



GLOBAL CCS
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**Victorian Independent Expert
Panel on Interim Emissions
Reduction Targets**

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Introduction to the Global Carbon Capture and Storage Institute

The Global Carbon Capture and Storage Institute (the Institute) is an international think-tank, backed by governments, business and NGOs, whose mission is to accelerate the deployment of carbon capture and storage (CCS) as an imperative technology in tackling climate change and delivering climate neutrality. The Institute is headquartered in Melbourne, Australia, with offices in Washington DC, London, Brussels, Beijing and Tokyo. The Institute is a specialist global organisation with deep expertise in all aspects of CCS including capture technology, geological storage, policy, law and regulation, economics, and public engagement.

Structure of this submission

The Institute congratulates the Independent Expert Panel on Interim Emissions Reduction Targets for Victoria for providing advice to the Victorian Government on the first two interim targets for 2021-2025 and 2026-2030, as well as opportunities to reduce emissions across the Victorian economy, and trajectories to net zero emissions by 2050. We welcome the opportunity to comment on the recent *Interim Emissions Reduction Targets for Victoria (2021-2030)* report (the Interim Report).

The Institute has provided answers to the most relevant questions identified in the on-line survey. Where applicable, references are provided for each question.

Introduction

Carbon capture and storage (CCS) is an essential suite of technologies for achieving climate change mitigation goals at the lowest possible cost. This statement has been backed by International Energy Agency Executive Director Fatih Birol who, in November 2018, said “Without #CCUS as part of the solution, reaching our climate goals is practically impossible”¹.

In addition, the UK Government’s Committee on Climate Change stated in May this year that the evidence base is clear “that UK deployment of CCS is required to unlock the greatest opportunities for cost reduction”².

Once again supporting CCS technologies’ essential role in climate mitigation at the lowest possible cost is the Intergovernmental Panel on Climate Change (IPCC) 2018 Report on 1.5 degrees, that noted: “...removing BECCS and CCS from the portfolio of available options significantly raises modelled mitigation costs”³.

CCS is the only feasible technology that can deliver deep emissions reductions in many industrial processes that are vital to the global economy, such as steel, cement and chemicals production. In their 2018 report⁴, the European Union’s Energy Transitions Commission said carbon capture will “have a crucial role to play in industrial decarbonization”. Lord Nicholas Stern of the London School of Economics stated in 2018 that “More and more, people are seeing the practicality and importance in deploying the one technology proven to decarbonise ‘difficult’ sectors such as cement and steel and “locked-in” fossil fuel-based infrastructure”⁵.

In combination with bioenergy used for power generation or biofuel production, CCS provides one of the few technologies that can deliver negative emissions at a relevant scale that will be crucial to long-term emissions reductions required to limit global temperature rises to well below 2°C.

CCS in the Victorian context

Of particular relevance to Victoria is the application of CCS to coal and gas fired power plants, providing dispatchable generation capacity to complement the increased deployment of intermittent renewables, and in the production of low emissions hydrogen for heat and transport. There is significant opportunity for the establishment of an industrial low emissions hub utilising CCS and a CO₂ transport and storage network in Eastern Victoria. This could deliver several million tonnes of emissions abatement per year, enable the development of a clean hydrogen export industry and provide Latrobe Valley communities with a just-transition to a low emissions future.

A single CCS facility can deliver large-scale, step-change emissions abatement necessary to rapidly reduce greenhouse gas emissions. For example, when operational, the Gorgon natural gas processing facility in Western Australia will capture and permanently store 3.4-4 Mtpa of CO₂. Today there are 18 large scale CCS facilities in operation in the power, natural and synthetic natural gas processing, fertiliser, hydrogen and chemical production and steel industries ([see Appendix 1](#)). Eleven of these have an annual CO₂ capture capacity equal to or exceeding 1 million tonnes per annum⁶. The largest, The Century Plant natural gas processing facility in Texas, has a capacity to capture 8.4 million tonnes of CO₂ per annum. [Appendix 1](#) contains a summary of commercial CCS facilities currently operating and [Appendix 2](#) contains a summary of facilities under construction.

Over 70 per cent of Victoria's emissions derive from electricity generation, direct combustion and industrial processes. These are all emission classes that are all amenable to mitigation through CCS as demonstrated by the current fleet of operational CCS facilities around the world.

CCS is very unlikely to have a role in Victoria before 2025, it could have a role by 2030 if planning commences very soon. If Victoria is to achieve net zero emissions in the next 30 years CCS is an essential part of any emissions reduction strategy.

CCS technologies are vital to achieving a 1.5°C scenario in Victoria

The Institute welcomes the Panel's identification of the IPCC special report on 1.5 degrees Celsius (°C). This authoritative report, and the detailed analysis that underpins it, demonstrates that there are a range of possible futures which all achieve a 1.5°C outcome. The IPCC presents four "Illustrative Pathways" to represent that range of futures.

CCS was acknowledged in three of the four illustrative pathways IPCC authors used to reach 1.5°C and was singled out for its ability to: "play a major role in decarbonising the industry sector in the context of 1.5°C and 2°C pathways, especially in industries with higher process emissions, such as cement, iron and steel industries."³ Specifically:

- Three of the four pathways require very significant deployment of CCS to meet abatement requirements.
- The pathway that requires no CCS requires the most radical changes in human behavior, consumption and lifestyle.
- The pathway that requires the most CCS relies to the greatest extent on technological solutions to deliver abatement and relatively minimal changes to patterns of behavior, lifestyle and consumption.

It is reasonable to assume that the actual, optimal, pathway towards deep decarbonisation lies somewhere between these two extremes and that CCS must play a significant role in meeting emission targets. That is certainly the conclusion one would draw from the many previous authoritative studies by the IPCC, IEA, the UK Committee on Climate Change and the EU Energy Transitions Commission; some of which were quoted in the introduction to this submission.

The state of Victoria represents a microcosm of the global economy examined in these studies and there is every reason to believe that their conclusions will also generally apply to Victoria. Further, Victoria has one of the world's best geological CO₂ storage resources in the Gippsland basin. This vast natural resource, located in close proximity to large industrial sources of CO₂, and coupled with the CCS expertise and experience present in this state, provides Victoria with a comparative advantage in CCS deployment compared to most other regions. If anything, this happy coincidence of assets and capabilities could indicate a larger role for CCS in Victoria than the global average, and the opportunity for Victoria to become a global leader in the deployment of CCS as an emissions reduction technology

As Professor Jim Skea very sagely said during the press conference to launch the IPCC 1.5 Report in October 2018: The linking word in the latest IPCC report is "and" not "or". It is time for Victoria to follow suit, embrace every option and CCS must be one.

CCS technologies are proven and working today

CCS technologies are a proven emissions reduction solution, they are working around the world, are ready to deploy at large-scale and are vital to achieving climate targets. The world's 18 large-scale facilities are already capturing almost 40 Mtpa of CO₂, and a total of over 230 Mt of CO₂ has been safely injected underground to date⁵. A further five large scale CCS facilities are in construction and at least another 20 in planning.

CCS has the distinct advantage of being applicable to a broad range of industrial sources of carbon dioxide. For example, it is capturing and storing CO₂ emissions at commercial scale from

- Biofuel production, hydrogen production, fertilizer production, coal power generation, natural gas processing and petcoke gasification in the USA
- Hydrogen production and coal power generation in Canada
- Natural gas processing in China
- Natural gas processing in Europe
- Steel production and natural gas processing in the middle east

This versatility of application has led to progressive countries such as the Netherlands, Norway and the UK, undertaking ‘hub and cluster’ studies where CCS is deployed across a number of emissions intense industries in a region, and economies of scale arising from this co-location reduce the cost of abatement. It is notable that the Gippsland region of Victoria is also amenable to the creation of a low emission industrial hub enabled by CCS.

CCS and other carbon dioxide removal options

The different pathways to achieving a 1.5°C outcome, and the role of negative emissions technologies, are presented within the Interim Report and detailed in Box 5.2. The following quote is taken from page 51-52:

“Options for removing carbon dioxide from the atmosphere include large-scale afforestation and reforestation, bioenergy with carbon capture and storage, enhancing natural weathering of silicates or carbonates, and direct air capture machines. Most are at very early stages of development, and many are not currently considered to be economically viable.”

Carbon dioxide removal options such bioenergy with carbon capture and storage (BECCS) are proven emissions reductions solutions and are working today.

The individual technologies to utilise biomass to produce energy or fuel, as well as the capture, transport and storage of CO₂, are all mature and active in commercial facilities around the world using a variety of feedstocks for the production of ethanol, biodiesel, methane and other products⁷. Currently, five facilities around the world are actively using BECCS technologies and are collectively capturing approximately 1.5 Mtpa of CO₂⁷.

The largest, the Illinois Industrial CCS facility, captures up to 1 Mtpa of CO₂. Owned by Archer Daniels Midland, this facility produces ethanol from corn at its Decatur plant, producing CO₂ as part of the fermentation process. The CO₂ is stored in a dedicated geological storage site deep underneath the facility. The remaining four BECCS facilities operating today are small-scale ethanol production plants, using most of the CO₂ for enhanced oil recovery (EOR). Additional projects are currently in the planning stages in Japan, the UK and Norway⁷.

Cost is considered a challenge in the deployment of DAC with estimates ranging from \$100-600 per tonne of CO₂. However, it is anticipated that costs will fall with deployment. For example, the passage of California’s Low Carbon Fuel Standard (LCFS)⁸ creates a significant financial incentive for deployment of Direct Air Capture (DAC).

There are three notable DAC facilities in operation: Zurich based Climeworks; Canadian based Carbon Engineering (CE) maintains that DAC technology can be built to capture one million tonnes of CO₂ per

year and achieve costs of \$100-150 per ton of CO₂ and; New York based Global Thermostat whose technology allows the capture of CO₂ in conjunction with heavy industrial processes such as metal smelting, cement production, and petrochemical refining.

CCS technologies and the opportunities for emissions reduction

Authoritative analyses of pathways to climate stabilization by the International Panel on Climate Change, International Energy Agency and others (as previously noted), all identify the need for a broad portfolio of technologies, including CCS, to deliver emissions reductions at lowest cost. Given this consistent finding, and Victoria's strong position regarding assets and capabilities necessary to deploy CCS, it is very surprising that CCS is absent from the range of measures that have the potential to reduce Victoria's emissions to zero, presented in Table 6.1 of the Report. Further, the following paragraph from page 63 of the Interim Report is concerning as it may be interpreted as justification for delaying action to mitigate climate change.

"It is likely, however, that before 2050, and potentially before 2030, technology advancement will provide new opportunities, and lower costs, in reducing Victoria's emissions. Examples could include a vaccine to address methane emissions from livestock rather than use of feed additives, or technologies for zero emissions industrial processes rather than use of carbon capture and storage."

There is no doubt that technological advances will present opportunities for lower cost abatement in the future. However, we cannot delay action to significantly reduce emissions in the hope of new technologies emerging. For Victoria to achieve net zero emissions by 2050, a fundamental transformation of how the State produces energy and products will be required. We must commence deploying existing proven technologies as soon as possible, in the most efficient manner possible, to start the rapid reduction in Victorian emissions.

Driving the rapid change needed to reach net-zero will require very large investments from the private sector. This investment will only be available, and flow, to proven technologies. There is always a lag between technological development and deployment at large industrial scale (requiring large capital investments) as operators and investors become confident in the technology and are prepared to accept the additional risk associated with being a first mover in return for the expected benefits of better performance/lower cost etc. Therefore, the time between the development of a new large industrial technology and it achieving significant market share may be measured in decades – time that Victoria, and the world, does not have. This is why we need to deploy proven CCS technologies that have been operating at commercial scale for decades, now.

The business case for CCS

CCS is a proven class of technologies. It has been in operation around the world for decades, across various industries and is available today from several suppliers with full performance guarantees.

CCS is often criticised as being high-cost compared to wind or solar because the comparison uses the levelised cost of electricity (LCOE) as its measure. This is an incomplete and inaccurate comparison, however, because it does not measure the total cost of electricity supply which includes transmission, distribution, system reliability and resilience. Additionally, costs continue to fall as new facilities come onstream and "learning by doing" allows more cost efficiencies to be identified. For instance, the actual capital cost per unit capture capacity reduced by approximately 20 per cent between the first CCS plant

on a coal generator (Boundary Dam) and the second CCS plant on a coal generator (Petra Nova). Further, the developers of both of these facilities have identified costs savings of 20-30 per cent were they to build their facilities again.

The familiar process of cost reductions with increasing deployment that is observed in all technologies is also being observed in CCS. New technologies will deliver further cost reductions. One current example is the Allam cycle which has been proven at the 30MW (electrical output) scale and is about to be scaled up to 300MW.

There are several applications where the cost of adding CCS to existing emitting facilities is relatively low. These are where CO₂ is already separated as part of the production process, including natural gas processing, fertiliser and bioethanol⁹.

Industries where the addition of CCS adds relatively higher incremental costs, such as power, steel and cement, are also industries in which capture techniques and technologies are developing. For these industries, the potential future cost reductions are likely to be relatively larger. For example, data from the United States demonstrates that the deployment of technologies still in development can reduce the cost of applying CCS by up to approximately 30 per cent in the power sector, 17 per cent in iron and steel, and 16 per cent in cement production⁹.

In 2018, UK MP and Chairman of the UK All Party Parliamentary Group for CCS, Alex Cunningham, observed: "The technology is proven and the government can no longer hide behind its claims that it is too expensive to implement. It is too expensive not to implement."¹⁰

Further, comparisons of the cost of CCS and concerns over its expense must be considered in the context of the very large scale of CO₂ reduction required to achieve climate goals. Indeed, this is the conclusion of the Intergovernmental Panel on Climate Change; that the cost of meeting climate targets more than doubles if CCS is not available.

Advanced decarbonisation technologies

The Allam Cycle

The Allam Cycle uses supercritical carbon dioxide to drive a highly-efficient gas turbine, producing power with inherent 100 per cent carbon capture. This thermodynamic cycle is now being operated in a 50MWth plant in LaPorte, Texas, owned by NET Power. Beyond power, the Allam Cycle can also form the cornerstone of a clean industrial ecosystem, whereby it combines with other process technologies to create different petrochemical products or hydrogen alongside power, all while maintaining a zero-emissions profile.

The Allam Cycle burns natural gas or syngas from coal gasification in pure oxygen, rather than air. This creates a high purity stream of carbon dioxide at high pressure and high heat. Instead of steam, this supercritical carbon dioxide is used to drive the turbine, and it is then directed into a pipeline at no additional cost for offsite sequestration or use. Thus, carbon dioxide capture is inherent to the system, and carbon dioxide can be utilised as a source of revenue rather than capture being a cost—meaning that economics will drive the decision not to pollute. Multiple revenue streams give NET Power a cost advantage. And by using carbon dioxide as a working fluid, this cycle can reach approximately the same efficiency as a conventional natural gas power plant while capturing virtually all carbon dioxide and creating zero other air pollutants such as NOx, SOx, etc.

The Allam Cycle presents a breakthrough opportunity not just for the electricity sector, but also for the oil and gas, environmental, and petrochemicals sectors globally. The technology has the potential to lower the cost of electricity from fossil fuels, while virtually eliminating all air emissions and co-generating carbon dioxide for domestic enhanced oil recovery, cement production and other forms of carbon utilization, as well as for underground sequestration and storage. And, it will co-produce other valuable gases (including nitrogen and argon) that support the manufacturing sector.

8RH2

Hydrogen holds the potential to reduce emissions across the global and domestic economy, assisting the transition to a low emissions future. It can fuel trucks, heat homes, create high-grade heat for factories, and be a fuel substitute for existing power plants, and is a vital feedstock for many chemical production processes. But to achieve this promise, hydrogen production must itself be clean and affordable.

Hydrogen is predominantly generated by steam methane reforming from natural gas, which is cheap but releases significant amounts of carbon dioxide. 8 Rivers' proprietary 8RH2 technology solves this problem by reforming natural gas with pure oxygen, and the process captures all produced carbon dioxide using a proprietary refrigeration-based carbon dioxide separation system. This is both cheaper and cleaner than traditional approaches that also release all their carbon dioxide.

The 8RH2 system, by design, captures its carbon dioxide ready for CCUS applications. It also has very high efficiency, reaching 87% efficiency with full carbon capture when integrated with the Allam Cycle, as opposed to conventional systems that operate with up to approximately 64% efficiency and no carbon capture*. Finally, 8RH2 is available today, using commercially available equipment ready for large-scale deployment, as manifested in the Pouakai development.

*Best in class steam methane reformation is approximately 64% efficient with zero carbon capture, giving the integrated 8RH2 process an efficiency advantage of ~27%.

Source: Pouakai NZ Limited Partnership (Pouakai) Submission on Zero Carbon Bill, July 16, 2019

Suggested Victorian Government priorities for reducing Victoria's greenhouse gases and the role of CCS

Electricity supply

There is enormous potential for CCS to deliver significant emissions reductions for Victoria's electricity sector. CCS technology enables low emissions fossil fuel electricity generation, delivering deep emissions reductions and dispatchable power. In addition, dispatchable fossil-based generation with CCS incurs no additional grid integration costs or risks, making it affordable and reliable.

Currently, just over 70 per cent of Victoria's emissions derive from electricity generation, direct combustion and industrial processes, with electricity generation alone expected to account for 42 per cent of Victoria's emissions by 2020**Error! Bookmark not defined..** There is no doubt a rapid shift to decarbonised electricity is essential to Victoria meeting emissions reduction targets. However, the challenge of meeting these targets whilst providing dispatchable electricity supply remains.

The Interim Report presents shifting electricity generation from coal/gas to renewables as the main 'potential emissions reduction action', stating that: "The largest volume of abatement opportunity lies in decarbonising electricity generation by moving to renewable energy sources, while land-based sequestration is an essential 'sink', or offset, to achieve net zero emissions by 2050." (p.67)

Safe, reliable and affordable electricity is reliant on a suite of technologies to meet changing supply and demand patterns. Intermittent renewable energy with energy storage will be an essential part of Victoria's future energy mix but renewable energy alone cannot provide reliable electricity at acceptable cost and risk.

An electricity system with a high penetration of intermittent renewable generation requires enormous energy storage and augmentation systems to ensure reliability and resilience. The cost of energy storage and augmentation increases rapidly as the penetration of intermittent energy sources increases. In 2017 Red Vector and Gamma Energy modelled the Australian east coast electricity grid to determine the cost of deep decarbonisation¹¹. They used a grid services and energy model that always ensures the following conditions are met:

- Energy must balance
- There is sufficient supply of reserve and response services
- There is sufficient inertia
- There is sufficient reliable capacity to meet peak demand.

Further, the model applied all the actual constraints of the NEM, including interconnector limitations, inertial requirements, wind and solar resources based on actual historical resource data etc. In summary, the model ensured that critical real-world engineering and regulatory requirements are met and the laws of physics are respected. In summary, the model found that the lowest cost pathway to deep decarbonisation of the NEM required new-build coal with CCS to reduce the emissions intensity of the NEM by more than 55 per cent (compared to the 2015 baseline used in the study). This is because the marginal cost of intermittent renewables increases dramatically with increasing penetration due to the additional cost of necessary energy storage (and other factors).

A significant finding of this modelling was that batteries can provide sufficient energy storage to ensure system reliability for minutes or perhaps hours, but not for days or longer. To meet current reliability standards, dispatchable generation like gas or coal with CCS or required.

Victoria has the opportunity to become a leader in the deployment of CCS for electricity generation. The State is uniquely placed in implementing this as an emissions reduction solution due to the massive geologic storage resource of the Gippsland Basin*, the proximity of these storage resources to significant brown coal reserves, and the current investment through the CarbonNet project in developing a CO₂ transport and storage network in the region.

CASE STUDY: PETRA NOVA CARBON CAPTURE – TEXAS, UNITED STATES

Petra Nova is the largest post-combustion carbon capture facility in the world on a coal-fired power plant in the world, capturing 1.4 Mtpa of CO₂. The plant entered commercial service in 1977, and the new carbon post-combustion emissions reduction system was first put into operation in January 2017.

The 240-megawatt (MW) carbon capture system that was added to Unit 8 (654 MW capacity) of the existing W.A. Parish pulverized coal-fired generating plant in 2017 and receives about 37 per cent of Unit 8's emissions, which are diverted through a flue gas slipstream. The factor which limited the proportion of flue gas treated to 37 per cent was the business case for the investment. There are no technical impediments to treating 100 per cent of the flue gas to capture 90 per cent of the plant's total emissions. Petra Nova's carbon-capture system is designed to capture about 90 per cent of the carbon dioxide (CO₂) emitted from the flue gas slipstream, or about 33 per cent of the total emissions from Unit 8.

* The Pelican Site has a storage resource of 125 MT CO₂ with high confidence. The 2009 basin-wide analysis by the Carbon Storage Taskforce concluded that the Gippsland Basin has Prospective Storage Resources of at least 31 GT.

Hydrogen

As noted in the Interim Report, the production of hydrogen presents a potentially significant new economic opportunity for Victoria. Hydrogen production using Victoria's brown coal resource and CCS presents the lowest cost method for clean hydrogen production.

A domestic supply of clean hydrogen in Victoria could be used for:

- Domestic heating by replacing methane in reticulated gas (note: greater than 10-15 per cent hydrogen requires conversion of appliances)
- To generate electricity; providing dispatchable, near zero-emissions power (H₂ turbine or fuel cells)
- Decarbonisation of transport, particularly heavy transport where batteries are inadequate
- Export; presenting Victoria with a unique opportunity to meet global hydrogen demand
- The establishment of a sustainable new energy economy for the State.

Commercial scale clean hydrogen production from fossil fuels with CCS

Hydrogen production from fossil fuels with CCS is the lowest cost source of clean hydrogen and is operating at full commercial scale today (e.g. the Quest Hydrogen production facility with CCS, see [Appendix 1](#)).

For hydrogen to make a meaningful contribution to global greenhouse gas emission reductions, it will need to be produced in very large quantities to displace a significant proportion of current fossil fuel demand. The August 2018 COAG hydrogen briefing paper provides one estimate of future hydrogen demand; growing from around 60Mtpa today to over 530Mtpa by 2050¹². Currently, only around four per cent of global hydrogen production (approximately 2.5Mtpa) is from electrolysis of water with the remainder produced from fossil fuel feedstocks (66 per cent) or chemical processes (30 per cent).

As reflected in actual hydrogen production described in the previous paragraph, the production of relevant quantities of hydrogen from renewable electricity and electrolysis is not credible. To illustrate, the production of 500Mtpa of clean hydrogen via electrolysis to meet potential global demand would require approximately 25,000TWh of electricity supplied by renewable or nuclear generation. This is approximately 2.8 times the total global electricity generated from all renewable sources and nuclear combined in 2017. The availability of sufficient nuclear and renewable generation capacity to meet this demand for hydrogen production, and the future demand for low emissions electricity is simply not credible. In comparison, scaling up hydrogen production from methane or coal with CCS is far less challenging. The necessary inputs (coal, methane, pore space for CO₂ storage) are plentiful, and the technology is proven at large scale to be the lowest cost source of clean hydrogen. Today there are four facilities in operation and two under construction, that produce clean hydrogen from fossil fuels with CCS at large scale (200 to 1,300 tonnes hydrogen/day) utilising local resources:

- Great Plains Synfuel Plant in North Dakota, United States, commenced operation in 2000, produces approximately 1,300 tonnes of hydrogen per day in the form of hydrogen rich syngas from brown coal gasification with CCS¹³
- Air Products Steam Methane Reformer for Valero Refinery with CCS in Texas, United States, commenced operation in 2013, produces approximately 500 tonnes of hydrogen per day from natural gas reforming with CCS¹⁴
- Coffeyville Gasification Plant in Kansas, United States, commenced operation in 2013, produces approximately 200 tonnes of hydrogen per day from petroleum coke gasification with CCS¹⁵

- Quest CCS in Alberta, Canada, commenced operation in 2015, produces approximately 900 tonnes of hydrogen per day from natural gas reforming with CCS¹⁶
- Alberta Carbon Trunk Line (ACTL)⁶ in Alberta, Canada, is in construction. ACTL will enable clean hydrogen production in two projects, the Alberta Sturgeon Refinery, producing more than 240 tonnes of hydrogen per day via asphaltene residue gasification with CCS and Agrium fertiliser, producing more than 800 tonnes of hydrogen per day via natural gas reforming with CCS.

Domestic potential of hydrogen

Production of hydrogen in Victoria is likely to be at a much smaller scale than the 500Mtpa required to meet projected global demand. Even at smaller scale, the production of hydrogen from renewable electricity and electrolysis in Victoria is not sustainable.

Today, and for a considerable time into the future, near-zero emissions electricity provided by renewable (or potentially nuclear energy) will be scarce in Australia. The majority of electricity will continue to be generated using coal or gas.

The production of clean hydrogen will add to demand for relatively scarce near-zero emissions electricity. To illustrate, consider a plant that produces sufficient hydrogen to supply 100MW of electricity production using fuel cells. This plant would produce approximately 100 tonnes of hydrogen per day.

The following table compares the power requirements for clean hydrogen production using steam methane reforming with CCS, coal gasification with CCS and Proton Exchange Membrane electrolysis. All figures quoted are approximate and based upon data contained in the paper by Mehmeti et al¹⁷.

	Specific Electricity Consumption (kWh/kg of H₂)	Approximate Continuous Power Requirement (MW)	Required Renewable Electricity Installed Capacity Assuming a Capacity Factor of 0.3
Electrolysis (PEM)	54.6	227	757MW
Steam Methane Reformation with CCS	2	9	30MW
Coal Gasification with CCS	4	18	60MW

Table 1. Electricity requirements for 100 tonne per day hydrogen production

This illustrative analysis shows that production of clean hydrogen using electrolysis uses 25 times more electricity than steam methane reforming with CCS and 12 times more energy than coal gasification with CCS. A plant producing 100 tonnes per day of clean hydrogen via electrolysis would require 750MW of installed renewable electricity capacity to power it.

Given the scarcity of renewable electricity, and its critical role in displacing high emission fossil fuel generation in the grid, its efficient utilisation should be a key consideration when comparing options. On that basis, the best option would be to produce clean hydrogen from gas or coal with CCS. In this example (100 tonne per day production), electricity demand would be reduced by over 200MW, or, if

sufficient renewable electricity was available, an additional 200MW of coal generation would be displaced from the grid, delivering over 1.5Mt CO₂ of domestic abatement per year.

Hydrogen for domestic use in Victoria

In Victoria, clean hydrogen could be used in domestic heating by replacing methane in reticulated gas. Reducing the emissions intensity of reticulated natural gas supply is a significant, immediate and low-cost opportunity.

The potential of hydrogen for domestic heating utilising existing gas reticulation infrastructure has been demonstrated by the UK city of Leeds in a 2016 detailed economic and technical feasibility study¹⁸. The study confirmed the opportunity to decarbonise domestic heating with hydrogen by converting the existing natural gas network with minimal new energy infrastructure required.

Hydrogen can be introduced into the natural gas network at concentrations of 10-15 per cent without any modification of the network or end-user appliances. This would deliver commensurate emission reductions. Over time, the gas network and end-user appliances can be modified to accept 100 per cent hydrogen, completely decarbonising domestic heating.

The production of hydrogen in the Latrobe Valley of Victoria with CCS can be the anchor investment required to establish a low-emission industry hub. The Latrobe Valley hosts coal and natural gas feedstock for hydrogen production and is adjacent to a world-class CO₂ storage basin with several prospective storage sites. CO₂ transport and storage infrastructure constructed to support a low-emission industry hub in this region can be utilised by nearby high-emission industry sources such as the Longford Gas Plant.

The Longford Gas Plant presents the ideal opportunity for a hydrogen production and distribution network by integrating CCS infrastructure, similar to the HyNet North West and H21 North of England projects of the UK (see below text box).

CASE STUDIES: HyNet and H21 facilities in the UK: Examples of CCS equipped hydrogen production facilities

The HyNet North West project is a CCUS-equipped hydrogen production and distribution network developed by the UK gas distribution company Cadent together with Progressive Energy and ENI. The facility will produce hydrogen from natural gas that will then be supplied to industrial sites, to households for heat supply and serve as transport fuel. The project has the potential to serve more than 2 million homes and businesses.

The H21 North of England project aims to decarbonise power, heat and transport across the North of England. It will convert the UK gas grid from natural gas to CCS decarbonised hydrogen, converting 3.7 million-meter points across Leeds, Bradford, Manchester, Liverpool, Hull, York, Teesside and Newcastle. The clean hydrogen will be produced from large-scale production plants with 12.15 GW capacity, with integrated CO₂ capture processes to capture up to 20 Mtpa CO₂ by 2035 in several phases. CO₂ storage is planned to be in saline aquifers and depleted gas fields in the Southern North Sea, which can potentially facilitate the advantages of the UK's growing CCS capacity and a CCS trade with Europe.

These facilities are exemplary for Victoria, as the HESC project can also be similarly instrumental in decarbonising the power, heat and transport sectors across Victoria.

Transport

Approximately 20 per cent of Victoria's emissions come from the transport sector. Deep emission reductions in the transport sector are available through a shift from conventional fossil fueled vehicles to a mix of plug-in electric vehicles, hydrogen fuel cell electric vehicles, and biofuel. Plug in electric vehicles will increase demand for low emission electricity. CCS on power generation can help meet that demand (e.g. the Petra Nova coal fired power plant with CCS).

The deployment of hydrogen fuel cell vehicles requires a large and competitively priced supply of clean hydrogen. If competitively priced, clean hydrogen is made available in Victoria, with staged investment in hydrogen refueling infrastructure, demand for hydrogen fuel cell powered vehicles will be initiated. Over time, as refueling infrastructure expands, and costs reduce, hydrogen could play a significant role in decarbonising Australia's transport sector.

The use of hydrogen as a clean fuel is already being acknowledged around the world. As demonstrated in the following section, the UK, Japan and China are emerging as leaders in hydrogen to decarbonise their transport sectors. The Victorian government has an enormous opportunity to take initiative in this regard by adopting hydrogen as the fuel of Victoria's low emissions transport future.

Decarbonising transport with Hydrogen

The UK's response to reducing emissions from the transport sector holds valuable lessons for the Victorian context. In the UK, a fleet of eight hydrogen buses have been introduced in the Transport for London network and have been in operation since 2011. By 2016, the city was benefiting from additional buses, as well as taxis, fuel cell vehicles and vans supported by hydrogen fueling stations¹⁹. In 2020, London will be the first city to introduce a fleet of double decker hydrogen buses, investing a further 12 million GBP into their hydrogen network. A hydrogen-powered train is also being tested in the UK with plans for it to run on the mainline within two years.

In Japan, with hydrogen-powered fuel cell vehicles (FCVs) running on public roads already, the country aims to increase the number of FCVs to 40,000 units by 2020 and 200,000 units by 2025. It also aims to increase the number of fuel cell buses in Japan to around 100 by FY 2020 and to around 1200 by FY 2030.

China has supported fuel cell vehicle initiatives since 2000 under an environmental program run by the United Nations Development Program. The program has led to the operation of 109 fuel cell buses in several cities across China. In 2016, China proposed a policy to foster the industrialisation of fuel cell vehicles, with an aim to produce and sell two million vehicles by 2020. In 2018, China's presence in the production of FCVs expanded, with the production of around 2000 small trucks.

CCS and the new energy economy

CCS has a vital “conduit” role to play in establishing a new, low emissions economy of the future by facilitating the creation of new energy economies, which are yet to reach their apex. A good example is the Hydrogen Energy Supply Chain (HESC) in the Latrobe Valley which will demonstrate hydrogen production from brown coal in the Latrobe Valley and export of hydrogen from Victoria to Japan. The HESC project is a collaboration between leading Japanese companies (Kawasaki, JPower, Iwatani, Marubeni), Shell, AGL and the Japanese, Victorian and Australian governments.

In a context where the energy matrix in Victoria is continuing to evolve, the decision to turn brown coal into clean hydrogen is an extremely significant development as it serves as the perfect opportunity to showcase the potential of CCS in establishing a new low emissions industry of the future. The development will be the epitome of a just transition; creating a new low emission industry hub to create and sustain high value jobs and investment for the local community whilst generating export revenue for Australia.

Policies needed to drive emissions reductions

Government alone cannot solve the challenge of climate change. The solutions will be developed, commercialised and deployed by the private sector which has enormous resources and capabilities. Government policy should create incentives for large private sector investments in climate solutions. In summary, government policy should align private and public good investment incentives to drive capital towards delivering emissions abatement. Some examples of policies that are proving effective at driving private sector investment in CCS are described below. Some of these may not be directly applicable to the State of Victoria due to the allocation of State and Commonwealth powers under the Australian Constitution. Nonetheless, their effectiveness in delivering tens of millions of tonnes of annual emission abatement warrants consideration to determine whether similar policies, or policies that establish similar incentives, could be relevant in the state of Victoria.

Tax credits

The introduction of credits in the US have provided an incentive for the geological storage of CO₂. This has been widely recognised as an important enabler of the six large-scale facilities in the US that have come on stream since 2011, including some in higher cost capture sectors such as coal fired power generation e.g. Petra Nova (see [Appendix 1](#)). Tax credits have the benefit of being well established in the context of climate change mitigation in the region, having been used to drive significant investment in renewables over the past two decades. Two of the most notable examples, from the United States, are:

“45Q” Tax Credit

This tax credit, known as 45Q in reference to the relevant section of US tax code, was extended and increased in February 2018. Under the current arrangements, 45Q provides tax credits worth \$18/tCO₂ for CO₂ used for EOR and \$29/tCO₂ for CO₂ stored through dedicated geological storage, rising linearly to \$35/tCO₂ and \$50/tCO₂ by 2026 respectively.

The credits can be used to reduce a company’s tax liability or, if they have no tax liability, transferred to the company that disposes of the CO₂ or traded on the tax equity market.

Low Carbon Fuel Standard

California's Low Carbon Fuel Standard (LCFS) places lifecycle carbon intensity targets on all transportation fuels sold in California, with the aim of diversifying the State's fuel mix, reducing petroleum dependency, and reducing GHG emissions and other air pollutants. Fuels that have a lower carbon intensity than the carbon intensity target generate credits and fuels with a higher carbon intensity than the target generate deficits.

In 2018, the LCFS was amended to enable CCS projects that reduce emissions associated with the production of transport fuels sold in California, and projects that directly capture CO₂ from the air, to generate LCFS credits. These changes came into effect in January 2019. To qualify, projects need to meet the requirements of the CCS Protocol which is subordinate to the LCFS Regulation Order. The changes have attracted attention from policymakers in other jurisdictions and CCS project developers keen to understand the program, particularly given the credits have been trading on average between \$122/tCO₂ and \$190/tCO₂ in the past 12 months to February 2019⁸.

Carbon Pricing

An alternative approach to placing a value on emissions reduction would be to introduce a cost for emitting. A carbon tax introduced in Norway in 1991 has been successful in incentivising the development of the Sleipner and Snøhvit CCS projects. At \$17/tCO₂, the cost of injecting and storing CO₂ for the Sleipner project was much less than the \$50/tCO₂ tax penalty at the time for CO₂ vented to the atmosphere²⁰. This was complemented by a commercial need to separate the CO₂ from natural gas to meet market requirements and provided a clear business case to invest in CCS. The current level of the tax is higher than the level when it was introduced, making the business case for CCS at Sleipner even stronger²¹.

Capital Support

In the early stages of deployment, capital support from government is likely to be necessary to mobilise private capital in the majority of cases. This strategy has been very effective in accelerating the global deployment of renewables which have received well over US\$1000 billion in direct subsidies this century. Capital support may take the form of grants, tax credits, concessional loans, or accelerated depreciation on CCS assets. Direct equity investment in CCS facilities is another option that may be considered by government. Over time, as the value (explicit or implicit) on CO₂ increases, and the cost of CCS decreases, the requirement for capital support will reduce until the business case for investment in CCS is created by normal market forces. Until that time, to deliver the public good of a stable climate, government can enable private investment in CCS by providing capital support where required. This has proven effective for commercial scale facilities in the North America which have typically received capital grants of around \$200 million each.

Regulation of emissions

Regulation has also played a role in supporting the deployment of CCS by placing an implicit value on emissions. For example, a mandatory condition for the approval of the Gorgon project in Australia was the injection of at least 80 per cent of the CO₂ released by the gas processing operations. As one of the

largest natural gas projects in the world, the additional costs of compressing and storing CO₂ were manageable in the context of the project as a whole, adding less than five per cent to the total project costs.

Once launched, the project is projected to be the world's largest dedicated CO₂ storage facility with the ability to store up to 4 Mtpa of CO₂²². The expectation of a future tax on carbon has also been raised as a reason for CCS being adopted for the Gorgon project. This highlights an important point, that it is not just current policies but also expected future policies that determine an investors decision to support a CCS project.

State ownership of CCS facilities

Some governments have overcome the barriers to private sector investment by supporting the construction of CCS facilities through State Owned Enterprises (SOEs). Stable governments can borrow at very low interest rates, helping to bring down the effective cost of capital of projects. Some elements of CCS also lend themselves well to state ownership due to their natural monopoly characteristics, such as the development of carbon dioxide transport and storage infrastructure.

For example, government could make the initial investment establishing transport and storage infrastructure for an anchor customer and then expand the network to service growing demand. This hub would attract further investment from other emissions intense industries seeking to establish operations in precincts that offer carbon dioxide storage services. In this way, Government can kickstart a hub and cluster development with the option of privatizing the business after it has recruited sufficient customers (CO₂ emitters requiring CO₂ transport and storage services) to deliver sound financial performance.

Initial government investment could represent any level of equity up to 100 per cent. The determining factor should be the minimum public sector investment necessary to establish and operate the infrastructure. This model of government making the initial investment in infrastructure followed by later privatization is proven in other sectors such as road and rail transport, power generation and transmission and telecommunication.

Role of government in CCS investment

In the context of government's role in providing for the public good, and the definition of a stable climate as a public good, government support of CCS and other climate mitigation technologies is justified. It also introduces the concept of government support being an investment which delivers returns in the form of public goods, rather than financial profits. This is an important concept with respect to opportunities for government to attract private sector investments in CCS by taking on certain costs and risks during the early stages of deployment.

Another important concept to recognise is that government alone will not solve the challenge of climate change. The solutions (and there are many) will be developed, commercialised and deployed by the private sector which has enormous resources and capabilities. All that is required are the incentives to mobilise private capital, and the creation of those incentives is entirely within purview of government.

Barriers to reducing greenhouse gas emissions in Victoria

The greatest barrier to the deployment of CCS as an essential emissions reduction solution in Victoria is the lack of business case, and the policies required to support such a business case.

The scaling up of CCS deployment will only be achieved if there is a clear commercial case to invest in CCS. Governments have a pivotal role to play, by providing a clear, stable and supportive policy framework. While the policy landscape has improved in recent years, there remain gaps that are holding back investment in CCS, and therefore preventing the achievement of global climate targets.

Investments in large-scale CCS facilities around the world have predominantly relied on supportive policies, revenue from Enhanced Oil Recovery and low-cost capture, transport and storage opportunities. This coincidence of circumstances has enabled a positive financial investment decision on 23 large scale facilities to date which has proven the technology over almost five decades of operational experience²³.

However, for CCS to be deployed at the rate required to meet emissions reductions targets, governments must implement policy frameworks that align private and public good investment incentives to drive private capital into CCS at a much greater scale.

Policy must not only support the business case for investment in CCS, it must win the confidence of investors, because once policy confidence is in place, long-term capital investments can be made and the virtuous cycle of investment and cost reduction will accelerate.

Conclusion

CCS presents an essential opportunity for Victoria to reduce emissions and reach reduction targets at least cost.

It is clear that CCS should be a key component of Victoria's broader strategy to achieve net-zero emissions by 2050.

However, the rate and scale of change in the Victorian economy necessary to deliver that outcome requires that planning and action occur now.

Appendix 1: Large scale CCS Facilities in operation

Title	Country	Operation Date	Industry	Capture Capacity	Capture Type	Storage Type
Terrell Natural Gas Processing Plant (formerly Val Verde Natural Gas Plants)	United States	1972	Natural Gas Processing	0.4 – 0.5	Industrial separation	Enhanced Oil Recovery
Enid Fertilizer	United States	1982	Fertiliser Production	0.7	Industrial separation	Enhanced Oil Recovery
Shute Creek Gas Processing Plant	United States	1986	Natural Gas Processing	7.0	Industrial separation	Enhanced Oil Recovery
Sleipner CO2 Storage	Norway	1996	Natural Gas Processing	1.0	Industrial separation	Dedicated Geological Storage
Great Plains Synfuels Plant and Weyburn-Midale	Canada	2000	Synthetic Natural Gas	3.0	Industrial separation	Enhanced Oil Recovery
Snøhvit CO2 Storage	Norway	2008	Natural Gas Processing	0.7	Industrial separation	Dedicated Geological Storage
Century Plant	United States	2010	Natural Gas Processing	8.4	Industrial separation	Enhanced Oil Recovery
Coffeyville Gasification Plant	United States	2013	Fertiliser Production	1.0	Industrial separation	Enhanced Oil Recovery
Air Products Steam Methane Reformer	United States	2013	Hydrogen Production	1.0	Industrial separation	Enhanced Oil Recovery
Lost Cabin Gas Plant	United States	2013	Natural Gas Processing	0.9	Industrial separation	Enhanced Oil Recovery
Petrobras Santos Basin Pre-Salt Oil Field CCS	Brazil	2013	Natural Gas Processing	1.0	Industrial separation	Enhanced Oil Recovery
Boundary Dam Carbon Capture and Storage	Canada	2014	Power Generation	1.0	Post-combustion capture	Enhanced Oil Recovery
Quest	Canada	2015	Hydrogen Production	1.0	Industrial separation	Dedicated Geological Storage
Uthmانيyah CO2-EOR Demonstration	Saudi Arabia	2015	Natural Gas Processing	0.8	Industrial separation	Enhanced Oil Recovery
Abu Dhabi CCS (Phase 1 being Emirates Steel Industries)	United Arab Emirates	2016	Iron and Steel Production	0.8	Industrial separation	Enhanced Oil Recovery
Illinois Industrial Carbon Capture and Storage	United States	2017	Ethanol Production	1.0	Industrial separation	Dedicated Geological Storage
Petra Nova Carbon Capture	United States	2017	Power Generation	1.4	Post-combustion capture	Enhanced Oil Recovery
Jilin Oil Field CO2-EOR	China	2018	Natural Gas Processing	0.6	Industrial separation	Enhanced Oil Recovery

Appendix 2: Large scale CCS Facilities in construction and advanced development

Title	Status	Country	Operation Date	Industry	Capture Capacity	Capture Type	Storage Type
Gorgon Carbon Dioxide Injection	In Construction	Australia	2019	Natural Gas Processing	3.4 - 4.0	Industrial separation	Dedicated Geological Storage
Alberta Carbon Trunk Line ("ACTL") with North West Redwater Partnership's Sturgeon Refinery CO2 Stream	In Construction	Canada	2019	Oil Refining	1.2 - 1.4	Industrial separation	Enhanced Oil Recovery
Alberta Carbon Trunk Line ("ACTL") with Agrium CO2 Stream	In Construction	Canada	2019	Fertiliser Production	0.3 - 0.6	Industrial separation	Enhanced Oil Recovery
Sinopec Qilu Petrochemical CCS	In Construction	China	2019	Chemical Production	0.4	Industrial separation	Enhanced Oil Recovery
Yanchang Integrated Carbon Capture and Storage Demonstration	In Construction	China	2020 - 2021	Chemical Production	0.4	Industrial separation	Enhanced Oil Recovery
Norway Full Chain CCS	Advanced development	Norway	2023-2024	Cement production and waste-to-energy	0.8	Various	Dedicated Geological Storage
CarbonNet	Advanced development	Australia	2020's	Under evaluation	3.0	Under Evaluation	Dedicated Geological Storage
Lake Charles Methanol	Advanced development	United States	2022 (Institute estimate)	Chemical production	4.2	Industrial separation	Enhanced oil recovery
Port of Rotterdam CCUS Backbone Initiative (Porthos)	Advanced development	Netherlands	2021	Various	2.0 -5.0	Various	Dedicated Geological Storage

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