Elizabeth Sullivan
elizabeth.sullivan@acf.org.au
476002534

Australian Conservation Foundation
To the Northern Territory Environment Protection Authority,

The Australian Conservation Foundation (ACF) is Australia's national environmental organisation. We are 700,000 Australians speaking out for the air we breathe, water we drink and places and wildlife we love.

ACF submits that the NTEPA should undertake assessment of the Darwin Pipeline Duplication Project and that, given the significant environmental impacts of this Project, the assessment should occur at the highest level, namely that of a public inquiry. Below we raise some more detailed concerns about potentially significant impacts of the project.

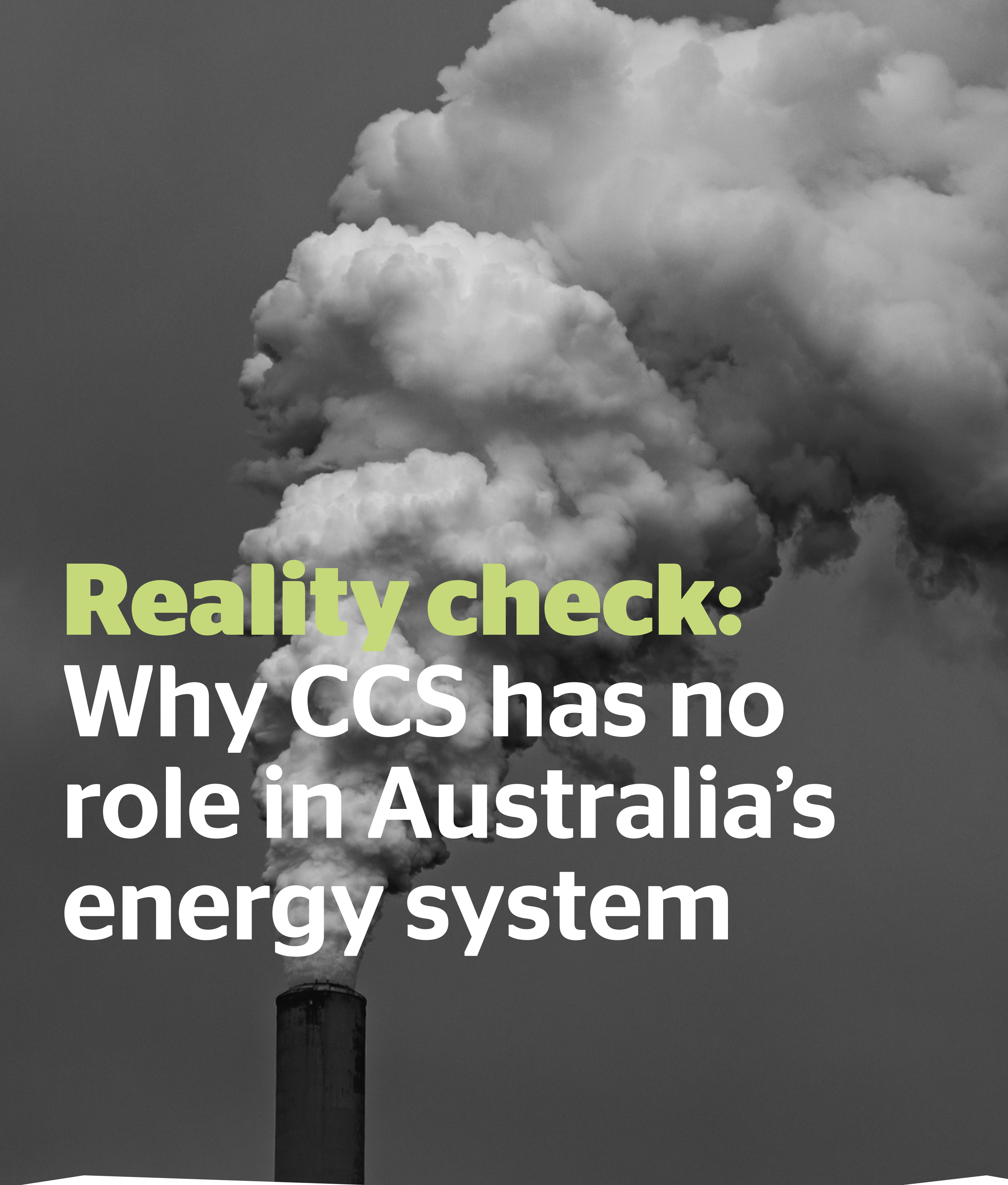
Emissions profile of the project

The referral documents submitted by the proponent claim that the greenhouse gas (GHG) emissions of the project are not relevant to this assessment because they have existing approvals. This is a flawed approach for the proponent to take and should not be accepted by the NTEPA. Previous approvals have been given under old legislation that has now been superseded by the Environment Protection Act 2019 (EP Act). We therefore believe it would be remiss for the overall emissions profile of the Barossa project not to be publicly assessed by the NTEPA under the current relevant Act. Whether the proposed Project will lead to an increase in emissions that exceeds the threshold established by previous approvals needs to be investigated, and the most appropriate method for this investigation is a public inquiry. Expert evidence suggests that emissions from the Barossa project will be significant and detrimental to Australia's carbon budget.

Carbon Capture and Storage (CCS)

Any decision concerning whether to undertake an assessment of the Project must consider the purpose for which the Project is being carried out, which is explicitly referred to by the proponent as making available the existing pipeline for CCS. Consequently, the claims made by the Proponent in the referral documents concerning the ability for CCS to allow net zero emissions targets to be reached must be appropriately scrutinised. The feasibility of CCS is not established, and in fact there is no successful example of an offshore gas field being used to reach emissions capture targets. We submit that a public inquiry, broad enough in its scope to investigate the feasibility and potential impacts of CCS, must therefore be undertaken.

The scope of a public inquiry must be wide enough to allow for an examination of the overall emissions of the Barossa project, the feasibility of CCS, the cumulative impacts of emissions from gas being transported in the pipelines relevant to this project, and local impacts to Darwin Harbour of the pipeline duplication. Anything less than an inquiry into the overall impacts of the entire project would be inadequate. An inquiry is needed to allow for community awareness of this enormously significant Project that will impact not just the local environment, but the ability for the Northern Territory Government to achieve its stated emissions reductions targets.



Reality check: Why CCS has no role in Australia's energy system

Victoria Energy Policy Centre

VICTORIA UNIVERSITY
MELBOURNE AUSTRALIA

A review of the evidence: Costs of carbon capture and storage applied to electricity generation in Australia

Report prepared for the Australian Conservation Foundation

Associate Professor Bruce Mountain

December 2020

Victoria Energy Policy Centre

VICTORIA UNIVERSITY
MELBOURNE AUSTRALIA

Publisher: Victoria Energy Policy Centre, Victoria University, Melbourne, Australia.

ISBN: 978-1-86272-821-9

Citation: Mountain, B. R. (2020). *A review of the evidence on the carbon capture and storage applied to electricity generation in Australia.* Report prepared for the Australian Conservation Foundation. Victoria Energy Policy Centre, Victoria University, Melbourne.

Authors' affiliations: Associate Professor Bruce Mountain is the Director of the Victoria Energy Policy Centre.

.

Table of contents

1 Introduction

This report responds to a request from the Australian Conservation Foundation to undertake a desk-top review of the cost of carbon capture and storage (CCS) applied to electricity generation in Australia.

We survey the latest available evidence from Australian sources (CO_2CRC, Global Carbon Capture and Storage Institute, the Federal Department of Energy and CSIRO). As a point of reference, we compare the estimated costs of coal generation plus CCS to the most recent publicly available data of the cost of wind generation (and including 50% storage as a proportion of capacity).

Our analysis suggests carbon capture and storage is likely to cost at least six times as much as wind generation plus storage, with comparable dispatchability (ability to generate electricity when needed to meet demand).

We would like to stress that this is a desk-top study of other organisation's estimates. The organisations we cite – while no doubt using their best endeavours to provide accurate estimates – have very limited data to draw on. For electricity generation, only two commercial-scale capture and storage examples exist globally and one of those two have already been mothballed and the second operates far below its design capacity. Another seven proposals have been studied but rejected and so their cost estimates (similar to the claims of the two that were developed) have limited value. New technologies may reduce capture costs in future, but none of these technologies appear to be anywhere close to commercialisation.

There are several other examples of CO_2 storage in the context of enhanced oil extraction. But this CO_2 is not sourced from electricity generation.

With regard to CO_2 transport and shipping, there seems to be less dispute on the range of these costs, but there is no experience of pipeline CO_2 transport or storage in Australia to validate the estimates that have been made (and which we have used).

Sections 2, 3 and 4 examine in order the costs of carbon capture, transport and storage. Section 5 examines the cost of renewable energy generation including firming through storage based on recent Australian evidence. The final section discusses the evidence and makes final conclusions.

2 Carbon capture

How much might carbon capture cost if applied to existing or new coal fired electricity generators in Australia? In answering this question we draw heavily on the most recent report we know of that seeks to answer this question (see (CO2CRC, 2017)). The main conclusion of their report (which we find their own numbers do not support) is (verbatim) "*retrofitting base load coal power with CCS will help achieve reliable 24/7, lowest cost and a clean energy future for Australia on some plants*" (p.XI).

Table 1 summarises the main claims in the report on the capital cost of carbon capture, the impact of capture on variable production costs, the efficiency reduction attributable to capture and the increase in the levelised cost of electricity[1] (LCOE) attributable to capture. The main points from this are that carbon capture will more than double the capital outlay of coal-fired generation, will reduce production efficiency by more than 40% for new plants or around 30% for retrofit plants, and will increase the levelised cost of electricity by between $90 and $125/MWh.

Table 1. Summary of costs and efficiency impact of carbon capture at coal plants (assuming 90% CO_2 emissions are captured)

Technology	Capital cost of carbon capture ($/kW sent-out)	Carbon capture variable cost ($/MWh)	Efficiency reduction attributable to capture	Increase in Levelised Cost of Electricity attributable to capture ($/MWh)
New Super Critical brown coal with CCS	$4,400	9	44%	102
New Ultra Super Critical Black coal with CCS	$3,900	6.5	27%	100
Retrofit brown coal CCS retrofit (Base Case)	$4,900	14	43%	125
Retrofit black coal CCS retrofit (Base Case)	$4,100	11	31%	90

The report also presents case studies of carbon capture retrofit, firstly to a 2,100 MW brown coal power station (the report does not mention Loy Yang A but presumably had it in mind, Loy Yang A being the only brown coal plant of comparable capacity in Australia) and secondly

[1] This is the average of cost of electricity over the life of the plant allowing for the recovery of all costs and a return on investment and taking account of the expected life and production of the plant over its life.

to a “single boiler” at a black coal plant in either New South Wales (NSW) or Queensland (QLD):

- for the brown coal retrofit, the report says capture retrofit will increase the levelised cost of electricity by $125/MWh; and
- for the NSW and QLD black coal “single boiler” capture retrofit they say that capture retrofit will increase levelised costs by $98/MWh and $97/MWh respectively.

The report does not provide the information (such as economic life and cost of capital) needed to understand how capital cost and efficiency assumptions have been translated into the estimate of the levelised cost of electricity. The report compares these increases (and their estimate of the all-up levelised cost of coal generation with CCS) to the levelised cost of wind and solar electricity (which the report says is $100/MWh and $108/MWh respectively – using the mid-point of their ranges).

In international studies of carbon capture and storage, a seminal report was prepared for the Inter-Government Panel on Climate Change (IPCC) in 2005 - see (Metz, Davidson, de Coninck, & Loos, 2005)). The IPCC report presented detailed estimates of capture costs. Academic research that reviewed the IPCC’s report a decade later (see (Rubin, Davison, & Herzog, 2015)) concluded that the capital cost of coal (and gas) generators both with and without increased carbon capture had increased substantially on the IPCC’s estimates. In the case of post combustion carbon capture (the most promising technology), the research concluded that capital costs increased by 119% on the amounts that had been estimated in the IPCC’s 2005 report.

The Global CCS Institute’s 2019 “Global Status of CCS Report” (see (Global CCS Institute, 2019)) provides data on the actual cost of carbon capture at the two post-combustion capture coal-fired plants that have been built (Boundary Dam in Canada and Petra Nova in Texas) at USD110 (AUD157) and USD65 (AUD93) per tonne CO_2 respectively.

Assuming Boundary Dam had managed to achieve the 90% capture rate that it was designed to achieve, this would translate into capture costs of AUD141/MWh and AUD84/MWh respectively. However in its four years of operation to mid 2018 it had only captured half as much as it was designed to achieve (Schlissel & Wamstad, 2018) and Saskpower (owner) decided not to proceed with CCS with the remaining two generating units at the plant and will instead close these units.

The Petra Nova plant captured CO_2 for 3.5 years but the CCS operation has now been mothballed (Wamstad & Schlissel, 2020), because the revenue it gained from the sale of CO_2 for enhanced oil recovery presumably did not cover its operating costs.

Another nine "previously studied" CCS projects (none of which proceeded to construction) were also identified in the GCCSI report, which claims that they have capture costs somewhere between Petra Nova (close to the cheapest) and Boundary Dam (close to the most expensive).

The GCCSI's report also identifies what it calls "*Recently proposed and new facilities*" and says the capture costs of these are in the range from USD35-45 per tonne CO_2. However, our review of the publicly available information on these "Recently proposed and new facilities"[2] finds that, with the exception of the San Juan and Project Tundra CCS retrofit proposals, none are "facilities" that will actually capture CO_2 from coal generators.

In respect of San Juan, it is difficult to conclude that San Juan is much more than an early-stage prospect. On its website, the developer (Enchant Energy) describes it merely as "a proposal to partner with the City of Farmington"[3] and the latest development seems to be the receipt of grants from the U.S. Department of Energy, to study it further.

---

2 Project Tundra: https://www.projecttundrand.com/
Surat CCS: http://ctsco.com.au/
Linde/BAS OASE: https://www.linde-engineering.com/en/images/Carbon-capture-storage-utilisation-Linde-BASF_tcm19-462558.pdf
Shand: https://www.saskpower.com/Our-Power-Future/Infrastructure-Projects/Carbon-Capture-and-Storage/Shand-Carbon-Capture-Test-Facility
Ion c3DC: https://www.globalccsinstitute.com/wp-content/uploads/2020/03/2-ION-CLEAN-ENERGY-DC-FORUM.pdf
San Juan: https://ieefa.org/wp-content/uploads/2020/02/Proposed-CCS-Project-at-San-Juan-Generating-Station_February-2020.pdf ; https://www.utilitydive.com/news/can-carbon-capture-save-the-san-juan-coal-plant/567678/
Our search for "Fuel cell MCSE" failed to find any information that could substantiate a claim on capture costs.

3 https://www.enchantenergy.com/los-alamos-analysis-of-san-juan-generating-station-carbon-capture-study-shows-promise/

In respect of Project Tundra, the Project Tundra website[4] describes it as a research project led by Minnkota Power Cooperative, supported by the Energy & Environmental Research Center at the University of North Dakota.

The focus of CO_2 capture in electricity generation tends to mainly focus on coal-fired rather than gas-fired electricity generation. The main reason for this is that CO_2 density in exhaust stacks from coal generators tends to be between twice and three times that of gas generators (Leung, Caramanna, & Maroto-Valer, 2014). The higher density results in far greater CO_2 volumes. This results in a large volume over which to amortise the capital outlays needed to capture the CO_2. Since these outlays are roughly comparable for gas and coal-fired generators, the resulting cost of CO_2 capture when expressed per unit of CO_2 or per MWh generated, tends to be much higher for gas generators than coal generators. For example, the International Energy Agency (2006) suggests that post combustion capture costs in gas generation are around twice those in coal; pre-combustion capture is around four times more expensive in gas than coal and oxy-fuel capture is around three times higher in gas than coal. For these reasons, it is not surprising that there is no evidence of any commercial scale carbon capture applied to gas-fired generators.

4 https://www.projecttundrand.com/about

3 Carbon transport

This section examines the cost of transporting captured (and liquefied) carbon dioxide to its storage location. CO_2 transport will be a significant part of the cost of CCS, at least comparable to the cost if storage itself.

Metz (2005) note that the properties of liquefied carbon dioxide are not greatly different from those of liquefied petroleum gases, that the technology can be scaled up to large carbon dioxide carriers and that carbon dioxide pipelines are not new: they extend over more than 2500 km in the western USA, where they carry 50 $MtCO_2$ yr^{-1} from natural sources to enhanced oil recovery projects in west Texas and elsewhere (p181).

The European Commission's Joint Research Centre Institute for Energy has comprehensively surveyed the technical and economic literature on CO_2 transmission pipeline infrastructure (see (Serpa, Morbee, & Tzimas, 2011)). Pipeline capital costs are generally quantified per unit length, and tend to increase linearly with the pipeline diameter, and pipelines exhibit significant economies of scale, e.g. a pipeline carrying 5 Mt/y of CO_2 may not be much more expensive than a pipeline carrying 1 Mt/y and a joint CO_2 pipeline network may be significantly cheaper than individual source-sink connections. The report uses two well specified models, one produced by the Centre for Energy Economics at Carnegie Mellon University (CMU) and the other produced by the International Energy Agency (IEA), to estimate the relationship between pipeline length and total transport cost (Euros per tonne per kilometre). Using this information, we can estimate the cost of pipeline CO_2 transport from coal generators in either Queensland or New South Wales. Specifically, a pipeline that is able to transport 10,000 tonnes CO_2 per day and is available all the time, can ship 3.7 million tonnes CO_2 per annum. Taking the mid-point of the CMU and IEA estimates of the relationship between pipeline length and transports cost, a pipeline designed to transport 3.7 mtpa, assuming unit costs are constant from 1000km to 1500km (the distance to ship CO_2 to Santos's proposed Eromanga basin storage) gives a pipeline cost of Euros17 per tonne to transport CO_2 to Santos' injection point at Moomba. At contemporary Euro/AUD exchange rates this translates into a shipping cost of AUD 31 per tonne CO_2.

This is comparable to the estimates in the then Department of Resources, Energy and Tourism's "National Carbon Mapping and Infrastructure Plan" (see (Carbon Storage Taskforce, 2009)) which estimates the cost of shipping CO_2 from south Queensland to Eromanga at $30 per tonne CO_2 (excluding injection costs) or $34 per tonne including injection costs.

4 Carbon storage

A comprehensive description of Australia's underground carbon sequestration potential is set out in Carbon Storage Taskforce (2009). This report identified that the most prospective sequestration opportunities were in the Eromanga/Cooper basin in central Australia, the Otway Basin in south west Victoria and the Gippsland basin off the coast of eastern Victoria. It also suggested storage costs in the Eromanga basin of around $30–60 per tonne avoided (p1).

Since the time of that report in 2009, there appears to be no further development of CO_2 sequestration options in either the Gippsland or Otway basin. However, in respect of the Cooper basin, South Australian gas producer Santos has frequently drawn attention[5] to its desire to develop CO_2 sequestration at Moomba. Most recently Santos has commissioned engineering studies to explore the potential of producing "blue hydrogen" (hydrogen produced by separating hydrogen molecules from the hydro-carbon pairing of gas) and sequestering the CO_2 in its Moomba gas fields. The most recent price of CO_2 capture that Santos has publicly claimed (on 22 October 2020) is $30/tonne. It is not clear whether this claimed price covers all costs associated with injection and storage, or just the storage cost; where the precise injection point is; how the claimed $30/tonne charge may change in time; and what liability Santos will accept for the risks associated with insecure long duration storage.

5 See for example: https://www.santos.com/news/santos-looks-to-hydrogen-future-through-carbon-capture-and-storage/; https://www.santos.com/news/santos-and-bp-enter-non-binding-agreement-on-moomba-carbon-capture-and-storage-project/; https://www.oilandgastoday.com.au/santos-supports-plan-to-pave-way-for-carbon-capture-and-storage/; https://www.santos.com/news/moomba-carbon-capture-and-storage-injection-trial-successful/

5 Comparative renewable electricity production prices

A point of comparison to coal generation with a very high proportion of CO_2 capture per MWh produced, is variable renewable energy generation (wind and solar) with sufficient integrated or contracted storage to provide comparable dispatchability.

A reliable publicly available estimate of the LCOE of such generation can be obtained from the results of the Australian Capital Territory's renewable energy auctions held in September 2020.

This shows that Neoen was awarded a 14-year contract, unindexed, paying $44.97/MWh for the 100 MW of wind generation that it offered[6]. As a condition of the auction, participants were required to develop or contract for front-of-meter storage equivalent to 0.1 MW and 0.2 MWh per MW of wind-equivalent production that they offered, although the auction provided no additional compensation for this storage.

Neoen choose to go considerably beyond this storage requirement, by offering to provide a 50 MW battery (i.e. 0.5 MW of storage per MW of wind generation that it offered).

A battery of this size (assuming around two hours storage capacity at peak continuous rating) along with its wind farm, will ensure Neoen is able to provide a substantially "firm" supply and leave only small residual spot price risk for a load portfolio it is likely to assemble. As such, we suggest that the price Neoen offered is a reasonable point of comparison to costs of coal plus CCS plant (assuming such a capacity is able to deliver reliable supply and noting that this has not yet been achieved).

In its 2019 generation cost projections, CSIRO (see (Graham, Hayward, & Havas, 2020)) estimate the costs of wind and solar with 2 hours of battery storage to be in the range of $48–$75/MWh; or $75–$140/MWh if including 6 hours of pumped hydro storage. The Neoen price is at the bottom end of this range.

6 https://www.neoen.com/var/fichiers/1599550179-neoen-awarded-14-year-contract-for-100-mw-in-australian-capital-territory-renewables-auction.pdf

In other markets, the Lawrence Berkely Laboratory[7] tracked 14 large scale solar plus battery storage projects recently developed in the United States. They estimate that a solar/battery combination with battery capacity equal to the solar capacity will add around $17/MWh to the solar-only price. For 38 solar/battery projects developed in the United States, which on average had battery capacity equivalent to 68% of the PV capacity, the weighted average levelised power purchase agreement prices was US$34/MWh.

[7] See https://emp.lbl.gov/utility-scale-solar/

6 Discussion and conclusions

The previous section set out evidence of the latest available information on the cost of carbon capture, shipping and storage when added to electricity generation. Here we put this information together to establish, on current expectations, how much electricity produced by a coal-fired generator with CCS might cost when measured using the Levelised Cost of Electricity (LCOE). As noted, LCOE is a standard measure for comparing the cost of electricity, taking into account both capital and operating costs. We stress that such estimates for carbon capture and storage are highly uncertain since there is no demonstrated experience of successful commercial-scale carbon capture from power generation, no experience of carbon pipeline transport (in Australia) and no experience (in the south and eastern states[8]) of commercial scale geological CO_2 sequestration.

Starting first with sequestration, Santos claims that it will charge \$30/tonne CO_2 to sequester at Moomba. As discussed earlier, exactly what this charge will cover is not clear. For the purposes of this study, we give Santos the benefit of the doubt and suggest that this price which we assume will be unchanged in real terms for the foreseeable future will be sufficient to cover injection and guaranteed permanent sequestration at Moomba.

Moving now to CO_2 transportation, we assume 1,500 km is needed (being the approximate distance for long haul transport from NSW or QLD's existing or possible future coal generators). We also make no allowance for additional pipeline infrastructure needed to connect to hubs at the injection or main withdrawal points, but acknowledge this would likely add further cost.

In respect of CO_2 capture, for the purposes of this study we apply the estimates in the CO_2CRC study – in round numbers \$100/tonne – noting that this is far below the actual CO_2 capture costs for either of the two commercial-scale coal generation capture plants. Noting that one has already been mothballed (suggesting costs are higher than publicly disclosed) and the other has not yet operated at more than half its design capacity.

8 Geological sequestration of CO_2 associated with the Gorgon LNG project is developing in Western Australia.

Adding together these costs of capture, transport and sequestration gives a total cost of CCS of $160 per tonne CO_2. If we assume that 90% of a coal generator's emissions are captured and stored, this can then be stated as a price per MWh produced of 0.9*$160 = $144/MWh. This needs to be added to the cost of producing the electricity in the first place (the LCOE). For this we use the latest available CSIRO Gencost estimates (see (CSIRO, 2019)). These are between $126 and $168 per MWh for black coal and $160 and $209 per MWh for brown coal. These assume current policies (that there is no carbon price and that the government does not insulate investors from future emission price risks).

Table 2. Compilation of results

	Low ($/MWh)	High ($/MWh)
Brown coal pre-capture	160	209
Black coal pre-capture	126	168
Capture	$100	
Transport	$27	
Storage	$27	
TOTAL (brown coal)	314	363
TOTAL (black coal)	280	322

Table 2 shows that, based on data used in this report drawn from the CO_2CRC, the then Department of Resources Energy and Tourism, SANTOS and CSIRO, the levelised cost of electricity from a coal plant that captures and sequesters 90% of its CO_2 emissions can be expected to be between $280/MWh and $363/MWh.

This can be compared to the known price of wind generation currently being installed in Australia, including 0.5 MW storage per MW of wind capacity, of $44.9/MWh (see previous section).

In summary, on the basis of the evidence provided mainly by Australia's authorities, carbon capture and storage applied to coal generation in Australia can be expected to cost at least six times as much (and quite possibly very much more) per MWh produced as comparably firmed renewable generation. The gap between gas generation (plus CCS) and comparably firmed renewable generation is even bigger.

References

Carbon Storage Taskforce. (2009). *NATIONAL CARBON MAPPING AND INFRASTRUCTURE PLAN – AUSTRALIA*. Canberra.

CO2CRC. (2017). *Retrofitting CCS to coal: Enhancing Australia’s Energy Security*. Retrieved from https://co2crc.com.au/resources/reports/

CSIRO. (2019). *GenCost 2019-20: preliminary results for stakeholder review*. Retrieved from https://aemo.com.au/-/media/files/electricity/nem/planning_and_forecasting/inputs-assumptions-methodologies/2019/csiro-gencost2019-20_draftforreview.pdf?la=en

Global CCS Institute. (2019). *Global status of CCS: 2019*. Melbourne.

Graham, P., Hayward, J., & Havas, L. (2020). *Gen Cost 2019-2020*. https://doi.org/https://doi.org/10.25919/5eb5ac371d372

International Energy Agency. (2006). *CO2 capture as a factor in power station investment decisions. Report No. 2006/8*. Paris.

Leung, D. Y. C., Caramanna, G., & Maroto-Valer, M. M. (2014). An overview of current status of carbon dioxide capture and storage technologies. *Renewable and Sustainable Energy Reviews*, *39*, 426–443. https://doi.org/10.1016/j.rser.2014.07.093

Metz, B., Davidson, H. C., de Coninck, M., & Loos, and L. A. M. (eds.)]. (2005). *IPCC Special Report on Carbon Dioxide Capture and Storage. Prepared by Working Group III of the Intergovernmental Panel on Climate Change*. New York.

Rubin, E. S., Davison, J. E., & Herzog, H. J. (2015). The cost of CO2 capture and storage. *International Journal of Greenhouse Gas Control*, *40*, 378–400. https://doi.org/10.1016/j.ijggc.2015.05.018

Schlissel, D., & Wamstad, D. (2018). *Holy Grail of Carbon Capture Continues to Elude Coal Industry*.

Serpa, J., Morbee, J., & Tzimas, E. (2011). *Technical and economic characteristics of a CO2 transmission pipeline infrastructure*. https://doi.org/10.2790/30861

Wamstad, D., & Schlissel, D. (2020). *Petra Nova Mothballing Post-Mortem: Closure of Texas Carbon Capture Plant Is a Warning Sign*.