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CCS For Power Yet to Stack Up Against Alternatives

Recent energy price inflation may force governments to rethink their support for CCS, adding to financing risks

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Key Findings

The cost of carbon capture and storage (CCS) remains unclear as no known new power plants have been built with the technology installed and operating at commercial scale.

Thermal power generation with CCS has a levelized cost of electricity of at least 1.5-2 times above current alternatives, such as renewable energy plus storage.

If CCS is applied with all costs borne by increasing electricity prices, annual volume weighted average wholesale prices could climb by 95% to 175% in Australia.

Optimism bias is rampant, favoring CCS as a decarbonization and "sustainable" solution in the power sector, but who ends up paying for it is an uncertainty adding to the financing risk.

Executive Summary

The prospects for carbon capture and storage (CCS) in the power sector are far from certain.

Not only is it unable to consistently deliver on performance claims, expensive to build and fraught with failures, but the impact on electricity prices if the cost is passed through to consumers would be unsustainable.

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Despite these challenges, CCS has been marketed as a decarbonization and "sustainable" solution in the power sector, to the extent that it has made its way into policymaking discussions. For example, green or sustainable finance taxonomies recognize fossil-fired power plants as "sustainable" investments if emissions meet a specified threshold, implying a need for CCS.

The issue is that CCS for fossil-generated plants would not be sustainable if consumers cannot afford electricity. This report takes a closer look into the economic case for CCS in the power sector. A summary of our findings is as follows:

The cost trajectory for CCS remains unclear. No known new power plants have been built with CCS installed and operating at commercial scale. While two major retrofit power projects have been implemented, one has since suspended operation and both projects had performed well below target capture rates of 90%.

Yet, optimism bias is rampant. Proponents of CCS provide low cost forecasts that are a long way from the estimates of prominent organizations and significantly more optimistic than the likely reality. Additionally, estimates generally do not include a range of other costs including transport, storage, monitoring and possible remediation or penalties, which have a high degree of variability, and so they only paint part of the picture of carbon capture expenses.

In addition to cost uncertainties, how the expenses would be recovered is an added ambiguity. Our analysis shows that if CCS is applied with all costs borne by increasing the electricity price, then annual volume weighted average wholesale prices could increase by 95% to 175% in Australia. If the hike in wholesale prices is passed on, consumers are unlikely to take well to increasing electricity prices to fund CCS in the power sector. Retail electricity prices have already significantly climbed due to recent global energy inflation, resulting in pressure on the budgets of households, particularly those on low incomes, and are expected to rise further due to ongoing supply chain and geopolitical issues.

Our analysis also shows that the levelized cost of electricity (LCOE) for power generation with CCS is at least 1.5-2 times above current alternatives, which include renewable energy plus storage. Additionally, although solar and wind LCOEs have recently crept up, they are expected to return to the downward trajectory.[1] Battery storage system prices and the resultant LCOEs will also likely improve dramatically as technology is deployed more widely at a much larger scale and is expected to displace gas-fired firming in the longer term.

Any significant government spending on or subsidization of less economically efficient technologies, including CCS, would ultimately be borne by the public through, for example, income taxes. However, this seems to contradict the need for government to use public funds responsibly in light of more technically sound options and the economical, rapidly improving and deflationary nature of renewable and battery storage alternatives.

Until a viable source of funding is available, who ends up paying for the cost of CCS in power generation is yet another uncertainty adding to the financing risk.

[1] BloombergNEF (BNEF), 1H 2022 LCOE Update, Brandily & Vasdev, 30 Jun 2022.

Introduction

Carbon capture and storage technology (CCS) directly captures carbon dioxide (CO_2) from a point source, such as a power plant or other industrial facility, then compresses, transports and stores it. Note that for CCS to qualify as a climate mitigation option, storage of CO_2 should be permanent.

CCS covers a wide variety of technologies and processes, varying levels of technical and commercial maturity, environmental and social risks and opportunities, and differing mitigation potential across a range of applications. The Institute for Energy Economics and Financial Analysis (IEEFA) previously completed a review[2] of the status and performance of the different applications of CCS.[3] This report focuses on CCS in the power sector and dives into the economics, including the impact on the cost of power and its practicalities.

Recap: Risks of CCS outweigh its benefits

IEEFA previously reported that carbon capture technologies were not yet ready to warrant them investable. A key impediment is the lack of available, and generally weak, data from the testing and operations of CCS across all applications, which makes the real technology, commercial readiness, costs and cost competitiveness uncertain.

CCS in the power sector is one of the new use cases being discussed as net-zero energy solutions, but it faces many challenges. Power plants or generators using fossil fuels, namely coal and gas, produce flue gas containing a mix of nitrogen, CO_2, water vapor, some other gases and particulate matter. CCS technologies can be designed to be built into new facilities or retrofitted at old facilities, and capture the CO_2 from flue gas, typically via chemical absorption. The CO_2 can then be transported, used and/or stored.

However, no commercial-scale new builds of these types are known to have been completed and operated, so the reality of this technology at commercial scale is untested. The Kemper CCS facility in the United States is an example of a failed attempt at deploying the technology from a new build.[4],[5] There have been two major retrofit projects, both in North America; however, one of the facilities has suspended operation and both projects had performed well below the target capture rate of 90%. China has several CCS-for-power projects that are possibly completed or being developed, but the status and configuration of these projects remain obscure.

[2] IEEFA, Carbon capture landscape 2022 – still too early to confidently fulfil promises, Salt, 7 Jul 2022.
[3] IEEFA, Investment risks of carbon capture and storage currently outweigh its potential, Salt, 7 Jul 2022.
[4] IEEFA, The carbon capture crux: Lessons learned, Robertson, 1 Sep 2022, p.44.
[5] International Energy Agency (IEA), We can't let Kemper slow the progress of carbon capture and storage, 7 Jul 2017.

Environmental concerns related to the application of CCS in the power sector have also emerged. These include:

- Fossil fuel usage: the continued use and promotion of fossil fuels through association with enhanced oil recovery conflicting with the decarbonization agenda.
- Technology effectiveness: the ability to live up to its claims as an emissions reduction strategy, given the poor performance and low capture rates to date.
- Storage risk: the uncertainty and risk around the long-term storage and leakage of CO_2.
- Energy efficiency: the consumption of additional energy to capture the CO_2 from flue gas. This results in more energy consumed and fossil fuels extracted, transported and burned when CCS is applied to generate the same amount of power.
- Chemicals used: the need for large quantities of ammonia, hydrogen sulfide and other chemical solvents, which have potential to harm the environment if a spill were to occur.
- Water usage: Power plants with CCS will require around 50% more water than non-CCS plants per megawatt (MW) of capacity.[6]

From a social perspective, operators of coal and gas power generation assets have traditionally benefited from government subsidies and protectionist policies to maintain their market position. They have also often danced around environmental and social responsibilities and regulations. As such, CCS for power generation will likely face organized public opposition and tougher environmental regulations.

Based on these findings, IEEFA concludes that the technology is not technically nor commercially ready for deployment.

IEEFA's July 2022 report[7] covers the issues mentioned above in more detail.

[6] Ibid.
[7] IEEFA, Investment risks of carbon capture and storage currently outweigh its potential, Salt, 7 Jul 2022.

Costs of Carbon Capture

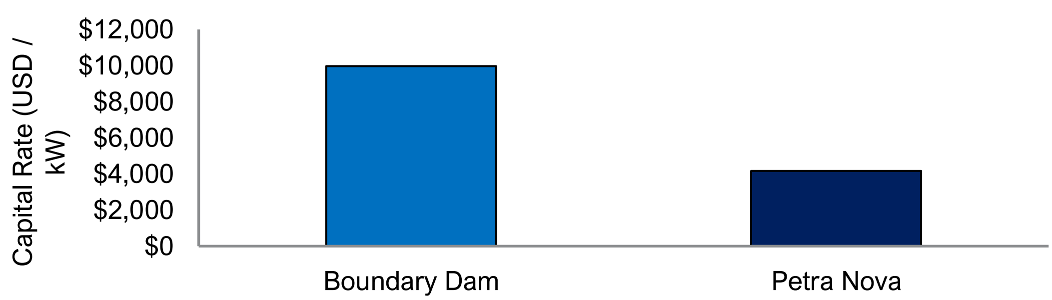
There are a range of unique technical, commercial, social and environmental costs to consider within each application of CCS.[8] S&P Global[9] analysis has shown that processes with dilute CO_2 concentrations, such as power generation, will have different cost drivers and risks than higher concentration processes such as ethanol and fertilizer production. For CCS in power, capital and operational expenditure will likely have the greatest impact on the actual cost of abating emissions.[10] The range of increased costs is explored in the following sections.

Increased Capital Expenditure

Applying carbon capture technology to coal and gas generation will significantly increase facility capital costs even without considering the required CO_2 transport and storage costs, and will affect the case for investment in the technology. A wide range of theoretical values are being discussed in the public domain for the capital required to apply carbon capture technology to coal and gas generators. However, with only two retrofitted facilities available to compare the actual costs, the real capital costs of the technology in the long run are very uncertain.

The two major carbon capture power projects, Boundary Dam in Canada and Petra Nova in the U.S., were both retrofitted with carbon capture technology and both have faced significant performance and cost challenges.[11] The capital cost in U.S. dollars per kilowatt (kW) capacity for these two projects is shown in Figure 1.

Figure 1: Capital Cost (US$/kW) for Commercial CCS Projects, Both Retrofits



Source: IEEFA analysis of various sources[12]

The capital costs of the two retrofit projects vary greatly, which in part could be down to the scale of the projects, the Boundary Dam being 115MW and Petra Nova, 240MW. Or this could just be due to

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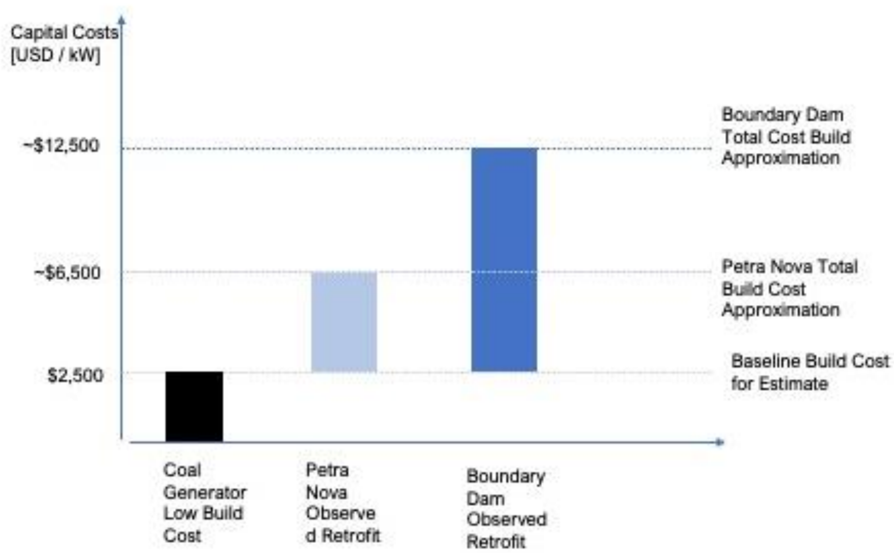
[8] Ibid.
[9] S&P Global, Levelized cost of CO2 avoided (LCCA) for CCUS projects - Cost drivers and long-term cost outlooks, 3 May 2022.
[10] Ibid.
[11] IEEFA, Two years behind schedule, Boundary Dam 3 coal plant achieves goal of capturing 4 million metric tons of CO2, Schlissel, Apr 2021, p.1-3.
[12] Massachusetts Institute of Technology (MIT), Boundary Dam Fact Sheet: Carbon Dioxide Capture and Storage Project, 30 Sep 2016.
MIT, Petra Nova W.A. Parish Fact Sheet: Carbon Dioxide Capture and Storage Project, 30 Sep 2016.

uncertainties in the technology, as the smaller Boundary Dam CCS retrofit costs around US$150 million more than the larger Petra Nova facility.

The cost to retrofit these projects comes on top of the underlying costs required for the base build of the coal generator. Costs to construct coal generators are currently estimated at US$2,500 to US$3,000/kW.[13] The total facility cost with carbon capture is therefore above these levels and is more than double the base build cost based on the observed cost of retrofitting.

The base build cost for a new project with carbon capture could be loosely gauged from a low benchmark of coal plant construction costs, at the rate of US$2,500/kW, plus the observed retrofit costs. Note that there should be some construction cost efficiency as a new build; however, this cannot be properly understood in the absence of an actual CCS new build. This approach is demonstrated in Figure 2 below.

Figure 2: Estimated Capital Costs of Total Facility Capital Rate (USD/kW)



Source: IEEFA analysis of various sources[14]
Note: This methodology does not consider the possible cost efficiency of a direct new coal plant build with CCS.

This approximation demonstrates that carbon capture technology significantly increases the total capital invested in the facility and is also highly variable with little justification provided. In a 2017 paper, the Global CCS Institute argued that critics had unfairly looked at unexpected plant refurbishment costs at the Boundary Dam during its start-up phase as representative of carbon

[13] Lazard, Lazard's Levelized Cost of Energy v15, Oct 2021, & Australian Energy Market Operator (AEMO), 2022 ISP: 2022 Forecasting Assumptions Update, 2022.
[14] MIT, Boundary Dam Fact Sheet: Carbon Dioxide Capture and Storage Project, 30 Sep 2016, MIT, Petra Nova W.A. Parish Fact Sheet: Carbon Dioxide Capture and Storage Project, 30 Sep 2016, Lazard, Lazard's Levelized Cost of Energy v15, Oct 2021; & AEMO, 2022 ISP: 2022 Forecasting Assumptions Update, 2022.

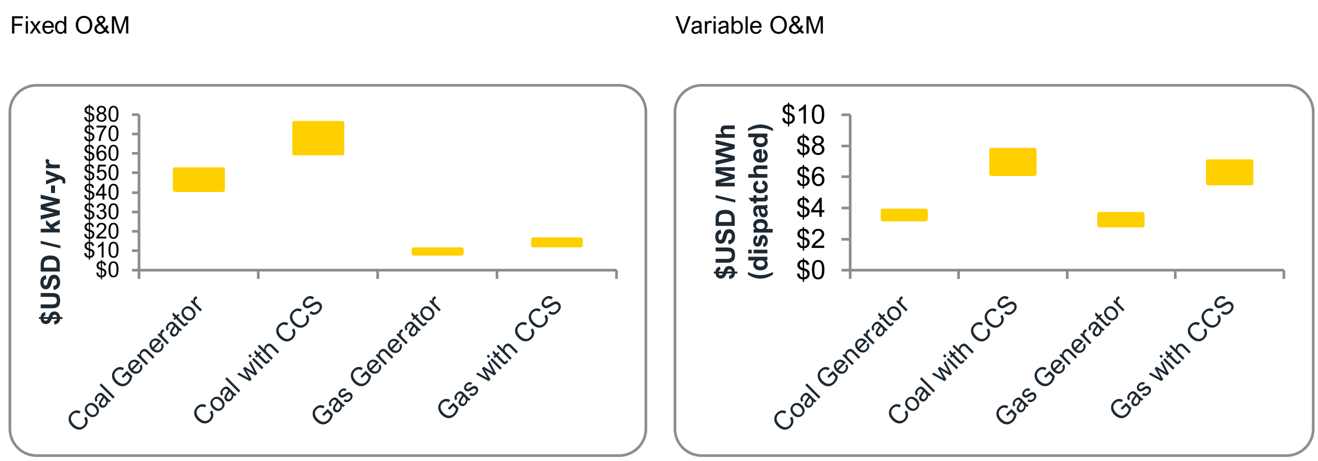
capture retrofit costs.[15] The author also described Petra Nova as having been developed without controversy;[16] however, IEEFA previously reported on cost and performance issues at the facility before it was mothballed in 2020 due to a lack of economy resulting from factors such as low oil prices.[17] What is clear is that adding carbon capture technology will significantly increase capital costs, which must be recovered through some mechanism.

Increased Operating Costs

Applying carbon capture technology, even before considering transport and storage, will raise operating costs. It will increase the use of water and fuel, and require additional facility maintenance costs through extra plant demands and usage.[18] For example, power plants with carbon capture will consume around 50% more water than non-CCS plants per MW of capacity.[19]

As such, facilities with carbon capture will face additional operating costs. The fixed and variable operating and maintenance (O&M) costs for generators without and with carbon capture are presented in Figure 3.

Figure 3: O&M Cost Increases for Power Generators with Carbon Capture



Source: IEEFA analysis of AEMO data[20]

Fixed O&M costs are expected to rise by about 45% and variable O&M costs by 95%, which again must be recovered through some mechanism.

[15] Global CCS Institute, Global Costs of Carbon Capture and Storage: 2017 Update, Irlam, Jun 2017.
[16] Ibid.
[17] IEEFA, Petra Nova Mothballing Post-Mortem: Closure of Texas Carbon Capture Plant is a Warning Sign, 3 Aug 2020.
[18] National Energy Technology Laboratory, Bituminous Coal and Natural Gas to Electricity: >90% Capture Cases Technical Note, Shultz, 30 Dec 2021.
[19] Ibid.
[20] AEMO, Current inputs, assumptions and scenarios, 2022.

Increased Fuel Costs

Carbon capture technology also requires additional energy to drive the capture of CO_2 from the flue gas. The capture technology alone is expected to consume up to 20% to 30% of the power generated, resulting in a net efficiency reduction of 6 to 12 percentage points.[21],[22] This means more fossil fuel will need to be extracted, transported and burned for a CCS-equipped system to generate the same amount of power.

Given parabolic global energy price inflation in 2021-22, use of the additional energy would inflict a severe cost penalty on carbon capture technology alone.

Figure 4: Soaring Fuel Price Inflation

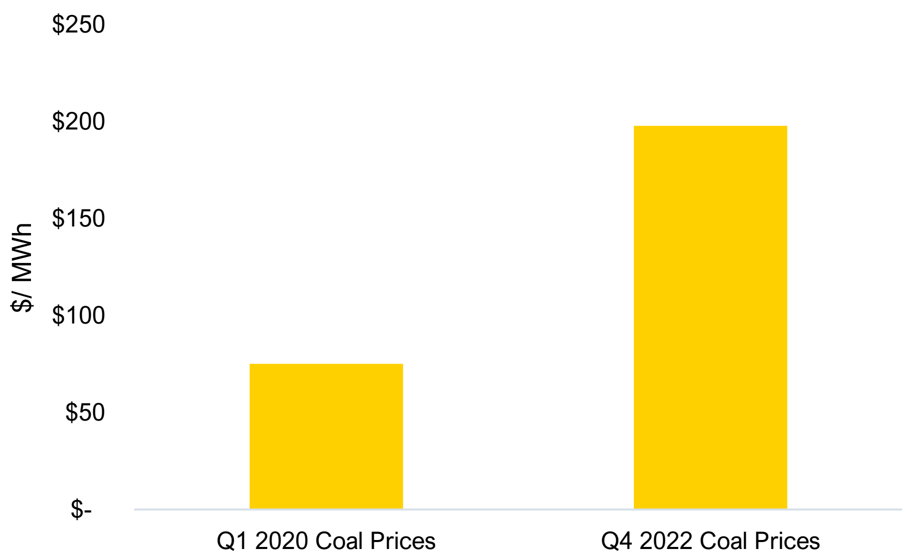
Source: Trading Economics: Newcastle coal futures[23]

Source: FRED: Global price of LNG, Asia[24]

The difference between historic and current energy commodity prices is driving the dispatch prices of thermal generators to unprecedented levels in markets where energy is priced at marginal thermal generator prices. The LCOE for coal facilities without carbon capture is estimated at historical (Jan 2020) and current (Nov 2022) prices in Figure 5.

[21] National Energy Technology Laboratory, Bituminous Coal and Natural Gas to Electricity: >90% Capture Cases Technical Note, Shultz, 30 Dec 2021, p.4.
[22] IEEFA, Carbon Capture in the Southeast Asian Market Context, Adhiguna, Apr 2022, p.34.
[23] Trading Economics, Newcastle Coal Futures, 13 Jan 2023.
[24] Federal Reserve Bank of St. Louis, Global price of LNG, Asia, 29 Sep 2022.

Figure 5: LCOE of Coal Power with no CCS



Source: IEEFA analysis
Note: This LCOE analysis assumes commodity prices are sustained at the observed levels for the stated quarter.

Increased fuel prices alone are driving up the costs of coal-powered electricity generation with carbon capture costs yet to be factored in. The same effect is observed for gas generators without carbon capture. Carbon capture technology will further exacerbate the electricity price increases from higher fuel prices.

Increased Costs Beyond the Capture Facility

The cost of CCS as a decarbonization option is more than just the cost of the carbon capture technology. The transport, storage, monitoring and verification, plus any additional compliance and liability costs will need to be taken into account for CCS to be considered as a climate solution. The additional elements of the CCS value chain are presented in Figure 6.

Figure 6: Indicative Costs for CCS Value Chain Components

Source: Global CCS Institute[25]

Transport costs are expected to vary between US$1 and US$25 per tonne of carbon dioxide (t-CO_2).[26] With cost proportional to distance, and if the transport is offshore, costs are expected to be around 15% higher.[27]

Storage costs are sensitive to whether the storage is onshore or offshore, and to the characteristics of the storage site, with saline aquifers estimated to be 10% to 15% more expensive than depleted oil and gas fields.[28] The costs are expected to vary widely based upon field capacity and well injectivity, and to a lesser degree on uncertainty in cost elements.[29] The estimated range is between US$1 and US$15/t-CO_2.[30,31]

The longevity and credibility of CO_2 storage will also depend on monitoring and verification practices, likely to be set by local regulations. Theoretical estimates suggest that the costs will probably be low

[25] Global CCS Institute, Technology Readiness and Costs of CCS, Kearns, Liu & Consoli, Mar 2021.
[26] The Royal Society, Total cost of carbon capture and storage implemented at a regional scale: northeastern and midwestern United States, Schmelz, Hochman & Miller, 14 Aug 2020, p.4-6.
[27] McKinsey & Company, Carbon Capture & Storage: Assessing the Economics, 2008, p.27.
[28] Ibid.
[29] European Technology Platform for Zero Emission Fossil Fuel Power Plants (ZEP), The Costs of CO2 Storage: Post-demonstration CCS in the EU, 2011, p.6.
[30] Global CCS Institute, Technology Readiness and Costs of CCS, Kearns, Liu & Consoli, Mar 2021.
[31] The Royal Society, Total cost of carbon capture and storage implemented at a regional scale: northeastern and midwestern United States, Schmelz, Hochman & Miller, 14 Aug 2020, p.4-6.

compared with other components of the supply chain.[32] However, as with other cost estimates for the technology, monitoring and verification costs are also uncertain.

Outside of the CCS value chain, compliance and liability costs also need to be provided for. These should provide coverage for risks of leakage or failure to reach abatement targets. As an example of the scale of costs, the Gorgon CCS project recently agreed to acquire and surrender US$100 million to US$184 million of credible greenhouse gas offsets recognized by the West Australian government to offset its target shortfall of CO_2 capture.[33] Appropriate liability and insurance will be required to help mitigate these cost risks.

Legal and regulatory frameworks to transfer liabilities to the state after an acceptable period post-closure and subject to performance requirements[34] may help to reduce the liability exposure for project owners; however, this approach simply transfers the risk and potential costs to future taxpayers.[35] "Claw-back" provisions that allow the state to recover costs from operators found to be at fault[36] could prove useless if the errant company is no longer in operation.

The topic of liability continues to be a critical issue for developers, policymakers and regulators in deploying carbon capture and storage.[37]

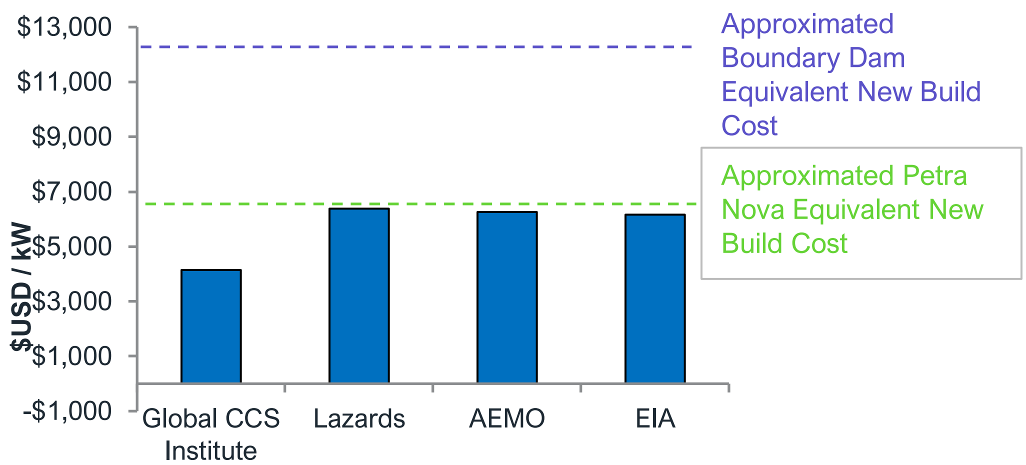
Costs in Practice Much Higher Than Estimated

Estimated benchmarks for CCS are provided on a new-build basis, yet no new CCS builds are available for comparison. Additionally, the estimates generally exclude transport and storage, likely due to the large variability of these costs, so they give only a part of the picture of carbon capture costs.

Figure 7 shows the range of cost estimates available for thermal generators with carbon capture alone, against the approximated costs of the actual major projects.

[32] Global CCS Institute, Technology Readiness and Costs of CCS, Kearns, Liu & Consoli, Mar 2021.
[33] IEEFA, Gorgon carbon capture and storage: the sting in the tail, Robertson & Mousavian, Apr 2022, p.1-2.
[34] Global CCS Institute, Unlocking Private Finance to Support CCS Investments, 2021, p.9.
[35] NOAH: Friends of the Earth Denmark, Information about Carbon Capture and Storage - CCS, Aug 2014.
[36] Global CCS Institute, Legal Liability and Carbon Capture and Storage, Havercroft and Macrory, Oct 2014, p.5.
[37] Global CCS Institute, Lessons and Perceptions: Adopting a Commercial Approach to CCS Liability, Havercroft, 2019, p.4.

Figure 7: Capital Cost Estimates for Carbon Capture Without Transport, Storage or Other Costs



Source: IEEFA analysis from various sources[38]

The approximated total build costs presented for the Boundary Dam and Petra Nova are base build costs without CCS, plus the reported retrofit costs. However, it is unclear whether the reported costs from the Boundary Dam and Petra Nova include transport and storage.

IEEFA observes that the actual plant costs for new builds would likely be above or at the upper range of current plant cost estimates made by a range of actors, including the Global CCS Institute, Lazard, the Australian Energy Market Operator (AEMO) and the U.S. Energy Information Administration (EIA).

The Global CCS Institute's estimate of CCS costs is a long way from the estimates of other prominent organizations, and a long way from the likely reality. Proponents of CCS are hopeful that learning effects come into play that would reduce costs over time through innovation and efficiency improvements.[39] However, the expected costs of CCS have increased from early estimates of around US$2,900/kW (in 2022 terms[40]) in 2007[41] to more recent estimates of around US$4,150/kW[42] (in 2022 terms[43]) in 2017. This shows a trend toward increasing costs rather than the expected decrease over time. With limited practical experience, the actual costs of currently deploying CCS and its cost trajectory remain uncertain.

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[38] Global CCS Institute, Global Costs of Carbon Capture and Storage, Jun 2017.
Lazard, Lazard's Levelized Cost of Energy Analysis v15, Oct 2021;
AEMO, ISP: 2022 Forecasting Assumptions Update, 2022; &
EIA. Capital Cost and Performance Characteristic Estimates for Utility Scale Electric Power Generating Technologies, Feb 2020.
[39] S&P Global, Levelized cost of CO2 avoided (LCCA) for CCUS projects - Cost drivers and long-term cost outlooks, 3 May 2022.
[40] Assuming 2.5% average annual inflation
[41] IEA Greenhouse Gas Research and Development Program, Capturing CO2, May 2007.
[42] Global CCS Institute, Global Costs of Carbon Capture and Storage: 2017 Update, Irlam, Jun 2017.
[43] Assuming 2.5% average annual inflation.

Does CCS in Power Sector Make Economic Sense?

While the real cost of applying CCS in the power sector is uncertain, this report considers how it could be recovered. The likely scenarios are:

- To embed the cost in increased wholesale electricity prices, which would be passed through to retailers and then consumers; or
- For the government to subsidize or find alternative sources of funding to bear the cost of CCS.

Impact on Price of Electricity: Australia Case Study

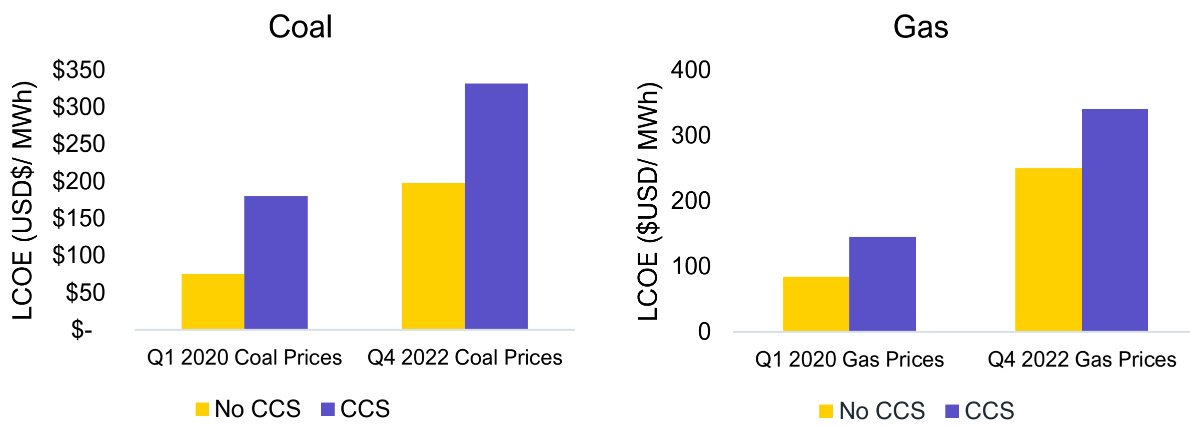
Australia's National Electricity Market (NEM) serves the east coast and major population centers, covering around 9 million customers. It consists of generators, network operators, retailers and consumers. Electricity is traded in a virtual pool to match supply with demand and set traded prices. The four largest privately owned "gentailers," being both generators and retailers, have traditionally dominated the share of customers, accounting for more than half the retail load.[44] These large "gentailers" own a big number of thermal generators; however, they are expecting the closure of many of the coal assets by the 2030s.[45]

The price of electricity in Australia is dependent on the LCOE for coal and gas generation. To understand the potential impact of adding CCS to the country's power market on electricity prices, we analyzed the LCOE for coal and gas generation with CCS application.

The analysis uses AEMO's capital expenditure estimates for non-CCS and CCS generators. These estimates are relevant to the Australian context, are industry-reviewed and publicly available[46] and generally align with other benchmarks. A full list of assumptions for the analysis can be found in the appendix.

[44] Australian Energy Regulator (AER), State of the Energy Market. 2021.
[45] The Sydney Morning Herald, Power giants feel heat on coal closures, green energy plans, 4 Jul 2022.
[46] AEMO, Current inputs, assumptions and scenarios, 2022.

Figure 8: LCOE of Historic and Current Facilities With and Without CCS



Source: IEEFA analysis (see Appendix for assumptions)

Our analysis found that, if CCS was applied with all costs borne by increasing the electricity price, then the LCOE would likely more than double for coal and increase by 75% for gas based on the historic fuel prices of Q1 2020, as seen in Figure 8. Given the heightened fuel prices from Q4 2022, the LCOE for CCS-equipped plants will probably be around 65% more for coal and 35% more for gas than the non-CCS case.

As such, adding CCS to the power sector will likely drive up the current cost of producing energy significantly, and that will need to be borne by someone.

Affordability discussion

With thermal resources providing around 70% of power generation in Australia's NEM,[47] applying CCS to these facilities to decarbonize could be expected to increase annual volume weighted average wholesale prices. These prices averaged between A$75 and A$95 per megawatt-hour (MWh) in NEM regions over the past decade,[48] and could rise by A$100 to A$130 per MWh through the inclusion of CCS.[49] This additional wholesale cost would then likely be passed on to energy consumers and increase electricity bills.

Raising electricity bills because of CCS would come on top of unprecedented electricity price increases.[50] Retail prices have already gone up and had been expected to increase by 56% over the

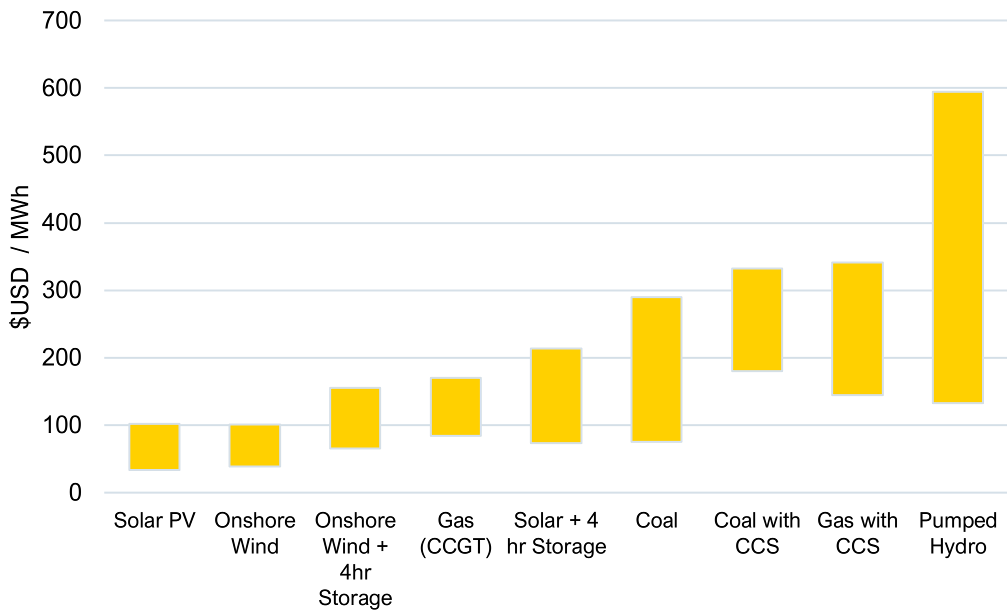
[47] Australian Energy Regulator (AER), Generation capacity and output by fuel source - NEM, 30 Sep 2022.
[48] AER, Quarterly volume weighted average spot prices – regions, 13 Jan 2023.
[49] Simply by assuming 62.5% coal (with CCS increase of +A$105-A$135/MWh) and 7.5% gas (with CCS increase of +A$60-A$90/MWh) being reflected in wholesale price increase.
[50] Australian Broadcasting Corporation (ABC) News, Russian invasion of Ukraine drives up energy costs and Australians will feel the pain, 26 Feb 2022.

next two years[51] prior to recent government intervention.[52] Any further climb in prices is expected to be taken well by neither consumers nor the government.

Consumers, businesses, industry and retailers alike would logically seek out the most affordable electricity options that meet their needs, a greater priority than environmental and social factors.

Based on new estimates (Figure 9), LCOEs for thermal power generation with CCS are at least 1.5-2 times above current alternatives, which include renewable energy plus storage. It is therefore difficult to contemplate electricity users willing to support the use of CCS on power generation when affordable decarbonized options exist.

Figure 9: Comparison of Energy Resources' LCOEs



Source: IEEFA analysis,[53] BNEF[54]

Even if CCS for thermal power generation may be required as a firming generation, that would happen only when the systems reach high levels of renewable energy generation. Firming generation would have lower capacity factors and further increase the resultant LCOEs. Meanwhile, battery storage system prices are expected to improve dramatically along with the LCOEs as technology is deployed more widely at a much larger scale and expected to displace gas-fired firming. [55]

[51] The Australian Financial Review, Labor's power prices promise dead: energy costs to spike 56pc, 25 Oct 2022.
[52] ABC News, Coal and gas price caps and whether they'll lower your energy bills explained, 10 Dec 2022.
[53] IEEFA LCOE Analysis (see Appendix for input assumptions).
[54] BNEF, 1H 2022 LCOE Update, Brandily & Vsdefv, 30 Jun 2022.
[55] Ibid.

Government Support

The government could support CCS in the power sector indirectly, for example, by taxing carbon emitters or granting direct project subsidies.

A carbon pricing or emissions trading scheme would create an incentive for coal and gas generators to implement CCS to minimize costs. However, it is worth noting that CCS has been commercially demonstrated to capture only around 75% of CO_2 emissions, according to experience at Petra Nova.[56] Accordingly, even if carbon pricing were to be applied, the plant owner or operator would have to pay the price of residual emissions not captured by CCS. This additional cost of residual emissions liability will need to be funded by some mechanism.

Carbon pricing in Australia has been a political land mine. The Clean Energy Act 2011 introduced a carbon pricing mechanism, which put a price on carbon pollution and was designed to lead to an emissions trading scheme. The mechanism was used as a political weapon to attack the government at that time and was repealed in July 2014.[57] The *Safeguard Mechanism*[58] now in place is largely seen as ineffective. The prospects of a direct carbon tax or pricing scheme in the near future seem uncertain at best.

Even if the government were to reintroduce and implement a similar initiative, businesses including high emitters will likely seek out more affordable electricity alternatives, as described earlier.

An alternative form of support may be to grant direct project capital support. However, any significant government spending on or subsidization of CCS would ultimately be borne by the public through, for example, income taxes. The public may be unwilling to accept subsidizing unproven CCS technologies and, in turn, express their views through public elections.

In other markets where the government subsidizes power via reduced input costs for producers or lower prices to consumers, more government subsidies will be required to cover the full or partial cost of CCS.

Until a viable source of funding is available, who ends up paying for the cost of CCS in power generation is yet another uncertainty.

[56] IEEFA, Where's the beef? Enchant's San Juan generating station CCS retrofit remains behind schedule, financially unviable, Schlissel, May 2021, p.3.
[57] Climate Scorecard, Australia's Ill-Fated Emissions Trading System, 6 Mar 2020.
[58] The Guardian, What is the 'safeguard mechanism' and how is it supposed to reduce Australia's carbon emissions? 17 Nov 2021.

Conclusion

IEEFA previously concluded that CCS technology was struggling to fully work at scale both technically and commercially. The current report concludes that the economic case for CCS in the power sector is weak, considering input cost and funding uncertainties, continued failures of the technology, and the constantly improving and rapidly growing alternatives.

Applying carbon capture technology to coal and gas power generation, even before considering the required transport and storage of CO_2, will significantly increase the facility capital expenditure, operating and fuel costs, and affect the case for investment in the technology. There are no known new build commercial-scale projects built and operated. Of the two major retrofit projects, one has suspended operation and both had performed well below target capture rates of 90%.

Actual plant costs for new builds are expected to be at or above the upper range of current plant cost estimates made by a variety of actors. The Global CCS Institute, as one of the main global proponents of the technology, has promoted a range of cost estimates for the technology. However, these are a long way from the estimates of other prominent organizations, and a long way from the likely reality.

The actual costs of deploying CCS are uncertain and the cost trajectory remains unclear. Additionally, estimated costs generally do not include other expenses, including transport, storage and possible remediation or penalties, which have a high degree of variability, and so they paint only part of the picture of carbon capture costs.

In Australia, retail electricity prices have increased and had been expected to go up by another 56% over the next two years, prior to recent government intervention. Our analysis found that, if CCS is applied in the Australian power sector, with all costs borne by raising the electricity price, then the LCOE could increase annual volume weighted average wholesale prices by 95% to 175%. The affordability of electricity with CCS added would become an issue and is unlikely to be taken well by consumers nor government alike.

Based on our analysis, LCOEs for thermal power generation with CCS are at least 1.5-2 times above current alternatives, which include renewable energy plus storage. CCS for power generation may be required for firming gas generation. But this would happen only when the systems reach very high levels of renewable energy generation and the lower capacity factors would further increase the LCOE. Meanwhile, battery storage system prices and the resultant LCOEs are expected to improve dramatically as technology is deployed more widely at a much larger scale and is expected to displace gas-fired firming. Any significant CCS spending or subsidy from the government would ultimately be borne by the public through, for example, income taxes. The public may be unwilling to accept subsidizing unproven CCS technologies and, in turn, express their views through public elections.

However, this seems to contradict the need for government to use public funds responsibly in light of more economical and technically sound options.

Until a viable source of funding is available, who ends up paying for the cost of CCS in power generation is yet another uncertainty.

Appendix - Assumptions for Analysis

AEMO's cost estimates for CCS have been used to develop Australia's national electricity market Integrated Systems Plan (ISP). Its alignment with other prominent estimates and our approximation of capital costs also makes it a reasonable base case from which to decide on assumptions in the current analysis. We have therefore adopted the Global CCS Institute's estimates for facilities as an optimistic long-run capital case.

Table 1: Fuel Cost Assumptions

Type	Q1 2020	Q4 2022
CCS for Coal Generator[59]	$58 / t	$390 / t
CCS for Gas[60]	$6.84 / GJ	$25.21 / GJ

[59] Trading Economics, Coal, 13 Jan 2023.
[60] AER, Gas Market Prices, 13 Jan 2023.

Table 2: CCS for Power Analysis – General Assumptions

Parameter	Coal	Gas	Justification & Source
Capital cost without CCS (A$)	$4,343	$1,559	Build cost - current policies[61]
Capital cost with CCS (A$)	$9,077	$4,011	Build cost - current policies[62]
Economic life	30	25	Economic life[63]
Efficiency loss	9%	10%	Difference between non-CCS and CCS facilities' thermal efficiency[64]
Capacity factor without CCS	83%	70%	Capacity factor from low-cost case[65]
Capacity factor with CCS	66%	60%	Coal: capacity factor from coal high-cost case[66] Gas: effective annual capacity factor[67]
Capture rate	90%	90%	Optimistic capture rates are often referenced in discussions of CCS[68]
Fixed O&M without CCS (A$/kW-yr)	$46.56	$9.54	Median value from non-CCS fixed O&M (AEMO workbook)[69]
Fixed O&M with CCS (A$/kW-yr)	$67.88	$14.32	Median value from fixed O&M with CCS (AEMO workbook)[70]
Variable O&M without CCS (A$/MWh)	$3.56	$3.24	Median value from non-CCS fixed O&M (AEMO workbook)[71]
Variable O&M with CCS (A$/MWh)	$6.96	$6.31	Median value from fixed O&M with CCS (AEMO workbook)[72]
Transport and storage (US$/t-CO2)	$20		Midpoint value from Royal Society's transport and storage costs[73]
A$-US$	0.69		Average 2022 exchange rate[74]

The analysis considers the price that electricity must be sold at to recover costs and pay back investors. The levelized cost of electricity (LCOE) is a common measure of the breakeven price that electricity must sell at to recover costs and service obligations.

[61] AEMO, 2022 ISP: 2022 Forecasting Assumptions Update, 2022.
[62] Ibid.
[63] Ibid.
[64] International Journal of Greenhouse Gas Control: 57. Carbon capture and storage across fuels and sectors in energy system transformation pathways. Muratori et al. p.34-41.
[65] Lazard, Lazard's Levelized Cost of Energy v15, Oct 2021.
[66] Lazard, Lazard's Levelized Cost of Energy v15, Oct 2021.
[67] Aurecon Group, 2021 Costs and Technical Parameter Review, 27 Oct 2021.
[68] International Renewable Energy Agency, Reaching Zero with Renewables: Capturing Carbon, Lyons, Durrant & Kochhar, Oct 2021, p.14.
[69] AEMO, 2022 ISP: 2022 Forecasting Assumptions Update, 2022.
[70] Ibid.
[71] Ibid.
[72] Ibid.
[73] The Royal Society, Total cost of carbon capture and storage implemented at a regional scale: northeastern and midwestern United States, Schmelz, Hochman & Miller, 14 Aug 2020, p4-6.
[74] Exchange Rates UK, US Dollar to Australian Dollar Spot Exchange Rates for 2022, 13 Jan 2023.

About IEEFA

The Institute for Energy Economics and Financial Analysis (IEEFA) examines issues related to energy markets, trends and policies. The Institute's mission is to accelerate the transition to a diverse, sustainable and profitable energy economy. www.ieefa.org

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