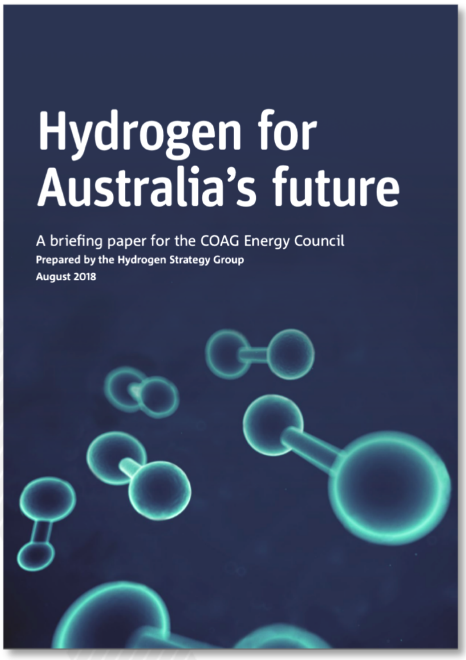
ENVIRONMENTAL CLEAN
TECHNOLOGIES LIMITED

ECT RESPONSE TO COAG ENERGY COUNCIL NATIONAL HYDROGEN STRATEGY ISSUES PAPERS

Overview

The COAG Energy Council Working Group is consulting with industry and the community to develop the national hydrogen strategy. Building on earlier consultation, the issues papers seek feedback on the potential role of policies and actions in realising hydrogen opportunities.

COAG's Hydrogen Strategy Group delivered a briefing paper in August 2018, titled 'Hydrogen for Australia's Future', also known as the 'Finkel' report, highlighting the vision, opportunity and challenges.



Environmental Clean Technologies Limited (ECT) is in the business of commercialising technologies which can deliver positive environmental and economic outcomes, three of which are relevant to the emerging hydrogen opportunity.

The Company is pleased to submit the following feedback generally in regard to the national hydrogen strategy and, where appropriate, specifically in relation to questions directly posed within the issue's papers.

Following is an overview of ECT's hydrogen-relevant technologies, followed by comment on the 'biggest' scale challenge facing the hydrogen industry and how ECT's technologies can help address the challenge.

388 Punt Rd, South Yarra, VIC 3141, Australia | Phone +613 9849 6203 | www.ectltd.com.au | ABN 28 009 120 405
Listed on the Australian Stock Exchange (ASX:ECT)

Hydrogen Innovation

Coldry:

The briefing paper "Hydrogen for Australia's Future" notes that hydrogen can be produced from a wide variety of our abundant fossil fuel and renewable energy sources. Hydrogen energy value chains can therefore readily adapt to changes in the nation's mix of energy sources.

The production of hydrogen via coal gasification is well established.

The recent commencement of the $500 million Japanese-led Hydrogen Energy Supply Chain (HESC) project in Victoria aims to leverage the competitive advantage of low-cost lignite.

Here's how Coldry can support innovation in this field:

- The production of hydrogen via gasification of lignite necessarily requires pre-drying
- Traditional lignite drying methods such as 'steam tube drying' are high temperature and/or high pressure, requiring high-cost energy input and emit significant CO_2
- The Coldry process is a low temperature, low pressure lignite drying process designed to utilise waste heat to achieve a zero direct-CO_2 footprint, delivering a lower cost solution in contrast to alternative drying methods
- Zero direct CO_2 emissions from the Coldry drying stage results in lower total CO_2 emissions from downstream uses of lignite and therefore a lower carbon capture and storage (CCS) requirement and cost

Coldry acts as a 'gateway' technology, enabling lower cost, lower emission lignite-to-hydrogen processes.

COHgen:

The briefing paper "Hydrogen for Australia's Future" notes:

> *Gasification is used for solid feedstocks such as coal and waste biomass. Chemically it is a more complex process than [natural gas-based steam methane reforming] and produces a higher ratio of CO_2 to hydrogen.*

The production of hydrogen from lignite could follow a 'traditional' path, utilising 'standard' gasification and gas refining technology, or it could seek to optimise its energy input and yield and minimise its CO_2 footprint via innovation.

ECT has developed an alternative method of hydrogen generation from lignite called Catalytic Organic Hydrogen generation, featuring:

- Enhanced hydrogen yield
- Lower operating temperature (lower operating cost, higher energy efficiencies)
- Lower CO_2 emissions - the majority of the carbon is deposited as a solid rather than being emitted, resulting in lower CCS cost

The successful outcome of R&D initiatives can be enhanced through collaborative programs, enabling the identification and joint development of innovative approaches to reducing cost and emissions.

HydroMOR:

The discussion around a hydrogen industry tends to focus on applications such as transport and grid storage and firming (firming is a term used to describe 'backing up' of intermittent wind and solar energy supply with dispatchable generation or storage). However, the ability of hydrogen to act as a reductant in primary iron production is well-known. The barrier to adoption has been high cost, relative to the incumbent carbon-based blast-furnace route.

It is envisaged that green hydrogen will one day deliver CO_2-free iron and steel via hydrogen-based methods.

Commercialisation of renewable hydrogen steel making is estimated to be a generation away given the scale and cost challenges.

ECT has developed a critically important transitional solution; HydroMOR. Short for Hydrogen-based Metal Oxide Reduction.

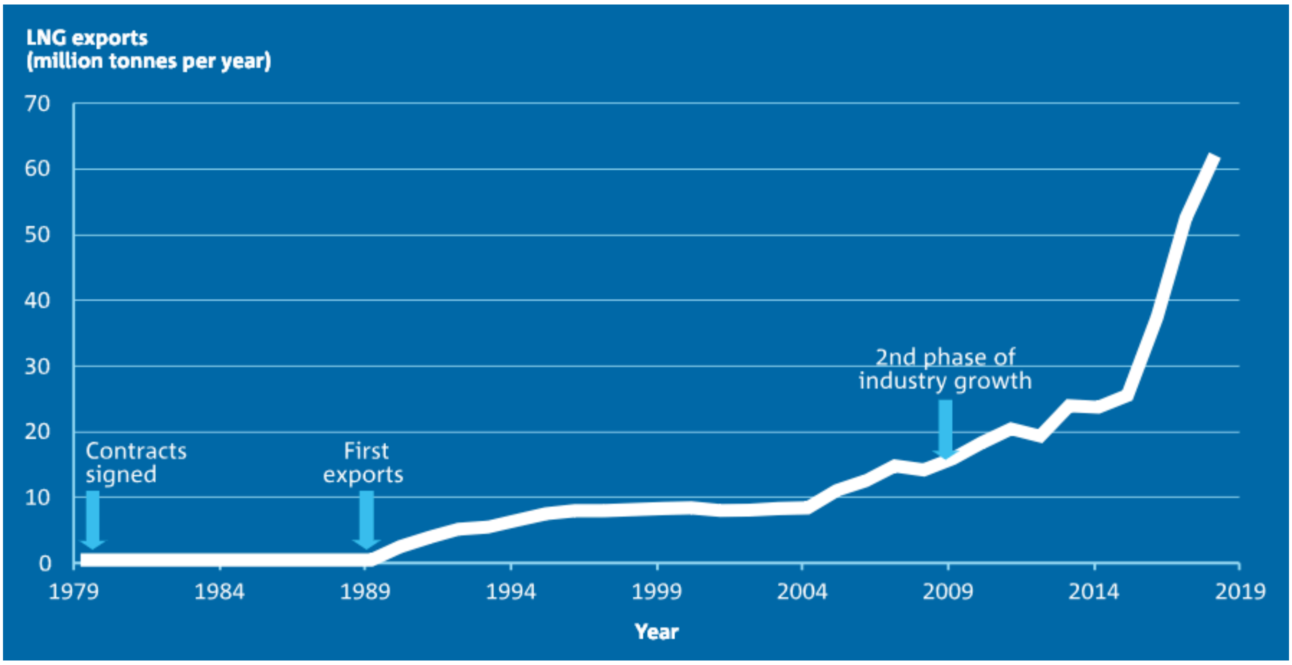
HydroMOR is the only lignite-based iron making process, replacing coking coal and thermal coal with lignite, combining it with iron ore fines or other metal oxide-bearing media via the Coldry process to produce a 'composite' pellet. The composite pellet is then fed into the unique HydroMOR furnace where several reactions take place:

- Pyrolysis & gasification of hydrocarbons within the lignite
- Catalytic thermal decomposition of light hydrocarbons to liberate hydrogen
- Reduction of iron oxide to iron at less than 900°C (relatively low temperature)
- Chemical looping of hydrogen within the process via a water-gas shift reaction (recycling the hydrogen for further reduction of iron oxides)

The result is the in-situ production and utilisation of hydrogen for iron making and the elimination of the cost needed to independently generate, transport, store and then apply it to iron ore, providing an advantage for regions with suitable lignite and iron ore resources.

Hydrogen - The 'real' scale challenge

The various reports prepared to drive and inform the discussion on hydrogen industry development highlight the challenge of scaling technology and supporting storage and distribution infrastructure. The emergence and development of Australia's LNG industry is used as a case study for overcoming scale up challenges.



And while the parallels are clear, the biggest challenge in scaling the hydrogen industry is actually scaling the primary energy source.

Few lay people understand that hydrogen is not a fuel in its own right like coal, gas or oil, but rather an energy carrier, taking energy from a primary source and storing a portion of that for later 'use' via combustion or electricity (fuel cell).

The issue papers outline the potential market for hydrogen, which is conservatively expected to grow from 8 to 18 Exajoules[1] by 2050. If realised, this is equivalent to 3 times Australia's entire 2016-17 energy consumption.

Estimates noted within the issue papers suggest Australia could 'easily' produce 100 million tonnes of oil equivalent (mtoe) of hydrogen. Restated, this is 4.18 exajoules or 34.8 million tonnes of hydrogen, equivalent to two-thirds of Australia's current total energy consumption (not just electricity), and just over half of current LNG exports highlighted in the above chart.

For reference, current global hydrogen production is ~70 million tonnes annually, with three quarters generated via the steam reformation of natural gas and the remainder via coal gasification (23%) and electricity-based electrolysis (2%).

Why are these figures important?

They quantify and provide context for the underlying scale challenge – production or sourcing of the primary energy needed to make the hydrogen. In the case of CCS hydrogen, the energy comes mainly from the coal or gas itself. In the case of renewable hydrogen, new wind and solar generation capacity is required.

[1] 1 Exajoule = 10^{18} Joules or 1,000,000,000,000,000,000 Joules

Scale up of hydrogen production, storage, distribution and transport infrastructure is certainly a significant challenge given the volume of hydrogen required, however the larger challenge is increasing our total energy supply to meet the primary energy needs to deliver the potential of 100 mtoe.

Therefore, it is important to couch the hydrogen scale challenge in terms of the features, benefits, pros, cons and total system cost of a particular primary energy source, or portfolio of sources, with benchmarking for each to ensure the principle of technology-neutrality is not 'gamed' through externalisation of hidden costs by renewable hydrogen proponents.

Further, it is important to understand the above in the context of the application, target market and how it compares with alternative energy sources in those markets.

For example, the issue papers estimate hydrogen to be competitive with petrol at $8kg while needing to achieve a $2kg landed cost to compete with LNG, clearly indicating the transport application to be the ideal early target. However, it is unclear from these estimates whether provision is made within the hydrogen price modelling to cater for the transition in fuel excise arrangements as petrol is phased out.

Understanding the primary-energy scale challenge

Three distinct opportunities for hydrogen have been highlighted through the consultation process:

1) Export
2) Domestic
3) Grid-firming (backing up of intermittent wind and solar with dispatchable generation or storage)

Two production routes are proposed:

1) Renewable hydrogen (wind & solar plus electrolysis)
2) CCS hydrogen (fossil-fuels plus carbon capture and storage)

These routes present profoundly different primary energy scale challenges.

Fossil fuels feature higher energy density presenting an opportunity for economies of scale.

Conversely, renewable energy has extremely low energy density, requiring additional electricity or gas network connection costs.

To understand the scope of the challenge, useful examples may be provided via indicative scenarios.

Export Scenario

The 'hydrogen at scale' issue paper states:

- Electrolysis presently requires 50kWh per kg of hydrogen
- It would take 2GW of wind capacity and 3GW of solar capacity to provide 100,000 tonnes of hydrogen annually via electrolysis
- The EIA estimates Australia could 'easily' produce 4.18 exajoules of hydrogen per year given our renewable resources (wind and sun)

The first target of 100,000 tonnes of hydrogen is modest, requiring 2GW of wind or 3GW of solar respectively. This is not a stretch.

However, scaling to a meaningful number such as 100 mtoe equates to 34.8 million tonnes of hydrogen at 120MJ per kg.

To achieve an outcome of 34.8 million tonnes of hydrogen, Australia would require dedicated additional wind or solar capacity of ~660GW or ~795GW, respectively. For context, Australia has ~6GW of wind meeting 7.1% of electricity demand and ~12GW of solar PV providing 5.2% of our electricity needs (end of 2018).

In terms of land area requirements, as a rule of thumb, wind and solar PV (Photovoltaic Panels) require 20 and 2 hectares per MW of capacity, respectively. Hence, 34.8 million tonnes of hydrogen production, using electrolysis, and powered by wind or solar would require an additional 13.4 million or 1.6 million hectares of land area respectively – the equivalent of 6.7 million Melbourne Cricket Ground's for wind and 805,000 for solar.

For further context, global wind and solar capacity only surpassed 600GW and 500GW, respectively in 2018.

Wind and solar resources are abundant and 'free', but the equipment and networks required to harness that 'free' energy requires massive investment. Wind and solar are diffuse and intermittent, requiring vast areas of land, additional network costs for transmission and additional firming costs, which are presently externalised. In short, the use of intermittent primary electricity supply compounds the hydrogen industry scale challenge.

CSIRO's National Hydrogen Roadmap highlights the three options for sourcing electricity for the electrolyser:

1. **Grid connected:** Electrolysers draw electricity directly from the network. Despite the emissions intensity of the network, low emissions electricity can still be utilised by securing power purchase agreements (PPAs) with utilities for low carbon electricity.
2. **Dedicated renewables**: Behind the meter (or off grid) electrolyser connection to dedicated renewable energy assets such as solar PV and wind. Electrolysers co-located with both solar PV and wind will allow for a higher capacity factor.
3. **Curtailed renewable energy**: Energy is sourced directly from the grid but only when there is surplus renewable energy available (or sourced directly from renewables when the economics do not favour export to the grid).

It may be helpful to define 'capacity factor' in the context of the above points and following table. Capacity factor is the percentage of actual electrical output out of the total possible electrical output of a generation asset.

Renewable energy sources such as wind, solar and hydro do not generate energy all the time.

The ability for wind and solar plants to reach their full generation capacity is totally dependent upon the intermittent availability and intensity of wind and solar energy, which is determined by weather conditions and the time of day. Put simply, they depend on how much the wind blows and the sun shines.

Generation can range from zero to one hundred percent. In Australia wind power achieves an average 30% of its installed capacity and solar PV achieves 25%.

In the case of hydro, capacity factor depends on when it is switched on to meet spikes in demand. Hydro's ability to be rapidly activated in this way, is essential to firming renewable energy, but limited by geography and rainfall.

Dispatchable generation such as fossil fuel and nuclear can produce electricity on demand. Variable or intermittent generation is at the whim of the elements.

Coal provides around 83% of Australia's electricity, operating at 75% of capacity (brown coal, ~90%; black coal, 75%; gas, 63%).

Scaling the deployment of the actual electrolysis units is relatively simple. In comparison, the associated techno-economic scale issues for the renewable energy required to run them are significant.

The cost of CCS hydrogen (that is, hydrogen produced from fossil-fuels plus carbon capture and storage) is estimated in the same report to be in the order of $2.14-$2.74kg.

In addition, the negative environmental impacts on wildlife and degraded natural scenic aesthetics presents a challenge for expansion of renewable energy infrastructure, with former Greens leader Bob Brown recently opposing the application for what would be Australia's single largest wind farm (up to 1000MW capacity) on Robbins Island, off the north coast of Tasmania, citing the impact on costal scenery and bird life.

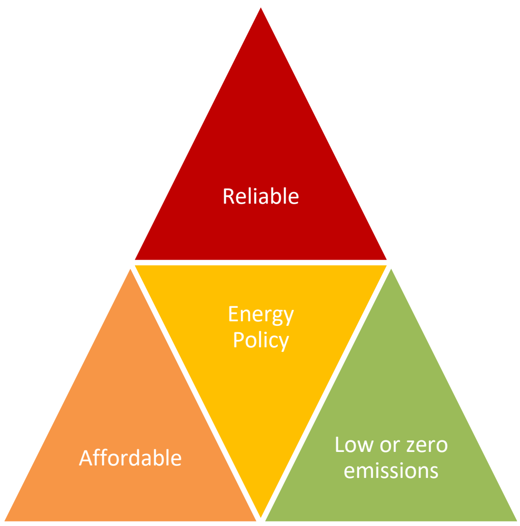
Based on the current available data, export volumes are best achieved, technically and economically, by CCS hydrogen. A healthy export market for CCS hydrogen will achieve economies of scale and reductions in cost that can benefit domestic markets and support the gradual, economically responsible entry of renewable hydrogen.

Domestic

The hydrogen strategy working group noted the potential for increased market coupling. In other words, hydrogen could supply the electricity generation market, the gas market or the transport market in addition to other industrial uses.

This presents an opportunity to increase energy diversity, which is good for consumers, but a threat to incumbent energy providers. Regulations should seek to prevent incumbent energy providers from using market position to prevent or delay hydrogen-based market coupling.

Further, the National Electricity Market (NEM) continues to face an energy trilemma: the challenge of achieving secure and reliable energy supply while reducing carbon emissions and ensuring affordability for consumers.



This trilemma is reminiscent of the trilemma popularised by the legendary oil well fire fighter, Red Adair: Good, cheap, fast. Pick any two.

In the case of energy policy: affordable, reliable, low emissions. Pick any two.

The Independent Review into the Future Security of the National Electricity Market by Chief Scientist Dr Alan Finkel (Finkel Review) convened a committee of energy market experts which made 50 recommendations aimed at addressing the energy trilemma.

Hydrogen-based solutions can clearly play a role in the domestic energy mix, across multiple industries, however further analysis is required to understand the point at which hydrogen becomes competitive in various applications and markets so that collective resources are focused predominantly on efforts that can achieve commercial scale, allowing subsequent advances in technology and cost reduction to open the door to other applications that require lower cost hydrogen to be competitive.

Grid-firming

There are two distinct considerations when discussing grid 'firming' (back up of intermittent wind and solar):

1) Lack of supply during times of demand
2) Lack of demand during times of higher supply

There is a third consideration – frequency control services – related to grid stability.

This is an increasingly important topic given AEMO report an additional 2.5GW of wind capacity is committed and a further 16.6GW is proposed.

The Finkel Review recommended a Generator Reliability Obligation which provides that if a "new" variable renewable energy (VRE) generator wishes to connect in a region that is close to the limit of minimum dispatchable capacity, that it must provide an amount of new dispatchable generation capacity from within the same region.

Under the recommendations, that additional dispatchable generation capacity cannot come from existing generation capacity. It must be new capacity.

There are times when the wind is blowing or the sun is shining, and no one needs the electricity. This electricity generation is generally curtailed and therefore lost. At present this may be as high as 10% of the time.

Directing this 'spare' renewable energy to storage, such as batteries, pumped hydro or hydrogen electrolysers would help firm the intermittency of wind and solar, creating dispatchable renewable electricity. This is covered in detail in the CSIRO's National Hydrogen Roadmap.

Unfortunately, according to the National Hydrogen Roadmap, while renewable hydrogen has the lowest electricity input cost (~2c/kWh) when it uses otherwise curtailed wind or solar, the capacity factor of the electrolyser is close to 10%, resulting in an estimated hydrogen cost of ~$26/kg due to inefficient electrolyser plant utilisation.

Renewable hydrogen may have a place as a solution for grid-firming in the context of a broader approach utilising a combination of batteries, pumped hydro and hydrogen. This is outlined in ARENA's 2018 report; 'Comparison of Dispatchable Renewable Energy Options' and should be considered a direct cost of wind and solar, per the Finkel Review recommendation.

TABLE 3. ELECTRICITY INPUT SCENARIO COMPARISON PEM (2018 COSTS)

	GRID CONNECTED	DEDICATED RENEWABLES	OTHERWISE CURTAILED ENERGY
Average electricity cost (c/kWh)	6	6	2
Average capacity factor (%)	85	35 (Co-located PV and wind)	10
LCOH ($/kg)	~$6.60/kg	~ $11/kg	~$26/kg

Bruce S, Temminghoff M, Hayward J, Schmidt E, Munnings C, Palfreyman D, Hartley P (2018) National Hydrogen Roadmap. CSIRO, Australia.

Further analysis is required to confirm the techno-economic feasibility thresholds for renewable hydrogen firming as a result of increased wind and solar penetration.

Summary

- Core to achieving hydrogen production at scale is higher volume at competitive cost in target applications without mandates or subsidies beyond those needed to overcome initial structural barriers.
- Key to understanding and subsequently meeting the scale challenge is being overt with the scale challenge of providing the primary energy required to produce the hydrogen, regardless of production route.
- The pros and cons of the scale challenge need to be articulated in terms that include the primary power source, it's impact on all environmental measures, in addition to the cost, scale and impact of supporting storage, distribution & transport systems required to get the hydrogen to market.
- The 'network overhead' needs to be articulated so the additional connection cost of diffuse, distributed green hydrogen can be assessed against geographically compact CCS hydrogen alternatives.
- CCS hydrogen production has the benefit of lower network overhead cost, as it doesn't require the additional power lines or hydrogen gas pipe infrastructure of dispersed or remotely located wind or solar.
- CCS hydrogen production has a CO_2 footprint. Technology R&D to advance CCS hydrogen production methods aimed at reducing costs and minimising or eliminating CO_2 emissions, should be supported.
- The energy trilemma is a feature of CO_2-contstrained energy markets, describing the relationship between affordability, reliability and emissions. CCS hydrogen production provides an affordable, reliable (dispatchable) route compared to renewable hydrogen, which can provide low or zero emission hydrogen, but with lower reliability and at higher cost.

ECT's suite of technologies are positioned to support the further improvement of the already superior techno-economic case for CCS hydrogen scale up via innovative approaches to lignite drying and hydrogen production.