentives for EU industry to switch from fossil fuels to renewable (as well as nuclear) energy and industrial inputs.

The decisive shift in demand is from gas to hydrogen, including to supply energy for European industry. Russia's invasion of Ukraine and the resulting move away from pipeline gas imported from Russia to Europe accelerates the demand for hydrogen in Europe, particularly in Germany.

European countries are preparing to subsidise initial deliveries of green hydrogen through competitive tender and contract-for-difference arrangements.

In Australia, a price penalty on carbon emissions would likewise be useful, to guide the emergence of an efficient and sustainable hydrogen industry. A price on emissions would make blue – and to an even greater extent grey, black and brown hydrogen – less competitive relative to green, by reflecting the costs their emissions impose on the community.

Governments at both federal and state levels have important roles in investment facilitation. They can make sure that regulatory requirements can be fulfilled without undue delays. They can help facilitate industry growth through spatial and infrastructure planning, and provide a general welcoming stance to the green hydrogen industry. Governments also have roles in creating and implementing certification schemes, allowing producers to demonstrate that their hydrogen has zero or very low emissions. And they need to fund applied research on technological as well as economic, social and regulatory aspects of a future hydrogen industry.

The federal government has a critical role in establishing international market access for zero-emissions products from Australia. Both federal and state governments can provide fiscal support for pilot and first-of-a-kind projects, recognising the risks taken by technological pioneers that confer benefits on the rest of the community.

Policy interventions that involve discretionary decisions by officials favouring particular projects, for example through subsidies or tax exemptions, should be avoided. These are especially costly for the Australian community when provided by state governments in competition with other state governments. Efficient allocation of investment requires a level playing field across the country. Necessary recognition of the costs of emissions and innovation in low-emissions technologies should be provided by mechanisms of general application.

The federal government, in particular, has an important influence on how attractive Australia is as a hydrogen-trading partner, through its commitments and actions on climate change. Governments in energy-importing countries that are committed to climate action will prefer to support hydrogen investments in countries that are like-minded on climate policy and act accordingly. The adoption of an internationally acceptable national emissions target and continuous strengthening of both the target and efforts to achieve it are key.

What is the national benefit from a hydrogen economy?

Where the possibility exists for the creation of potentially very large-scale energy and energy-intensive export industries, with extremely large revenues, it may seem that it is self-evidently desirable to make them happen.

But we should ask how the national interest is best served. Will Australia be better off as a result of a hydrogen industry? Who will reap the benefits, who will wear the costs?

Past experience with resource industries in Australia is that they have provided some national economic benefits, with large gains to many; but that they overall have had environmental and sometimes also social costs, and that the benefits have typically been unequally distributed in favour of the owners of capital rather than the community at large.

The birth of a new industry offers the chance to do better.

First, let’s consider the potential financial benefits. Large-scale resource developments in Australia are almost always owned by private industry, and effective tax rates tend to be relatively low. As a result, a large share of profits typically goes to shareholders, including those overseas, while the public receive a relatively small share of the pie via their governments. The liquefied natural gas (LNG) industry is a case in point. Attempts at higher taxation, such as a super-profits tax on resource industries, have often failed due to the outsized political influence of vested interests.

Lessons from resource industry taxation apply in some ways but not in others. A green hydrogen draws on inexhaustible renewable energy, not finite physical resources. Similarities are that large projects of this kind have potential for damage to local environmental and Indigenous values. Their scale and associated opportunities for oligopolistic control can result in excess profits and risk capture of policy and regulatory processes. Appropriate analysis and policy development is needed from the start.

Next, we should look at the social and cultural benefits and costs, including regional development. Hydrogen production systems will bring very large investments to regional and remote areas. This is on the whole desirable, especially since the coal industry and then the gas industry will be phasing down in rural and regional Australia. Hydrogen production will bring obvious regional economic benefits; however, the number of jobs and thus the direct benefits to local communities are typically quite limited in developments of this kind, as the degree of mechanisation and automation is very high.

Questions around how such facilities would affect Indigenous communities, socioeconomically, environmentally and culturally, are critical considerations. First Nations people and communities must be involved in the decision-making, including about siting, design and implementation, to ensure that projects proceed in ways that best reflect their priorities. Where the direct impacts are negative, ways need to be found to arrange project siting and implementation to minimise adverse effects and to maximise the benefits to First Nations communities.

In this light, benefit sharing for new hydrogen industries is of paramount importance. The national interest would be best served by securing a significant share of the value and profits created for the public purse, to allow for investments that are in the community interest. Appropriate and ambitious regulatory requirements also need to be placed on the developments.

Finally, let us consider the environmental impact. Creating a large-scale hydrogen industry in Australia will be damaging to some extent for parts of Australia's environment. The standard computation is to weigh up such local environmental impacts against the financial benefits. But there is another, more fundamental consideration. That is the environmental effect on the world overall. The question then is: would building the hydrogen industries that are needed for decarbonising the world economy, in another part of the world, impose greater or lesser local environmental damages than building them in Australia? The answer may well be that Australia is a good location from a global point of view.

By establishing a green hydrogen industry, Australia will help the world to displace fossil fuels at large scale, and consequently to reduce emissions and limit climate change. This will be the direct opposite of Australia's historical contribution as a provider of fossil fuels. Hydrogen is a way to use more of Australia's near unlimited potential for clean energy – and make it available to the world.