The Australia Institute
Research that matters.

Polling - Climate Change Policy

Key Results

The Australia Institute surveyed 1,417 Australians between 5th and 7th of December 2017 about Australian greenhouse gas emissions and climate change policy.

Emissions have increased now for three years in a row, since the repeal of the carbon price. Energy emissions are now at record highs. Under the Paris Agreement, Australia has pledged an emissions target of 26-28% reduction on 2005 level by 2030, but there are no credible policies to get there. The Paris Agreement also includes a commitment to review and consider increasing ambition. Yet while Australia's government considers subsidising new coal mines and power plants, and a 'National Energy Guarantee' policy touted as a support for coal, other countries – like the UK, Canada, France, Italy and New Zealand - are pledging to phase out coal power by 2030.

- More than two thirds (70%) of respondents said Australia's emissions are staying about the same (36%) or going up (34%).
    - Only 9% said emissions are going down.
- 44% said Australia is not on track to meet its 2030 emissions target, while only 25% said it is on track.
    - 31% said they don't know.
- 58% said Australia should increase its ambition on cutting emissions.
    - 25% said Australia should not increase its ambition.
    - Increased ambition was supported by most voters for ALP (64%), Greens (85%), Other (57%) and undecided voters (51%).
    - Around half of LNP voters supported increase ambition (47%), higher than opposed it (37%). One Nation voters had the lowest support (36%).
- 60% supported Australia joining the Powering Past Coal Alliance to phase out coal power by 2030.
    - Only 22% opposed joining the Alliance.
    - There was majority support from voters for most parties, including LNP (50%), ALP (67%), and Other (56%). The exception was One Nation voters (36%)

Method

The Australia Institute conducted a national survey of 1417 people between 5th and 7th of December 2017 online through Research Now with nationally representative samples by gender, age and state and territory.

Results are shown only for larger states. Income crosstabs show household income.

Voting crosstabs show voting intentions for the lower house. Those who were undecided were asked which way they were leaning; these leanings are included in voting intention crosstabs, but results are also shown separately for undecideds. “LNP” includes separate responses for Liberal and National. “Other” includes Nick Xenophon Team and Independent/Other.

Detailed results

To the best of your knowledge, are Australia's greenhouse gas emissions currently going up or down?

	Total	Male	Female	NSW	Vic	Qld
Going up	34%	33%	35%	33%	33%	32%
Staying about the same	36%	38%	33%	38%	34%	38%
Going down	9%	11%	8%	8%	10%	10%
Don't know / note sure	21%	18%	24%	21%	23%	20%

	LNP	ALP	GRN	PHON	Other	Undec
Going up	25%	38%	55%	19%	32%	31%
Staying about the same	43%	32%	28%	44%	31%	23%
Going down	15%	6%	4%	15%	7%	6%
Don't know / note sure	18%	23%	13%	21%	30%	40%

Australia currently has a target of cutting emissions by 26-28% on 2005 levels by 2030.

Thinking about current policy settings, do you think Australia is currently on track to meet its emissions targets?

	Total	Male	Female	NSW	Vic	Qld
Yes	25%	29%	21%	26%	25%	26%
No	44%	44%	45%	46%	43%	42%
Don't know	31%	28%	34%	29%	32%	32%

	LNP	ALP	GRN	PHON	Other	Undec
Yes	35%	22%	21%	25%	15%	11%
No	33%	48%	60%	34%	52%	38%
Don't know	32%	30%	19%	41%	32%	51%

In the Paris Agreement on climate change, countries agreed to review their targets and consider increasing ambition.

Do you think Australia should increase its ambition on cutting emissions?

	Total	Male	Female	NSW	Vic	Qld
Yes	58%	53%	63%	58%	59%	55%
No	25%	32%	18%	26%	21%	29%
Don't know	17%	15%	19%	16%	20%	16%

	LNP	ALP	GRN	PHON	Other	Undec
Yes	47%	64%	85%	36%	57%	51%
No	37%	17%	6%	44%	24%	13%
Don't know	16%	19%	10%	20%	19%	36%

Countries like Canada, France, the UK, Italy and New Zealand have joined an international alliance pledging to phase out coal power in their countries by 2030.

Should Australia join this alliance?

	Total	Male	Female	NSW	Vic	Qld
Yes	60%	57%	63%	58%	63%	55%
No	22%	28%	15%	23%	18%	27%
Don't know / now sure	18%	15%	22%	19%	19%	18%

	LNP	ALP	GRN	PHON	Other	Undec
Yes	50%	67%	87%	36%	56%	50%
No	30%	13%	6%	43%	22%	15%
Don't know / now sure	19%	20%	7%	21%	22%	35%

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The impact of Galilee Basin development on employment in existing coal regions

Development of the Galilee Basin would displace production in other coal regions. Galilee mines would be more automated and less job-intensive than existing mines. Based on coal industry analysis, central estimates of employment reduction are 9,100 in the Hunter Valley, 2,000 in the Bowen Basin & 1,400 in the Surat Basin compared to a no-Galilee scenario. Galilee mines are likely to employ between 7,840 and 9,800 people, resulting in overall negative impact on coal jobs.

Discussion paper

Cameron Murray
Bill Browne
Rod Campbell
July 2018

ABOUT THE AUSTRALIA INSTITUTE

The Australia Institute is an independent public policy think tank based in Canberra. It is funded by donations from philanthropic trusts and individuals and commissioned research. We barrack for ideas, not political parties or candidates. Since its launch in 1994, the Institute has carried out highly influential research on a broad range of economic, social and environmental issues.

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As we begin the 21st century, new dilemmas confront our society and our planet. Unprecedented levels of consumption co-exist with extreme poverty. Through new technology we are more connected than we have ever been, yet civic engagement is declining. Environmental neglect continues despite heightened ecological awareness. A better balance is urgently needed.

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Level 1, Endeavour House, 1 Franklin St
Canberra, ACT 2601
Tel: (02) 61300530
Email: mail@tai.org.au
Website: www.tai.org.au
ISSN: 1836-9014

Summary

With global coal demand stable or declining, production from new mines will displace production in existing mines. Large scale coal development in the Galilee Basin in Queensland will significantly increase the supply of traded thermal coal and decrease coal prices. Lower prices will reduce investment in other Australian coal regions, and by extension employment in the mines of those regions.

New Galilee Basin mines will be large and highly automated, meaning they will employ fewer people per tonne of coal production. Adani have stated that in their project eventually "everything will be autonomous from mine to port." Automated Galilee Basin mines will come at the expense of relatively job-intensive mines in other regions.

Industry analysts Wood Mackenzie modelled the effects of Galilee Basin production on other coal mining regions – the Hunter Valley, Bowen Basin and Surat Basin. They estimate that Galilee Basin production of 150 million tonnes per year would reduce coal volumes in other areas by 116 million tonnes in 2035 relative to a baseline scenario with no Galilee Basin development.

This paper estimates the effect on jobs of this relative reduction in production from established coal regions. Three methods are used to estimate this impact:

- Applying average labour productivity of existing coal mines to relative reduction in coal volume.
- Applying marginal labour productivity of existing coal mines to relative reduction in coal volume.
- Analysing estimated workforce of mines identified as being delayed or cancelled by Galilee Basin development.

Results from these three estimates are presented in the Summary Table below:

Summary Table: Relative reduction in employment per region in 2035

	Average productivity	Marginal productivity	Workforce in impacted mines
Hunter Valley	9,737	9,102	7,650
Bowen Basin	2,212	2,015	2,456–3,326
Surat Basin	1,692	1,363	2,444
Total	*13,641*	*12,480*	*12,550 – 13,420*

Based on Adani's estimates of labour productivity in its mines, the Galilee Basin would employ between 7,840 and 9,800 people to produce 150 million tonnes per year. Taking the relative employment reductions in other regions of between 12,480 and 13,641, this would see a relative reduction of employment of between 2,680 and 5,801 workers in the coal industry in 2035.

These estimates are based on some important assumptions. Firstly, Wood Mackenzie assumes the world does not act on climate change – they assume Australian thermal coal exports will increase substantially in either scenario. They see demand for traded thermal coal increasing out to 2035. By contrast, the International Energy Agency expects the traded thermal coal market to decline by 60% to 2040 if the world acts in line with the Paris targets. If these targets are achieved and this decline in the coal trade occurs, the impact of Galilee Basin development on other coal regions is likely to be larger still.

Secondly, the degree and effects of automation are unclear. Galilee Basin employment estimates appear to underestimate proponent intentions to automate. Not only would this produce fewer jobs overall, but these more would be located in capital cities, not in regional areas. A University of Queensland study supported by the mining industry found that mine automation can reduce in-pit roles by 50% and overall mine workforce by 30–40%. This has a particular impact on indigenous employment, which is focused in regional areas rather than capital cities.

Government agencies have not conducted analysis on the impacts of Galilee Basin development on other coal regions. Some stakeholders such as NSW Minister for Resources Don Harwin have even dismissed the need for any analysis, saying he is "comfortable and not concerned about ongoing coal exports".

Federal and state government economists and coal analysts should investigate the potential impact of subsidised Galilee Basin development in detail as part of a plan for transitioning our coal regions into a carbon constrained future.

Introduction

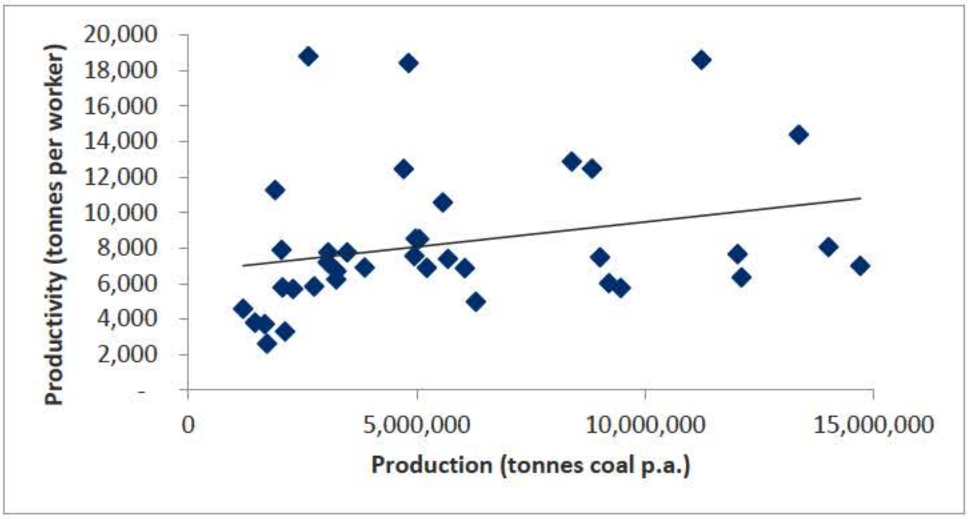
If the world is to avoid dangerous climate change it will use less coal, not more. Indeed, the latest World Energy Outlook from the International Energy Agency states:

> Against a background of falling coal use in Europe, the United States and China, global coal demand fell by 2% in 2016, for the second year in a row.[1]

With demand for coal declining, or at best stable, production from new mines will come at the expense of existing mines. In Australia, the world's largest coal exporter, large new thermal coal mines in the Galilee Basin would displace some amount of coal production in regions such as the Hunter Valley in NSW and Queensland's Surat and Bowen Basins.

The displacement of coal production also displaces employment in these mines. Making matters worse, Galilee Basin mines will be very large and highly automated, employing fewer people per tonne of coal produced. Replacing relatively job-intensive smaller mines with larger, more-automated mines will reduce employment. The trend for larger mines to employ fewer people relative to coal production is evident in existing Queensland and NSW mines, shown in Figures 1 and 2 below.

Figure 1: Worker productivity and production, Queensland

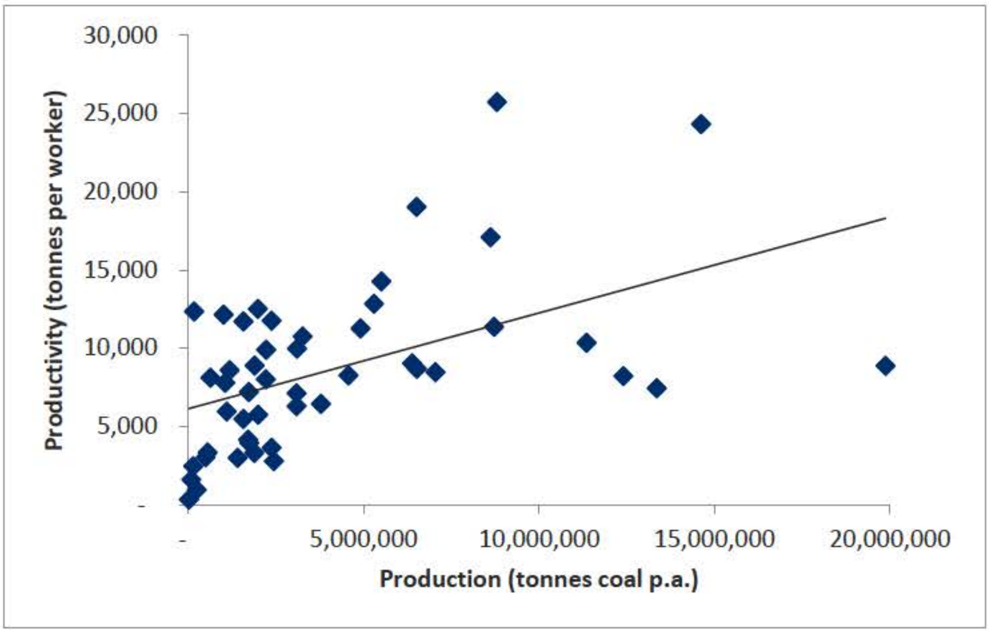


Source: Department of Natural Resources and Mines (2017) *Coal industry review tables 2016-17*, https://data.qld.gov.au/dataset/coal-industry-review-statistical-tables/resource/1b7fb643-c880-42bf-940b-fc3c582d239d; Queensland Government (2017) *Mining industry worker*

[1] IEA. (2017). *World Energy Outlook 2017*, p 203. https://www.iea.org/weo2017/

numbers, https://www.business.qld.gov.au/industries/mining-energy-water/resources/safety-health/mining/accidents-incidents/safety-performance[2]

Figure 2: Worker productivity and production, NSW



Source: Department of Resources and Energy (2014) *NSW Coal Industry Profile 2014 – Volume 1*

The upward sloping lines in Figures 1 and 2 show that, in general, larger mines use fewer workers to produce a given amount of coal. The mines proposed for the Galilee Basin are far larger than all those represented in Figures 1 and 2. The best known is Adani's Carmichael mine, which aims to produce 60 million tonnes per year, three times more than the highest producing mine in Figure 2.[3]

Galilee Basin proponents are aiming to have highly automated mining operations. Adani has stated that it plans to automate the Carmichael coal mine in the Galilee Basin, with CEO of Adani Mining Jeyakumar Janakaraj saying:

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[2] Note: This analysis excludes four outliers. Newlands Suttor Creek would have an output of 19 tonnes per worker, but this is a consequence of the mine winding down production in 2016-17. Three other mines – Burton Coal, Commodore and Kogan Creek – all report productivity of over 40,000 tonnes per worker. This is more than double the productivity of the next most productive mines. Commodore and Kogan Creek supply nearby power stations. Burton Coal went into care and maintenance.

[3] The highest production mine in Figure 2 is BHP's Mt Arthur mine in the Hunter Valley, which produced 19.88 million tonnes of saleable production in 2013-14.

> We will be utilizing at least 45, 400-tonne driverless trucks. All the vehicles will be capable of automation. When we ramp up the mine, everything will be autonomous from mine to port. In our eyes, this is the mine of the future.[4]

The planned automation of the Adani mine (and other Galilee mines) will not only reduce the number employed, but also affect where these jobs are distributed. Existing automation and remote-operation technology has led to mining jobs being concentrated in capital cities. For example, the centralised Iron Ore Operational Control Centre in Perth is one of the pillars of Rio Tinto's *Mine of the Future* scheme,[5] which has been developing and deploying remote and automated technology for 10 years. One-fifth of the Rio Tinto truck fleet is autonomous, including some iron ore mines that have only autonomous trucks in operation, and new railway tracks will be compatible with fully autonomous rail.[6]

Despite the political and media focus on Adani and jobs, the extent to which Galilee Basin Development would displace employment in existing Australian mines has not been widely researched. The well-publicised Adani job claims are based on analyses that do not consider this effect. Adani's preferred 10,000 job claim makes no consideration of the wider coal industry, while Adani's evidence in the Queensland Land Court estimating direct and indirect average employment increase of 1,464 jobs assumes no change in the coal price and therefore no change to the viability of other Australian coal projects.[7]

Analysis of how Galilee Basin development would affect other coal producing areas has not been conducted by Australian government agencies. The Department of Industry's Office of the Chief Economist confirmed in answers to questions on notice in 2017 that it does not conduct analysis on potential price impacts of changes to Australian coal

[4] ANZ Business Chief. (2015). *Adani Mining: Investing in Queensland.* ANZ Business Chief. 13 April 2015. http://anz.businesschief.com/Adani-Mining-Pty-Ltd/profiles/137/Adani-Mining:-Investing-in-Queensland

[5] Rio Tinto. (2018). *Pilbara: Mine of the Future*. http://www.riotinto.com/australia/pilbara/mine-of-the-future-9603.aspx and http://www.riotinto.com/japan/growth-and-innovation-19795.aspx

[6] Rio Tinto. (2016). *Driving productivity in the Pilbara.* http://www.riotinto.com/ourcommitment/spotlight-18130_18328.aspx ;
Rio Tinto. (2016) *Annual report 2016,* p 33. http://www.riotinto.com/documents/RT_2016_Annual_report.pdf

[7] See GHD (2013) *Carmichael Coal Mine and Rail Project SEIS Report for Economic Assessment*, http://eisdocs.dsdip.qld.gov.au/Carmichael%20Coal%20Mine%20and%20Rail/SEIS/Appendices/Appendix-E-Economic-Assessment-Report.pdf and Fahrer (2015) Carmichael coal and rail project: economic assessment, expert report to the Queensland Land Court. Note that Fahrer's analysis does estimate an impact on other mining projects from increased demand for mining labour and other inputs, but no consideration is given to competition within the coal market.

production. Instead, it conducts "broad analysis on coal markets, including global prices".[8]

While Adani and governments have not researched the impact of Galilee Basin development on employment in other coal regions, in 2017, commodity analysts Wood Mackenzie were commissioned by the owners of the world's largest export coal port, the Port of Newcastle, to model the impact that the development of the Galilee Basin would have on volume of coal produced in other regions in Australia.[9] This analysis provides a starting point for estimating employment impacts.

[8] Department of Industry, Innovation and Science. (2017). *Answers to Questions on Notice, Economics Legislation Committee, 2016-17 Additional Estimates, Question No.: AI-88.*

[9] Reported in Long, S. (2017). *Galilee Basin mines will slash coal output, jobs elsewhere, Wood Mackenzie says.* ABC News. 6 July 2017. http://www.abc.net.au/news/2017-07-06/galilee-basin-mining-project-will-reduce-coal-output:-research/8682164

Volume analysis

Wood Mackenzie estimated the impact on other coal regions of the Galilee Basin producing up to 150 million tonnes per annum (Mtpa) of thermal coal. An increase of 150 Mtpa is greater than the capacity of the Adani project alone, but is less than the approximately 200 Mtpa total capacity of all Galilee Basin projects.

The 150 Mtpa would represent an increase in the supply of traded coal of around 15%. Wood Mackenzie estimated that the Galilee Basin production would begin to come online from 2023, keeping coal prices lower than would otherwise have been the case – around $3 per tonne lower in 2026, increasing to $25 per tonne lower in 2030.

These lower prices lead to delays or cancellations of other coal projects in Queensland and NSW under Wood Mackenzie's modelling. Eleven mines in NSW and eight in Queensland would be affected, seeing production from Hunter, Bowen and Surat basins lower than would have occurred in the absence of Galilee development.

Importantly, Wood Mackenzie's modelled scenarios effectively assume the world takes little action on climate change. Both scenarios modelled by Wood Mackenzie see world demand for traded thermal coal increase by around 10% to 2035 and Australian thermal coal exports increase substantially. By contrast, the International Energy Agency models the thermal coal trade as declining by 60% in 2040 if the Paris targets are achieved.[10] The effect of Galilee Basin development on other coal regions would likely be greater still if policies to reduce emissions are successful.

The Wood Mackenzie analysis focuses on coal volumes and price, rather than on employment impacts. It does not provide an estimate of how many jobs could be affected in New South Wales and other Queensland coal regions if Galilee Basin production proceeds. This question is addressed here firstly by applying average and marginal labour productivity rates in existing mines to Wood Mackenzie estimates of reduced coal production. Secondly, we consider the potential employment numbers of identified mines and proposed mines that will be affected — either delayed or cancelled — due to the price effects and output from the Galilee Basin.

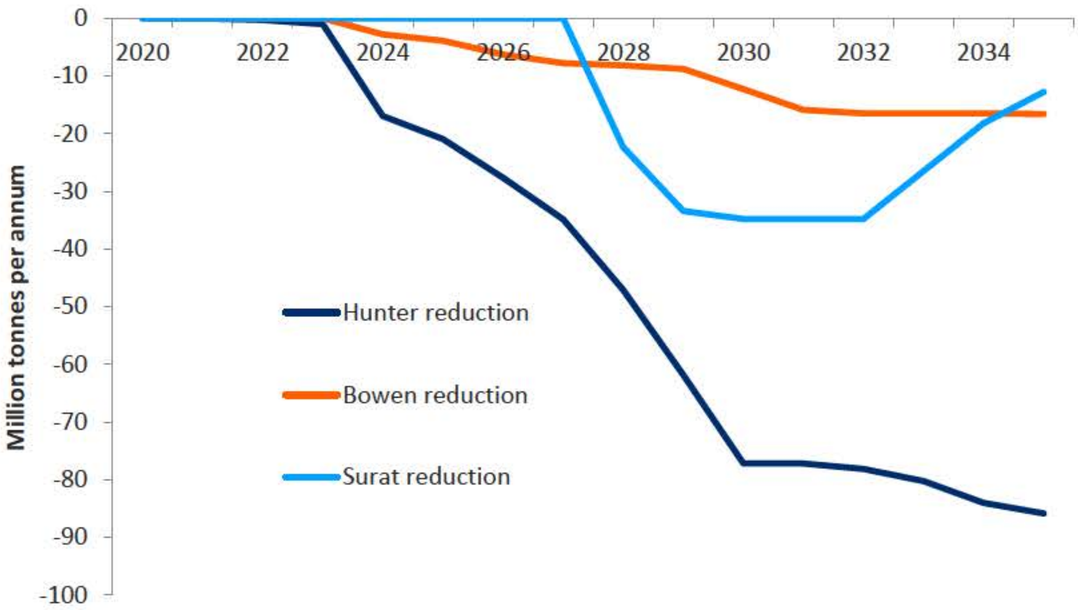
[10] International Energy Agency (2017) *World Energy Outlook 2017*, https://www.iea.org/weo2017/, see Table 5.1 World coal demand, production and trade by scenario, p207

Additionally, the automation of the Galilee coal production chain is likely to affect the location of mining jobs associated with this coal production, with control of automated process likely to be established in capital cities, leading to less regional employment.

Reduced volume

Wood Mackenzie estimated the impact of Galilee Basin development on the volume of thermal coal produced by three other coal producing areas, or potential areas: the Hunter Valley (NSW), the Bowen Basin and the Surat Basin (both in Queensland). Figure below summarises the estimated future declines in coal production in these three regions compared with the scenario of no coal production from the Galilee Basin.

Figure 3: Reduced coal production volumes with Galilee Basin production



Source: Long, S. (2017). Galilee Basin mines will slash coal output, jobs elsewhere, Wood Mackenzie says

Figure shows that the Hunter Valley is most affected by Galilee Basin development, as it has the most existing thermal coal mines. The Bowen Basin is least affected, as many of its mines produce high grade metallurgical coal, a market that would be largely unaffected by the increase in supply of low-grade thermal coal from the Galilee Basin. Wood Mackenzie's analysis accounts for the coal quality of different mines.

Figure also shows that coal production in the Surat Basin is affected later, as most of its mines are currently little more than proposals for new thermal coal mines. Wood Mackenzie expects that in the absence of Galilee Basin production, these Surat Basin mines will come into production in the late 2020s. Large scale production from the Galilee Basin would delay this start into the 2030s, which is why Figure shows the effect on Surat Basin coal production reducing in that period.

Job displacement

EMPLOYMENT INCREASES IN THE GALILEE BASIN

The Adani coal mine is expected to employ 3,920 people (according to the Queensland Department of State Development).[11] This is similar to figures Adani provided in its SEIS, where it said that the mine's operational workforce would be 3,400–3,800 people for most of its lifespan.[12] It is unclear what impact Adani's plans to fully automate the mine would have on these estimates, which appear to include minimal levels of automation.

60 million tonnes from 3,920 employees is equivalent to 15,306 tonnes per person employed per year. This would make the Adani project the second most productive mine per worker in Australia according to the data in Figures 1 and 2.

Wood Mackenzie assesses Galilee Basin coal production up to 150 million tonnes per year, including Adani.[13] Assuming that other Galilee Basin mines have the same labour productivity as the Adani mine is claimed to have, between 7,840 and 9,800 people would be employed per year.

[11] Department of State Development, Manufacturing, Infrastructure and Planning. (2018). *Carmichael Coal Mine and Rail Project Overview*. https://www.statedevelopment.qld.gov.au/assessments-and-approvals/carmichael-coal-mine-and-rail-project.html

[12] GHD. (2013). *Report for Carmichael coal mine and rail project SEIS – Economic Assessment.* http://eisdocs.dsdip.qld.gov.au/Carmichael%20Coal%20Mine%20and%20Rail/SEIS/Appendices/Appendix-E-Economic-Assessment-Report.pdf

Note: The Queensland Land Court heard evidence from Adani based on a 40 million tonne per year version of the project. Peak project employment under that version was estimated at 1,717 people in 2045, with an average over the life of the project around 1,500.

[13] Long, S. (2017). *Galilee Basin mines will slash coal output, jobs elsewhere, Wood Mackenzie says*. ABC News. 6 July 2017. http://www.abc.net.au/news/2017-07-06/galilee-basin-mining-project-will-reduce-coal-output:-research/8682164

IMPACTS ON EMPLOYMENT IN OTHER COAL REGIONS

Average productivity

Employment impacts of Galilee Basin development can be estimated in a variety of ways. The simplest is to take existing average labour productivity figures and assume they hold for the mines in each basin.

In 2016-17, Queensland produced 238m tonnes of coal with 30,925 workers - each employee produced on average 7,684 tonnes of coal.[14] The most recent figures available for NSW are for 2013–14, where 22,262 people produced 261.0 million tonnes of saleable coal, or 8,832 tonnes per person per year on average.[15] In Table 1 below, these average labour productivity figures are applied to Wood Mackenzie's estimates of relative reduction in coal output in each region in 2035:

Table 1: Relative employment reduction with Galilee, average productivity

Region/Time	Relative reduction in production (Mtpa)	Productivity (tonnes per worker)	Relative employment reduction
Hunter Valley	86	8,832	9,737
Bowen Basin	17	7,684	2,212
Surat Basin	13	7,684	1,692
Total	*116*		*13,641*

Sources: Qld DNRM (2017), NSW DRE (2014), Long (2017)

Table 1 shows that coal mine employment would be expected to be 13,641 lower in the Galilee development scenario than under the no-Galilee scenario. Impacts are greatest in the Hunter, 9,737 lower, 2,212 lower in the Bowen Basin and 1,692 lower in the Surat Basin.

[14] Queensland Department of Natural Resources and Mines (2017) *Coal industry review tables 2016-17*, https://data.qld.gov.au/dataset/coal-industry-review-statistical-tables

[15] The Coal Industry Profile 2014 breaks down coal production by region, but uses a narrower definition for the Hunter Valley than the Wood Mackenzie report does. As such, an overall figure for NSW has been used. Division of Resources and Energy. (2014). *NSW Coal Industry Profile 2014 – Volume 1,* p 1, 16–17. https://www.resourcesandenergy.nsw.gov.au/__data/assets/pdf_file/0005/664826/CIP-2014-Vol-1-final.pdf

Marginal productivity

Estimates based on averages have the benefit of simplicity, but from an economic point of view the marginal change in coal output per worker is more useful. Productivity may differ due to any economies or diseconomies of scale in each region.

To estimate the marginal productivity of an additional worker at a coal mine, data from 2011-12 to 2016-17 on Queensland and New South Wales coal mine output and employed workforce are used to estimate a linear model of the relationship between mine output and workforce, accounting for factors such as mine type (underground or open cut) in each coal region. For each coal region, the average workforce and output per year is used for each of the mines where data is available on production and workforce over this period. The equation:

$$Workforce_i = \alpha + \beta Coal\ Output_i + \gamma Underground_i + \varepsilon_{i,j}$$

is estimated each *i* mine in the Bowen Basin, Surat Basin, and Hunter Valley. The output of these regression estimates for each coal region is in Table , with the coal output variable significant in all regions, and the effect of underground mining, unexpectedly, having little average effect on mine workforce.

Table 2: Regression results for each coal region

	Bowen Basin	Surat Basin	Hunter Valley
Coal output (Mt) (*β*)	121.4***	106.5***	106.0***
Underground (*γ*)	-50.1	NA	161.9*
Intercept (*α*)	130.2	-88.3	-18.8
R squared	0.70	0.76	0.74
N	31	8	40

** significant at 10%, ** significant at 5%, *** significant at 1%.*

Sources: Queensland Government. (2017). *Mining industry worker numbers.* https://www.business.qld.gov.au/industries/mining-energy-water/resources/safety-health/mining/accidents-incidents/safety-performance; Department of Resources and Energy. (2014). *NSW Coal Industry Profile 2014 – Volume 1.* https://www.resourcesandenergy.nsw.gov.au/__data/assets/pdf_file/0005/664826/CIP-2014-Vol-1-final.pdf.[16]

[16] Note: QLD mines apply average output from 2012-13 to 2016-17 to reported workforce in 2014 for Blackwater, Caval Ridge, Clermont Coal, Curragh, Daunia, Ensham OC, Foxleigh, Jellinbah East, Middlemount, Minerva, Yarrabee, German Creek – Grasstree, Kestrel, Oaky Creek No 1, Oaky North, Collinsville Opencut, Coppabella, Goonyella – Riverside, Hail Creek, Isaac Plains, Lake Vermont, Millennium, Moorvale, Newlands, Peak Downs, Poitrel, Saraji, South Walker Creek, Carborough Downs, Moranbah North, North Goonyella, Callide & Boundary

In this model the coefficient estimate of each region's coal output variable is the marginal effect of an additional million tonnes of coal output on jobs for typical mines in that region. The marginal effect relationship can then be applied to Wood Mackenzie's forecast relative output reductions to estimate the employment impact.

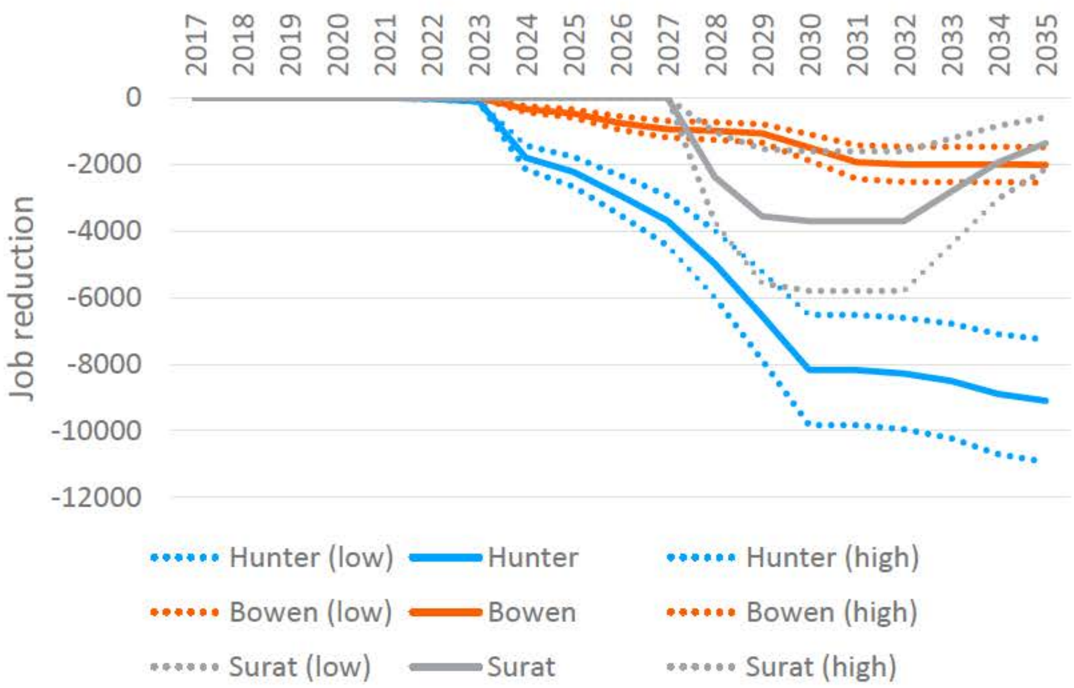
The significant coefficient for coal output in all regions represent the number of jobs related to a 1Mt change in coal output. In the Hunter Valley, for example, there are 106 mining jobs per additional Mt of coal output. Or in other words, an additional worker is associated with an increase in mine output of 9,433 tonnes per year. These relationships between output and workforce in each region that exist in the data for established mines can then be applied to the estimated changes in coal output from Wood Mackenzie to determine an estimate of jobs effect in those regions.

An alternative model specification that did not break coal output into regional associations, but instead applied regional dummy variables, was also tested. The coefficient of 112.3 for coal output, not surprisingly, was around the average of the regional estimates. However, because the Wood Mackenzie estimates of relative volume reduction are regional in nature, the current approach better serves this purpose by matching marginal output and jobs at a coal region level.

Mapping this marginal relationship between coal output and jobs in each region to the relative production reductions estimated by Wood Mackenzie gives the likely job impacts over time in the three regions, shown in Figure 4 below. Note that the dashed lines are the 95% confidence intervals around the coefficient estimates of the coal output variable for each region.

Hill, Cameby Downs, Commodore, Dawson, Kogan Creek, Meandu, and New Acland. NSW mines apply average output from workforce for 2011-12 to 2013-14 for Rolleston, Angus Place UG, Appin UG, Ashton UG, Austar UG, Bulga UG, Chain Valley UG (b), Dendrobium UG, Mandalong UG, Metropolitan UG, Narrabri UG (c), Springvale UG, Tahmoor UG, Ulan UG, Wambo UG, West Cliff UG, West Wallsend UG, Abel UG, Clarence UG, Myuna UG, Bengalla OC, Bloomfield OC, Boggabri OC, Drayton OC, Duralie OC, Hunter Valley Operations OC, Liddell OC, Mangoola OC, Moolarben OC, Mt Arthur Coal OC, Mt Owen OC, Mt Thorley Warkworth OC, Muswellbrook OC, Ravensworth North OC (d), Rix's Creek OC, Rocglen OC, Stratford OC, Tarrawonga OC, Ulan OC (e), Wambo OC, and Wilpinjong OC.

Figure 4: Coal industry job impacts in affected regions (dashed 95% con. intervals)



As shown in Table 1, Wood Mackenzie's scenario of relatively lower coal production in these regions of 116m by 2035 would reduce coal employment by around 12,480 jobs relative to no-Galilee Basin under current coal productivity figures.

Table 1: Approximate employment losses per region (in 2035)

Region/Time	Relative reduction in production (tonnes p.a.)	Assumed productivity (tonnes per employee)	Employment reduction
Hunter Valley	86,000,000	9,432	9,102
Bowen Basin	17,000,000	8,240	2,015
Surat Basin	13,000,000	9,389	1,363
Total	*116,000,000*		*12,480*

Notes: Tonnes per employee is one million divided by the coal output coefficient estimates for each region.

Table 2 shows that under this method, relative employment declines would be slightly lower than under the average productivity method above. The Hunter would experience 9,100 fewer workers, 2,000 fewer in the Bowen Basin and around 1,360 in the Surat Basin, compared to the no-Galilee development scenario.

Estimated workforce in impacted mines

An alternative approach is to consider the estimated workforces that would be engaged in mines that Wood Mackenzie forecasts will be delayed or scrapped under the Galilee development scenario. Many of these projects have published estimates of their workforce, while others have been estimated using state productivity rates to calculate relative job losses from their expected production declines. The results of this analysis are in Table 2 and 4 below:

Table 2: Employment in impacted Queensland coal mines

Mine	Extant	Basin	Predicted coal output p.a. (tonnes)	Jobs (provided)	Jobs (estimated)
Bowen Basin					
Drake	Y, operating	Bowen	6m	>150[17]	
Ensham	Y, operating	Bowen	4.5m	550[18]	
Meteor Downs South	N, advanced	Bowen	1.5m[19]		195
Springsure Creek	N, advanced	Bowen	11m	585[20]	
West Rolleston	Y, operating, planned expansion	Bowen	7.5–12.5m[21]		976–1,846
Bowen sub-total			*30.5–35.5m*	*2,456–3,326*	
Surat Basin					
Collingwood	N	Surat	6m[22]		780
The Range	N, deposit	Surat	6.3m[23]		820
Wandoan	N, deposit	Surat	22m[24]	844	
Surat sub-total			*34.3m*		*2,444*
Queensland Total			*64.8–69.8m*	*4,900–5,552*	

[17] QCoal Group. (2018). *Our Projects: Drake Mine*. http://qcoal.com.au/our-projects/drake-mine/

[18] Idemitsu. (2018). *Operations: Ensham Resources*. https://www.idemitsu.com.au/operations/ensham-resources/

[19] UD Coal. (2018). *Projects: Meteor Downs South*. http://www.udcoal.com.au/default.asp?section_id=34

[20] DEHP. (2018). *Environmental Impact Statement: Springsure Creek Coal Mine Project*. Department of Environment and Heritage Protection. Queensland Government. https://www.ehp.qld.gov.au/management/impact-assessment/eis-processes/springsure-creek-coal-project.html

[21] Ker, P. (2011). *Xstrata gives green light to Rolleston expansion*. Sydney Morning Herald. 18 May 2011. http://www.smh.com.au/business/xstrata-gives-green-light-to-rolleston-expansion-20110517-1erd6.html

[22] State Development. (2018). *North Surat - Collingwood Coal Project*. Department of State Development, Manufacturing, Infrastructure and Planning. Queensland Government. https://www.statedevelopment.qld.gov.au/assessments-and-approvals/north-surat-collingwood-coal-project.html

[23] DEHO. (2018). *Environmental Impact Statement: The Range Project*. Department of Environment and Heritage Protection. Queensland Government. https://www.ehp.qld.gov.au/management/impact-assessment/eis-processes/the-range.html

[24] Xstrata Coal. (2018). *Wandoan Coal Project - Environmental Impact Statement*. https://www.statedevelopment.qld.gov.au/resources/project/wandoan-coal-project/eis-integrated-exec-summary.pdf

Sources: See footnotes for company estimates. Other mines estimated with state-wide productivity average.

Table 3: Employment in impacted Hunter Valley coal mines

Mine	Predicted coal output p.a. (tonnes)	Jobs (Coal Industry Profile)	Jobs (estimated)
Austar and modification	3.6m	473 (current), 275 (modification)	
Dartbrook	4m		453
Ferndale	3m		340
Mt Penny	5m		566
Mt Pleasant	8m	340	
Mt Pleasant (new)	8m		906
Mt Thorley	2.8m	1,300	
Mt Thorley (underground)	4m		
Tarrawonga	2.1m	159 (current), 140 (extension)	
Vickery	3.6m	200	
Wallarah 2	4m	300	
Watermark	5m	500	
West Muswellbrook	15m		1,698
Total	*66.6m*		*7,650*

Sources: Division of Resources and Energy. (2014). *NSW Coal Industry Profile 2014 – Volume 1.*Note: Mines not estimated in DRE (2014) estimated with state-wide productivity average. In some cases, Wood Mackenzie's predicted coal output is lower than the mine's capacity according to DRE (2014).

Tables 3 and 4 show larger relative declines in output (130 Mtpa instead of 116Mtpa) and similar effects on employment (between 12,550 and 13,420) compared to the estimates above. The main reason for the higher output estimate is that data from government and proponent sources is for peak expected output for each mine. Many of these estimates are likely to be optimistic and in any particular year it is unlikely that all mines would have been operating at their peak. However, the data on mine workforce is more likely to be an average, rather than peak, with some proponents publishing a workforce range instead.

Regardless of the method used, the estimates of relative employment reduction are similar. Somewhere between 12,480 and 13,641 fewer people would work in Hunter, Bowen Basin and Surat Basin thermal coal mines with Galilee Basin development in 2035. The Galilee Basin itself would likely employ between 7,840 and 9,800 people. Overall, this would see a relative reduction of employment of between 2,680 and 5,801 workers in the coal industry overall.

Effects of automation

The sections above base estimates of Galilee Basin mine employment on submissions by Adani to state planning processes. It is unclear what degree of automation those estimates envisage, though the opportunity to automate in new coal basins is greater than in other coal mining regions with established mine and rail infrastructure. This is one of the reasons that there are likely to be net jobs losses in coal mining from development of the Galilee Basin even though there will be a net increase in Australian coal production — coal production from a highly labour-efficient automated 'mine to port' system will be offsetting coal production from established coal mining regions with less scope for whole-of-production chain automation. The automation of the Galilee also will affect the location of the jobs it creates, with control of automated functions likely to occur from capital city head offices.

Research from the University of Queensland, partly funded by the mining industry, into autonomous and remote-operated mining outlines a number of likely consequences of these technologies for employment. The research found that, in open pit iron ore mines, a fully autonomous haul truck fleet would reduce in-pit roles by 50%, for an overall decrease in the mine workforce of 30–40%. There are also autonomous drilling rigs and underground equipment that could replace workers.[25]

Existing remote operations centres have been mostly set up in capital cities, increasing employment there but at the expense of regional centres. The University of Queensland researchers only found one example of a regional town having a remote operations centre at the time of writing in 2013, with the remainder being placed in capital cities. Because of increased competition and lower risk, remote operators working in capital cities may also receive lower salaries. The study found that when remote operations centres were built in capital cities, residential employment near the mines would fall.[26]

Fewer on site roles, which subsequently reduce the number of mine-related jobs in regional areas, is "likely to reduce town populations, economic activity in the local and regional area and population-driven social services". In scenarios where remote

[25] McNab,K.,et. al. (2013). *Exploring the social dimensions of autonomous and remote operation mining: Applying Social Licence in Design*. Prepared for CSIRO Minerals Down Under Flagship, Mineral Futures Collaboration Cluster, Sustainable Minerals Institute, The University of Queensland.
https://www.csrm.uq.edu.au/publications/exploring-the-social-dimensions-of-autonomous-and-remote-operation-mining-applying-social-license-in-design

[26] *Ibid.*

operations were placed in capital cities, the regional towns saw decreased population, average annual expenditure and services.[27]

The research also found that automation and remote operations would disproportionately affect Aboriginal Australians, both because a disproportionate share of Aboriginal people are employed in mining (21% of Aboriginal employment in the Pilbara, for example) and because most Aboriginal employees live regionally (up to 90% in some cases). This potentially threatens commitments from both industry and government to increase Aboriginal employment in mining.[28]

Due to automation and remote control, many of the jobs created in the development of mining in the Galilee Basin are likely to be in major cities, rather than near to the mines themselves.

[27] *Ibid.*
[28] *Ibid.*

Conclusion

Debate around the impacts of future coal development have often focused on the Adani Carmichael mine and the competing claims around how many jobs that project would result in. Despite Adani's own economist telling the Queensland Land Court that the project would see employment increase by less than 1,500, supporters of the project and the company itself resolutely repeat the fabled 10,000 jobs claim. Prime Minister Turnbull went further still proclaiming "tens of thousands of jobs".[29]

None of these estimates consider some basic points. Firstly, the Adani project is unlikely to proceed in isolation. Other projects in the Galilee Basin would be likely to go into production if infrastructure for Adani's mine is built.

This leads to the second point – the Galilee Basin mines would represent a significant expansion of the traded thermal coal market. This expansion would push down coal prices and see some competing mines not proceed or leave the market. Some of these mines will be in Australia.

Despite these important points, no analysis has been conducted on the impacts of Galilee Basin development on the country's other main coal producing regions. On the contrary, stakeholders such as NSW Minister for Resources Don Harwin have dismissed the need for any analysis, saying he is "comfortable and not concerned about ongoing coal exports".[30]

Harwin's lack of concern is based on his belief that the lower ash content of NSW coal makes Galilee Basin coal irrelevant to his state. This is like one brewer ignoring a new brewery entering the market because their beer is slightly stronger. If the price of XXXX Gold reduces by 15 percent with the assistance of government subsidies, it is unlikely the makers of Carlton Draft would pay no attention due to their slightly different alcohol contents.

Furthermore, this analysis is based on an assumption of expanding coal demand and export sales when the latest data and many projections are for declines. The Paris Agreement makes it clear that the world needs to burn less coal, not more. The level of

[29] Kenny (2017) Adani mine edges closer after Malcolm Turnbull's India visit, https://www.smh.com.au/politics/federal/adani-mine-edges-closer-after-malcolm-turnbulls-india-visit-20170411-gvilmk.html

[30] Legislative Council Hansard (2017) Adani Carmichael Coalmine Proposal Impact, https://www.parliament.nsw.gov.au/Hansard/Pages/HansardResult.aspx#/docid/HANSARD-1820781676-73150

automation that Galilee Basin development would see is also unclear, but appears to be optimistically low in much of the above analysis.

Australia's governments need to address the question of the likely impacts of Galilee Basin Development. The federal Office of the Chief Economist, NSW Resources and Energy and the Queensland Department of Natural Resources, Mines and Energy should investigate this in detail as part of a plan for transitioning our coal regions into a carbon constrained future.

Suboptimal supercritical

Reliability issues at Australia's supercritical coal power plants

There have been recent calls for Australian taxpayers to subsidise the building of supercritical coal power plants (so-called "HELE" plants), but existing supercritical plants experience frequent breakdowns that affect electricity prices and can push grid frequency outside of safe ranges.

Discussion paper

Mark Ogge
Bill Browne
January 2019

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Level 1, Endeavour House, 1 Franklin St
Canberra, ACT 2601
Tel: (02) 61300530
Email: mail@tai.org.au
Website: www.tai.org.au
ISSN: 1836-9014

Summary

A number of federal and state politicians and mining industry groups have called for new supercritical or ultra-supercritical coal-fired power stations to be built in the National Electricity Market (NEM).

Data from The Australia Institute's Gas & Coal Watch shows that coal plants are unreliable and prone to break downs – as they have dozens of times since the Institute began monitoring in 2017.

Furthermore, of Australia's black coal plants, the supercritical plants have performed just as badly as subcritical plants relative to generating capacity, despite being newer.

A close study of Kogan Creek, Australia's newest supercritical coal plant, shows that its breakdowns:

1. Occur often,
2. Are the biggest in the NEM,
3. Have contributed to price spikes, and
4. Have caused frequency losses outside of the safe operating band.

The Victorian Nationals, the "Monash Forum" of federal Coalition backbenchers and the Minerals Council of Australia have proposed building supercritical plants in Victoria that would burn brown coal. This raises two concerns. Firstly, Australia's brown coal plants are more unreliable than its black coal plants and, secondly, supercritical brown plants would still be more emissions intensive than the majority of Australia's existing coal plants.

Introduction

In recent years, a number of politicians and mining industry groups have pushed for so-called "high efficiency, low-emissions" or "HELE" coal power stations to be built – either entirely by the government or with government subsidies if new coal plants are not economically viable on their own.

"HELE" is an industry promotional term for supercritical coal plants, which operate above a 'critical' temperature and pressure level, in theory making them more efficient and with lower emissions than "subcritical" coal plants. They still have higher emissions than other energy sources like natural gas and renewable energy.

In 2017, Barnaby Joyce (then Deputy Prime Minister) and Minister for Resources Matt Canavan called for the Federal Government to "fund or indemnify" a new plant in Queensland.[1] One Nation wants the Queensland government to build a new coal plant in North Queensland, with the federal government paying half of the $3 billion cost.[2] The Queensland Resources Council has also called on the federal government to "encourage" investment in a Queensland supercritical plant.[3]

In 2018, backbench Coalition MPs calling themselves the "Monash Forum"[4] called for government assistance for new coal plants, with spokesperson Craig Kelly saying the federal government should be prepared to "build one in its entirety, from scratch". Craig Kelly nominated the Latrobe Valley in Victoria as the potential site for a new plant, meaning that it would burn brown coal.[5] The Victorian Nationals have described

[1] Murphy (2017) *Coal to stay in energy mix for foreseeable future, says Barnaby Joyce,* https://www.theguardian.com/australia-news/2017/jun/18/coal-to-stay-in-energy-mix-for-foreseeable-future-says-barnaby-joyce

[2] Daily Mercury (2017) *One Nation reveals $1.5b plan for NQ coal power station,* https://www.dailymercury.com.au/news/one-nation-reveals-15b-plan-for-nq-coal-power-stat/3261961/#/0

[3] Queensland Resources Council (2018) *Queensland ideal place for HELE coal investment,* https://www.qrc.org.au/media-releases/queensland-ideal-place-for-hele-coal-investment/

[4] Including Tony Abbott, Eric Abetz, Kevin Andrews, George Christensen and Barnaby Joyce.

[5] Hasham (2018) *A new coal-fired power plant would cost $3 billion, drive up energy prices and take eight years to build*, https://www.theage.com.au/politics/federal/a-new-coal-fired-power-plant-would-cost-3-billion-drive-up-energy-prices-and-take-eight-years-to-build-20180403-p4z7jg.html; Chang (2018) *Are you willing to pay $4 billion to support 'clean' coal-fired power plants?,* https://www.news.com.au/technology/environment/climate-change/are-you-willing-to-pay-4-billion-to-support-clean-coalfired-power-plants/news-story/1f1b51d97c0027176c96e5f596860665

such a plant as “essential”[6] and the Minerals Council of Australia ”strongly support” the move, releasing modelling on the emissions intensity of supercritical brown plants that is used in this paper.[7]

When he was Minister for Energy and Environment, Josh Frydenberg – now Treasurer and deputy leader of the Liberal Party – said new supercritical coal plants “have a role to play” and “the government stands ready to ensure the best possible outcomes in the marketplace if the market itself can’t deliver that”.[8] New environment minister Melissa Price has said that she would support a new coal plant being built.[9] In the Australian Senate, the Coalition and One Nation voted for the government “to facilitate the building of new coal-fired power stations”.[10] The Minerals Council has called for new coal to be built in NSW or Victoria.[11]

With repeated, prominent and forceful calls for new supercritical coal-fired power stations to be built with taxpayer money, it is important to reflect on the performance of Australia’s existing supercritical coal plants.

[6] The Nationals for Regional Victoria (2017) *Keeping the lights on in Victoria,* http://vic.nationals.org.au/keeping_the_lights_on_in_victoria

[7] Minerals Council of Australia (2017) *Latrobe Valley HELE plant would deliver reliable, affordable power,* https://www.minerals.org.au/latrobe_valley_hele_plant_would_deliver_reliable_affordable_power; Nethercote, Aldred and Gibbons (2017) *Securing energy, jobs and Australia’s export advantage,* https://www.minerals.org.au/sites/default/files/Latrobe_Valley_Securing_energy_and_jobs_and_Australias_export_advantage_June_2017.pdf

[8] Karp (2017) *New coal plants have a role in Australia's energy future, Josh Frydenberg says,* https://www.theguardian.com/australia-news/2017/aug/13/new-coal-plants-have-a-role-in-australias-energy-future-josh-frydenberg-says

[9] Hondros (2018) *Environment minister backs Paris targets, open to coal-fired power,* https://www.canberratimes.com.au/national/western-australia/environment-minister-backs-paris-targets-open-to-coal-fired-power-20180903-p501eq.html

[10] Murphy (2018) *Coalition backs Hanson motion for new coal-fired power stations,* https://www.theguardian.com/australia-news/2018/jun/27/coalition-backs-hanson-motion-to-build-new-coal-fired-power-stations

[11] Evans (2017) *Independent report backs modern coal generation for Australia,* https://www.minerals.org.au/news/independent-report-backs-modern-coal-generation-australia-0

Subcritical and supercritical coal-fired power plants

The original "subcritical" coal-fired power plants used coal to boil water, with the steam driving a turbine, which in turn drives a generator to generate electricity. In this process, energy is lost as the liquid water turns to steam.

Since 1957, some coal-fired power plants have been designed to reduce this energy loss – and therefore operate more efficiently – by turning the water into a "supercritical fluid" that has properties of both gas and liquid. "Supercritical" coal plants have the specialised equipment needed to keep water at such a temperature and pressure that it turns supercritical.

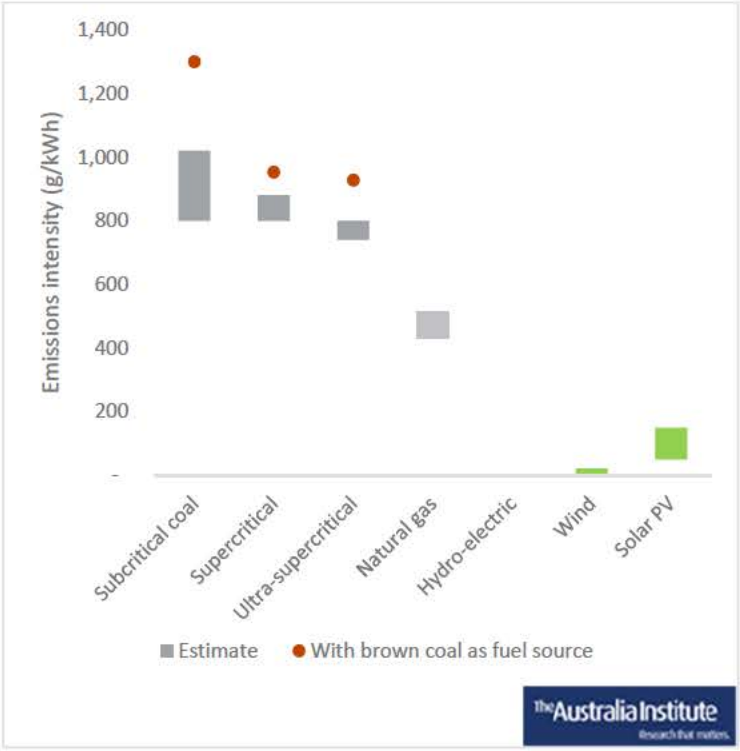
The next generation "ultra-supercritical" plants operate at even higher temperatures and pressures and can further reduce energy loss and make the process more efficient. Since the 1990s, some ultra-supercritical plants have been built overseas. The industry hopes to develop "advanced ultra-supercritical" plants that would take it a step further and increase efficiency through even higher temperatures and pressures.

Supercritical plants (including ultra-supercritical plants) require less coal than subcritical plants in order to generate the same amount of electricity. By burning less coal, these plants emit less pollution. This has lead them to be described as "High-Efficiency, Low-Emissions" technology by coal advocates.

However, this is only true relative to other coal plants, as shown in Figure 1.

The most efficient current coal technology, "ultra-supercritical", still emits upwards of 740 grams of CO2 per kWh of electricity produced. This is more than the standard range for natural gas, of between 430 and 517 grams of CO2/kWh. Australia has never successfully built an ultra-supercritical coal power plant.

Figure 1: Approximate lifetime emissions intensity of power sources



Source: See Table 1 below

Exacerbating this is the proposal by the Victorian Nationals, the Minerals Council and the "Monash Forum" of federal Coalition backbenchers to build the supercritical plant in the Latrobe Valley, where it would burn brown coal.

The brown dots in Figure 1 demonstrate how changing the fuel source from black to brown coal increases the emissions intensity of different technologies. Research from CO2CRC shows that an "ultra-supercritical" plant burning brown coal would emit 928 grams CO2/kWh, which is well above the current emissions intensity of the NEM (around 800 grams CO2/kWh),[12] and above the emissions intensity of many of Australia's existing subcritical coal plants. In 2016–17, 10 coal plants in the NEM reported emissions intensity below 928 grams CO2/kWh.[13]

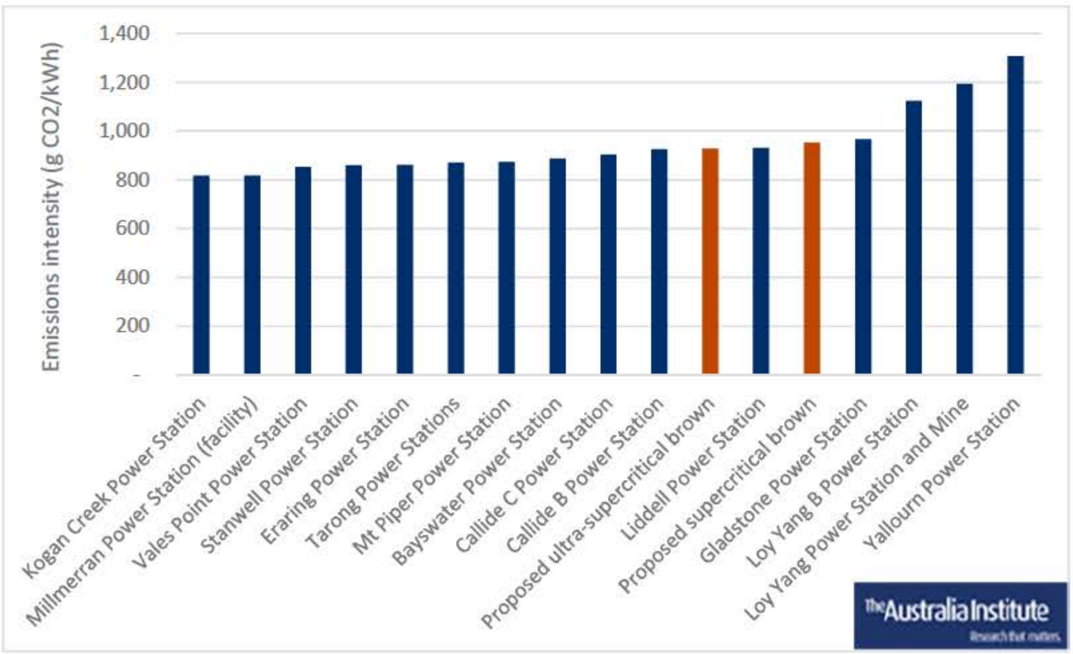
[12] Climate Change Authority (2013) *Analysis of electricity consumption, electricity generation emissions intensity and economy-wide emissions,* http://climatechangeauthority.gov.au/files/files/Target-Progress-Review/Analysis-of-electricity-consumption-electricity-generation-emissions-intensity-and-economy-wide-emissions/Australia%20electricity%20and%20emissions%20final%20report%202013%2010%2018.pdf

[13] Clean Energy Regulator (2018) *Electricity sector emissions and generation data 2016–17,* http://www.cleanenergyregulator.gov.au/NGER/National%20greenhouse%20and%20energy%20repor

In other words, as illustrated in Figure 2, state-of-the-art, brand new "High Efficiency, Low Emissions" coal plants burning brown coal would be no more efficient or lower emissions than some of Australia's oldest subcritical black coal plants – whether or not they are "ultra-supercritical". As Figure 1 demonstrated, even ultra-supercritical plants burning black coal (i.e., the most efficient existing coal technology burning the "cleaner" variety of coal) are far closer in efficiency and emissions to other coal plants than they are to natural gas, which is itself a polluting fossil fuel.

Calling any coal plant "High Efficiency, Low Emissions" is at best inaccurate, and at worst, a deliberate attempt to muddy the waters.

Figure 2: Emissions intensity, current coal plants (2016–17) and proposed brown supercritical plants



Source: Clean Energy Regulator (2018) *Electricity sector emissions and generation data 2016–17*; Nethercote, Aldred and Gibbons (2017) *Securing energy, jobs and Australia's export advantage;* CO2CRC (2016) *Australian power generation technology report*, p 119, http://www.co2crc.com.au/wp-content/uploads/2016/04/LCOE_Report_final_web.pdf

ting%20data/electricity-sector-emissions-and-generation-data/electricity-sector-emissions-and-generation-data-2016-17

Table 1: Emissions intensity by generation type

Generation type	Estimate (grams CO2/kWh)
Subcritical	≥880 (black coal) Up to 1,306 (brown coal)
Supercritical	800–880 (black coal) 953 (brown coal)
Ultra-supercritical	740–800 (black coal) 928 (brown coal)
Advanced ultra-supercritical (not commercially deployed)	670–740 (black coal) 750 (brown coal)
Natural gas	430–517
Hydro-electric	4
Wind	3–22
Solar PV	50–150

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Source explanation: Black coal subcritical, supercritical and ultra-supercritical ranges are from the World Coal Association's *High efficiency low emissions coal* resource. The advanced ultra-supercritical figure for brown coal is from the figure for BOA Plus in *Securing energy, jobs and Australia's export advantage,* p 16. Supercritical and ultra-supercritical figures for brown coal are from *Australian power generation technology report,* p 119. The subcritical figure for brown coal is Yallourn Power Station's emissions intensity for 2016–17. Figures for natural gas and renewables are from *1 kilowatt-hour*.

Sources (Table 1 and Table 2): IEA (2016) *An overview of HELE technology deployment in the coal power plant fleets of China, EU, Japan and USA*; World Coal Association (n.d.) *High efficiency low emissions coal*, https://www.worldcoal.org/reducing-co2-emissions/high-efficiency-low-emission-coal; Molyneaux (2017) *Is 'clean coal' power the answer to Australia's emissions targets?,* https://theconversation.com/is-clean-coal-power-the-answer-to-australias-emissions-targets-71785; Holmes À Court (2017) *How clean are Australia's 'clean coal' power stations?,* https://reneweconomy.com.au/clean-australias-clean-coal-power-stations-14224/; BlueSkyModel (n.d.) *1 kilowatt-hour*, http://blueskymodel.org/kilowatt-hour; Nethercote, Aldred and Gibbons (2017) *Securing energy, jobs and Australia's export advantage*; Jotzo and Mazouz (2015) *Farewell to brown coal without tears: How to shut high-emitting power stations,* https://theconversation.com/farewell-to-brown-coal-without-tears-how-to-shut-high-emitting-power-stations-50904; CO2CRC (2016) *Australian power generation technology report*, http://www.co2crc.com.au/wp-content/uploads/2016/04/LCOE_Report_final_web.pdf

Note: Where possible, figures are for lifecycle emissions and/or based on electricity "as generated". Because power stations consume some share of energy themselves (as "auxiliary power"), the actual emissions intensity of "sent out" energy is likely to be higher.

Table 2: Pressure and temperature ranges for coal plant technologies

	Temperature	Pressure	Efficiency (LHV, net)
Subcritical	Up to 560 degrees Celsius	Less than 22.1 MPa	Up to 38%
Supercritical	540–580 degrees Celsius	22.1–25 MPa	Up to 42%
Ultra-supercritical	Greater than 580 degrees Celsius	Greater than 25 MPa	Up to 45%
Advanced ultra-supercritical	Greater than 620 degrees Celsius	Greater than 32 MPa	45–50%

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Source explanation: Subcritical, supercritical and ultra-supercritical ranges are from *Securing energy, jobs and Australia's export advantage,* p 13, and the World Coal Association's *High efficiency low emissions coal* resource.

Many breakdowns at supercritical plants

While supercritical plants are higher efficiency than subcritical plants (when burning similar fuels), this is in physical terms: they are better at converting input energy into useful output energy. They are not necessarily superior to subcritical plants in practical or economic terms. Supercritical plants can have higher capital costs, require more complicated and expensive components and be less able to "ramp" up and down – in other words, slower to respond to changes in demand.

These limitations can cause problems for electricity consumers. For example, boiler tube leaks are the main causes of breakdowns at coal plants.[14] Higher pressures and temperatures, like those seen in supercritical plants, will put greater stress on coal plant boilers. These greater temperatures and pressures could be a reason for the high rate of coal breakdowns at the newer supercritical power plants in Australia.

Australia has four coal power plants that have been built in the last 20 years, all of which are in Queensland. All of these are supercritical power stations.

Table 3: NEM supercritical coal plants in Queensland

Power Station	Age (Years)
Callide Power Plant	18
Millmerran Power Station	17
Tarong North Power Station	17
Kogan Creek Power Station	12

Source: Senate Environment and Communications References Committee (2017) *Retirement of coal fired power stations: Final report*, p 3, https://www.aph.gov.au/Parliamentary_Business/Committees/Senate/Environment_and_Communications/Coal_fired_power_stations

Other than these four power stations, all other black coal power plants in the NEM are older subcritical plants.

[14] Bamrotwar and Deshpande (2014) *Root Cause Analysis and Economic Implication of Boiler Tube Failures in 210 MW Thermal Power Plant*, https://www.scribd.com/document/306366367/RCA-of-Boiler-Tube-Failure-in-210-MW-plant

The Australia Institute began monitoring breakdowns of gas and coal plants in the NEM in late 2017. In 2018, there have been 74 breakdowns at black coal power plants in the NEM, approximately one every five days.

The older subcritical plants have enormous issues with reliability. This is illustrated by the NSW "energy crisis" in June this year.[15]

New South Wales has no new supercritical coal power plants. All are old subcritical plants between 27 and 48 years old. In early June 2018 they failed spectacularly when up to almost half the New South Wales fleet was offline during peak demand periods, triggering a power "crisis" that resulted in five price surges to over AUD 2,400 per MWh within a few days.

Despite the decidedly low bar set by the antiquated fleet of subcritical coal power plants in the NEM, the newer supercritical power plants are just as unreliable.

In 2018, these plants have broken down more often than the older subcritical plants.

Of the 74 breakdowns at black coal power in 2018, 61 have been at subcritical black coal plants and 13 have been at the newer supercritical plants.

However, the older subcritical power stations make up a far larger proportion of the capacity of the NEM (30%), with the supercritical plants making only up 6%.

As shown in Table 4 below, there have been 4.4 breakdowns per gigawatt of capacity at supercritical plants in the NEM over this period compared to 4.0 breakdowns per gigawatt of capacity at the older subcritical black coal plants.

Table 4: NEM unit trips (2018)

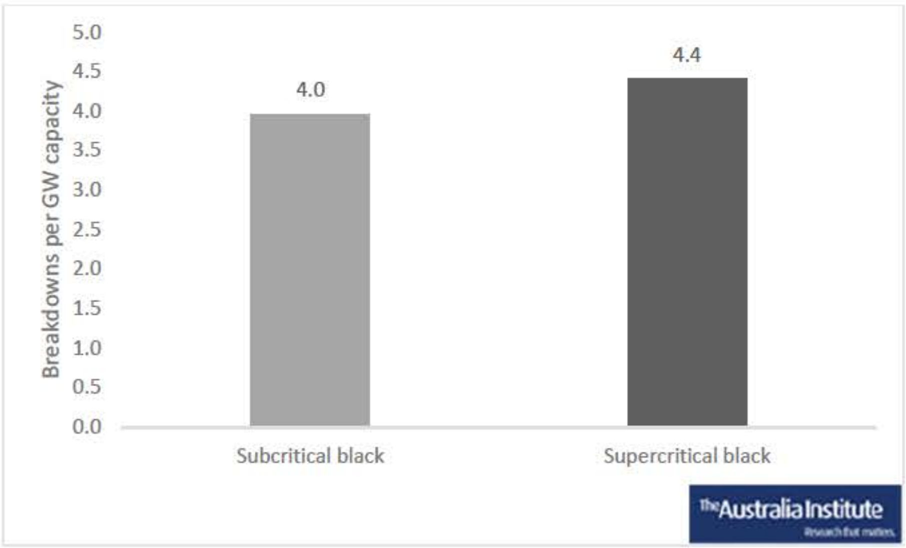
Group	Capacity (GW)	Share of NEM	Breakdowns	% of breakdowns	Breakdowns/ GW capacity
Subcritical black	15.4	30%	61	45%	4.0
Supercritical black	2.9	6%	13	10%	4.4
Subcritical brown	4.7	9%	44	33%	9.4
Gas	12.0	24%	17	13%	1.4
Total	*35.0*	*69%*	*135*	100%	*3.9*
Total NEM capacity	*50.5*				

[15] Ogge (2018) *Coalapse! The New South Wales winter "energy crisis"*

Source: Australia Institute Gas and Coal Watch, Open NEM

As shown in Figure 3 below, the rate of breakdowns of the newer supercritical plants is higher than that of the older subcritical plants.

Figure 3: Breakdowns at black coal plants in the NEM per gigawatt of capacity (2018)



Source: Calculations based on The Australia Institute's Gas & Coal Watch

It is worth emphasising that both subcritical and supercritical black coal plants have performed better than Victoria's brown coal plants, which broke down 9.4 times per GW of capacity. Despite this, Coalition backbenchers and the Minerals Council of Australia have specifically called for new brown coal supercritical plants to be built. This would couple the less reliable technology – supercritical – with the less reliable fuel type – brown coal.

The hapless HELE: Problems with Australia's newest coal plant

Kogan Creek Power Station deserves particular study because – despite being the newest coal plant in the country – its breakdowns are frequent and often the largest in the NEM, causing price spikes and frequency losses.

Built in 2007, Kogan Creek is "one of Australia's most efficient and technically advanced coal-fired power stations".[16] It is also one of the more unreliable power stations in the NEM, having broken down on seven occasions since mid-December last year, including the three largest single breakdowns in the NEM since monitoring began.

Table 5 below shows the breakdowns at supercritical coal power stations in the NEM since mid-December 2017.

Table 5: Supercritical plant breakdowns, 13 December 2017 to 31 December 2018

Plant	Date	Generation actually lost (MW)	Registered capacity of unit lost (MW)
Millmerran	13/12/2017	~580	426
Kogan Creek	23/12/2017	350	744
Millmerran	01/01/2018	156	426
Kogan Creek	11/01/2018	195	744
Callide Power Plant	16/01/2018	405	420
Callide Power Plant	09/02/2018	406	420
Millmerran	19/02/2018	417	426
Tarong North	03/03/2018	255	443
Kogan Creek	18/04/2018	~750	744
Callide Power Plant	30/04/2018	~400	420
Kogan Creek	05/06/2018	750	744
Kogan Creek	16/06/2018	752	744
Kogan Creek	13/08/2018	~286	N/A*
Kogan Creek	13/12/2018	334	N/A*
Tarong North	18/12/2018	442	450

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[16] CS Energy (n.d.) *Kogan Creek Power Station,* https://www.csenergy.com.au/what-we-do/generating-energy/kogan-creek-power-station

Notes: 13 of the 15 breakdowns were unit trips. The (*) marks a decrease, which did not cause the entire unit to be lost. The registered capacity of plants is typically lower than the maximum capacity, so for example Kogan Creek's capacity is given here as 744 MW although it is seen generating more.

As shown in Table 5, Kogan Creek Power Station had seven breakdowns over this period, more than any other supercritical plant. Kogan Creek consists of one generating unit – the largest single unit in the NEM. This means that each breakdown resulted in the single largest loss of capacity of any breakdown in the NEM. In the case of three breakdowns, the unit was at full capacity – meaning that the NEM suddenly lost upwards of 750 MW of generation that it was relying on. In the other three cases, the unit had already been generating below capacity when it broke down.

The breakdowns at Kogan Creek Power Station on 18 April, 5 June and 16 June are shown in Figure 4, Figure 5 and Figure 6 below. The dark shaded area of the charts shows the output remaining fairly constant at around 750 MW before suddenly and unexpectedly dropping to zero. These breakdowns are the three largest breakdowns in the NEM since Gas & Coal Watch began monitoring in mid-December 2017. Since Kogan Creek is a single generating unit, each of these unit trips represents the loss of all generation from Kogan Creek.

Figure 4: Kogan Creek unit trip of 18 April 2018

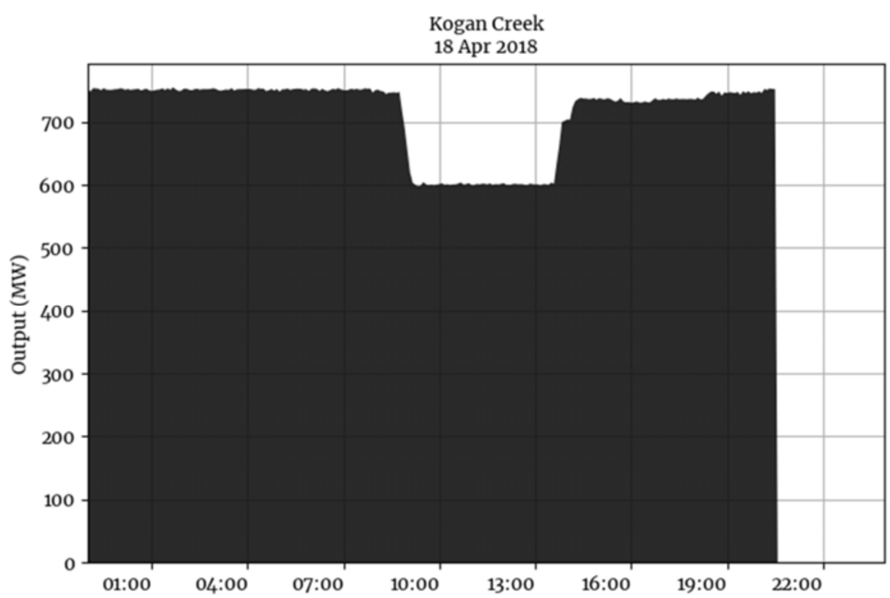


Figure 5: Kogan Creek unit trip of 5 June 2018

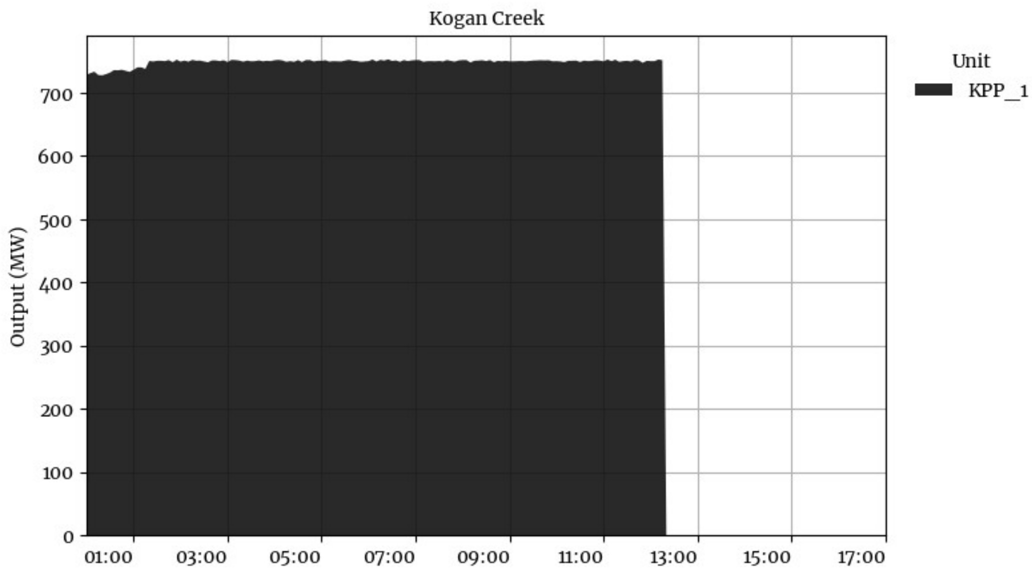
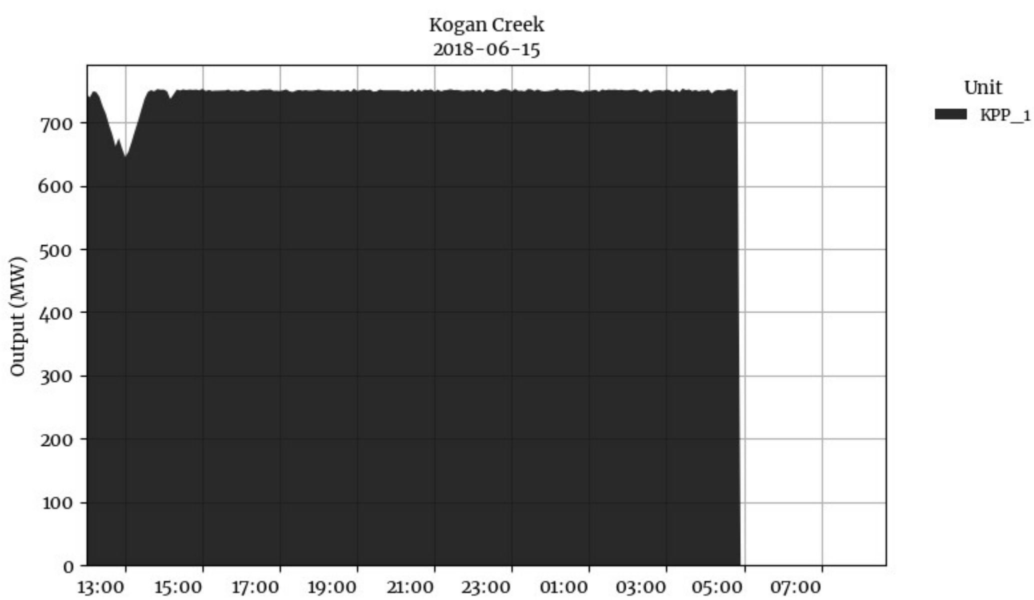


Figure 6: Kogan Creek unit trip of 16 June 2018



Source: OpenNEM

Note: The date on the figure is 15 June as the graph begins in the afternoon of the previous day.

GRID FREQUENCY DISRUPTIONS

When sudden decreases in supply push grid frequency out of its safe range there are a number of risks, including damage to equipment on both the power generation and demand sides. As the largest single generator in the NEM, and with its record of breakdowns, Kogan Creek power station poses a particular threat to grid frequency.

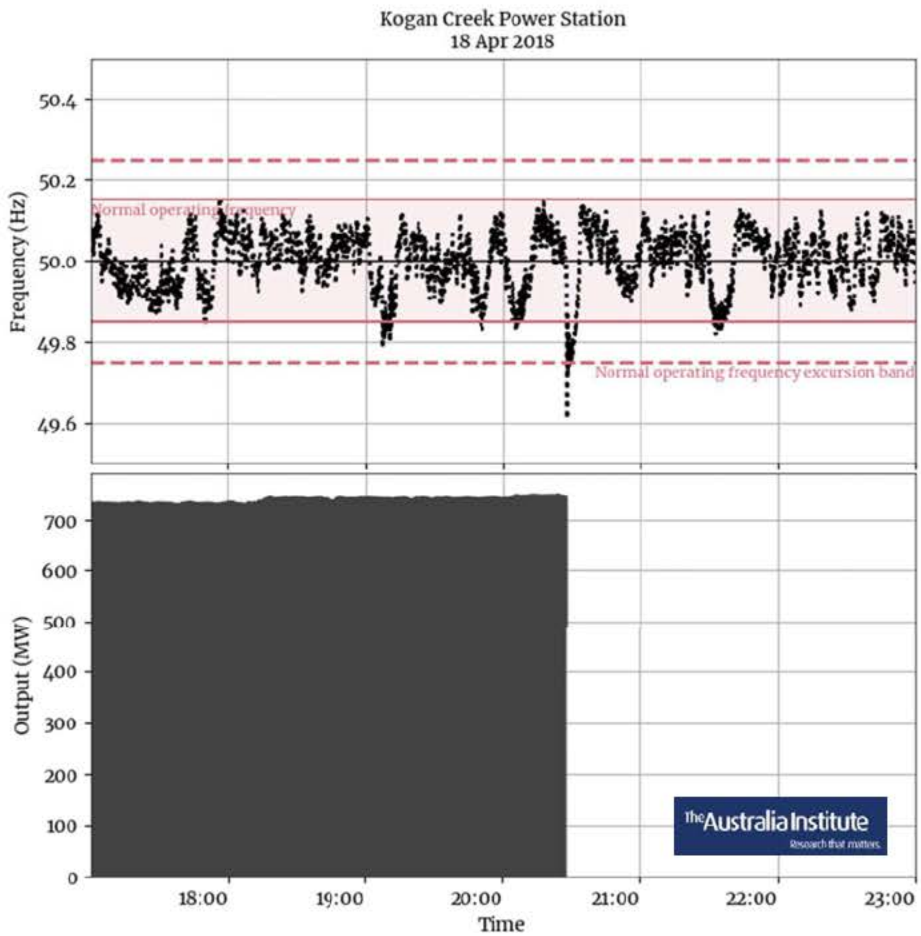
If supply exactly meets demand, the frequency of the power system is 50 Hertz (Hz). Because demand and supply never remain exactly matched, routine frequency fluctuation is between 49.85 and 50.15 Hz (the "normal operating frequency band").

When a gas or coal plant breaks down, the frequency will often fall below 49.85 Hz, at which point new supply needs to be brought on quickly to restore the frequency. The Frequency Control Ancillary Services market is activated to address the fall in frequency.

The lowest level of frequency that is acceptable when there is a contingency event like a power plant breakdown is 49.75 Hz (the "normal operating frequency excursion band").

As can be seen in Figure 7 below, the sudden breakdown at Kogan Creek on breakdown on 18 April this year caused a drop in frequency to well below the acceptable lower limit of a secure power system.

Figure 7: Frequency impact of Kogan Creek unit trip of 18 April 2018



Source: OpenNEM

PRICE IMPACTS

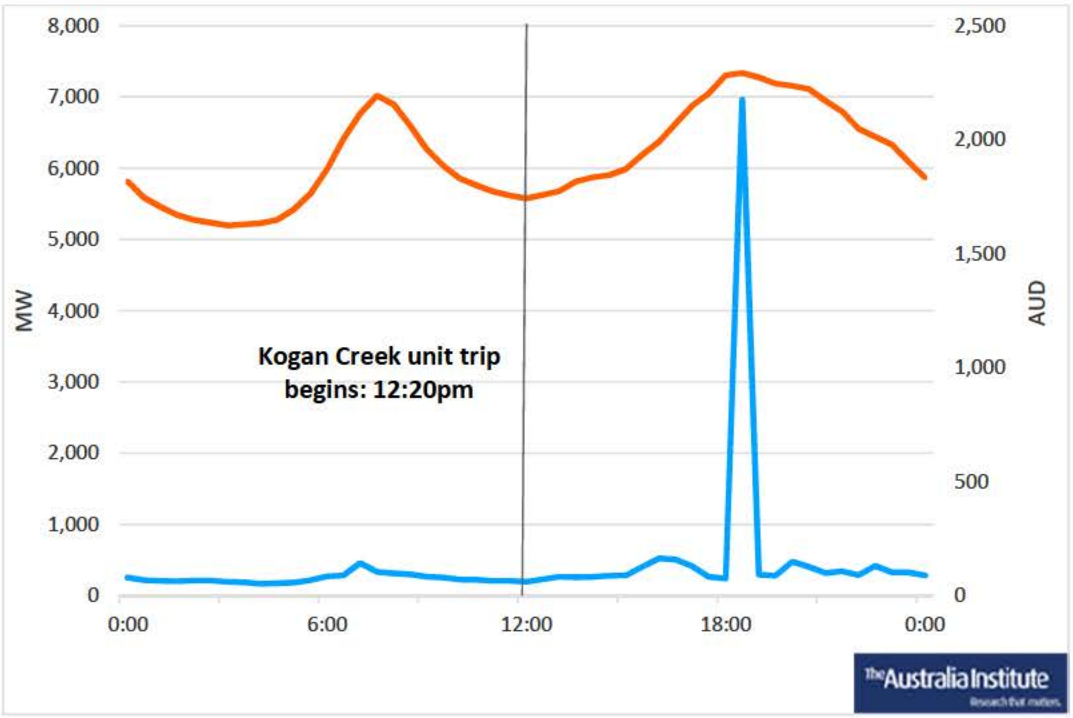
The larger and more sudden the loss of power from a coal breakdown, the more disruptive it is to the electricity supply. When coal plant breakdowns contribute to or cause spikes in wholesale electricity prices, these price increases are ultimately passed on to consumers.

5 June 2018 was a day of relatively high winter demand in Queensland. Supply was already tight as another supercritical coal plant, Tarong North, was not operating.

Figure 8 below shows the Queensland electricity demand plotted against the wholesale electricity price on 5 June this year. The beginning of the 5 June breakdown at Kogan Creek Power Station is indicated by the line.

The loss of Kogan Creek's entire 750 MW of capacity around 12:20pm occurred in a period of relatively low demand. However, Kogan Creek did not come online again by evening, meaning that when the peak demand trading interval occurred at 6:30pm prices surged to over AUD 2,000 per MWh. Had Kogan Creek still been generating, there would have been an extra 750 MW of supply helping to keep prices down.

Figure 8: Queensland electricity demand (orange) and price (blue) on 5 June 2018



Source: OpenNEM

Table 6 shows the output of all of Queensland's power stations during this trading interval and price surge. During this period the average wholesale electricity price was AUD 2,175 per MWh. During this interval another supercritical power plant, Tarong North, was also offline – as was the combined cycle gas power station at Swanbank.

Table 6: Output of QLD gas and coal power plants June 6 2018, 18:00-18:30 hr

Power Station	Technology	Registered Capacity	Average Output	Difference
Barcaldine	Gas (CCGT)	37	0	37,0
Braemar	Gas (OCGT)	504	506.4	-2.4
Braemar 2	Gas (OCGT)	519	289.2	229.8
Callide	Black coal	760	662.5	97.6
Callide C Nett Off	Black coal	840	619.7	220.3
Condamine A	Gas (CCGT)	143	42.7	100.3
Darling Downs	Gas (CCGT)	643	475.2	167.8
Gladstone	Black coal	1,680	1,050.4	629.6
Kogan Creek	Black coal	744	0	744.0
Millmerran Power Plant	Black coal	852	843	9.0
Oakey	Gas (OCGT)	282	170.6	111.4
Roma Gas Turbine Station	Gas (OCGT)	80	70.2	9.8
Stanwell	Black coal	1460	1,283.3	176.7
Swanbank B & Swanbank E Gas Turbine	Gas (CCGT)	385	0	385.0
Tarong	Black coal	1,400	1,253.3	146.7
Tarong North	Black coal	443	0	443.0
Townsville Gas Turbine	Gas (OCGT)	242	238.9	3.1
Yarwun	Gas (CCGT)	154	159.8	-5.8
Total (Gas)		*2,989*	*1,953.0*	*1,036.0*
Total (Coal)		*8,179*	*5,712.1*	*2,466.9*
Total		*11,168*	*7,665.1*	*3,502.9*

Source: OpenNEM

Conclusion

Energy policy should improve reliability, reduce energy prices and reduce emissions. Building new coal plants in Australia will introduce unreliable, expensive and polluting power plants.

There are four coal plants in Australia built within the last twenty years. In 2018, these supercritical plants have broken down at a higher rate than the antiquated subcritical black coal plants in the NEM, relative to capacity. This is despite serious reliability issues with the subcritical black coal fleet as evidenced by the “energy crisis” in New South Wales in June this year.

Australia’s newest black coal power plant at Kogan Creek in Queensland is particularly unreliable, having experienced seven breakdowns since mid-December last year, including the three largest breakdowns in the NEM.

A particular focus on two of Kogan Creek’s breakdowns reveal the effects that coal unreliability has on the electricity market as a whole.

The Kogan Creek breakdown on 18 April this year caused a drop in frequency to below the acceptable level for a secure electricity system.

The Kogan Creek breakdown on 5 June this year contributed to a massive price spike during the period of highest demand.

Australia is experiencing a boom in renewable energy. The September 2018 issue of the National Energy Emissions Audit reports that by the end of 2020 there will be 41% more wind generation capacity attached to the National Electricity Market, and almost three times as much solar capacity as there currently is. The new renewables generation will equal the total annual output from Eraring coal plant, Australia’s largest power station, and be double the Liddell coal plant’s current output.

Building new coal power plants at this point would displace renewable energy and lock in far higher emissions for decades to come, at a time when Australia is experiencing the devastating impacts of global warming.

The heat goes on

Breakdowns at gas and coal plants in NSW, 2018

So far in 2018, there have been 27 major breakdowns at gas and coal power stations in NSW. Every coal power station experienced at least one breakdown. The Tallawarra gas power station experienced three breakdowns. Aging plants Liddell and Vales Point experienced the most breakdowns.

Discussion paper

Mark Ogge
Bill Browne
January 2019

ABOUT THE AUSTRALIA INSTITUTE

The Australia Institute is an independent public policy think tank based in Canberra. It is funded by donations from philanthropic trusts and individuals and commissioned research. We barrack for ideas, not political parties or candidates. Since its launch in 1994, the Institute has carried out highly influential research on a broad range of economic, social and environmental issues.

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Level 1, Endeavour House, 1 Franklin St
Canberra, ACT 2601
Tel: (02) 61300530
Email: mail@tai.org.au
Website: www.tai.org.au
ISSN: 1836-9014

Summary

This year, The Australia Institute's Gas & Coal Watch identified 27 major breakdowns at gas and coal power stations in New South Wales (NSW), each one removing hundreds of megawatts of capacity from the system, sometimes for hours at a time.

Gas and coal plants can break down in the heat, and older coal plants are particularly vulnerable. In addition, extreme heat drives high demand, meaning that the fossil fleet is most likely to break down at times when people need it most.

The breakdowns at coal and gas plants over summer were not only at NSW's old coal power plants, but also at the "state-of-the-art" Tallawarra plant, which is less than a decade old.

There were 24 breakdowns at black coal power plants and three at the Tallawarra gas plant. This is the equivalent of more than one breakdown every fortnight through the year.

Figure 1: Overall breakdowns (NSW, 2018)

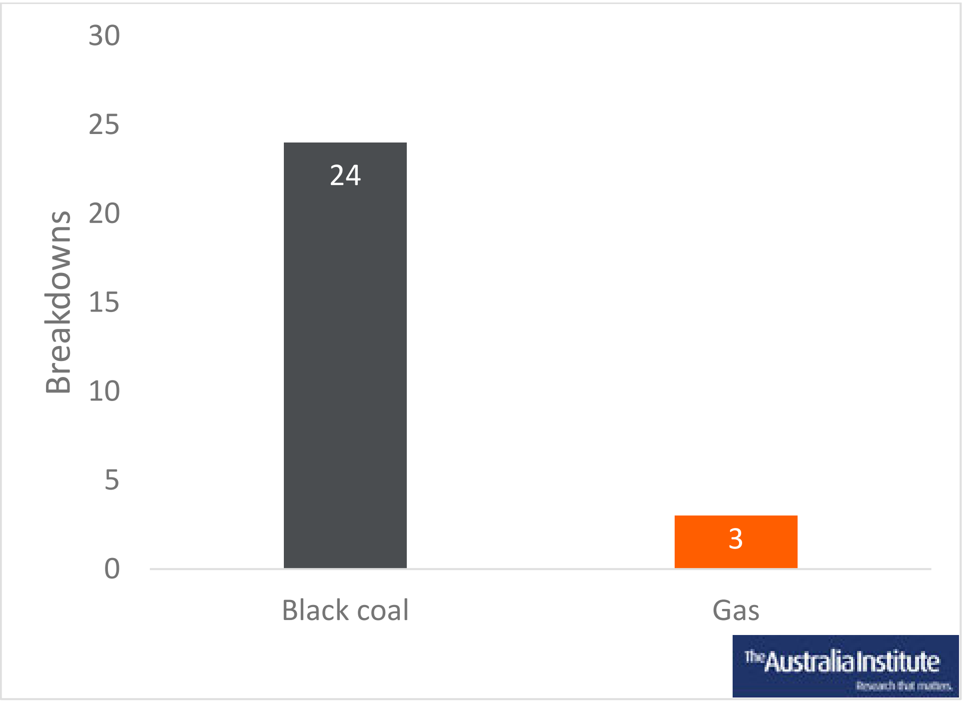


Figure 2: Breakdowns per GW of capacity (NSW, 2018)

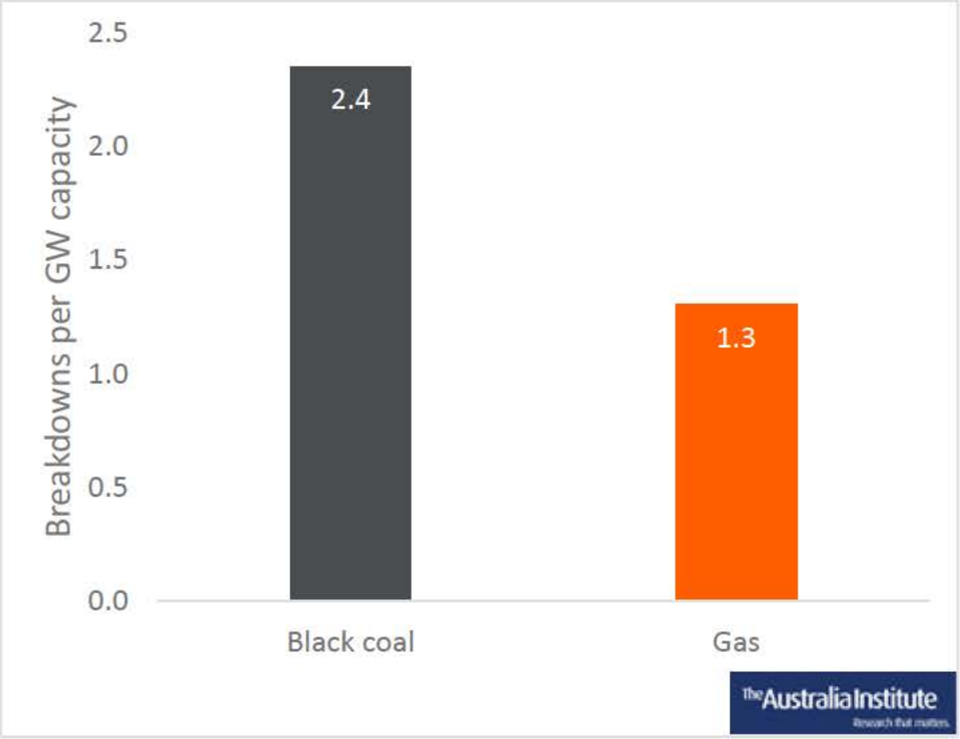


Table 1: Breakdowns by fossil fuel type, share of capacity

Group	Capacity	Share of NSW	Breakdowns	Share of breakdowns	Breakdowns per GW
Black coal	10.2 GW	60%	24	89%	2.4
Gas	2.3 GW	14%	3	11%	1.3
Fossil fuels	*12.5 GW*	*74%*	*27*		*2.2*
NSW capacity	*17.0 GW*				

Note: The remaining capacity in NSW is mostly from renewables.

Introduction

The Australia Institute founded Gas & Coal Watch in December 2017 to monitor the National Energy Market's fossil fuel power plants for breakdowns, particularly during high heat when generating units are vulnerable.

This report summarises the results for NSW from Gas & Coal Watch between 1 January and 31 December 2018. It identifies 27 breakdowns, including 25 unit trips. A unit trip is one of a power plant's generating units being taken off the grid suddenly (and typically without warning). Two breakdowns in 2018 were in the form of sharp, sudden decreases in electricity output that did not involve a unit being taken totally offline.

Three-quarters of NSW's electricity generation capacity consists of fossil fuel generators: five black coal plants and five main gas plants.[1]

The heat particularly affects thermal electricity generation because the efficiency of thermal generation depends on temperature extremes between input and output. Closed-system generators typically use water for cooling, and during periods of extreme heat power stations can fail if the water from the cooling tower is too warm, if access to water is limited, or if the discharged water being pumped out of the cooling tower is too hot.[2] About two-thirds (65 per cent) of generating capacity in the NEM depends on water for cooling coal and gas fired power stations.[3] Air-cooled plants are less efficient overall, and lose efficiency in the heat.

As global warming results in more hot days, this vulnerability exacerbates. This is compounded by increased demand for electricity on hot days.

[1] There is about 0.3 GW of gas generation not covered by the nameplate capacity of the five main gas plants: AEMO (2018) *Generation Information Page*, https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Generation-information

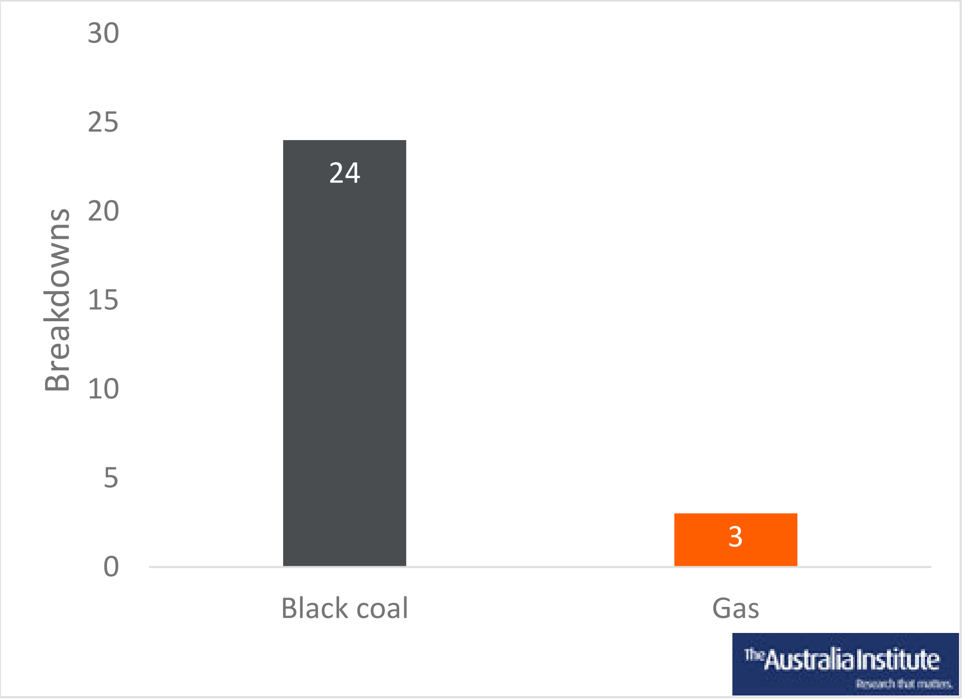
[2] Union of Concerned Scientists (2011) *Energy and Water in a Warming World: Freshwater Use by US power plants*, http://www.ucsusa.org/clean_energy/our-energy-choices/energy-and-water-use/freshwater-use-by-us-power-plants.html#.WfEcCohx3IU

[3] Smart and Aspinall (2009) *Water and the electricity generation industry,* Australian Water Commission

Overall breakdowns

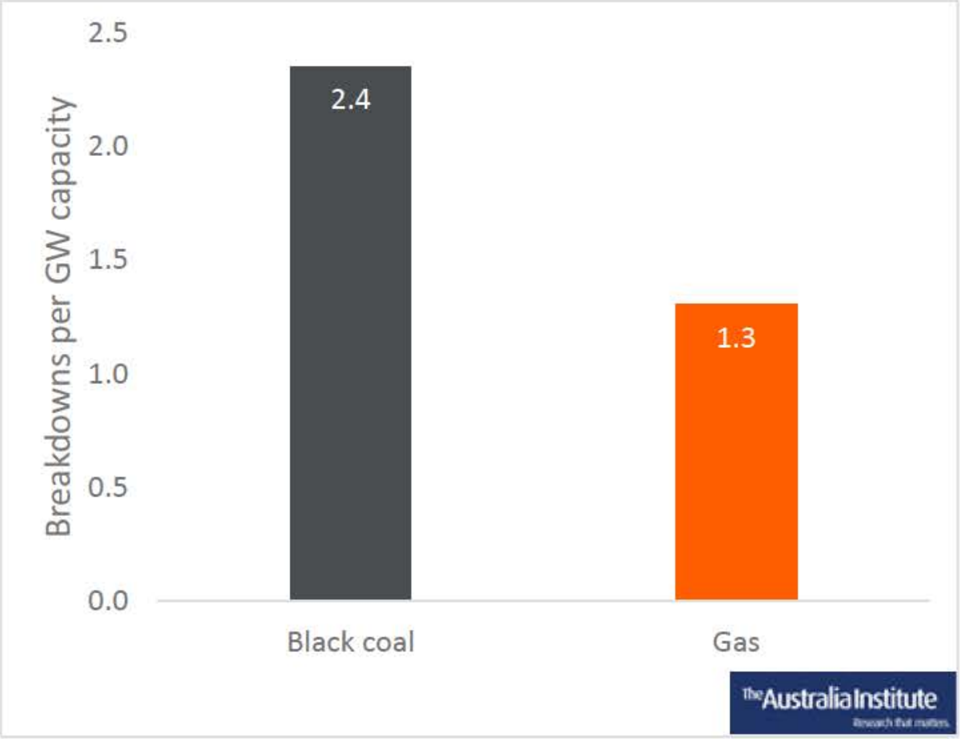
Black coal was the worst performer in NSW, breaking down 21 times in 2018. The Tallawarra gas plant was the only gas plant to break down – but it broke down three times. Together, this represents a gas or coal breakdown more than once a fortnight through the year 2018.

Figure 3: Overall breakdowns (NSW, 2018)



Absolute figures can be misleading, because black coal in NSW contributes more than five times the capacity of gas. Taking capacity into account, black coal still performed worse, with 2.1 breakdowns per GW of capacity. Gas had 1.3 breakdowns per GW capacity.

Figure 4: Breakdowns per GW of capacity (NSW, 2018)



The table below shows the full details of breakdowns by fossil fuel group and share of capacity.

Table 2: Breakdowns by fossil fuel type, share of capacity

Group	Capacity	Share of NSW	Breakdowns	Share of breakdowns	Breakdowns per GW
Black coal	10.2 GW	60%	24	89%	2.4
Gas	2.3 GW	14%	3	11%	1.3
Fossil fuels	*12.5 GW*	*74%*	*27*		*2.2*
NSW capacity	*17.0 GW*				

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Note: The remaining capacity in NSW is mostly from renewables.

Coal

Australia's 16 coal plants are responsible for almost half (48%) of the NEM's capacity, or 30 GW. Coal is even more overrepresented in NSW, where it consists of 60% of generation capacity to gas' 14%.

Table 3 shows breakdowns at each NSW coal power station during 2018. All coal plants experienced breakdowns.

Table 3: Coal power station breakdowns, NSW 2018

Name	Breakdowns	Capacity (MW)	Breakdowns per GW capacity
Bayswater	3	2,640	1.1
Eraring	4	2,880	1.4
Liddell	11	2,000	5.5
Mt Piper	1	1,320	0.8
Vales Point	5	1,320	3.8
Total	**21**	**10,160**	

Liddell and Vales Point experiencing the most breakdowns (10 and five respectively) and the most breakdowns per GW of capacity (5.5 and 3.8 respectively). They are also the two plants that federal politicians have proposed extending beyond their normal operating life.

In late 2017, then Prime Minister Malcolm Turnbull called on AGL to keep the aging Liddell Power Station open.[4] Then Treasurer Scott Morrison, now Prime Minister, had said earlier that it was "very important" to keep Liddell open.[5] Former Prime Minister Tony Abbott said that the government should compulsorily acquire Liddell as part of plans to keep it open.[6] After the change in Prime Minister to Scott Morrison, new Energy Minister Angus Taylor warned that the Federal Government might force AGL to

[4] Yaxley and Lowrey (2017) *Malcolm Turnbull in talks with AGL to keep Liddell coal power station operating beyond 2022,* https://www.abc.net.au/news/2017-09-05/turnbull-in-talks-with-agl-keep-liddell-coal-power-station-open/8874874

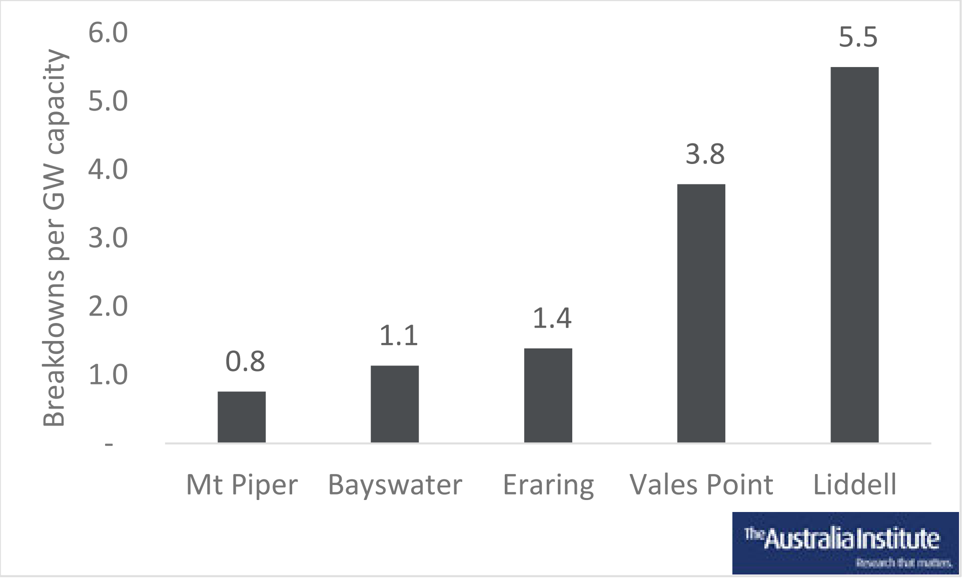
[5] Slezak and Knaus (2017) *Liddell power station: five extra years could give government $1bn rehab bill,* https://www.theguardian.com/australia-news/2017/sep/08/liddell-power-station-five-extra-years-could-give-government-1bn-rehab-bill; Grattan (2017) *Government leans on AGL over Liddell ahead of meeting,* https://theconversation.com/government-leans-on-agl-over-liddell-ahead-of-meeting-83778

[6] Murphy (2018) *AGL rejects Alinta's bid for Liddell power plant, confirming its closure,* https://www.theguardian.com/australia-news/2018/may/21/agl-rejects-alintas-bid-for-liddell-power-plant-confirming-its-closure

sell Liddell to prevent its closure.[7] Despite changes in its executive, AGL has consistently said that it will close Liddell in 2022.[8]

Owner Delta Electricity is considering extending the life of Vales Point by 20 years, from its current closure date of 2029 to the early 2030s or even 2049.[9] Energy insiders speculate that it would be the likely target of a government-underwriting proposal.[10]

Figure 5: Breakdowns per GW capacity, by plant



Liddell and Vales Point are also the oldest coal plants in NSW, with their current generators being commissioned in 1971 (for Liddell) and 1978 (for Vales Point). There is a clear trend with the older plants experiencing more breakdowns (per GW capacity) than the newer plants.

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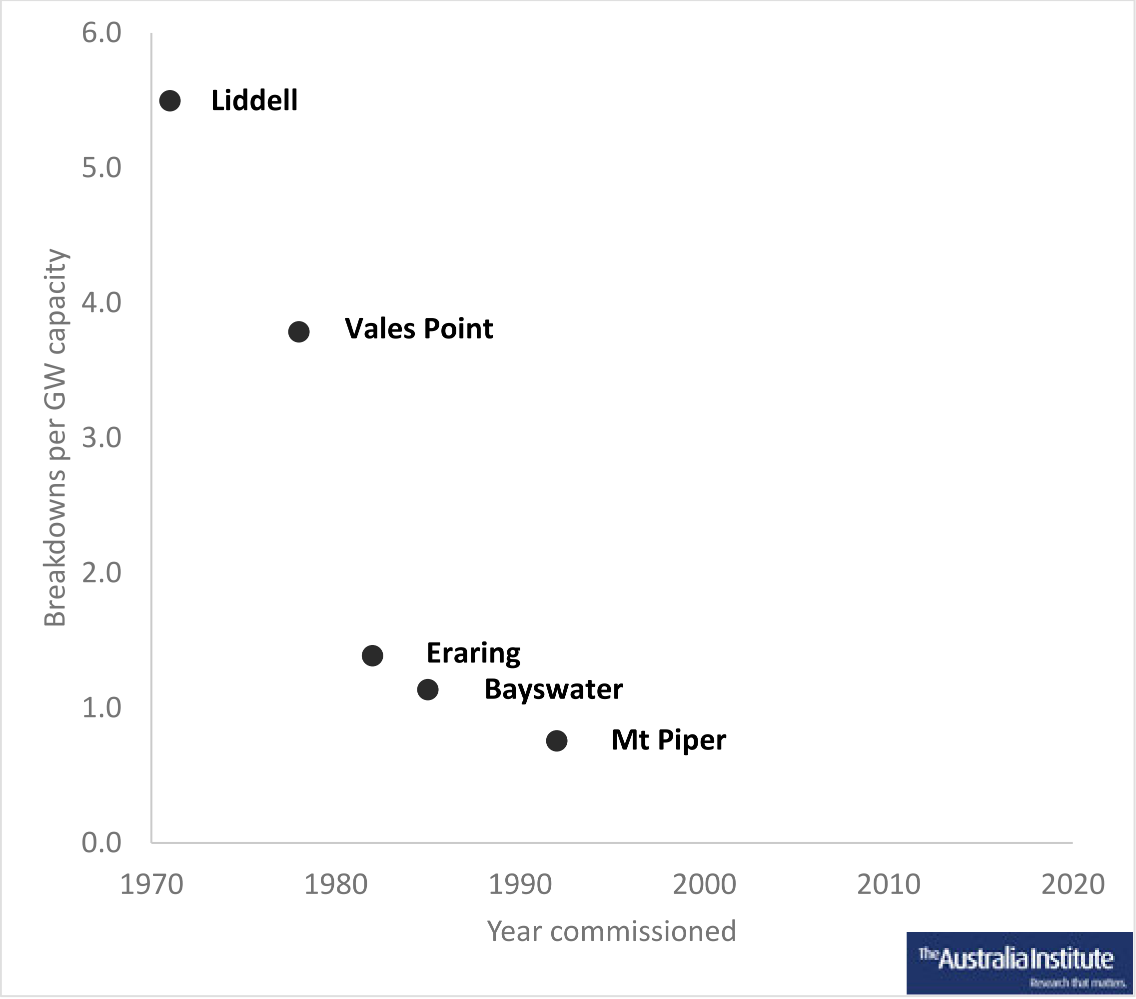
[7] McCarthy (2018) *The power station offloaded by the NSW Government for $1 million suddenly has a future,* https://www.theherald.com.au/story/5632203/powering-on-delta-electricitys-plan-for-a-70-year-old-vales-point-power-station/

[8] Latimer (2018) *AGL says it remains committed to closing Liddell power plant in 2022,* https://www.smh.com.au/business/companies/agl-tells-shareholders-it-will-close-liddell-power-plant-in-2022-20180926-p50633.html

[9] McCarthy (2018) *The power station offloaded by the NSW Government for $1 million suddenly has a future,* https://www.theherald.com.au/story/5632203/powering-on-delta-electricitys-plan-for-a-70-year-old-vales-point-power-station/; Latimer (2018) *Power grab: Rich lister eyes partner's share in coal power station,* https://www.smh.com.au/business/companies/power-grab-rich-lister-eyes-partner-s-share-in-coal-power-station-20180703-p4zp7r.html

[10] Murphy (2018) *Underwriting coal power exposes taxpayers to billions, industry group says,* https://www.theguardian.com/australia-news/2018/nov/16/underwriting-coal-power-exposes-taxpayers-to-billions-industry-group-says

Figure 6: Breakdowns at coal plants by age



Gas

About 40 gas plants in NSW, Victoria, Queensland, SA and Tasmania contribute 11.6 GW to the NEM, 24.0% of its total generation capacity.[11] Gas provides a smaller share of NSW capacity, just 14%.

In 2018, one gas plant – Tallawarra – experienced three breakdowns. Since the other gas plants did not experience breakdowns, this means gas in NSW experienced fewer breakdowns than coal by plant and by capacity.

However, Tallawarra's breakdowns make it the least reliable plant in NSW, with 7.1 breakdowns per GW of capacity – greater than Liddell's 5.5 or Vales Point's 3.8.

Described as "state-of-the-art" with "fast-start capability", the Tallawarra plant was only commissioned in 2009.[12] Tallawarra uses the new Combined Cycle Gas Turbine (CCGT) technology that allows it to be used for bulk electricity supply as well as dispatchable energy.

As well as failing three times this year, Tallawarra failed in Summer 2016–17 with dramatic consequences outlined in our report *Can't stand the heat*.[13]

Table 4: Gas power station breakdowns, NSW 2018

Name	Breakdowns	Capacity (MW)	Breakdowns per GW capacity
Tallawarra	3	420	7.1

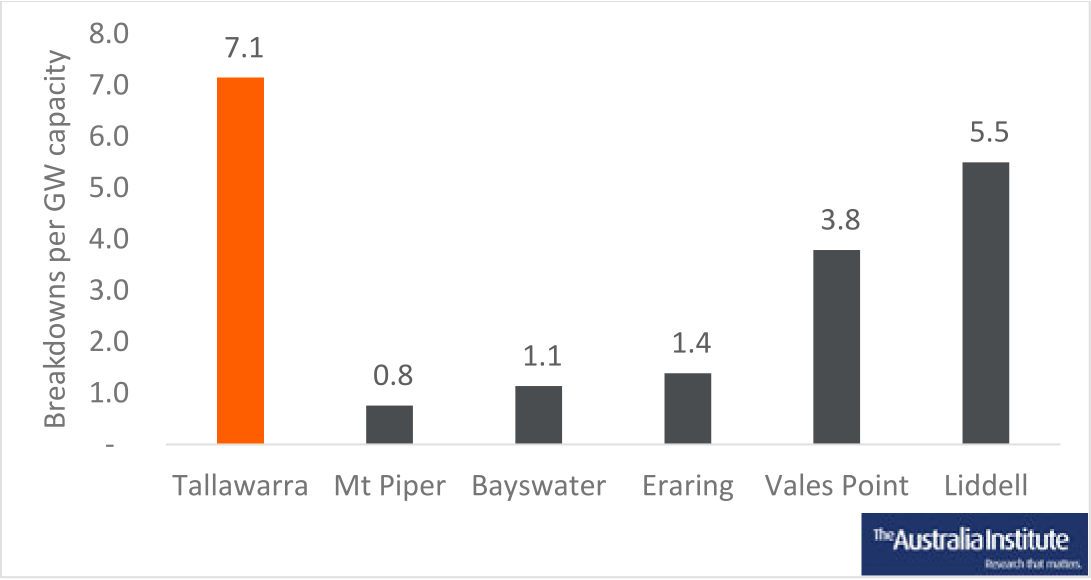
Note: This table only shows the gas station that had a breakdown. There are about five gas stations in NSW, depending on classification.

[11] Total NEM coal capacity 22,916 MW minus Victorian brown coal capacity 4,630 MW = 18,286 MW. Total existing generation capacity is 48,352 MW. AEMO (2018) *Generation Information Page*, https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Generation-information

[12] Energy Australia website, Tallawarra Power Station, Accessed 23/04/18, https://www.energyaustralia.com.au/about-us/energy-generation/tallawarra-power-station

[13] Ogge (2017) *Can't stand the heat,* http://www.tai.org.au/content/coal-and-gas-reliability-liability-heat-report

Figure 7: Breakdowns per GW capacity, by plant – including Tallawarra



Conclusion

Gas and coal power stations broke down more than once a fortnight on average in 2018. Coal plants broke down more often than gas plants, with the two oldest plants – Liddell and Vales Point – breaking down the most. These are the plants that politicians have proposed keeping open beyond their scheduled closure dates.

While gas outperformed coal overall, the “state-of-the-art” Tallawarra plant is the single worst performing plant in NSW, with 7.1 breakdowns per GW of capacity – more than Liddell or Vales Point.

Gas and coal have been tested, and they have been found wanting. As climate change worsens, there will be more heatwaves, putting more pressure on fossil fuel generation.

If NSW is to have reliable electricity generation, heat-sensitive gas and coal plants should be phased out in favour of renewable energy and storage.

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Meltdown 2018

Breakdowns at gas and coal plants over 2018

In 2018 there were 135 major breakdowns at gas and coal power stations in the National Energy Market. While the oldest coal plants were responsible for a large proportion of the breakdowns, newer supercritical plants were also unreliable. There were three breakdowns at one of the newest gas plants. Victoria's brown coal plants were the least reliable overall.

Discussion paper

Mark Ogge
Bill Browne
January 2019

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As we begin the 21st century, new dilemmas confront our society and our planet. Unprecedented levels of consumption co-exist with extreme poverty. Through new technology we are more connected than we have ever been, yet civic engagement is declining. Environmental neglect continues despite heightened ecological awareness. A better balance is urgently needed.

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The Institute publishes research that contributes to a more just, sustainable and peaceful society. Our goal is to gather, interpret and communicate evidence in order to both diagnose the problems we face and propose new solutions to tackle them.

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Level 1, Endeavour House, 1 Franklin St
Canberra, ACT 2601
Tel: (02) 61300530
Email: mail@tai.org.au
Website: www.tai.org.au
ISSN: 1836-9014

Summary

In 2018, The Australia Institute's Gas & Coal Watch identified 135 major breakdowns at gas and coal power stations in the National Electricity Market (NEM), each one removing hundreds of megawatts of capacity from the system.

Gas and coal plants can break down in the heat, and older coal plants are particularly vulnerable. In addition, extreme heat drives high demand, meaning that the fossil fleet is most likely to break down at times when it is most needed.

The breakdowns at coal and gas plants in 2018 were not only at old coal power plants, but also at the newest gas plants and supercritical coal plants.

There were 74 breakdowns at black coal power plants in New South Wales and Queensland and 44 at Victoria's brown coal plants. There were more black coal breakdowns overall, but more breakdowns at brown coal plants relative to capacity. There were also 17 breakdowns at gas plants.

Figure 1: Overall breakdowns (2018)

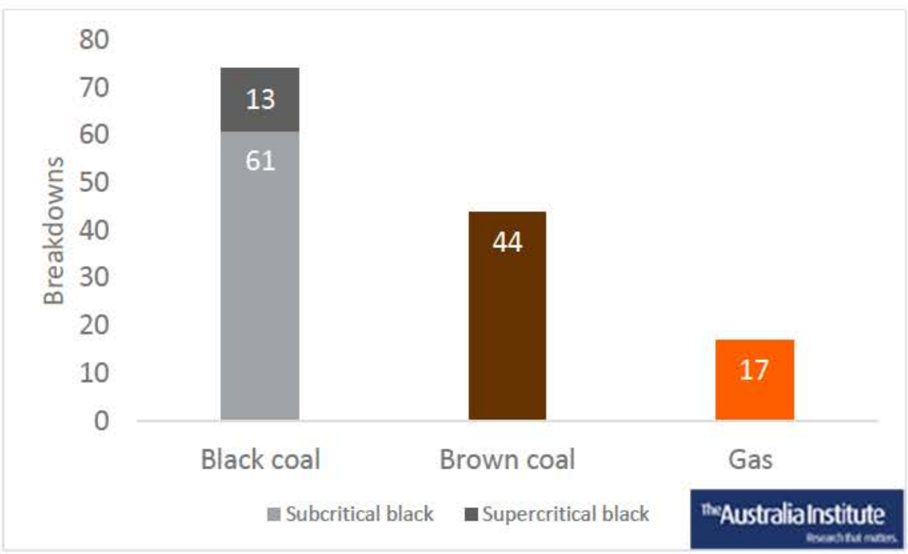


Figure 2: Breakdowns per GW of capacity (2018)

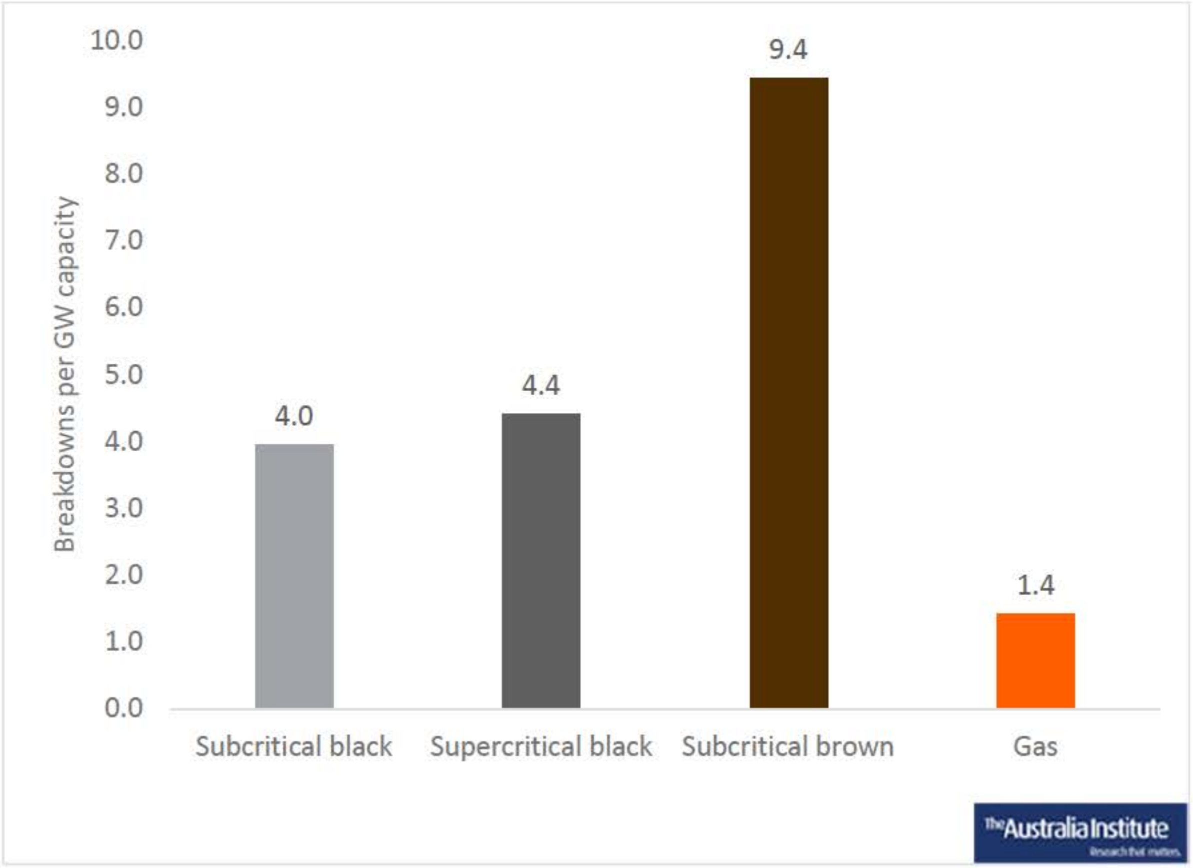


Table 1: Breakdowns by fossil fuel type, share of capacity

Group	Capacity (GW)	Share NEM	B'downs	Share b'downs	B'downs/GW
Black coal	18.3	36%	74	55%	4.0
Brown coal	4.7	9%	44	33%	9.4
Gas	12.0	24%	17	13%	1.4
Total	**35.0**	**69%**	**135**	**100%**	**3.9**

Note: The remaining capacity in the NEM is mostly from renewables.

Introduction

The Australia Institute founded Gas & Coal Watch in December 2017 to monitor the National Energy Market's fossil fuel power plants for breakdowns, particularly over the summer when generating units are vulnerable.

This report summarises the results from Gas & Coal Watch's first year of operations. It identifies 135 breakdowns, of which the vast majority were unit trips. In a unit trip, one of a power plant's units is suddenly, typically unexpectedly, taken off the grid. 10 breakdowns were in the form of sharp, sudden decreases in electricity output that did not involve a unit being taken totally offline.

Thermal electricity generation is particularly affected by the heat because its efficiency depends on temperature extremes between input and output. Closed-system generators typically use water for cooling, and during periods of extreme heat power stations can fail if the water from the cooling tower is too warm, if access to water is limited, or if the discharged water being pumped out of the cooling tower is too hot.[1] 65 per cent of generating capacity in the NEM depends on water for cooling coal and gas fired power stations.[2] Air-cooled plants are less efficient overall, and also lose efficiency in the heat.

As global warming results in more hot days, this vulnerability exacerbates. This is compounded by increased demand for electricity on hot days.

[1] Union of Concerned Scientists (2011) *Energy and Water in a Warming World: Freshwater Use by US power plants*, http://www.ucsusa.org/clean_energy/our-energy-choices/energy-and-water-use/freshwater-use-by-us-power-plants.html#.WfEcCohx3IU

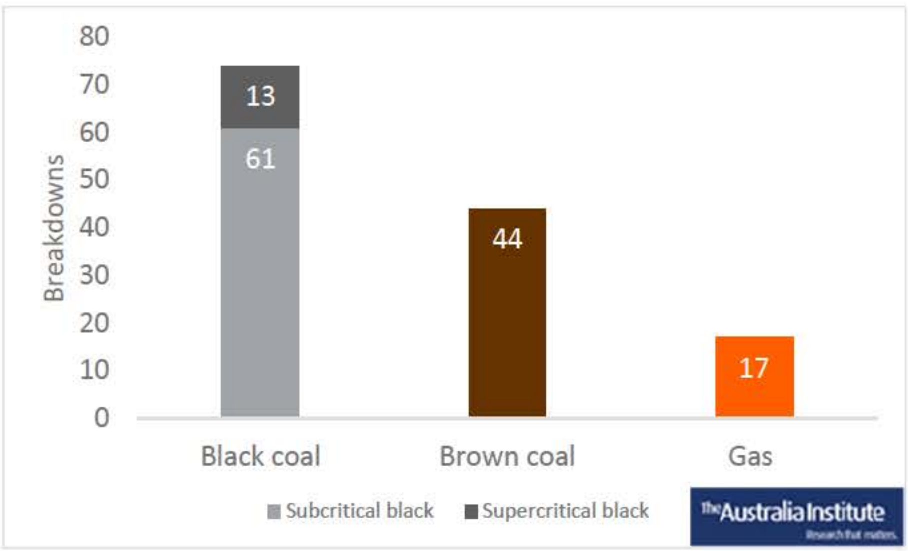
[2] Smart and Aspinall (2009) *Water and the electricity generation industry,* Australian Water Commission

Overall breakdowns

In the NEM, brown coal plants are found only in Victoria, while black coal plants are found only in Queensland and NSW. NSW, Victoria, Queensland and South Australia all have at least one gas plant that broke down in 2018. Tasmania has gas plants, but they did not break down.

In absolute terms, black coal was the worst performer, with 74 breakdowns to brown coal's 44 and gas' 17.

Figure 3: Overall breakdowns (2018)



Absolute figures can be misleading, because there are more black coal plants than brown coal plants. Black coal is the single largest contributor to electricity in the NEM, responsible for 36% of capacity.

Taking capacity into account, brown coal is the worst performer with 9.4 breakdowns per GW capacity. Gas is the best at 1.4 breakdowns per GW capacity.

Figure 4: Breakdowns per GW of capacity (2018)

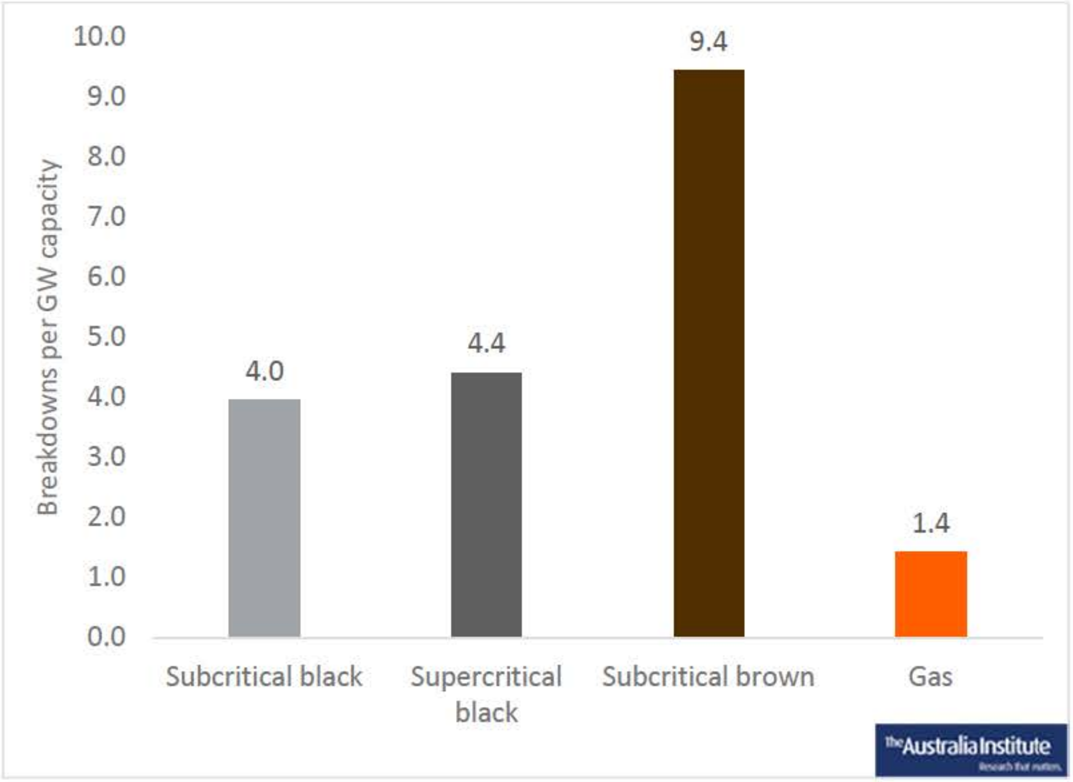


Table 2 shows the full details of breakdowns by fossil fuel group and share of capacity.

Table 2: Breakdowns by fossil fuel type, share of capacity

Group	Capacity (GW)	Share NEM	B'down s	Share b'downs	B'downs/G W
Black coal	18.3	36%	74	55%	4.0
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Total	**35.0**	**69%**	**135**	**100%**	**3.9**

Note: The remaining capacity in the NEM is mostly from renewables.

Coal

Australia's 16 coal plants are responsible for 46% of the NEM's capacity, or 23 GW. Gas & Coal Watch further categorises plants by whether they burn brown coal (a lower efficiency, more polluting form of coal) or black coal. Black coal generation is almost four times larger than brown coal generation, with 18.3 GW of capacity to brown coal's 4.7 GW.

Our analysis also distinguishes between "supercritical" black coal plants and "subcritical" black coal plants. A supercritical plant keeps water at high pressures and temperatures for greater efficiency. Australia's supercritical plants are newer than all subcritical plants in Australia. All of Australia's brown coal plants are subcritical.

Brown coal plants are the worst performers overall, with 14.7 breakdowns per plant, followed by subcritical black coal plants (6.8 breakdowns per plant) and then supercritical black coal plants (3.3 breakdowns per plant).

Table 3: Breakdowns at coal stations by group

Group	Plants	Breakdowns	Share of coal stations	Share of coal breakdowns	Breakdowns per plant
Subcritical black	9	61	56%	52%	6.8
Supercritical black	4	13	25%	11%	3.3
Brown coal	3	44	19%	37%	14.7
Total	***16***	***118***			***7.4***

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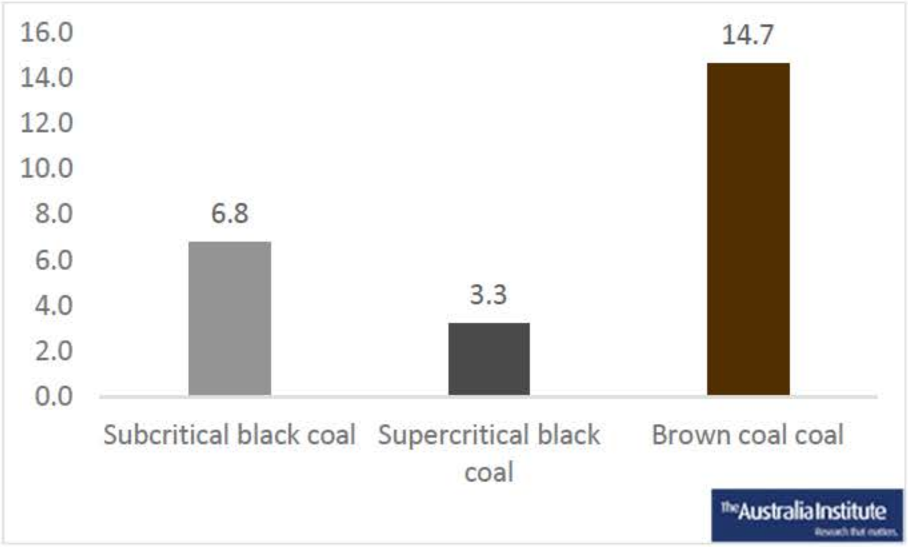
Figure 5: Breakdowns per coal plant



The number and type of coal plant in each state result in different rates and severities of breakdowns. Victoria's three coal plants are just 19% of all coal plants in the NEM, but experienced 37% of coal breakdowns (14.7 breakdowns per plant). Queensland experienced more breakdowns per coal plant, at 6.3 per plant in 2018, than NSW did, at 4.8 per plant.

Table 4: Breakdowns at coal stations by state

State	Stations	Breakdowns	Share of coal stations	Share of coal breakdowns	B'downs per plant
NSW	5	24	31%	20%	4.8
Queensland	8	50	50%	42%	6.3
Victoria	3	44	19%	37%	14.7
Total	***16***	***118***			***7.4***

Table 5 shows breakdowns at each coal power station during 2018. Every coal plant experienced at least one breakdown. Loy Yang A and Yallourn W experiencing the most breakdowns of all plants in the NEM, at 22 and 18 breakdowns respectively.

Table 5: Coal power station breakdowns in 2018

Name	State	Group	Breakdowns	Breakdowns per GW
Bayswater	NSW	Subcritical black	3	1.1
Eraring	NSW	Subcritical black	4	1.4
Liddell	NSW	Subcritical black	11	5.5
Mt Piper	NSW	Subcritical black	1	0.8

Vales Point	NSW	Subcritical black	5	3.8
Callide A and B	Queensland	Subcritical black	5	7.1
Callide Power Plant	Queensland	Supercritical black	3	3.6
Gladstone	Queensland	Subcritical black	14	8.3
Kogan Creek	Queensland	Supercritical black	6	8.1
Millmerran	Queensland	Supercritical black	2	2.3
Stanwell	Queensland	Subcritical black	12	8.2
Tarong	Queensland	Subcritical black	6	4.3
Tarong North	Queensland	Supercritical black	2	4.4
Loy Yang A	Victoria	Subcritical brown	22	10.1
Loy Yang B	Victoria	Subcritical brown	4	4.0
Yallourn W	Victoria	Subcritical brown	18	12.4
Total			**118**	

BLACK COAL

Thirteen black coal plants, all in Queensland or NSW, contribute 18.3 GW to the NEM, 36% of its total generation capacity.[3]

In 2018, each of these plants experienced at least one breakdown – and collectively, they experienced 74 breakdowns, making this group the single largest source of breakdowns.

Two of the oldest and largest plants, Liddell in New South Wales and Gladstone in Queensland, had frequent breakdowns, with 11 and 14 breakdowns respectively. However, the relatively new (commissioned in 1993) coal plant Stanwell had more breakdowns than Liddell, with 12.

Supercritical black coal

Despite being much newer and somewhat more efficient than the subcritical plants, supercritical plants did not perform better than subcritical plants overall.

Australia has four supercritical coal plants, all in Queensland:

- Kogan Creek
- Callide C (also known as "Callide Power Plant")
- Tarong North

[3] AEMO (2018) *Generation Information Page*, https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Generation-information

- Millmerran

These plants are described as High Efficiency, Low Emissions (HELE) plants because they are typically more efficient than subcritical coal plants. However, they are less efficient and have worse emissions than competing power generation like gas and renewables.

Supercritical plants, the newest black coal power plants in the NEM, broke down more often than subcritical black coal plants. Supercritical black coal plants represent 16% of total black coal generation and experienced 18% of total black coal breakdowns.

The nine worst unit trips, in terms of lost capacity, were all at black coal power plants. The supercritical Kogan Creek plant was responsible for the three largest losses of capacity in the NEM, as its single unit can generate up to 750 MW.

Table 6: Greatest losses of capacity from unit trips (2018)

Station	Unit	Category	State	Date	MW lost
Kogan Creek	KPP_1	Supercritical black	Queensland	16/06/2018	752
Kogan Creek	KPP_1	Supercritical black	Queensland	18/04/2018	750
Kogan Creek	KPP_1	Supercritical black	Queensland	5/06/2018	750
Eraring	ER03	Subcritical black	NSW	13/07/2018	698
Bayswater	BW04	Subcritical black	NSW	8/02/2018	657
Eraring	ER02	Subcritical black	NSW	25/12/2018	657
Vales Point	VP6	Subcritical black	NSW	7/06/2018	631
Bayswater	BW02	Subcritical black	NSW	19/07/2018	626
Mt Piper	MP2	Subcritical black	NSW	24/10/2018	583
Loy Yang A	LYA3	Subcritical brown	Victoria	22/06/2018	562
Loy Yang A	LYA3	Subcritical brown	Victoria	4/11/2018	562

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Note: Actual generation can somewhat exceed nameplate capacity, which is why Kogan Creek lost 752 MW on the 16th of June when its nameplate capacity is just 750 MW.

Note: Two unit trips at Loy Yang A are tied for 10th place.

BROWN COAL

Three brown coal plants, all in Victoria, contribute 4.7 GW to the NEM, 9% of its total generation capacity.[4]

[4] AEMO (2018) *Generation Information Page*, https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Generation-information

During 2018, the three plants experienced 44 breakdowns, making these plants the group with the highest rate of breakdowns.

Older plants were more susceptible to breakdowns, with the older Yallourn W (commissioned in 1975) and Loy Yang A (commissioned in 1984) experiencing 18 and 22 breakdowns respectively in 2018. The younger Loy Yang B (commissioned in 1993) had four breakdowns.

These vulnerabilities will be an increasing liability for the NEM as these antiquated plants continue to age while extreme heat events continue to increase in frequency, intensity and duration as a result of global warming.

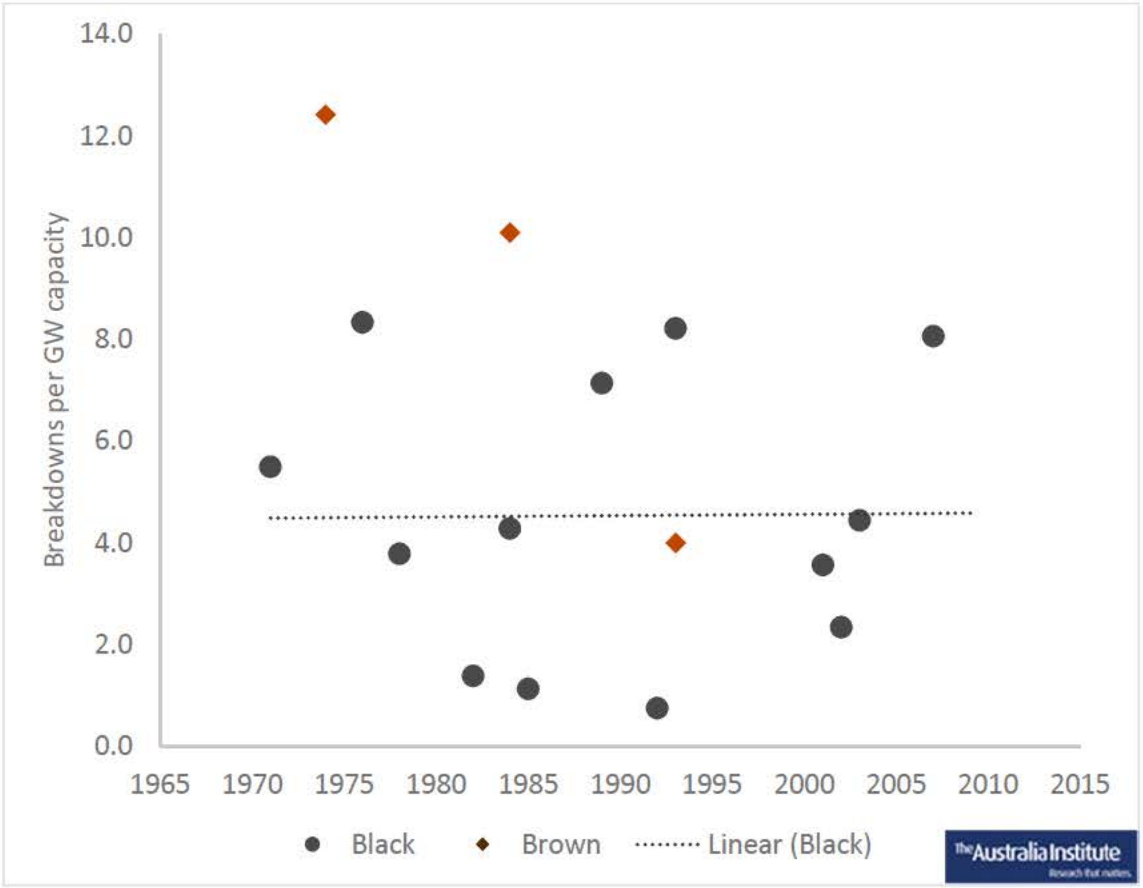
AGE

The National Electricity Market's coal fleet was commissioned between 1971 (Liddell) and 2007 (Kogan Creek). There are large fluctuations in breakdowns, with some of the older stations having fewer breakdowns than the newer plants.

Out of the three brown coal plants, the newest (Loy Yang B) performs best and the oldest (Loy Yang A) performs worst.

Age has no apparent effect on how often black coal plants break down. Newer black coal plants break down as often, or even a little more often, than older black coal plants. The linear trend for black coal in Table 7 displays this phenomenon, rising from 4.57 breakdowns per GW to 4.67. The most recently commissioned coal plant – Kogan Creek – is the third most unreliable black coal plant in the market.

Table 7: Coal plants by age and rate of breakdowns



Note: Some power plants had units commissioned at different times. In that case, the earliest commissioning date is used.

Gas

About 40 gas plants in NSW, Victoria, Queensland, SA and Tasmania contribute 12.0 GW to the NEM, 24% of its total generation capacity.[5]

In 2018, six plants experienced 17 breakdowns, making this group the plants with the lowest rate of breakdowns by plant and by capacity.

There are three main types of gas power plants in Australia: steam cycle, Open Cycle gas Turbines (OCGT) and Combined Cycle Gas Turbines (CCGT). CCGT plants combine gas turbines with steam technology so they can be used for bulk electricity supply as well as dispatchable energy.

Gas breakdowns did not discriminate by technology type or age, with breakdowns at both the newest CCGT power plants (Tallawarra, Swanbank and Pelican Point) and at one of the oldest steam cycle plants (Newport in Victoria).

Described as "state-of-the-art" with "fast-start capability", the Tallawarra plant was only commissioned in 2009.[6] As well as failing three times in 2018, it failed in Summer 2016–17 with dramatic consequences outlined in our report *Can't stand the heat*.[7]

Table 8: Gas power station breakdowns (2018)

Name	State	Group	Breakdowns	Breakdowns per GW capacity
Braemar	Queensland	OCGT	3	6.0
Newport Power Station	Victoria	Gas other	4	7.8
Oakey	Queensland	OCGT	1	3.5
Pelican Point	SA	CCGT	4	8.4
Swanbank	Queensland	CCGT	2	5.2
Tallawarra	NSW	CCGT	3	7.1
Total			**17**	**N/A**

Note: This table only shows gas stations that had breakdowns. There are about 40 gas stations in the NEM, depending on classification.

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[5] AEMO (2018) *Generation Information Page*, https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-

[6] Energy Australia (n.d.) *Tallawarra Power Station,* https://www.energyaustralia.com.au/about-us/energy-generation/tallawarra-power-station

[7] Ogge (2017) *Can't stand the heat,* http://www.tai.org.au/content/coal-and-gas-reliability-liability-heat-report

Conclusion

Older brown coal power stations are particularly vulnerable to breakdowns, but the newer supercritical power stations (so-called High Efficiency, Low Emissions plants) were more likely to experience breakdowns than other black coal plants. Two of Australia's newer gas plants also experienced an unusually high rate of breakdowns.

If Australia is to have reliable electricity generation, unreliable gas and coal plants should be phased out in favour of renewable energy and storage.

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Breaking brown

Gas and coal plant breakdowns in Victoria

Victoria's brown coal fired power stations suffer from frequent breakdowns and Loy Yang A is responsible for the largest number of breakdowns on the National Energy Market, since monitoring began in December 2017, and Loy Yang A's Unit 2 is the most unreliable unit on the grid.

Discussion paper

Bill Browne

Mark Ogge

June 2019

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Introduction

The Australia Institute founded Gas & Coal Watch in December 2017 to monitor the National Energy Market's fossil fuel power plants for breakdowns, particularly during high heat when generating units are vulnerable. Victoria remains highly reliant on its three brown coal fired power stations for its electricity. Victoria is responsible for around 20% of the National Electricity Market's gas and coal capacity, but 35% of its gas and coal breakdowns. That is largely due to its three brown coal plants, particularly Loy Yang A and Yallourn W.

Victorian coal is responsible for around 13% of the National Electricity Market's gas and coal capacity but 32% of its gas and coal breakdowns. All three of Victoria's coal plants burn brown coal using "subcritical" technology. Coal plants in other states burn black coal only, using either subcritical or "supercritical" technology.

This special report summarises the breakdowns at Victoria's brown coal power stations and compares them to rest of the NEM. It is released in response to the recent long-term breakdown of Unit 2 at Loy Yang A.[1]

[1] AGL (June 2019) *FY20 impact of extended unit outage at Loy Yang,* https://www.agl.com.au/about-agl/media-centre/asx-and-media-releases/2019/june/fy20-impact-of-extended-unit-outage-at-loy-yang

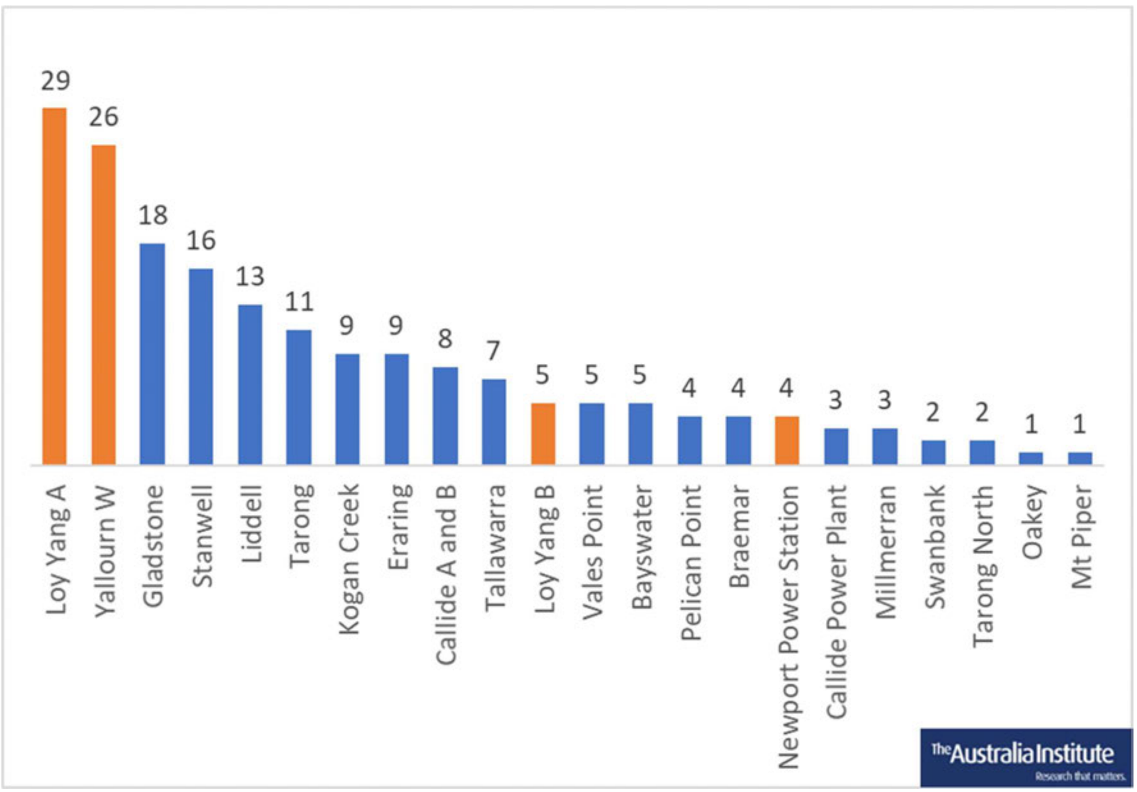
Breakdowns

Since Gas & Coal Watch began in mid-December 2017, there have been 185 breakdowns at gas and coal plants. 64 were at Victorian gas and coal plants:

- 29 at Loy Yang A (brown coal)
- 26 at Yallourn W (brown coal)
- 5 at Loy Yang B (brown coal)
- 4 at Newport Power Station (gas)

That makes Loy Yang A and Yallourn W the least reliable coal plants in the National Electricity Market (NEM), by number of breakdowns.

Figure 1: Breakdowns by power plant (Victorian plants in orange)



Note: Figures as of 17 June 2019.

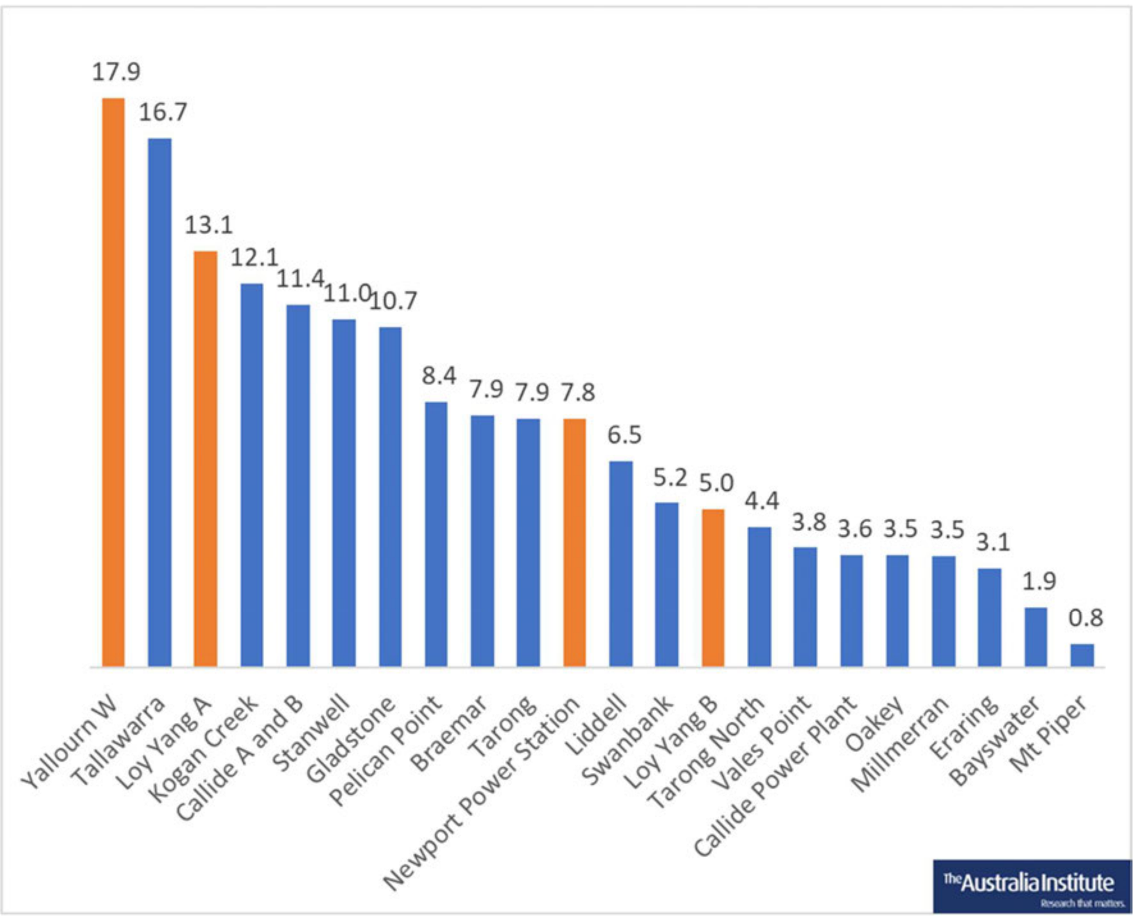
Breakdowns per GW

We also measure breakdowns by Gigawatt of capacity, to reflect that some plants are much larger than others.

- Yallourn W had 17.9 breakdowns per GW
- Loy Yang A had 13.1 breakdowns per GW
- Loy Yang B had 5.0 breakdowns per GW
- Newport Power Station had 7.8 breakdowns per GW

That makes Yallourn W the least reliable coal plant by breakdowns per GW. Loy Yang A is the second least reliable coal plant, and the third least reliable *gas or coal* plant. Newport Power Station is the fourth least reliable gas plant.

Figure 2: Breakdowns per GW (Victorian plants in orange)

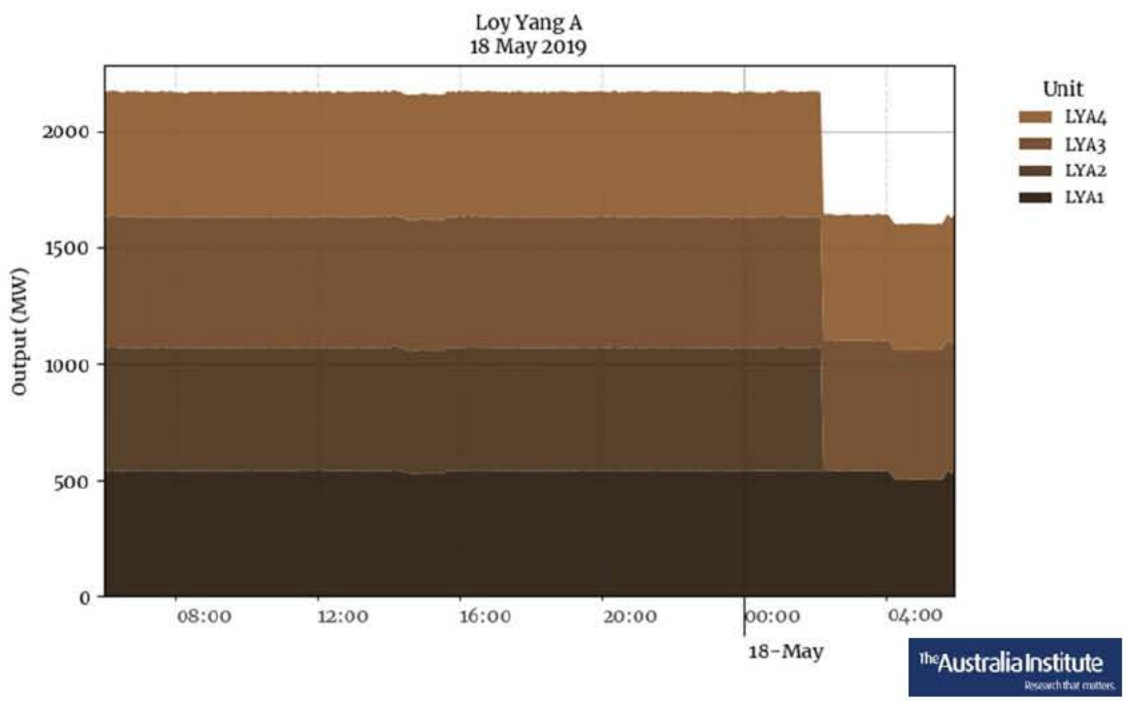


Note: Figures as of 17 June 2019.

Individual units

As reported, Unit 2 at Loy Yang A is out of operation following an 18 May 2019 unit trip – and is expected to remain so for seven months.

The precipitating unit trip appears in Gas & Coal Watch (supplied by OpenNEM):



Unit 2 is the worst performing unit in the National Electricity Market, with 10 breakdowns recorded by Gas & Coal Watch. Victorian coal units are five of the top 10 worst performing units (by number of breakdowns).

Unit name	Type	State	Breakdowns
Loy Yang A Unit 2	Brown coal	Victoria	10
Kogan Creek (only unit)	Supercritical black coal	Queensland	9
Loy Yang A Unit 1	Brown coal	Victoria	9
Yallourn W Unit 3	Brown coal	Victoria	9
Stanwell Unit 4	Subcritical black coal	Queensland	8
Yallourn W Unit 1	Brown coal	Victoria	8
Liddell Unit 2	Subcritical black coal	NSW	7
Yallourn W Unit 2	Brown coal	Victoria	7
Tallawarra Unit 1	Gas (CCGT)	NSW	7
Callide B Unit 1	Subcritical black coal	Queensland	6

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Summer out (2019)

On the 25th of January 2019, the two most unreliable power stations in the country were not operating at capacity. According to the Victorian Minister for Energy Lily D'Ambrosio, three units at Loy Yang A and Yallourn W were not working.

As temperatures soared to 44 degrees, Minister D'Ambrosio admitted:

> This means we can't rule out brownouts … We have ageing coal-fired power stations. They are becoming less reliable.[2]

The units were brought offline following tube leaks or because of scheduled maintenance. These examples were not included in the tally of breakdowns given there was some notice given, however their being offline did feed into the unreliability already experienced by these two power stations, which will only increase with the rise in extreme heat.

The heat particularly affects thermal electricity generation because the efficiency of thermal generation depends on temperature extremes between input and output. Closed-system generators typically use water for cooling, and during periods of extreme heat power stations can fail if the water from the cooling tower is too warm, if access to water is limited, or if the discharged water being pumped out of the cooling tower is too hot.[3]

As climate change results in more hot days, this vulnerability exacerbates. This is compounded by increased demand for electricity on hot days.

On the 25th of January, large scale solar farms were running at 93 per cent of their maximum output, which is in stark contrast to Victoria's brown coal generators, where 1,600 MW of generation was offline.[4]

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[2] Chang (January 2019) *Power outage in Melbourne as electricity generators fail and Victorians brace for hottest day since Black Saturday* https://www.news.com.au/technology/environment/power-stations-fail-as-victorians-brace-for-hottest-day-since-black-saturday/news-story/b404770015b841f39e348b19e5eec3a7

[3] Union of Concerned Scientists (2011) *Energy and Water in a Warming World: Freshwater Use by US power plants* http://www.ucsusa.org/clean_energy/our-energy-choices/energy-and-wateruse/freshwater-use-by-us-power-plants.html#.WfEcCohx3IU

[4] Saddler (February 2019) *NEEA January* http://www.tai.org.au/sites/default/files/NEEA%20Electricity%20Update%20Feb%202019%20%5BWEB%5D_0.pdf

With no more generation available, all interconnectors flowing at capacity and all contracted reserves used up, the Australian Energy Market Operator was forced to directly load shed (i.e. forced blackouts).[5]

To some extent, the events of January 2019 were foreseeable, unlike those of the previous summer.

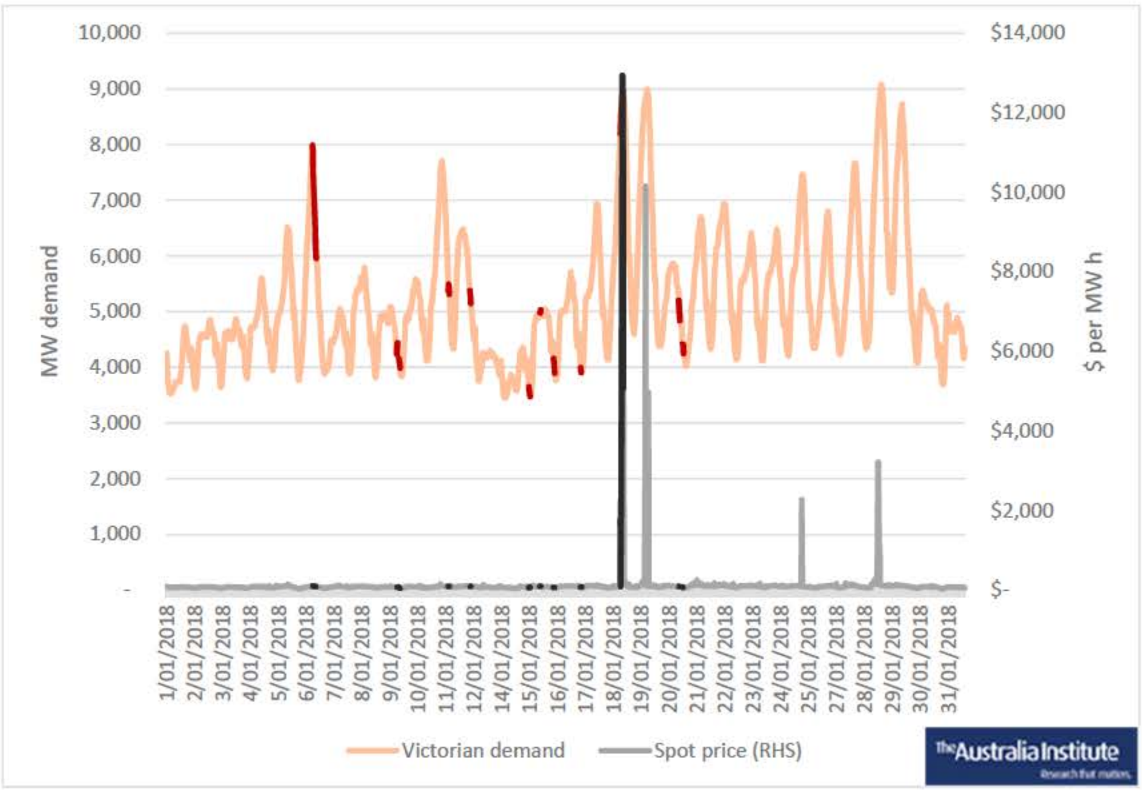
[5] AEMO (April 2019) *Load Shedding in Victoria 24 and 25 January 2019* https://www.aemo.com.au/-/media/Files/Electricity/NEM/Market_Notices_and_Events/Power_System_Incident_Reports/2019/Load-Shedding-in-VIC-on-24-and-25-January-2019.pdf

Bad timing (2018)

Victoria's gas and coal breakdowns in January 2018 coincided with some of Victoria's periods of highest demand – and highest electricity prices.

The following graphs show Victoria's demand for electricity (in MW) and the spot price of electricity (in MW h) for January 2018.

Figure 3: Victorian electricity demand and prices, January 2018



Source: Australian Energy Market Operator (2019) *Data Dashboard*, https://aemo.com.au/Electricity/National-Electricity-Market-NEM/Data-dashboard

Note: The darker colours indicate times when there was a gas or coal breakdown.

January 2018 was a particularly bad period for Victorian brown coal. There were 12 breakdowns in the 16 days between the 6th and 21st of January. Summer is a period of high demand for the National Electricity Market, and two of these breakdowns coincided with periods of particularly high state electricity demand. In other words, the breakdowns came at the worst possible time for the grid. In one of these incidents, the breakdown coincided with large price increases.

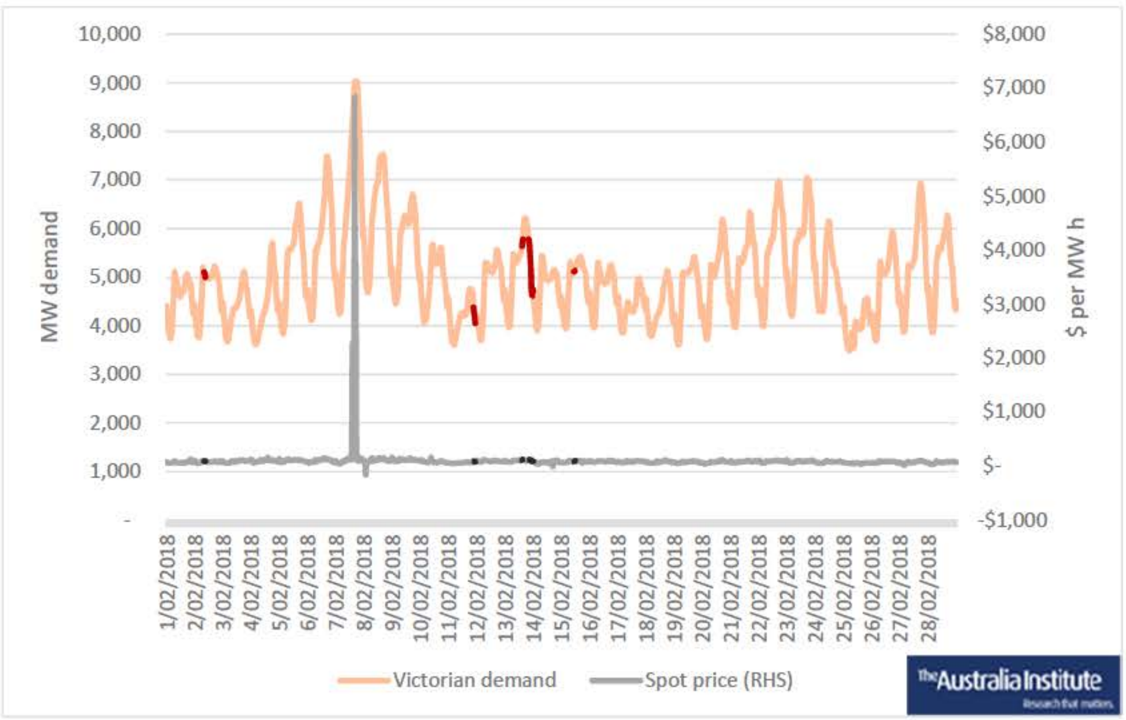
At 4:30pm on the 6th of January, Loy Yang A lost 264 MW, and did not recover for several hours. This came during the highest demand for the first half of January, and the seventh highest demand in the summer months of 2018.

At 3:30pm on the 18th of January, Loy Yang B lost 528 MW, and did not recover until 6:00pm. This was during the second highest demand in January. During this period, prices reached their highest point for the summer months of 2018, going to $12,931 per MW h. This is 97 times higher than the average price in January, of $134.

This price speak was reported by Fairfax at the time,[6] and energy analysts subsequently warned that these problems would become more likely as the plants get older.[7]

In February and December 2018, gas and coal breakdowns did not coincide with any particular demand or price peaks, as shown in Figure 4 and Figure 5.

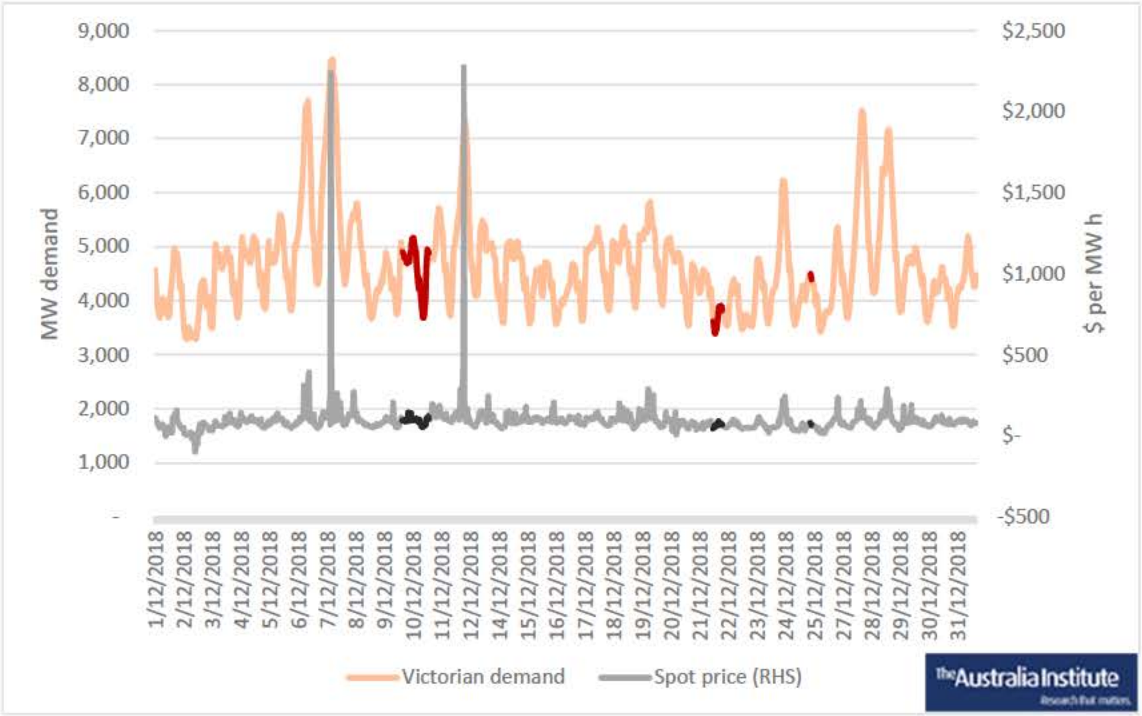
Figure 4: Victorian electricity demand and prices, February 2018



[6] Latimer (2018) *Loy Yang B failure sends prices soaring, triggers supply safeguards*, https://www.smh.com.au/business/the-economy/loy-yang-b-failure-sends-prices-soaring-triggers-supply-safeguards-20180119-p4yymr.html

[7] Latimer (2018) *Victorian coal power station failures put NEM reliability at risk*, https://www.canberratimes.com.au/business/the-economy/victorian-coal-power-station-failures-put-nem-reliability-at-risk-20180409-p4z8l9.html

Figure 5: Victorian electricity demand and prices, December 2018



Source: Australian Energy Market Operator (2019) *Data Dashboard*,

Note: The darker colours indicate times when there was a gas or coal breakdown.

Conclusion

As climate change worsens, there will be more heatwaves, putting more pressure on Victoria's brown coal power generation.

The solution to the energy trilemma of reliability, price and pollution is more renewable energy and storage. Renewables bring down the peak demand during summer, are the cheapest new energy and are emissions-free.

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Money for nothing

Despite over a billion dollars of Australian government spending on CCS initiatives since 2003, there are still no large-scale coal with CCS operations in Australia. Directing CEFC funds into coal with CCS is a uniquely poor policy proposal.

Discussion paper

Bill Browne
Tom Swann
May 2017

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Summary

In 2007, then-Environment Minister Malcolm Turnbull announced a $100 million grant for a proposed coal plant at Loy Yang "suitable for" CCS. Turnbull said "Projects like this one … will play an integral role in helping to reduce emissions in Australia".[1] Five years later, the grant was withdrawn. The operator has been liquidated.

In February 2017, Prime Minister Malcolm Turnbull put CCS back on the agenda. He argued as the world's largest coal exporter, Australia has a "vested interest" in promoting clean coal, and lamented that despite substantial public investment over the years "we do not have one modern high-efficiency low-emissions coal-fired power station, let alone one with carbon capture and storage".[2]

In 2009, the head of the Australian Coal Association promised that that we will "have commercial scale demonstration plants with carbon capture and storage in operation in Australia by 2015".[3] In 2017 the chief national coal lobbyist said it is "pretty early days" with regards to CCS, which is "an evolving technology".[4]

Despite the poor track record of coal with CCS, the Turnbull government is now proposing to fund it through the Clean Energy Finance Corporation, which has previously focused on commercial or near-commercial projects, mostly renewables.

In light of Turnbull's proposal, this report outlines previous funding to CCS and how little Australia has to show for it.

Since 2003, successive Australian governments have backed their promises that CCS will preserve the coal industry with promises of public money. Over $3.5 billion has been committed towards a wide range of CCS-related projects, initiatives and programs. Over $1.3 billion was identified as actually distributed.

The government found it difficult to find projects to fund, and funded projects often failed. While funding was sometimes 'clawed back', other times this was not possible. ZeroGen, a proposed coal plant with CCS, went into administration despite at least

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[1] Macfarlane and Turnbull (2007) *Additional $100 million boost to clean coal,* https://www.environment.gov.au/minister/archive/env/2007/pubs/mr12mar07.pdf

[2] Turnbull (2017) *Address at the National Press Club and Q&A,* http://malcolmturnbull.com.au/media/address-at-the-national-press-club-and-qa-canberra

[3] Jones (2009) *Ralph Hillman and Richard Denniss join Lateline,* http://www.abc.net.au/lateline/content/2008/s2575402.htm

[4] Sky News (2017) *PM Agenda*, https://twitter.com/SkyNewsAust/status/833553271503466496

$187 million in subsidies. The 99% Australia-funded Global CCS Institute backed more overseas projects than Australian ones and had extravagant operational spending.

The coal industry also announced a $1 billion CCS industry fund, which they said would match federal government spending. The fund has collected and committed only $300 million (mostly for CCS projects), and some of this fund has been spent on election campaign promotion of “clean coal”. Contributions to the fund were deducted against royalties in some states, meaning the fund was subsidised by the taxpayer.

Controversies and poor progress led to government funding for CCS being repeatedly cut. Conservative politicians showed scepticism. In 2009, then-Resources Minister Ian MacFarlane said:

> The reality is, you are not going to see another coal fired power station built in Australia. … You can talk about all the stuff you like about carbon capture storage, that concept will not materialise for 20 years, and probably never.[5]

Despite the promises and spending, there has never been an operational large-scale deployment of coal with CCS in Australia. Attempts to develop coal with CCS, such as the ZeroGen project, have been expensive failures.

Australia’s only close-to-operational CCS project is connected to gas extraction. Apart from three carbon storage projects, not expected to be operational until the 2020s, there are no other large-scale CCS projects at any stage of development.[6]

Australia has only ever had two small ‘operational’ carbon capture projects at coal-fired power plants. Callide-A, a demonstration operated by CS Energy and heavily subsidised by government and industry, successfully captured small volumes of CO2 but there was no place to store the carbon once it was captured. A pilot plant at the Hazelwood brown coal plant captured an even smaller amount.

Asked about the Callide-A project in 2017, CS Energy CEO Martin Moore said:

> We proved that technologically it’s possible to retrofit [CCS] to existing coal-fired plants, but commercially, the numbers don’t stack up … It’s unlikely there

[5] Ferguson (2009) *Malcolm and the malcontents,* http://www.abc.net.au/4corners/content/2009/s2737676.htm

[6] Global CCS Institute (n.d.) *Large scale CCS projects,* https://www.globalccsinstitute.com/projects/large-scale-ccs-projects

> will be [a commercial operation for CCS in Australia], I think that technology may well be bypassed … simply because of the economics.[7]

This track record is all the more remarkable given Australia's disproportionally large focus on CCS compared with other countries. From 2009 to 2015, Australia spent more of its energy RD&D budget on CCS than nearly every other country in the OECD.

CCS has also struggled internationally. There are only 16 large-scale CCS facilities operating globally and only two involve coal. Both sell their captured CO2 for enhanced oil recovery. Neither can be considered 'near-zero emissions'.

In 2016 the International Energy Agency emphasised that *if* CCS is commercialised, it will then need a stable and substantial carbon price, or regulatory mandates, in order to be successful. Advocates for CCS have consistently identified a price on carbon as necessary. The first chief executive of Australia's Global CCS Institute, Nick Otter, said:

> In order to get the CCS deployed, ultimately you're going to need a carbon price. In the end, the big driver will be a good, strong carbon price.[8]

There are other barriers. According to CO2CRC, a CCS research group, by 2030 coal with CCS will be far more expensive than most renewables, and more expensive than gas with CCS. Investors are unlikely to choose the most expensive way to use CCS.

Moreover, coal with CCS is less flexible than solar thermal with storage and hydro-electric, further reducing its competitiveness in an increasingly variable grid.

Despite successive government's CCS expenditure, there are few large-scale, currently-operating CCS projects worldwide, none in Australia, and no plans for large-scale coal with CCS. The company that ran Australia's biggest carbon capture demonstration says it is unlikely it will ever be commercial. It is less flexible than other energy sources, is likely to be more expensive than about every other energy source – including gas with CCS – and it needs a carbon price, which is not being proposed.

In short, the Turnbull government's idea to direct the CEFC to fund coal with CCS is a uniquely poor one. It would redirect funds from commercial or near-commercial clean energy towards a technology that remains virtually non-existent in Australia, despite

[7] Cooper (2017) *No more coal-fired power stations will be built in Australia, Queensland provider CS Energy says,* http://www.abc.net.au/news/2017-02-16/coal-power-generator-says-new-plants-not-viable/8277210

[8] Kirkland (2010) *Can Australia afford carbon capture and storage for coal?,* https://www.scientificamerican.com/article/can-australia-afford-carbon/

substantial government support. Australians should ask: is it time to stop throwing good money after bad?

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Introduction

Over the past two decades, successive federal and state Australian governments from both major parties have held up carbon capture and storage (CCS) as the future for the coal industry in a world that is tackling climate change. In CCS, carbon dioxide (CO2) emissions from an industrial source, such as a power plant, are captured and stored indefinitely, typically underground.

Government promises about CCS have been backed with substantial government funding. The coal industry has been similarly enthusiastic, although it has provided a much smaller share of the funding. Despite the promises and the large amount of money spent, CCS is still far from commercial viability and uptake. There are very few large-scale CCS projects in operation worldwide (capturing hundreds of thousands or millions of tonnes of CO2 per annum),[9] fewer still are capturing emissions from coal-fired power plants, and none of these are in Australia.[10]

The Turnbull government is now proposing support for CCS and other coal technologies via the Clean Energy Finance Corporation (CEFC). This government-owned corporation invests in renewables and other clean energy projects.

This paper enumerates federal government and industry spending on CCS since 2003, especially coal with CCS, and puts it in the context of spending from comparable countries. It compares this spending against the record of CCS projects in Australia and worldwide. The poor track record for CCS projects provides little support for the government's proposal to divert money from commercially-viable renewables towards coal with CCS. Despite two decades of promises, there are few CCS projects in operation and the technology remains very expensive. By contrast, renewables are booming and costs are falling rapidly.

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[9] The Global CCS Institute's current threshold for "large-scale" is 400,000 tonnes per annum, or 800,000 tonnes per annum for a coal plant, although at one point it used a one million tonnes per annum threshold. Global CCS Institute (n.d.) *Large-scale CCS projects – definitions,* http://www.globalccsinstitute.com/projects/large-scale-ccs-projects-definitions; Global CCS Institute (n.d.) *G8 objective,* https://hub.globalccsinstitute.com/publications/strategic-analysis-global-status-carbon-capture-storage-report-5/12-g8-objective

[10] Global CCS Institute (n.d.) *Large scale CCS projects*

A long history of broken promises

The term 'clean coal' was first used to market the relatively low impurities of some of Australia's coal, in the context of concerns about local health impacts from burning coal. The term was soon used to refer to CCS, in the context of climate change.

In a 1998 speech to the Australian Coal Association, Resources and Energy Minister Warwick Parer highlighted "new advanced clean coal technologies" other than increasing efficiency, and warned that failure to deploy these technologies "could effectively exclude coal as a viable energy source post 2010" as the world started to tackle climate change.[11] Ministers subsequently turned this warning around, arguing that unless CCS could be made to work, the world would not successfully tackle climate change.

In 2003, the Howard government founded the CO2 Cooperative Research Centre (CO2CRC), a university-based initiative working on CCS. The next year, it set up the $500 million Low Emission Technology Demonstration Fund (LETDF) to encourage industry to reduce greenhouse gas emissions.

In 2007, then-Environment Minister Malcolm Turnbull announced the LETDF's final grant: $100 million to HRL Ltd's coal gasification plant at Loy Yang, which would be "suitable for" CCS. Turnbull said "Projects like this one … will play an integral role in helping to reduce emissions in Australia".[12] Five years later, the grant was withdrawn. HRL Ltd and its associated entities have since been liquidated.[13]

Kevin Rudd's victory in the 2007 election resulted in a boom for CCS spending, with billions of dollars committed through various bodies. These included the CCS Flagships program and the National Low Emission Coal Initiative, both intended to support industry and research projects. The Global CCS Institute was to attract international funding and find global solutions for CCS, but has achieved neither.

[11] Cited in Pierce, McKnight, Burton (2013) *Big Coal,* p158
[12] Macfarlane and Turnbull (2007) *Additional $100 million boost to clean coal,* https://www.environment.gov.au/minister/archive/env/2007/pubs/mr12mar07.pdf
[13] Environment Victoria (n.d.) *How the community stopped a coal-fired power station,* http://environmentvictoria.org.au/how-the-community-stopped-a-coal-fired-power-station-a-timeline/; ASIC (2016) Notice of deemed special resolution to wind up a company, https://insolvencynotices.asic.gov.au/browsesearch-notices/notice-details/Dual-Gas-Pty-Ltd-117102244/5cfbb2fa-db25-4f99-af4d-5706356c3502

Rudd's enthusiasm for CCS was echoed by the coal industry. Ralph Hillman, head of the Australian Coal Association, announced that we will "have commercial scale demonstration plants with carbon capture and storage in operation in Australia by 2015", a commitment that has "the whole G8 behind it".[14]

Treasury Research into the carbon price in 2011 argued there could be a role for CCS, but found it would be modest. The modelling predicting that without CCS domestic emissions would be higher by about 25 million tonnes per annum in 2050.[15] Australia's emissions are currently about 550 million tonnes per annum, so CCS was projected to reduce emissions by less than 5%. Moreover, the modelling predicted that it would mostly be gas, not coal, that would have CCS deployed.

At the time, the Coalition was highly sceptical. Then-Coalition climate change spokesperson Ian Macfarlane (now head of the Queensland Resources Council), said:

> The reality is, you are not going to see another coal fired power station built in Australia. That's, that's a simple fact. You can talk about all the stuff you like about carbon capture storage, that concept will not materialise for 20 years, and probably never.[16]

As problems mounted in the CCS programs, successive Labor budgets pared back CCS funding. The Abbott government also substantially cut CCS funding, although it introduced its own CCS initiative in 2015.[17]

Now the Turnbull government is showing enthusiasm for CCS not seen since the Rudd government. In February 2017, Malcolm Turnbull said that as the world's largest coal exporter, Australia has a 'vested interest' in promoting clean coal. He lamented that:

> We've invested $590 million since 2009 in clean coal technology research and demonstration and yet we do not have one modern high-efficiency low-emissions coal-fired power station, let alone one with carbon capture and storage.[18]

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[14] Jones (2009) *Ralph Hillman and Richard Denniss join Lateline,* http://www.abc.net.au/lateline/content/2008/s2575402.htm

[15] Commonwealth of Australia (2011) *Strong growth, low pollution,* pp 113, 120

[16] Ferguson (2009) *Malcolm and the malcontents,* http://www.abc.net.au/4corners/content/2009/s2737676.htm

[17] Macfarlane (2015) *New support for carbon capture and storage R&D,* http://www.minister.industry.gov.au/ministers/macfarlane/media-releases/new-support-carbon-capture-and-storage-rd

[18] Turnbull (2017) *Address at the National Press Club and Q&A,* http://malcolmturnbull.com.au/media/address-at-the-national-press-club-and-qa-canberra

Unlike the Rudd government's programs, which were drawn from general revenue, the Turnbull government would apparently fund CCS with money intended for renewables and energy efficiency.

Greg Evans of the Minerals Council of Australia, said in early 2017 that we are in "pretty early days" with regards to CCS, which is "an evolving technology". Evans stressed that any proposals to build a CCS coal plant in Australia "are currently being costed" and there are "no precise figures at this stage" on how much it would cost to implement in Australia.[19] Evans' reserved comments about CCS stand in stark contrast to Hillman's enthusiastic predictions in 2009, when he said the technology would be commercially operational by 2015.

The last eight years have been extremely unrewarding for CCS. That is despite hundreds of millions of dollars of support, big promises it, and warnings of the need to make CCS work – whether for the climate or for the coal industry.

[19] Sky News (2017) *PM Agenda*, https://twitter.com/SkyNewsAust/status/833553271503466496

Federal spending on CCS

The Australia government has spent substantial volumes of public funds on CCS over the last fifteen years, but has little to show for it.

The government has committed over $3.5 billion since 2003. Much of this has been either clawed back in later budgets, or returned by cancelled and failed projects. Nonetheless, since 2003 taxpayers have contributed over $1.3 billion towards CCS initiatives. These initiatives are identified in Table 1, which outlines commitments and identified expenditure for CCS projects.

Table 1 Federal government CCS initiatives

Initiative	Scope	Lifetime	Federal funding Committed ($m)	Distributed or to be distributed ($m)
CO2CRC	CCS	2003–present	$75	$75[20]
Low Emission Technology Demonstration Fund	Mostly CCS or CCS-compatible	2004–?	$500	≤$260–$410[21]
Asia-Pacific Partnership on Clean Development and Climate	25% to renewables; CCS' share unclear	2006–2011	>$0–$75	$0–$75[22]

[20] Figures include $25 million from CCS Flagships in 2015, deducted from the overall totals to avoid double counting. Taylor (2012) *Coal hard light of day for dud scheme*; medianet (2015) *Australian Government injects $25 million into CO2 capture & storage research*, http://www.medianet.com.au/releases/release-details/?id=820598

[21] At least two projects, with federal grants worth a total of $150 million, had their grants withdrawn. It is not clear if some or all of the grant money was recovered. Parliament of Australia (2005) *$500m low emissions technology fund takes final shape*, http://parlinfo.aph.gov.au/parlInfo/search/display/display.w3p;query=Id%3A%22media%2Fpressrel%2F1K8G6%22; Macfarlane and Turnbull (2007) *Additional $100 million boost to clean coal;* Environment Victoria (n.d.) *How the community stopped a coal-fired power station: A timeline,* http://environmentvictoria.org.au/how-the-community-stopped-a-coal-fired-power-station-a-timeline/; Department of Industry (2011) *Low Emission Technology Demonstration Fund (LETDF) Round 1,* http://www.industry.gov.au/Energy/Documents/energy-programs/REVISED_LETDF_Funded_projects_30_May_2011.doc

[22] Australia contributed $100 million, of which 25% was reserved for renewables. CCS' share is therefore some portion of $75 million. Fyfe (2006) *$445m for cleaner energy, but it won't stop climate change,* http://www.theage.com.au/news/national/445m-for-cleaner-energy/2006/01/12/1136956302252.html

National Low Emissions Coal Initiative	CCS or CCS-compatible	2008–?	$500	$343–$370[23]
Global CCS Institute	CCS	2009–present	$400	$305[24]
CCS Flagships	CCS	2009–present	$2,000	$271–$299[25]
CCS RD&D	CCS	2015–2016	$25	$24[26]
Geoscience Australia's National CO2 Infrastructure Plan	CCS; note that GA also works on CCS using its regular funding	2012–2016	$61	$61[27]
Totals			*$3,536–$3,611*	*$1,341–$1,594*

Notes: This is data as reported. These numbers are indicative only. The figures have not been adjusted for inflation.

The totals account for $25 million paid to CO2CRC by CCS Flagships, and $27 million taken out of CCS Flagships and NLECI without indication of what share was taken from each fund.

Note this includes all CCS – not simply coal with CCS. As discussed below, coal with CCS is a small part of the CCS story.

[23] $27.4 million was cut from NLECI and CCS Flagships in the 2016 budget. It is not clear what share came from each fund. Alexander (2008) *$500m to set up coal emissions bodies*, http://www.smh.com.au/national/500m-to-set-up-coal-emissions-bodies-20080728-3lyn.html; Australian Government (2009) *Carbon Capture and Storage Flagships,* http://www.budget.gov.au/2009-10/content/glossy/infrastructure/html/infrastructure_overview_30.htm; Department of Resources, Energy and Tourism (2012) *National Low Emissions Coal Initiative (NLECI)* [recovered from Internet Archive], https://web.archive.org/web/20120320171643/http://www.ret.gov.au/resources/resources_programs/nleci/Pages/NationalLowEmissionsCoalInitiative.aspx; Australian Government (2016) *Budget Part 2: Expense Measures,* http://budget.gov.au/2016-17/content/bp2/html/bp2_expense-17.htm

[24] Taylor (2012) *Coal hard light of day for dud scheme*

[25] $27.4 million was cut from NLECI and CCS Flagships in the 2016 budget. It is not clear what share came from each fund. Australian Government (2009) *Budget Part 2: Expense Measures;* Australian Government (2010) *Budget Part 2: Expense Measures (continued);* Australian Government (2011) *Budget Part 2: Expense Measures (continued);* Australian Government (2013) *Budget Part 2: Expense Measures (continued);* Australian Government (2013) *MYEFO Appendix A: Policy decisions taken since the 2013–14 Budget (continued);* Australian Government (2014) *Budget Part 2: Expense measures (continued);* Australian Government (2016) *Budget Part 2: Expense Measures (continued)*

[26] Department of Industry (n.d.) *Carbon Capture and Storage Research Development & Demonstration Fund,* https://industry.gov.au/resource/LowEmissionsFossilFuelTech/Pages/Carbon-Capture-and-Storage-Research-Development-Demonstration-Fund.aspx ; Canavan (2016) *$23.7 million for carbon capture and storage,* http://www.minister.industry.gov.au/ministers/canavan/media-releases/237-million-carbon-capture-and-storage

[27] Australian Government (2011) *Budget Part 2: Expense measures (continued)*

The Low Emission Technology Demonstration Fund, set up by the Howard government, committed $410 million to six projects. Four of these were CCS or CCS-related. Four of the projects were cancelled or went into administration, including two of the CCS-related projects.

The trifecta of funds established by the Rudd government – the Global CCS Institute, CCS Flagships and the National Low Emission Coal Initiative – struggled to identify and fund successful CCS projects.

CCS Flagships was announced with an initial commitment of $2.0 billion. This was cut in almost every successive budget, to under $300 million as of the 2016 budget. CCS Flagships ended up supporting only two projects: the CarbonNet Project and the South West Hub Project. Projects supported by CCS Flagships were initially expected to be operational by 2015.[28] Instead, both projects now have start dates in the 2020s.

The National Low Emission Coal Initiative was allocated $500 million, of which it committed about $370 million to several coal with CCS and related coal projects. These included the:

- Wandoan project (cancelled),
- a NSW coal capture project (not found),
- the Hazelwood 2030 project (cancelled) and
- Callide-A (successfully captured CO2 but could not store it).[29]

The initiative also funded a number of research programs and plans.

The Global CCS Institute was allocated $400 million, with the expectation that other countries would contribute. In practice, 99% of the institute's funding came from the Australian government.

The fund attracted considerable controversy over its priorities. It spent $31 million on projects in other countries, including $18 million on four US and Canadian projects (all cancelled). The fund spent $54 million on "operational expenses" in its first two years

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[28] Department of Resources, Energy and Tourism (n.d.) *CCS Flagship program: Information for applicants to support project nominations*

[29] The descriptions on the project's webpage are general in nature. If they do not describe the Wandoan project and the Hazelwood 2030 project, then they describe other projects that are also not operating: Department of Industry, Innovation and Science (n.d.) *National Low Emission Coal Initiative,* https://industry.gov.au/resource/LowEmissionsFossilFuelTech/Pages/National-Low-Emission-Coal-Initiative.aspx ; Department of Resources, Energy and Tourism (n.d.) *National Low Emissions Coal Initiative (NLECI)* [recovered from Internet Archive], https://web.archive.org/web/20120320171643/http://www.ret.gov.au/resources/resources_programs/nleci/Pages/NationalLowEmissionsCoalInitiative.aspx

(2009–2010), compared with $6 million spent on Australian projects in its first four years. The institute also gave over $50 million to the Asian Development Bank, the IEA and the Clinton Foundation.[30]

In 2012, the institute's second chief executive, Brad Page, said that it is "actually impossible to spend that amount of money … responsibly".[31]

While the Abbott government cut substantial funding from CCS projects, in 2015 it announced a $25 million CCS Research Development and Demonstration Fund, which allocated $24 million to seven applicants in 2016.

[30] Atkin (2014) *Cloud hangs over Rudd's clean coal vision*; Taylor (2012) *Coal hard light of day for dud scheme*

[31] Taylor (2012) *Coal hard light of day for dud scheme*

Industry spending on CCS

In 2004, the coal industry established Coal21. This was intended to grow to a $1 billion fund for clean coal R&D, paid for by a voluntary levy on the black coal industry. The levy was deductible against royalties in some states. Individual companies have also paid for part of the CCS projects that they own and operate, but industry does not appear to collect and collate this information.

The fund was expected to match federal and state contributions. Ralph Hillman, head of the Australian Coal Association, said in 2009:

> the [Commonwealth] Government's actually picking up about a third of the cost. It does it on the basis of a Commonwealth a third, the state a third and industry a third.[32]

This does not appear to have occurred. The federal government's contribution to CCS exceeds a billion dollars, while Coal21 has stalled at about $300 million committed after industry's four-year freeze on the levy.[33] In addition, since the Coal21 voluntary levy is deductible against mining royalties in some states,[34] it has ultimately been funded by the taxpayer in those states.

By 2014, the fund had spent $250 million and a further $46 million of grants were under assessment.[35] In October 2015, when the Coal21 site was last updated, there were 13 projects with $301 million committed. Ten of these, with about $270 million of commitments, involved CCS.[36]

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[32] Jones (2009) *Ralph Hillman and Richard Denniss join Lateline*

[33] Taylor (2014) *Carbon capture and storage research budget slashed despite PM's coal focus;* Long (2017) *Pre-election coal advertising funded by money meant for clean coal research,* http://www.abc.net.au/news/2017-02-20/coal-advertising-funded-by-money-meant-for-clean-coal-research/8287326

[34] See for example: Queensland Treasury (2015) *Determination of coal royalty,* https://www.treasury.qld.gov.au/taxes-royalties-grants/royalties/mra001.php

[35] Taylor (2014) *Carbon capture and storage research budget slashed despite PM's coal focus*

[36] Minerals Council of Australia (n.d.) *Coal21,* http://www.minerals.org.au/resources/coal21/about_coal21

In 2013, Coal21's mandate was quietly changed to allow the fund to also "promote the use of coal".[37] Recently it was revealed that the publicly subsidised fund was used during the 2016 election campaign to fund $2.5 million of 'clean coal' advertising.[38]

Coal21 has not delivered working commercial-scale CCS nor has it matched federal government spending, as promised by Hillman in 2009. The fund, which is at least partly funded by deductions from royalty payments, has not expanded its commitment since 2014 – but has funded advertising to promote clean coal.

[37] Taylor (2014) *Carbon capture and storage research budget slashed despite PM's coal focus;* Brewster (2013) *'Clean coal' money used to promote coal use,* http://www.abc.net.au/lateline/content/2013/s3787338.htm

[38] Long (2017) *Pre-election coal advertising funded by money meant for clean coal research*

Australia has spent disproportionately on CCS

Australia's government is not the only government to spend public money on CCS, but it has spent more than most.

Since 2007, total global CCS investment has been less than US$20 billion.[39] Australia's federal spending of over $1.3 billion represents about 5% of the world's total expenditure on this technology. That is much higher than Australia's share of global population (0.3%) or of GDP (1%).

The IEA reports data on government spending on energy research, development and deployment, as reported by OECD members. Australia has spent more of its energy RD&D budget on CCS than nearly every other country, putting it first or second in the OECD every year between 2009 and 2015, peaking at 44% in 2012, with an annual average of 28%. In 2015, the last reported year, this fell to 19%.

The Australian federal government was responsible for an annual average of 13% of all OECD spending over this period.

By comparison, the US is responsible for between 16% and 48% of world CCS RD&D spend in various years, but this is just 3 to 5% of the total US energy RD&D spend; they also spent substantial amounts on other technologies.[40]

In February 2017, IEA head Fatih Birol said that for CCS to succeed, "there is a need for a greater initiative from countries, maybe such as Australia and others".[41] In fact, Australia has already punched well above its weight – with little to show for it.

[39] Macdonald-Smith (2015) *Carbon capture and storage needs government support: industry,* http://www.smh.com.au/business/energy/carbon-capture-and-storage-needs-government-support-industry-20151105-gkrfxa.html

[40] Calculations by The Australia Institute, based on: IEA (2015) *Energy Technology RD&D Statistics,* http://www.oecd-ilibrary.org/energy/data/iea-energy-technology-r-d-statistics/rd-d-budget_data-00488-en

[41] Ferguson (2017) *IEA calls on Australia to lead world in carbon capture and storage technology,* http://www.abc.net.au/news/2017-02-22/international-body-says-australia-should-be-clean-coal-leader/8294312

Projects in Australia

There are no large-scale CCS operations anywhere in Australia, despite the Australian government having spent over a billion dollars on a plethora of projects, partnerships and institutes.

Identified CCS projects in Australia, their cost and their status are outlined in Table 2.

Table 2 CCS projects in Australia

Name	Proponent	Cost ($m)	Funding ($m)	Scope	Outcome
		Large-scale CCS projects			
Gorgon CO2 Injection Project	Chevron	$2,000	$60 (federal)	Gas extraction CCS	Ready, not operational[42]
ZeroGen	Qld government	$4,300 (planned)	$103–116 (Qld) $39–48 (fed) $41–50 (Coal21)	Coal with CCS	Cancelled
Wandoan IGCC Plant	Xstrata/Glencore	?	$8–50 (federal) $7 (Coal21)	Coal with CCS	Cancelled
Hazelwood 2030	International Power/Engie	$369	$30m, withdrawn (Vic) $50, withdrawn (federal)	Coal with CCS	Cancelled
IGCC Clean Coal Demonstration	HRL Ltd	$750	$50 (Vic) $100 (federal)	Coal "suitable for" CCS	Cancelled
		Large-scale storage projects			
Surat Basin	CTSCo (Glencore)	?	$9 (federal) $24 (Coal21)	Carbon storage	Ongoing
CarbonNet	Vic government	?	$30 (Vic) $72 (federal)	Carbon storage	Ongoing
South West Hub	WA government	?	$55 (federal)	Carbon storage	Ongoing
		Demonstration projects			
Callide-A	CS Energy	$245	$10m (Qld) ? (Japan) $63–65 (fed) $83 (Coal21)	Coal with capture (no storage)	Completed, not operational
Otway Research Facility	CO2CRC	$60	$5 (Vic) $25 (federal) $10 (Coal21)	CCS	Operational
Hazelwood Carbon Capture Pilot Plant	Engie	$10	?	CCS	Completed, not operational

[42] Commissioned and started-up, with CO2 compressors expected to be operated in early 2017 when they are needed. Global CCS Institute (n.d.) *Gorgon Carbon Dioxide Injection Project,* https://www.globalccsinstitute.com/projects/gorgon-carbon-dioxide-injection-project

Australia has only ever had one 'operational' carbon capture project at a black coal power plant: Callide-A, a small demonstration plant. While this plant successfully captured carbon, the volumes were small and required a very large subsidy, and the operator could not find a place to store it. A brown coal demonstration, the Hazelwood Carbon Capture and Mineral Sequestration Pilot Plant, also operated but was even smaller.

As shown in Table 2, there is one large-scale CCS project operational or ready to operate: the Gorgon CO2 Injection Project. This project will store CO2 separated from gas during the extraction and purification process.

There are three carbon storage projects underway:

- CarbonNet,
- the South West Hub project, and
- a nascent Surat Basin feasibility study.

These projects are looking for sites that could take and safely store millions of tonnes of CO2 per year. If the two most advanced projects are successful, they would allow for the storing of 1.8–11 tonnes of CO2 per annum. This represents 0.3–2% of Australia's annual emissions. They are not expected to be operational until the 2020s.

Australia also has one non-commercial demonstration project, the Otway project, which is successfully capturing and storing a small volume of CO2.

There are a number of CCS projects that failed, despite government subsidies, including:

- ZeroGen is the most prominent and expensive, but others include
- HRL Ltd's coal gasification plant,
- International Power's Hazelwood 2030 project and
- CTSCo's Wandoan coal gasification plant,

There are no other Australian large-scale CCS projects at any stage of development, even the most remote "identify" stage, as classified by the Global CCS Institute.[43]

The following sections outline some of these projects, showing the great difficulties involved in getting CCS to work.

[43] Global CCS Institute (n.d.) *Large scale CCS projects*

ZEROGEN (ZERO RESULTS)

The ZeroGen project was a plan to build a $4.3 billion, 530 MW IGCC coal power plant in central Queensland, with the "longer term potential" for CCS to capture 2 million tonnes of CO2 per annum.[44]

The bulk of the project funding was spent trying to identify a storage location for captured CO2. ZeroGen spent four years and $90 million exploring and appraising the Denison Trough, finding it "unsuitable for large scale commercial storage". Having failed in Denison, ZeroGen had its eye on two "undiscovered, un-risked resources" – the Galilee Basin and the Surat Basin. A $300 million pipeline would have been required to transport the CO2 to either basin.[45]

The project went into administration in October 2011, despite having received $183–214 million from the federal government's NLECI fund, the industry Coal21 fund and from the Queensland government (including $6 million transferred to the Australian Coal Association after the project's collapse).[46] The Queensland government had earmarked a further $200 million for the project.[47]

The Minerals Council of Australia website describes ZeroGen as a "completed" "feasibility study".[48] The Minerals Council is correct: ZeroGen's failure shows that coal with CCS is not feasible in Australia, and suggests it will not be for some time, if ever.

CALLIDE-A

The Callide-A Oxy-firing Demonstration, built by CS Energy, has the distinction of being Australia's only successful carbon capture from a black coal-fired generator.

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[44] Bonney (2010) *ZeroGen Project: Low emissions coal fired power with carbon storage,* p 3, https://www.engineersaustralia.org.au/sites/default/files/shado/Divisions/South%20Australia%20Division/Resources/Groups/ZeroGen%20-%20EESA%2014th%20July%202010.pdf; ZeroCO2 (n.d.) *ZeroGen,* http://www.zeroco2.no/projects/zerogen; Minerals Council of Australia (n.d.) *Coal21;* MIT Carbon Capture and Sequestration Technologies (2016) *ZeroGen fact sheet,* https://sequestration.mit.edu/tools/projects/zerogen.html

[45] Bonney (2010) *ZeroGen Project: Low emissions coal fired power with carbon storage*

[46] Lion (2011) *Anna Bligh's team wastes another $116m on controversial ZeroGen clean-coal debacle,* http://www.couriermail.com.au/news/queensland/clean-coal-plan-goes-to-zero/news-story/1e99a6d01bdecaa62bc34ac1273da6cd?nk=2e467983dd127e480f2d57a43e72fd20-1487559359; MIT Carbon Capture and Sequestration Technologies (2016) *ZeroGen fact sheet;* Minerals Council of Australia (n.d.) *Coal21*

[47] MIT Carbon Capture and Sequestration Technologies (2016) *ZeroGen fact sheet*

[48] Minerals Council of Australia (n.d.) *Coal21*

The project, which cost $245 million, was never expected to be profitable. It received in-kind support from Japanese industry, and funding from the Queensland state government, the Japanese government, the Coal21 fund and two to four different federal government programs. These subsidies dwarf the project's expected revenue of $18 million.[49]

The demonstration project operated for two years and nine months and achieved a "partial capture" of 75 tonnes of CO_2 per day (27,300 tonnes per annum), but storage for the captured CO_2 could not be found. Eight potential storage sites were examined but were unsuitable because of location, availability and geological profile.[50]

Chief executive of CS Energy, Martin Moore, said in 2017 on *ABC 730*:

> We proved that technologically it's possible to retrofit [CCS] to existing coal-fired plants, but commercially, the numbers don't stack up … It's unlikely there will be [a commercial operation for CCS in Australia], I think that technology may well be bypassed … simply because of the economics. … If you could decarbonise coal by capturing and sequestering the emissions, then you'd have clean coal. It sounds easy if you say it fast enough, but it's not that simple.[51]

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[49] About $50 or $60 million of funding is attributed to the LETDF by MIT, but NLECI also says it distributed about that much to the project, and media reports the project received an unspecified amount of funding from CCS Flagships. It is not clear if one grant has been wrongly attributed to multiple funds, or if multiple funds contributed to the project. The Global CCS Institute also provided $2 million. Oxyfuel Technologies (2016) *The Callide Oxyfuel Project,* p 24, http://www.callideoxyfuel.com/Portals/0/Callide_Oxyfuel_Project_Legacy_Publication.pdf; CS Energy (2015) *Callide Oxyfuel Legacy* (video), https://www.youtube.com/watch?v=tlP4dIZ0BxQ; Asia-Pacific Partnership on Clean Development and Climate (n.d.) *Callide-A Oxy-Fuel Demonstration Project,* http://www.asiapacificpartnership.org/pdf/Projects/CFETF/CPD/CFE-06-05.pdf; Greig, Bongers, Stott and Byrom (2016) *Overview of CCS roadmaps and projects,* http://www.co2crc.com.au/wp-content/uploads/2017/02/WP3_CCS-Roadmaps-and-Projects.pdf; MIT Carbon Capture and Sequestration Technologies (2016) *Callide-A Oxyfuel fact sheet,* https://sequestration.mit.edu/tools/projects/callide_a_oxyfuel.html; CS Energy (n.d.) *Callide Oxyfuel Project,* http://www.csenergy.com.au/content-(91)-callideoxyfuelproject.htm; Department of Resources, Energy and Tourism (n.d.) *National Low Emissions Coal Initiative (NLECI)* [recovered from Internet Archive]; Rollo (2014) *Budget not expected to impact carbon capture plant*, http://www.abc.net.au/news/2014-05-16/budget-not-expected-to-impact-carbon-capture-plant/5456858

[50] Greig, Bongers, Stott and Byrom (2016) *Overview of CCS roadmaps and projects,* p 16; MIT Carbon Capture and Sequestration Technologies (2016) *Callide-A Oxyfuel fact sheet*

[51] Cooper (2017) *No more coal-fired power stations will be built in Australia, Queensland provider CS Energy says,* http://www.abc.net.au/news/2017-02-16/coal-power-generator-says-new-plants-not-viable/8277210

CS Energy, the only company to demonstrate carbon capture on a black coal plant in Australia, does not have faith in the commercial viability of CCS.

SURAT BASIN INTEGRATED CCS PROJECT

Storage in the Surat Basin was originally considered in conjunction with Glencore's Wandoan coal gasification plant. Although the Wandoan project has been cancelled, CTSCo continues to consider the suitability of the basin for carbon storage. To this effect, it has received $8 million in federal and $24 million in Coal21 funding for pre-feasibility and feasibility studies, and a University of Queensland appraisal of the Surat Basin received a further $6 million of federal funding.[52]

Although the feasibility study is still ongoing, CTSCo anticipates that the demonstration project will have first storage of CO2 by 2020–2021.[53]

CARBONNET PROJECT

The CarbonNet Project is investigating the viability of storing 1–5 million tonnes of CO2 per annum in the Gippsland region, from carbon captured from Latrobe Valley brown coal plants.[54]

The project received $102 million in federal and state funding.[55] As a CCS Flagships project, the CarbonNet Project was expected to be operating in 2015.[56] It has been in the "feasibility" stage since 2012 and now has an expected operation date of "2020's".[57]

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[52] Minerals Council of Australia (n.d.) *Coal21;* Department of Industry (n.d.) *Carbon Capture and Storage Research Development and Demonstration Fund: Project descriptions*

[53] CTSCo (n.d.) *When,* http://ctsco.com.au/when/

[54] Victoria State Government (n.d.) *The CarbonNet Project,* http://earthresources.vic.gov.au/earth-resources/victorias-earth-resources/carbon-storage/about-carbon-capture-and-storage/the-carbonnet-project

[55] CO2CRC (n.d.) *CCS projects in Australia*; Global CCS Institute (n.d.) *The CarbonNet Project: CCS flagship status,* https://hub.globalccsinstitute.com/publications/carbonnet-project/carbonnet-project-ccs-flagship-status; Victoria State Government (2012) *The Carbon Net Project* (brochure), https://hub.globalccsinstitute.com/sites/default/files/publications/50856/carbonnet-corporate-brochure.pdf

[56] Department of Resources, Energy and Tourism (n.d.) *CCS Flagship program: Information for applicants to support project nominations*

[57] Global CCS Institute (n.d.) *Large scale CCS projects;* Victoria State Government (2012) *The Carbon Net Project* (brochure); Victoria State Government (n.d.) *The CarbonNet Project – Current Stage,*

SOUTH WEST HUB PROJECT

The South West Hub Project in Perth aims to store 2 million tonnes of CO2 annually, captured from industry and power plants. When the project was announced in 2009, it was an integrated project with six major CO2 emitters in the region serving as joint venture partners. These partners pulled out in 2015.[58]

The project has received $55 million in federal funding.[59] It is still in the preparation phase, which was expected to conclude in 2013.[60] As a CCS Flagships project, the South West Hub was expected to be operating in 2015.[61] It is now expected to be operational in 2025.[62]

In October 2016, the project found with confidence that the site (the Lesueur) could have 0.8 million tonnes of CO2 injected per annum. The researchers believe that the rate could be as high as 6 million tonnes per annum.[63]

The Collie–South West region of Western Australia is a major industry hub that generates 25 million tonnes of CO2 per annum,[64] so even 6 million tonnes successfully captured and stored per annum would represent less than a quarter of the region's

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http://earthresources.vic.gov.au/earth-resources/victorias-earth-resources/carbon-storage/about-carbon-capture-and-storage/the-carbonnet-project/why-we-need-the-carbonnet-project

[58] The partners were Alcoa Australia, Griffin Energy Developments, Perdaman Cehmicals and Fertilisers, Verve Electrical Generation Corporation and Premier Coal Limited: Government of Western Australia (2012) *South West CO2 Geosequestration Hub,* p 2, http://www.ceg.uwa.edu.au/__data/assets/pdf_file/0008/2186846/South-West-Hub.pdf; Western Australia Department of Mines and Petroleum (2016) *The South West Hug Project: Developing a project in unconventional geology* (webinar), 31:45–33:30, http://www.globalccsinstitute.com/insights/authors/WebinarOrganiser/2016/06/09/south-west-hub-project-developing-project-unconventional-geology?author=MTc1OTM%3D

[59] CO2CRC (n.d.) *CCS projects in Australia;* the project is not explicitly named in this DOI announcement, but it fits the description: Department of Industry (n.d.) *Carbon Capture and Storage Research Development and Demonstration Fund: Project descriptions*

[60] Government of Western Australia (2012) *South West CO2 Geosequestration Hub,* p 2, http://www.ceg.uwa.edu.au/__data/assets/pdf_file/0008/2186846/South-West-Hub.pdf

[61] Department of Resources, Energy and Tourism (n.d.) *CCS Flagship program: Information for applicants to support project nominations*

[62] Global CCS Institute (n.d.) *South West Hub,* https://www.globalccsinstitute.com/projects/south-west-hub

[63] Western Australia Department of Mines and Petroleum (2016) *The South West Hug Project: Developing a project in unconventional geology* (webinar), 29:40 onwards, 51:40 onwards, slides 30, 37

[64] Calder (2012) *How the carbon price works,* https://www.slideshare.net/globalccs/wayne-calder-department-of-resources-energy-and-tourism-ccs-and-carbon-price-policy-in-australia/11-The_CollieSouth_West_Hub_Major

emissions. The next-best site for CCS in Western Australia is 400 kilometres north of Perth, but there are no CO2-generating industries in that area.[65]

HAZELWOOD CARBON CAPTURE AND MINERAL SEQUESTRATION PILOT PLANT

From 2009 until an unspecified date, the Hazelwood Carbon Capture Pilot Plant captured about 25 tonnes per day of carbon from the flue gas of one of boiler at the Hazelwood brown coal power plant. This represents 9,000 tonnes per annum, or about one third of Callide-A's captured carbon. The captured CO2 was used for water treatment, turning it into inert calcium carbonate.[66]

The project received an unspecified amount of funding from the federal government's Low Emission Technology Demonstration Fund and the Victorian government.[67]

Hazelwood power plant will close in March 2017.

OTWAY RESEARCH FACILITY

The Otway research facility (run by CO2CRC in south-western Victoria) is Australia's only successful demonstration of the complete carbon capture and storage lifecycle, from production to geological storage. It cost $60 million, of which at least $40 million came from government and Coal21 funding, and successfully injected 80,000 tonnes of CO2.[68]

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[65] Western Australia Department of Mines and Petroleum (2016) *The South West Hug Project: Developing a project in unconventional geology* (webinar), 29:40 onwards, 51:40 onwards, slides 30, 37

[66] Global CCS Institute (2011) *A look at the Latrobe Valley's carbon capture pilot plants,* http://www.globalccsinstitute.com/insights/authors/petercoombes/2011/10/19/look-latrobe-valleys-carbon-capture-pilot-plants ; Global CCS Institute (n.d.) *Hazelwood Carbon Capture and Mineral Sequestration Pilot Plant,* https://www.globalccsinstitute.com/projects/hazelwood-carbon-capture-and-mineral-sequestration-pilot-plant

[67] International Power (2009) *Hazelwood carbon capture project under way* [retrieved from Internet Archive], https://web.archive.org/web/20110217051851/http://www.ipplc.com.au/uploads/2010/02/InternationalPowermrCCSlaunch080709.pdf

[68] Minerals Council of Australia (n.d.) *Coal 21;* CO2CRC (n.d.) *CCS projects in Australia,* http://old.co2crc.com.au/research/ausprojects.html; Victoria State Government (n.d.) *The CO2CRC Otway Project,* http://earthresources.vic.gov.au/earth-resources/victorias-earth-resources/carbon-storage/about-carbon-capture-and-storage/co2crc-otway-project

Projects internationally

Across the world, completed and operational CCS projects are extremely rare. According to the Global CCS Institute, there are only 16 large-scale CCS facilities operating globally – and only two of these projects involve coal:

- Boundary Dam
- Petra Nova

In January 2017, the Global CCS Institute also identified Kemper County as "coming on-stream in the next few weeks". If it does so, that will make three coal plants with CCS in the world.[69]

The *Financial Times* reports that there are no other coal with CCS plants "on the horizon" in the US.[70]

The final report of the MIT Carbon Capture and Sequestration Technologies program identified 43 "cancelled and inactive" projects – 32 of which were coal projects.[71] The MIT program itself shut down in September 2016.

It is also worth mentioning that all three coal with CCS plants offset or expect to offset some of their costs by selling captured CO2 for enhanced oil recovery.[72] Oil recovered using sequestered CO2 will itself be burned, contributing to global warming.

[69] Papaspiropoulos (2017) *On clean coal,* https://www.crikey.com.au/2017/01/11/comments-entitlements-rorts/; Global CCS Institute (n.d.) *Large scale CCS projects*

[70] Crooks (2017) *World's biggest carbon capture project on schedule,* https://www.ft.com/content/eee0d5d6-d700-11e6-944b-e7eb37a6aa8e

[71] The figure of 32 includes ZeroGen, wrongly listed as having a gas feedstock, and Swan Hills, with in situ coal gasification, but not the two petcoke projects: MIT Carbon Capture and Sequestration Technologies (2016) *Cancelled and inactive projects,* https://sequestration.mit.edu/tools/projects/index_cancelled.html

[72] Burton (2014) *Is the Boundary Dam CCS plant in Canada really a success story?,* http://reneweconomy.com.au/is-the-boundary-dam-ccs-plant-in-canada-really-a-success-story-32486/ ; Irfan (2016) *World's largest carbon-capture plant to open soon,* https://www.scientificamerican.com/article/world-s-largest-carbon-capture-plant-to-open-soon/ ; Kemper (n.d.) *Kemper FAQ,* http://kemperproject.org/kemper-faq/

BOUNDARY DAM

Boundary Dam in Canada is the first CCS project to operate commercially. It is an existing plant retrofitted for CCS. The project cost C$1.5 billion, which Toohey notes is:

> about three times the capital cost of a standard coal plant. It also has higher operating costs.[73]

Owner Saskpower "feels they can cut capital costs 20–30% on the next unit".[74] That would still make the plant over twice as expensive as standard coal.

PETRA NOVA

Unlike Boundary Dam and Kemper County, Petra Nova appears to have been built on time and to its budget. Its commercial viability relies on US$190 million in government subsidies, and revenue from selling the captured CO2 for use in recovering an additional 60 million barrels of oil from a nearby oil field.[75]

KEMPER COUNTY

The Kemper County coal plant, was intended to be operational by 2014. Instead, in mid-2016, the *New York Times* wrote:

> The Kemper coal plant is more than two years behind schedule and more than [US]$4 billion over its initial budget, [US]$2.4 billion, and it is still not operational.
>
> The plant and its owner, Southern Company, are the focus of a Securities and Exchange Commission investigation, and ratepayers, alleging fraud, are suing the company. Members of Congress have described the project as more boondoggle than boon.[76]

Two years ago, when the plant had cost just US$5.2 billion, the Sierra Club has concluded that, per energy output, the Kemper County coal plant would be the most

[73] Toohey (2014) *Clean coal dream little more than dust*
[74] MIT Carbon Capture and Sequestration Technologies (2016) *Boundary Dam fact sheet,* https://sequestration.mit.edu/tools/projects/boundary_dam.html
[75] Irfan (2016) *World's largest carbon-capture plant to open soon,* https://www.scientificamerican.com/article/world-s-largest-carbon-capture-plant-to-open-soon/
[76] Urbina (2016) *Piles of dirty secrets behind a model 'clean coal' project,* https://www.nytimes.com/2016/07/05/science/kemper-coal-mississippi.html

expensive power plant ever built, about six times more expensive than a gas plant of equivalent power.[77] It was due (after many other delays) to come online in January 2017, as its cost exceeded US$7 billion, but it did not do so.[78]

At the time of writing in March 2017, proponent Southern Company has released an economic viability study that found that burning coal at the Kemper County plant is not economically viable unless gas prices rise substantially.[79]

[77] Drajem (2014) *Coal's best hope rising with costliest US power plant,* https://www.bloomberg.com/news/articles/2014-04-14/coal-s-best-hope-rising-with-costliest-u-s-power-plant

[78] Perez (2017) *Costs top $7b, deadline extended as Kemper plant reaches milestone,* http://www.sunherald.com/news/business/article129898054.html

[79] Balch and Bingham LLP (2017) *2017 Kemper Economic Viability Analysis,* http://psc.state.ms.us/InsiteConnect/InSiteView.aspx?model=INSITE_CONNECT&queue=CTS_ARCHIVEQ&docid=382134

Commercialisation

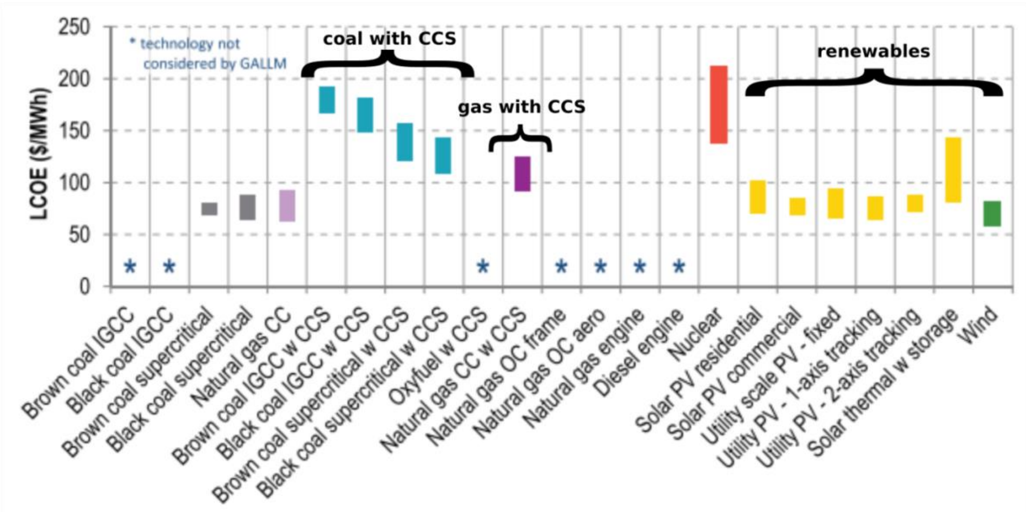
Coal with CCS faces challenges that may make it difficult to commercialise even if CCS can be implemented in Australia at scale.

PRICE AND RELIABILITY

The government has identified price and reliability as two areas where coal outperforms renewables.[80] While this may be true for coal without CCS, industry research shows that coal with CCS is as expensive or more expensive than renewables, and that solar thermal with storage and hydro-electric power are actually more flexible than coal with CCS, meaning they are better able to respond to the periods of peak demand that can cause price spikes and blackouts.

CO2CRC have presented their expected levelised cost of emissions for different power sources. By 2030, solar thermal will be at most about as expensive as the cheapest coal with CCS. Wind and solar PV also perform better:

Figure 2 2030 Levelised cost of electricity



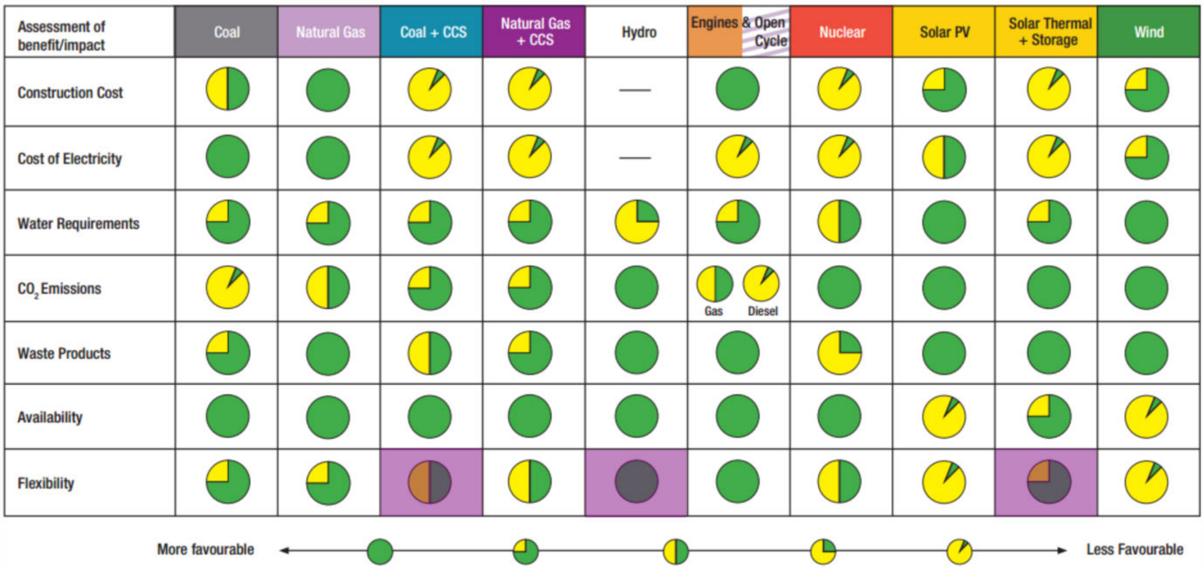
Source: CO2CRC (2016) Australian power generation technology report, p v
Note: Labels and braces added to make the figure easier to parse.

As well as outperforming CCS on cost, some renewables are also more reliable. A 2016 report from CO2CRC shows that two renewables – solar thermal with storage and

80 For example, in the wake of the South Australian blackouts: Borrello (2017) *Josh Frydenberg flags changes to allow CEFC to invest in carbon capture and storage*

hydro-electric – are “more favourable” than coal with CCS in terms of flexibility in “increase[ing] or decreas[ing] output to meet changes in demand, to respond to changing output from other plants, and to respond to changing grid conditions”.[81]

Figure 3 Electricity technology comparisons



Source: CO2CRC (2016) *Australian power generation technology*, p 21

Note: Purple highlighting added to emphasise the flexibility ratings under consideration.

According to Australia’s premier CCS R&D organisation, coal with CCS is less capable of dealing with peaks in demand than solar thermal or hydro-electric power, and is more expensive than renewables. Given that, it is difficult to see what niche it would fill.

NEED FOR A CARBON PRICE

Advocates for CCS consistently identify a carbon price as necessary for CCS to be successful, and cited its absence as a reason that projects failed to be commercialised.

The first chief executive of the Global CCS Institute, Nick Otter, said it clearly:

> [T]o get the CCS deployed, ultimately you're going to need a carbon price. In the end, the big driver will be a good, strong carbon price.[82]

[81] CO2CRC (2016) *Australian power generation technology report*, p 22, http://www.co2crc.com.au/wp-content/uploads/2016/04/LCOE_Report_final_web.pdf
[82] Kirkland (2010) *Can Australia afford carbon capture and storage for coal?*, https://www.scientificamerican.com/article/can-australia-afford-carbon/

This has been repeated by numerous CCS proponents:

- The CEO of International Power, proponent of Hazelwood 2030, said €30–40/tonne was needed for CCS in Europe[83]
- Queensland's ZeroGen project was uncommercial on a figure of $57/tonne[84]
- TransAlta's Pioneer Project, subsidised by the Global CCS Institute, was uncommercial at US$30/tonne[85]
- CO2CRC has said that a "carbon price alone will be too low", and government will have to make up the gap[86]
- At Callide-A, CO2CRC described the lack of GHG legislation as "a challenge"[87]

The need for a carbon price was also clear in Treasury modelling that concluded that commercial uptake of CCS would "depend on the level of the carbon price in place".[88]

The same point has also been made by the IEA, which wrote in 2012 that "CCS is a high cost abatement option and will remain so in the short-term".[89] In 2013 they added that "If CCS technology becomes fully proven at commercial scale", widespread adoption will require "a stable economy-wide carbon price", or other regulation.[90]

Note however that the IEA does not consider CCS to be close to proven at commercial scale. This is well understood in the CCS sector in Australia. Dick Wells of the National Low Emissions Coal Initiative said that a carbon price alone would not drive CCS investment until the 2030s.[91]

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[83] CO2CRC (2007) *CO2 futures* issue 5, p 4, http://old.co2crc.com.au/dls/co2futures/CO2FUTURES_Issue_05.pdf

[84] 2010 dollars. Garnett, Greig and Oettinger (2014) *ZeroGen IGCC with CCS: A case history,* p 81, https://energy.uq.edu.au/files/1084/ZeroGen.pdf

[85] TransAlta Corporation (2013) *Project Pioneer,* p 24, http://hub.globalccsinstitute.com/sites/default/files/publications/98046/project-pioneer-summary-report.pdf

[86] Aldous (2011) *Carbon capture and storage – a vital part of our climate change response*

[87] Greig, Bongers, Stott and Byrom (2016) *Overview of CCS roadmaps and projects*

[88] Commonwealth of Australia (2011) *Strong growth, low pollution,* p 161

[89] International Energy Agency (2012) *A policy strategy for carbon capture and storage,* p 8, https://www.iea.org/publications/freepublications/publication/policy_strategy_for_ccs.pdf

[90] International Energy Agency (2013) *Technology roadmap: Carbon capture and storage,* p 27, https://www.iea.org/publications/freepublications/publication/technologyroadmapcarboncaptureandstorage.pdf

[91] Wells (2012) *Dick Wells says clean coal will remain unviable for two decades,* http://www.abc.net.au/news/2012-02-15/dick-wells/3772184

Conclusion

The Turnbull government is showing an enthusiasm for CCS not seen since the first Rudd government. Some have cynically suggested that "anything's possible with a big enough subsidy".

The troubled history of CCS in Australia suggests that the cynics could be wrong. CCS is so uncommercial that even the enormous subsidies of the last decade have mostly resulted in cancelled, failed and bankrupt projects.

Moreover, even if the technology could be demonstrated reliably at scale, the proponents of these projects consistently identify a high carbon price as being necessary for their commercial viability. Without such a price, any new projects will need an even greater subsidy from government. Meanwhile, the cost of renewables and storage continues to fall.

Prime Minister Turnbull put it well:

> We've invested $590 million since 2009 in clean coal technology research and demonstration and yet we do not have one modern high-efficiency low-emissions coal-fired power station, let alone one with carbon capture and storage.[92]

$590 million is a conservative figure. Spending more money on CCS because we have already lost so much would risk throwing good money after bad.

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[92] Turnbull (2017) *Address at the National Press Club and Q&A,* http://malcolmturnbull.com.au/media/address-at-the-national-press-club-and-qa-canberra

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Sunk costs

Carbon capture and storage will miss every target set for it

The IEA, the IPCC, the G8, the Australian Government, the Australian Coal Association and the Council of the European Union have set targets for carbon capture and storage. None of these targets have been met, and none of these targets are on track to be met.

Discussion paper

Bill Browne

November 2018

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Level 1, Endeavour House, 1 Franklin St
Canberra, ACT 2601
Tel: (02) 61300530
Email: mail@tai.org.au
Website: www.tai.org.au
ISSN: 1836-9014

Summary

Industry, government and international organisations have given CCS credibility by making predictions about its success and setting targets that give it a clear place in emissions reductions plans.

The only institutional target that CCS has met concerns the number of CCS projects launched. All targets for number of projects actually built and operating or for millions of tonnes of CO_2 actually stored each year (“Mtpa”) have either not been met, or are not on track to be met.

The floundering of CCS over the past decade means that we cannot rely on it to reduce emissions from electricity generation. That sector should be decarbonised through uptake of renewable energy, closure of fossil fuel power plants and increased energy efficiency.

Table 1: Institutional targets and progress/outcome

Institution	Target	Progress/Outcome
G8	20 new large-scale CCS demonstration projects launched by 2010, operating by 2020	**First target (20 launched by 2010) achieved.** **Second target (20 operating by 2020) not on track.** 12 new projects operating, not all of which meet the criteria. 17 new projects *maximum* by 2020
Australian Coal Association	Large-scale demonstration projects operating in Australia by 2015	**Failed.** No large-scale projects operating by 2015, or since. One project *maximum* by 2020.
Carbon Capture and Storage Flagships (Australia)	Both funded projects operating by 2015, later 2020.	**Initial target failed.** **Revised target not on track.** Neither project expected to be operating by 2020.
Council of the European Union	12 power projects operating in the EU by 2015	**Failed.** No power projects operating by 2015. None expected by 2020.
International Energy Agency (I)	100 large-scale CCS projects operating by 2020 (new and existing) Revised to 34 projects	**Initial target not on track.** **Revised target not on track.** 18 new and existing projects operating. 23 projects *maximum* by 2020
International Energy Agency (II)	255 Mtpa stored by CCS projects by 2020 (new and existing) Revised to 50 Mtpa by 2020	**Initial target not on track.** **Revised target not on track.** ~30 Mtpa capacity in 2017 9.3 Mtpa proven capture rate in 2017 ~38 Mtpa capacity by 2020
International Energy Agency (III)	400 Mtpa stored by large-scale CCS projects by 2025	**Not on track.** ~30 Mtpa capacity in 2017 9.3 Mtpa proven capture rate in 2017 ~45 Mtpa capacity by 2025
IPCC	2,600–4,900 Mtpa by 2020	**Not on track.** 38 Mtpa capacity projected in 2020.
CFMEU, WWF, The Climate Institute, Australian Coal Association	10,000 GWh from CCS power plants in 2020	**Not on track.** No commercial-scale CCS power plants happening or planned

Note: Mtpa stands for "million tonnes of CO2 stored per annum".

Introduction

International organisations and carbon capture and storage (CCS) boosters have made bold predictions about the uptake and success of CCS technologies. The G8, the International Energy Agency, Australian Coal Association and the Council of the European Union have all set targets for CCS uptake.

CCS' progress towards these targets is used to justify taking money from renewables and energy efficiency projects in order to fund more CCS. Last year, the Minerals Council of Australia argued for the Clean Energy Finance Corporation to extend to funding CCS projects, partly on the grounds that the world has met the G8 target of 20 large-scale CCS projects by 2020[1] (although this is not the case; see below).

The targets that were set represent credible milestones for how CCS must advance if it is to play a key role in the fight against climate change. If it has failed to meet these targets, the technology is less developed than expected – and cannot be depended on.

[1] Minerals Council of Australia (2018) *Clean Energy Finance Corporation Amendment (Carbon Capture and Storage) Bill 2017,* p 4, https://web.archive.org/web/20180416063911/http://www.minerals.org.au/file_upload/files/annual_reports/180921_CEFC_Amendment_(CCS)_Bill_2017.pdf

Target categories and criteria

Ambitions for carbon capture and storage projects fall into two main categories, each with its own sub-categories:

- **Number of large-scale projects:** These targets specify how many large-scale projects must exist to meet the target.
    - **Launched:** Count of projects "launched" or otherwise progressed (but not necessarily complete)
    - **Completed:** Count of projects operational
- **Capture and storage volume:** These targets specify how many Mtpa of CO2 should be captured and stored to meet the target.
    - **Potential capture:** Total potential for capture ("capacity") in a year
    - **Actual capture:** Total actually captured in a year
    - **Proven capture:** Total "proven" to be captured (meeting strict standards around reporting, reliability and safety) in a year

Some targets fall into both categories, for example the IEA 2009 Roadmap's target of 100 large-scale projects capturing 255 Mtpa between them.

The particular criteria set for the target will determine whether projects, capacity and storage count towards the target. For example, the definition of "large-scale" differs across projects, as does what level of verification is required for storage to be "proven".

There is also a temptation to blur the lines, for example counting storage capacity as "actually captured", even if the project's potential is not fully utilised, or to count "launched" projects towards the completed projects target. However, this is not appropriate. If the target is completed projects or CO2 actually captured, that is what progress must be measured against.

LARGE-SCALE PROJECTS

A number of targets reference the number of "large-scale" projects launched or operational (completed). The main criteria are:

- What counts as a large-scale project
- Whether existing completed projects count towards the target

Large-scale

The definition of large-scale has changed over the years, even within organisations.

The Global CCS Institute worked with the G8 to set the particular criteria required for its targets. They initially used a threshold of 1 Mtpa captured as the measure of "large-scale" or "commercial-scale". By the time the G8 criteria were settled, the threshold for non-coal projects had been lowered to "in the order of" 0.5 Mtpa captured (coal projects remained at "in the order of" 1 Mtpa captured).[2]

The Global CCS Institute further revised its criteria to capturing "not less than 80 per cent" of 1 Mtpa for coal-fired power stations (i.e., 0.8 Mtpa captured and stored) and capturing "not less than 80 per cent" of 0.5 Mtpa for other projects (i.e., 0.4 Mpta captured and stored), which is the threshold adopted by the IEA.[3]

Existing completed projects

A key detail is whether a project that pre-dates the target counts towards it. In other words, is it a target for X *new* projects by a certain year, or just a target for X *total* projects by a certain year.

Where there were no existing projects, this is a moot point. For example, since the EU had no large-scale projects to begin with, its goal of 12 power projects by 2015 is necessarily for 12 *new* projects.

On the other hand, this is a vital question for the G8 target. There are six CCS projects that pre-date the G8 target being set, five of which would probably meet the G8's definition of "large-scale". If these projects are not counted, there is no conceivable way for the G8 target to be met.

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[2] Global CCS Institute (2009) *Strategic analysis of the global status of carbon capture and storage, report 5: Synthesis report,* p 9, https://hub.globalccsinstitute.com/sites/default/files/publications/5751/report-5-synthesis-report.pdf; Global CCS Institute (2010) *The global status of CCS: 2010,* p 71, http://hub.globalccsinstitute.com/sites/default/files/publications/12776/global-status-ccs-2010.pdf; IEA and CSLF (2010) *Carbon capture and storage: Progress and next steps,* p 9-10, http://hub.globalccsinstitute.com/sites/default/files/publications/5701/iea-cslf-report-muskoka-2010-g8-summit.pdf

[3] IEA (2013) *Technology Roadmap: Carbon capture and storage, 2013 edition,* p 19, https://www.iea.org/publications/freepublications/publication/TechnologyRoadmapCarbonCaptureandStorage.pdf; see also Global CCS Institute (2010) *The global status of CCS: 2010,* p 48, http://hub.globalccsinstitute.com/sites/default/files/publications/12776/global-status-ccs-2010.pdf

POTENTIAL AND ACTUAL CAPTURE

A number of targets involve the potential to capture and store or the actual capture and storage of a certain volume of CO2. The main criteria are:

- Whether potential, actual or proven capture is the measure
- Whether the capture from any project counts towards the total, or just that done by large-scale projects

Potential, actual or proven capture/storage

A project might have the nominal ability to capture some amount of CO2, but whether it actually captures that amount is a key question. In addition, a project's actual capture may be higher than its proven capture if it cannot satisfactorily demonstrate that its capture is secure for the long-term.

In fact, all existing targets specify that it is the actual or proven capture – and not the capture potential – that is the criteria. However, it is worth emphasising because capture potential is the data that is more readily available – and so it is tempting to use it as a proxy for actual or proven capture.

ENHANCED OIL RECOVERY ("EOR")

Whether to count EOR projects and EOR capture towards CCS development is a contentious question, for a number of reasons as provided by the Global CCS Institute:[4]

- EOR projects may also require dedicated geological storage because EOR projects do not use a constant volume of CO2 over their lifetime
- Not all regions and countries have opportunities for EOR
- Not all oil fields are suitable for EOR
- The timeframe for EOR is narrow
- Public support for taxpayer funding of EOR is limited

The G8 target does include EOR projects, despite describing EOR as a "distraction to CCS development" and saying that "the majority of the CO2 EOR experience has yielded very little information on CO2 storage, monitoring and risk assessment".[5]

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[4] Global CCS Institute (2011) *Global storage resources gap analysis for policy makers, report: 2011/10,*, http://hub.globalccsinstitute.com/sites/default/files/publications/23707/2011-10-global-storage-resources-gap-analysis-policy-makers.pdf

Targets

This documents the institutional targets and projections that have been made for CCS.

IEA TARGETS

Roadmaps

2009 Roadmap:

- **100 projects capturing 255 Mtpa by 2020**
- **OECD Pacific has seven projects storing 17 Mtpa by 2020**
- **Coal makes up 37% of CCS, storing 94 Mtpa, by 2020**

2013 Roadmap:

- **34 projects capturing 50 Mtpa by 2020**

In the IEA's 2009 roadmap, the IEA proposed a "BLUE Map" scenario in which CCS reduced carbon emissions by 9.5 Gt CO2 in 2050, or 19% of the total. This would require 100 projects by 2020, storing 255 Mtpa.[6]

In 2011, the IEA confirmed:

> Some 100 projects globally are still required by 2020 if we are to set CCS technologies on the right pathway to delivery.[7]

However, in 2013 the Roadmap was re-published and the IEA cut its ambition from 100 CCS projects to "upwards of 30", not including the four that were operational in 2013,[8]

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[5] Global CCS Institute (2009) *Strategic analysis of the global status of carbon capture and storage, report 5: Synthesis report,* p 25-26, https://hub.globalccsinstitute.com/sites/default/files/publications/5751/report-5-synthesis-report.pdf; Global CCS Institute (2011) *Global storage resources gap analysis for policy makers, report: 2011/10,* http://hub.globalccsinstitute.com/sites/default/files/publications/23707/2011-10-global-storage-resources-gap-analysis-policy-makers.pdf

[6] IEA (2009) *Technology roadmap: Carbon capture and storage,* p 6, 14–22, https://www.iea.org/publications/freepublications/publication/CCSRoadmap2009.pdf

[7] Lipponen, Burnard, Beck, Gale and Pegler (2011) *The IEA CCS Technology Roadmap: One Year On,* p 5755, https://www.sciencedirect.com/science/article/pii/S1876610211008502

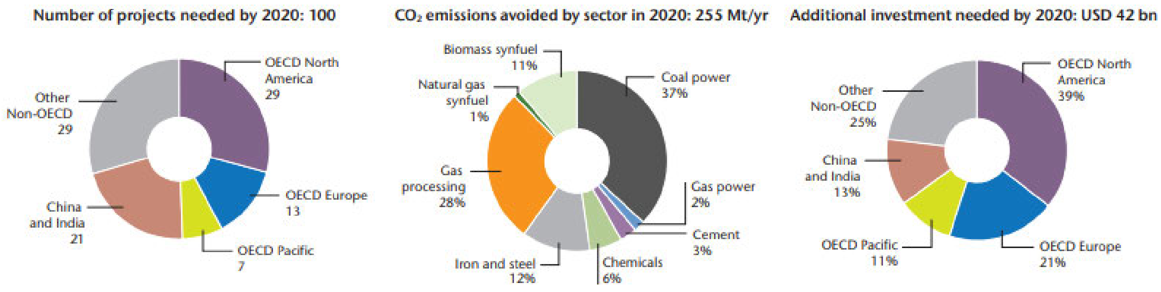
capturing around 50 Mt CO2 p.a.[9] The explanation given was practical – too few projects were in the advanced stages of planning and the revised goal was "set in this context" – rather than based on what was required for fossil fuel technology to remain viable in a carbon-constrained world.[10]

The IEA's 2009 Roadmap broke down the number of projects and emissions avoided needed by region and sector.[11] See Figure 1.

Although we do not have the resources to track the performance of each of these regions and industries, we have analysed the coal industry and the OECD Pacific region (Australia, Japan, New Zealand and South Korea)[12] as areas of particular interest.

The 2013 Roadmap did not update region- and industry-specific targets for CCS, for example for the OECD Pacific or for the coal industry.

Figure 1: 2009 Roadmap's breakdown of projects and Mtpa



[8] IEA (2003) *Technology Roadmap: Carbon capture and storage, 2013 edition,* p 10, 23, 25, https://www.iea.org/publications/freepublications/publication/TechnologyRoadmapCarbonCaptureandStorage.pdf; note they must be using somewhat different criteria to the Global CCS Institute.

[9] Lipponen, McCulloch, Keeling, Stanley, Gerghout and Berley (2016) *The politics of large-scale CCS deployment,* https://ac.els-cdn.com/S1876610217320933/1-s2.0-S1876610217320933-main.pdf?_tid=87f6e6fc-f8cd-466f-b2fc-eefdfe2c60bc&acdnat=1524462638_c2be0b12e1f13132574480cdf7541b28

[10] IEA (2003) *Technology Roadmap: Carbon capture and storage, 2013 edition,* p 23, https://www.iea.org/publications/freepublications/publication/TechnologyRoadmapCarbonCaptureandStorage.pdf

[11] The IEA 2009 Roadmap and the IEA 2009 Roadmap foldout give different figures for the CO2 emissions avoided (299 Mtpa vs 255 Mtpa), and by extension coal's contribution. We have chosen the lower figures to be more conservative, and because the Roadmap foldout was updated more recently than the Roadmap. See IEA (2009) *Carbon capture and storage roadmap,* p 17, 20, https://www.iea.org/publications/freepublications/publication/CCSRoadmap2009.pdf; IEA (2010) *Technology roadmap – carbon capture and storage 2009: foldout,* https://webstore.iea.org/technology-roadmap-carbon-capture-and-storage-2009-foldout

[12] IEA (2009) *Carbon capture and storage roadmap,* p 14, https://www.iea.org/publications/freepublications/publication/CCSRoadmap2009.pdf

Source: IEA (2009) *Carbon capture and storage roadmap,* https://www.iea.org/publications/freepublications/publication/CCSRoadmap2009.pdf; IEA (2010) *Technology roadmap – carbon capture and storage 2009: foldout,* https://webstore.iea.org/technology-roadmap-carbon-capture-and-storage-2009-foldout

Criteria

The IEA provided criteria for projects to count as eligible towards the Roadmaps targets:

- **Large-scale:** The IEA defined the projects needed by 2020 as "large-scale",[13] later clarifying that they were using the new Global CCS Institute definition of 0.8 Mtpa captured and stored for coal-fired power stations and 0.4 Mtpa captured and stored for other projects.[14]
- **Storage:** The Mtpa target is based on storage, not storage potential.
- **New and existing:** The 2009 Roadmap target did not require new projects. The 2013 Roadmap target did require 30 new projects, but also identified that there were only four existing projects that met its criteria.
  This paper therefore sets the target at 34 new and existing projects.

2DS Target

- **Over 400 Mtpa stored in 2025**

The IEA's 2DS scenario identifies changes required for the world to have a 50% chance of limiting global warming to 2 degrees Celsius.[15]

In 2017, the IEA reviewed 26 technologies to assess how they were tracking towards "2DS". Large-scale CCS received the worse assessment of "red", significantly off-track.[16]

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[13] "The roadmap's recommendation [is] of 100 large-scale projects": IEA (2009) *Carbon capture and storage roadmap,* https://www.iea.org/publications/freepublications/publication/CCSRoadmap2009.pdf; Saether (2010) *European Zero Emissions Platform: 'We are ready to go',* http://bellona.org/news/ccs/2010-10-european-zero-emissions-platform-we-are-ready-to-go

[14] IEA (2013) *Technology Roadmap: Carbon capture and storage, 2013 edition,* p 19, https://www.iea.org/publications/freepublications/publication/TechnologyRoadmapCarbonCaptureandStorage.pdf; see also Global CCS Institute (2010) *The global status of CCS: 2010,* p 48, http://hub.globalccsinstitute.com/sites/default/files/publications/12776/global-status-ccs-2010.pdf

[15] IEA (n.d.) *Scenarios and projections,* https://www.iea.org/publications/scenariosandprojections/

[16] IEA (2017) *Tracking clean energy progress 2017,* p 6, 11, https://www.iea.org/publications/freepublications/publication/TrackingCleanEnergyProgress2017.pdf

G8 TARGETS

- **20 new large-scale CCS projects launched by 2010**
- **20 new large-scale CCS projects operating by 2020**

In 2008, the G8 leaders announced:

> We strongly support the launching of 20 large-scale CCS demonstration projects globally by 2010, taking into account various national circumstances, with a view to beginning broad deployment of CCS by 2020.[17]

The requirement for "broad deployment" was interpreted to mean that the 20 projects would be operational by 2020.[18]

Criteria

Involved parties set criteria for projects to count as eligible towards the target.[19]

- **New projects:** The projects must be "in addition to those already operating" when the target was set.[20]
- **Large-scale:** 0.5 Mtpa captured (non-coal) or 1 Mtpa captured (coal). This was a revision down from the initial metric of 1 Mtpa for all projects.[21]

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[17] Global CCS Institute (2010) *The global status of CCS: 2010,* p 71, http://hub.globalccsinstitute.com/sites/default/files/publications/12776/global-status-ccs-2010.pdf; sometimes described as a G20 target, see for example: Page (2011) *Global status of CCS: 2011,* https://www.youtube.com/watch?v=DxhbLGDig_g

[18] Global CCS Institute (2009) *Strategic analysis of the global status of carbon capture and storage, report 5: Synthesis report,* p 172, https://hub.globalccsinstitute.com/sites/default/files/publications/5751/report-5-synthesis-report.pdf

[19] Global CCS Institute (2010) *The global status of CCS: 2010,* p 71, http://hub.globalccsinstitute.com/sites/default/files/publications/12776/global-status-ccs-2010.pdf; see also IEA and CSLF (2010) *Carbon capture and storage: Progress and next steps,* p 9-10, http://hub.globalccsinstitute.com/sites/default/files/publications/5701/iea-cslf-report-muskoka-2010-g8-summit.pdf

[20] IEA (2016) *20 years of carbon capture and storage,* p 10, 17, https://www.iea.org/publications/freepublications/publication/20YearsofCarbonCaptureandStorage_WEB.pdf; see also SBC Energy Institute (n.d.) *Leading the energy transition: Bringing carbon capture and storage to market,* p 7; see also World Coal Association (2018) *Fluctuating policy and political support for CCS,* https://twitter.com/WorldCoal/status/1034498402216824832

[21] Global CCS Institute (2009) *Strategic analysis of the global status of carbon capture and storage, report 5: Synthesis report,* p 9, https://hub.globalccsinstitute.com/sites/default/files/publications/5751/report-5-synthesis-report.pdf; Global CCS Institute (2010) *The global status of CCS: 2010,* p 71, http://hub.globalccsinstitute.com/sites/default/files/publications/12776/global-status-ccs-2010.pdf;

- **Storage:** The scale requirement is based on *capture,* not capacity.
- **Integrated:** The project integrates capture and storage, and transport (if applicable).
- **Proven capture:** A monitoring, measurement and verification plan must be provided.

In the Global CCS Institute's initial assessment in 2010, only one project met all seven criteria – the Gorgon Gas Project, which is still not operating. Four operating projects met six criteria (one of these, In Salah, has since closed) and five operating projects met five criteria.[22]

The Minerals Council of Australia said in 2017:

> there will be over 20 large scale CCS projects operating by 2020 including Western Australia's Gorgon Carbon Dioxide Injection Project. This meets the G8's 2008 objective of 20 such projects by 2020.[23]

This is based on a misunderstanding the G8 target, because it is counting projects that already existed when the target for new projects was set.

CCS academics Lipponen, McCulloch, Keeling, Stanley, Berghout and Berley confirm in their 2017 paper that the G8 target will be missed because at best, there will be 14 new large-scale CCS projects operating by 2020.[24] They must be using more conservative criteria than the Global CCS Institute – a count of the Global CCS Institute database of large-scale projects operating or under construction gives a slightly higher figure of 17.[25]

IEA and CSLF (2010) *Carbon capture and storage: Progress and next steps,* p 9-10, http://hub.globalccsinstitute.com/sites/default/files/publications/5701/iea-cslf-report-muskoka-2010-g8-summit.pdf

[22] Global CCS Institute (2010) *The status of CCS projects: Interim report 2010,* p 16-17, http://hub.globalccsinstitute.com/sites/default/files/publications/5686/status-ccs-projects-interim-report-2010.pdf

[23] Minerals Council of Australia (2018) *Clean Energy Finance Corporation Amendment (Carbon Capture and Storage) Bill 2017,* p 4, https://web.archive.org/web/20180416063911/http://www.minerals.org.au/file_upload/files/annual_reports/180921_CEFC_Amendment_(CCS)_Bill_2017.pdf

[24] Lipponen, McCulloch, Keeling, Stanley, Berghout and Berley (2017) *The politics of large-scale CCS deployment,* p 7583, https://ac.els-cdn.com/S1876610217320933/1-s2.0-S1876610217320933-main.pdf?_tid=d215c205-2d22-47ec-bf33-6fea38654996&acdnat=1524528931_13e1c799ed0a985fb5ef6aeb2361e1f4

[25] Global CCS Institute (2018) *Large-scale CCS facilities,* http://www.globalccsinstitute.com/projects/large-scale-ccs-projects

In either case, these are best case scenarios. The true number of CCS projects that meet the G8 target by 2020 could be significantly lower, for several reasons.

- **Under construction:** The five projects "under construction" could be delayed or cancelled, as so many other CCS projects have been. The rate of failure over project lifetime is two-to-one.[26]
- **Closures:** Some of the currently operating CCS projects could close, as the In Salah project did in 2011.[27]
- **EOR projects:** Whether to include EOR projects in the count is controversial. At most five projects would meet the target by 2020 if EOR projects are excluded.
- **G8 criteria:** A project can be operating without meeting all seven G8 criteria. In 2010 (the last time this analysis appears to have been conducted), only one of the projects met all seven criteria: the Gorgon Gas Project. Half of all operating projects met fewer than six of the criteria.[28]
  One example is that the Global CCS Institute database lists two different CCS projects associated with the Alberta Carbon Trunk Line (Agrium CO2 Stream and Sturgeon Refinery CO2 Stream). However, G8 projects are meant to cover the whole process – so these two projects may be properly counted as just one.
- **Large-scale:** The Global CCS Institute's definition of "large-scale" has loosened since the G8 criteria were fixed, and now includes smaller projects. Two or three upcoming projects are below 0.5 Mtpa in capacity.[29]
  Even if a project's capacity exceeds the target, the G8 target is to *store* that much CO2. For example, Boundary Dam Power Station is listed as having a capacity of 1 Mtpa, which meets the G8 requirement for coal-fired power plants to store 1 Mtpa *only* if it operates at full capacity. In fact, over the 41

[26] Lipponen, McCulloch, Keeling, Stanley, Gerghout and Berley (2016) *The politics of large-scale CCS deployment,* https://ac.els-cdn.com/S1876610217320933/1-s2.0-S1876610217320933-main.pdf?_tid=87f6e6fc-f8cd-466f-b2fc-eefdfe2c60bc&acdnat=1524462638_c2be0b12e1f13132574480cdf7541b28
[27] MIT (n.d.) *In Salah Fact Sheet,* https://sequestration.mit.edu/tools/projects/in_salah.html
[28] Global CCS Institute (2010) *The status of CCS projects: Interim report 2010,* p 16-17, http://hub.globalccsinstitute.com/sites/default/files/publications/5686/status-ccs-projects-interim-report-2010.pdf
[29] Sinopec Qilu Petrochemical CCS and Yanchang Integrated Carbon Capture and Storage Demonstration are 0.4 Mtpa. The Alberta Carbon Trunk Line and Terrell Natural Gas Processing Plant have ranges given for their capacity, and part of the range falls below the 0.5 Mtpa target. See Global CCS Institute (2018) *Large-scale CCS facilities,* http://www.globalccsinstitute.com/projects/large-scale-ccs-projects

months between October 2014 and March 2018, Boundary Dam stored 2 million tonnes of CO2.[30] That represents less than 60% of capacity.

Unfortunately, the Global CCS Institute seems to have stopped doing detailed analysis against G8 criteria for each project. Some projects that were previously non-compliant may have become compliant (the reverse is also possible), but this analysis would have to be conducted anew for each project.

The world is not on track to meet the G8 target by 2020 because the target was for new projects, not counting the six existing ones. Of the 17 new built and under construction projects, several do not meet the G8's criteria and would not count towards the target.

Australian Coal Association Target

- **G8-style CCS projects in Australia operating by 2015**

In 2009, Ralph Hillman of the Australian Coal Association (since merged with the Minerals Council of Australia) used the G8 targets to justify his claim that Australia will "have commercial scale demonstration plants with carbon capture and storage in operation in Australia by 2015", adding:

> Well, we have the whole G8 behind [the target]. There's a G8 commitment, there's a commitment from the Commonwealth Government, there's a commitment from state governments and there's commitment from industry.[31]

As an extension of the G8 target, this target has the same criteria as the G8 target.

IPCC EMISSIONS SCENARIOS

- **2.6–4.9 Gt CO2 per annum (2,600–4,900 Mtpa) by 2020**

In 2000, the IPCC Special Report on Emissions Scenarios considered six scenarios for the world's carbon emissions, and identified the "projected potential of CO2 capture" as being between 2.6 and 4.9 Gtpa by 2020.[32]

[30] SaskPower (2018) *SaskPower Carbon Capture and Storage Surpasses Two Million Tonne Mark,* http://www.saskpower.com/about-us/media-information/saskpower-carbon-capture-and-storage-surpasses-2-million-tonne-mark/

[31] Jones (2009) *Ralph Hillman and Richard Denniss join Lateline,* http://www.abc.net.au/lateline/ralph-hillman-and-richard-denniss-join-lateline/1689002

COUNCIL OF THE EUROPEAN UNION TARGET

- **12 power projects by 2015**

The European Union aimed to:

> stimulate the construction and operation by 2015 of up to 12 demonstration plants of sustainable fossil fuel technologies in commercial power generation [in the European Union].[33]

CARBON CAPTURE AND STORAGE FLAGSHIPS TARGET

- **2–4 projects by 2015 (later 2020)**

Prime Minister Kevin Rudd's CCS Flagships program aimed to have two to four commercial-scale projects operating in Australia by 2015. Later the target was moved to 2020 and only two projects were selected for funding.[34]

PATHWAY TO ACCELERATED DEPLOYMENT OF CARBON CAPTURE AND STORAGE

- **10,000 GWh of power generation from integrated CCS technologies in 2020**
- **Commercial-scale (>300 MW) plants operating by 2020**

A pathway to accelerated deployment of carbon capture and storage was a strategy to increase the uptake of CCS in Australia proposed in April 2008 by the Australian Coal Association (which would later merge with the Minerals Council); the Construction, Forestry, Mining and Energy Union – Mining and Energy Division; The Climate Institute

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[32] Referenced in IPCC (2005) *Carbon dioxide capture and storage,* p 24, https://www.ipcc.ch/pdf/special-reports/srccs/srccs_wholereport.pdf

[33] Council of the European Union (2007) *Presidencv conclusions*, p 22, http://www.consilium.europa.eu/ueDocs/cms_Data/docs/pressData/en/ec/93135.pdf; see also Kapetaki and Scowcroft (2017) *Overview of Carbon Capture and Storage (CCS) Demonstration Project Business Models: Risks and Enablers on the Two Sides of the Atlantic*, https://www.sciencedirect.com/science/article/pii/S1876610217320180#bib0010

[34] Van Puyvelde (2016) *What about Carbon Capture and Storage?,* https://www.energynetworks.com.au/news/energy-insider/what-about-carbon-capture-and-storage

(the assets and intellectual property of which were bestowed on The Australia Institute) and WWF Australia.[35]

[35] The Climate Institute (2008) *A pathway to accelerated deployment of carbon capture and storage,* http://www.climateinstitute.org.au/verve/_resources/finalpolicydoc.pdf

CCS progress

What follows is an analysis of CCS progress over time, and projected into the future. It shows that CCS is not on track to meet *any* target.

LARGE-SCALE PROJECTS

New and existing CCS projects

IEA 2009 Roadmap:

- **100 projects by 2020**

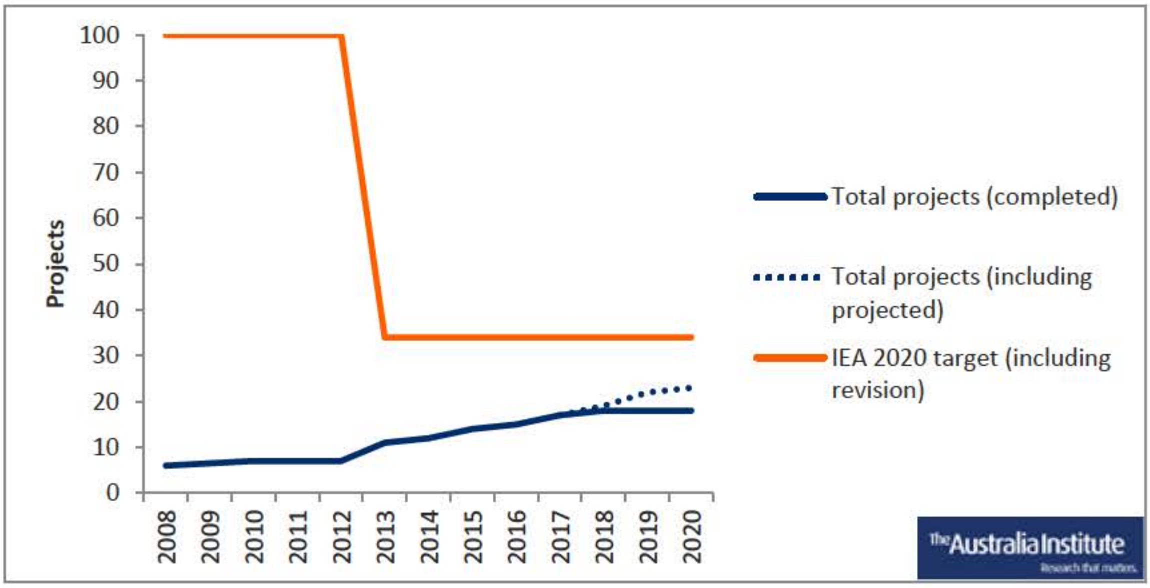
IEA 2013 Roadmap:

- **34 projects by 2020**

There are 17 CCS projects currently operating that might satisfy at least the most generous definition of "large-scale" – that is to say, that they have the capacity to store at least 0.4 Mtpa. There are a further five in the pipeline that could be complete by 2020.

This is well short of the IEA's initial target of 100 large-scale projects by 2020. It is also short of the IEA's revised target of 34 large-scale projects by 2020.

Figure 2: New and existing large-scale projects



Source: Global CCS Institute (2018) *Large-scale CCS facilities,* http://www.globalccsinstitute.com/projects/large-scale-ccs-projects; Australia Institute calculations

New CCS projects only

G8 2008 Target:

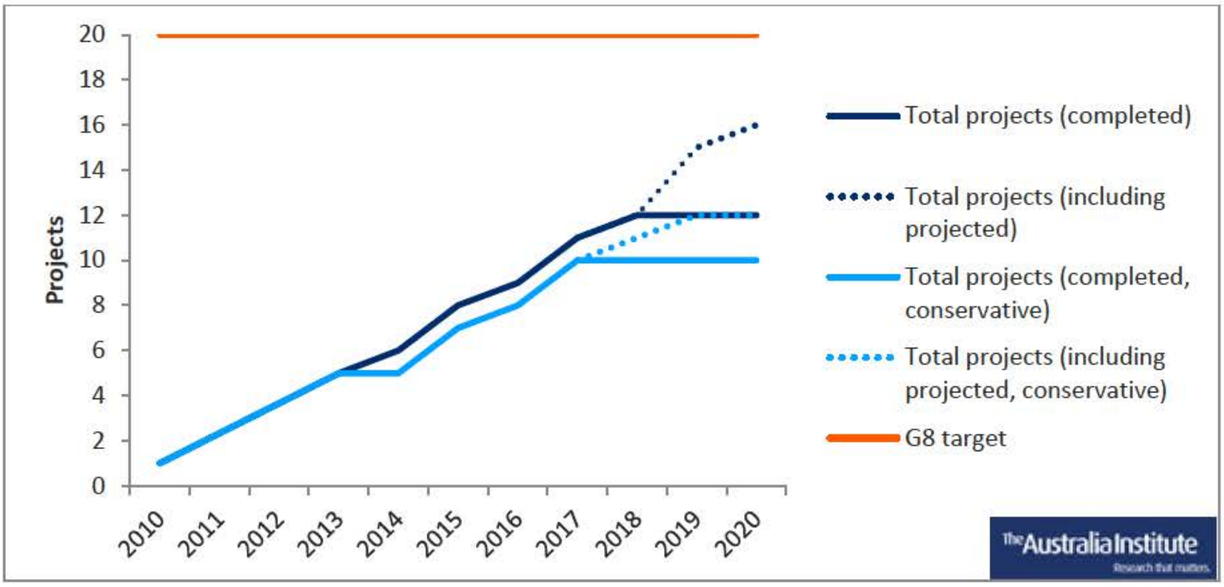
- **20 new large-scale CCS projects operating by 2020**

The IEA analysis counts the six projects completed between 1972 and 2009 that are still operational today. These projects pre-date the G8 target, which was for *new* projects. In Figure 3, we show only those projects begun after the G8 target was set.

The G8 target also used a higher threshold for "large-scale", being "in the order of" 0.5 Mtpa (non-coal projects) or 1 Mtpa (coal projects), as opposed to 0.4 Mtpa and 0.8 Mtpa respectively. The "conservative" count (excluding those projects that are or may be below 0.5/1 Mtpa) is shown in lighter blue in the figure below.

However, as the figure clearly shows, the G8 target will not be met even with the inclusion of all of these potentially ineligible projects.

Figure 3: New large-scale projects (following G8 target)



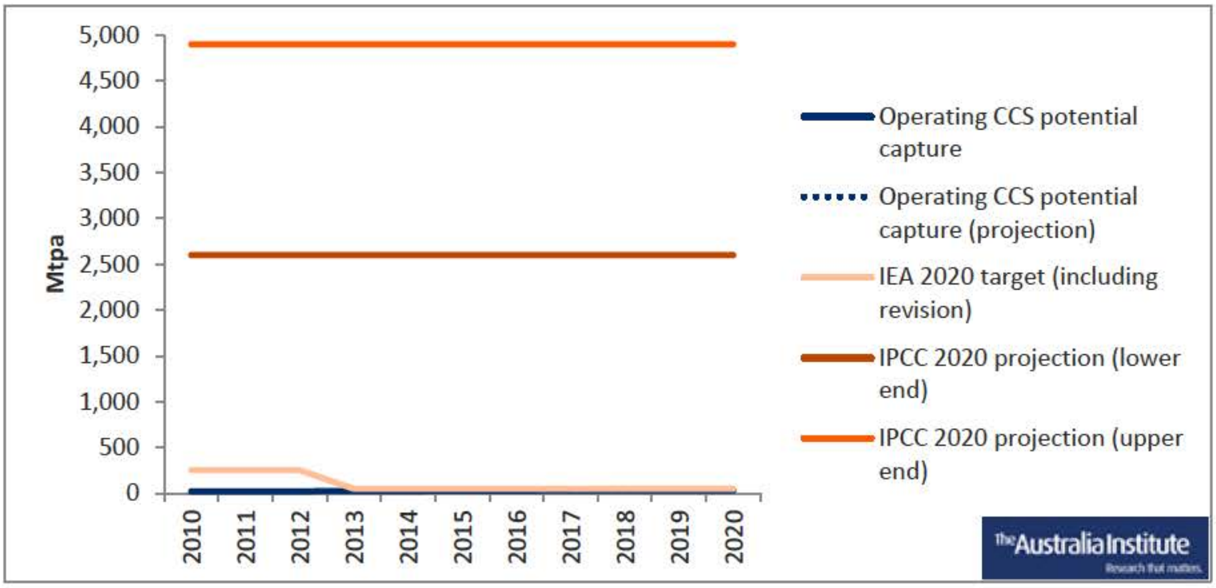
Source: Global CCS Institute (2018) *Large-scale CCS facilities,* http://www.globalccsinstitute.com/projects/large-scale-ccs-projects; Australia Institute calculations

POTENTIAL AND CAPTURE

Potential capture by 2020

The potential capture from CCS projects in 2020 is 38.6 Mtpa. This is so far short of the IEA 2020 target of 253 Mtpa or the IPCC 2020 projection of between 2,600 and 4,900 Mtpa potential capture that the figure is not even readable. See Figure 4 for the extreme disparity between projected capture potential in 2020 and the IEA target and IPCC projection.

Figure 4: New and existing capture capacity

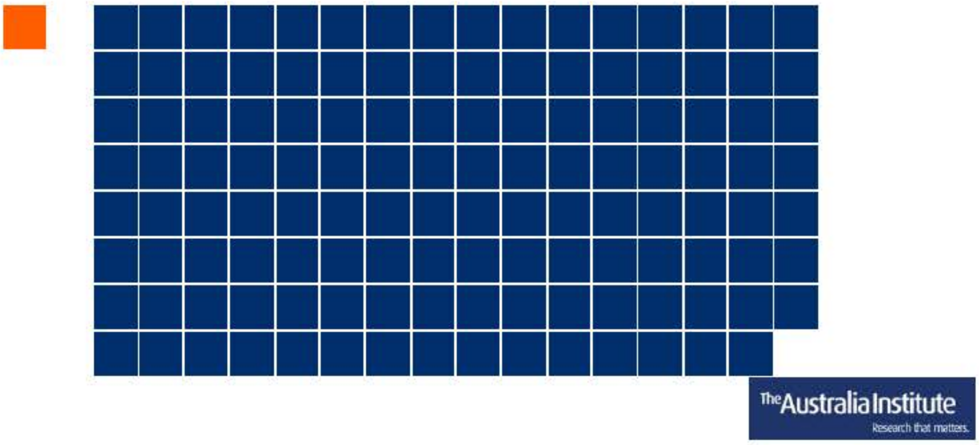


Source: Global CCS Institute (2018) *Large-scale CCS facilities,* http://www.globalccsinstitute.com/projects/large-scale-ccs-projects; Australia Institute calculations

Note: The 2020 IEA target is set at 253 Mtpa to reflect 2 Mtpa of small-scale CCS capacity.

Another way of depicting this is in Figure 5, below, showing in orange how much CCS capture potential is expected in 2020 versus the upper range of what the IPCC projected would be needed. There will 1/127th as much as the upper range of the IPCC projections.

Figure 5: Projected capture potential (orange) vs IPCC best-case projections (navy)



Source: Global CCS Institute (2018) *Large-scale CCS facilities,* http://www.globalccsinstitute.com/projects/large-scale-ccs-projects; Australia Institute calculations

Proven capture by 2020

IEA 2009 Roadmap:

- **Capturing 255 Mtpa by 2020**

IEA 2013 Roadmap:

- **Capturing 50 Mtpa by 2020**

IPCC 2000 Scenarios:

- **Capturing 2,600–4,900 Mtpa by 2020**

The situation is worse for CCS than the above section suggests. That is because the targets are for CO2 actually captured/stored, rather than the potential for capture/storage.

There can be a significant difference between how much CO2 a project has the potential to capture and how much it actually captures.

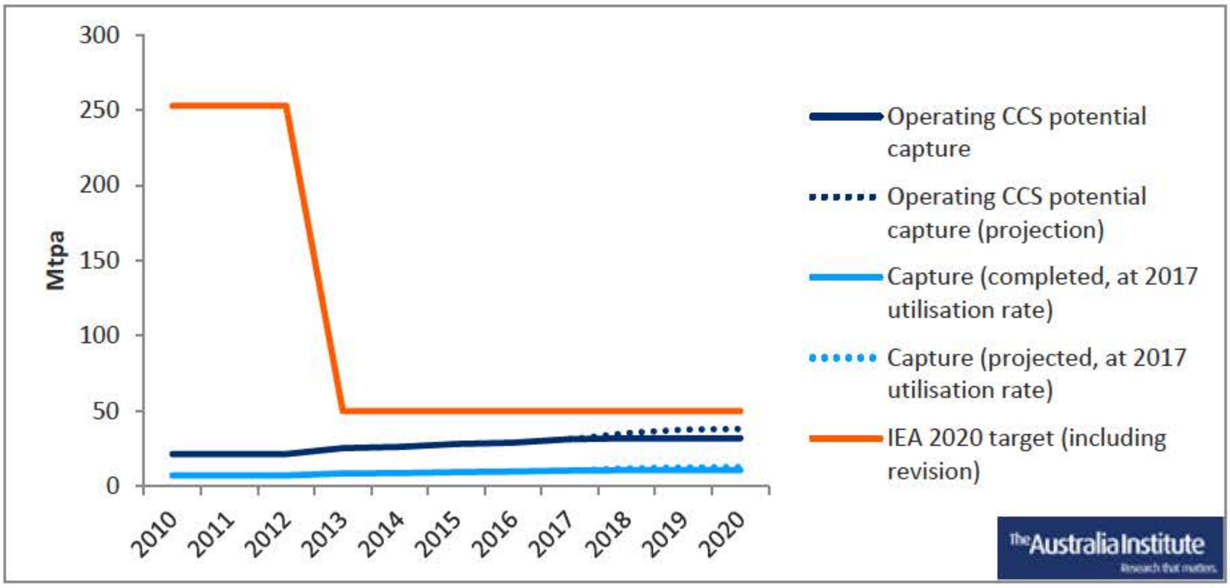
While we do not have good data on the actual capture/storage rate, we do have good data on the *proven* rate. This is more selective than the actual capture rate, because it requires monitoring to prove that the CO2 will not escape after storage.

In 2017, the world's CCS potential was about 30 Mtpa, but its proven capture was just 9.3 Mt – meaning that CCS was overall operating at less than a third of capacity.[36] Even if all projects currently under construction are completed by 2020, and they all start operating at full capacity, there will still only be 38 Mtpa captured.

Figure 6 shows the IEA 2020 target of 255 Mtpa captured compared to potential capture. It also shows what the proven capture rate would be if CCS continues to operate at less than a third of capacity (13 Mtpa).

The same problem applies to the IPCC CCS potential projections of 2,600–4,900 Mtpa, but those are so much larger than the projected capacity that including them in the figure would make the distinction impossible to make out.

Figure 6: New and existing capture capacity, including 2017 utilisation rate – out to 2020



Source: Global CCS Institute (2017) *The global status of CCS 2018,* p 18, 29, http://www.globalccsinstitute.com/sites/www.globalccsinstitute.com/files/uploads/global-status/1-0_4529_CCS_Global_Status_Book_layout-WAW_spreads.pdf; Global CCS Institute (2018) *Large-scale CCS facilities,* http://www.globalccsinstitute.com/projects/large-scale-ccs-projects

Note: The initial 2020 target is set at 253 Mtpa to reflect 2 Mtpa of currently operating small-scale CCS capacity.

[36] IEA (2017) *Tracking clean energy progress 2017,* p 11, https://www.iea.org/publications/freepublications/publication/TrackingCleanEnergyProgress2017.pdf

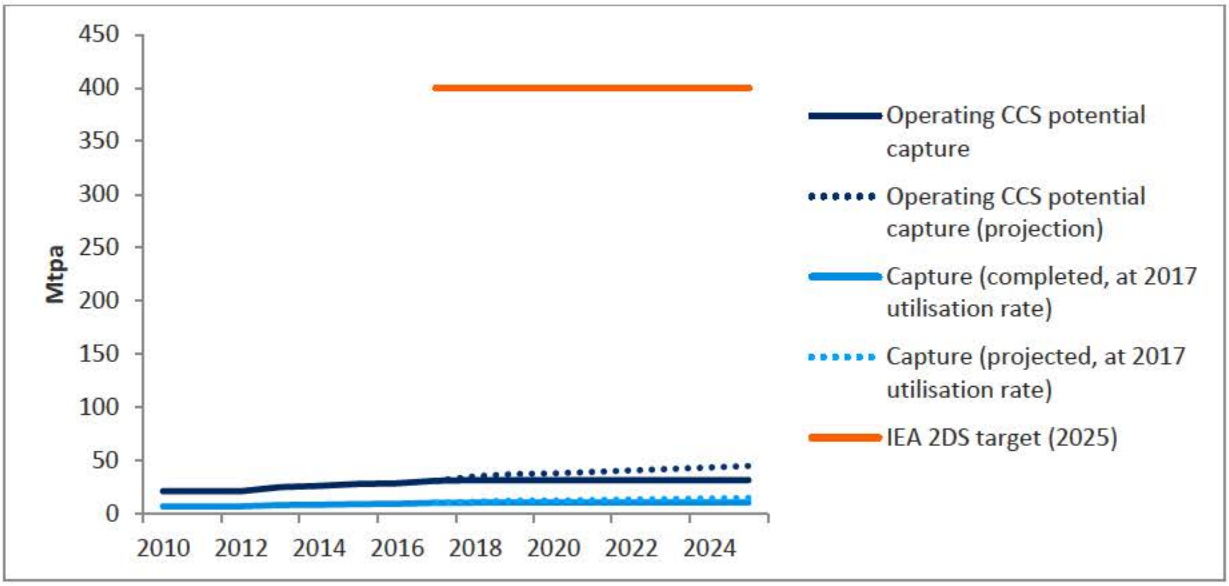
Proven capture by 2025

IEA 2017 2DS Target:

- **Over 400 Mtpa stored in 2025**

The figure below compares the IEA 2DS 2025 target of 400 Mtpa captured compared to potential capture. It also shows what the proven capture rate would be if CCS continues to operate at less than a third of capacity.

Figure 7: New and existing capture capacity, including 2017 utilisation rate – out to 2025



IEA (2017) Tracking clean energy progress 2017, p 11, https://www.iea.org/publications/freepublications/publication/TrackingCleanEnergyProgress2017.pdf; Global CCS Institute (2018) Large-scale CCS facilities, http://www.globalccsinstitute.com/projects/large-scale-ccs-projects

Note: The IEA projects 45 Mtpa capacity in 2025. This figure assumes a steady increase between 2020 and 2025 to reach that volume. In practice, it would increase in steps as projects are completed.

REGION- AND INDUSTRY-SPECIFIC PROGRESS

IEA 2009 Roadmap:

- **OECD Pacific has seven projects storing 17 Mtpa by 2020**
- **Coal makes up 37% of CCS, storing 94 Mtpa, by 2020**

Australian Coal Association 2009 Target:

- **G8-style CCS projects in Australia operating by 2015**

Council of the European Union 2007 Target:

- **12 power projects by 2015**

Carbon Capture and Storage Flagships Target:

- **2–4 projects by 2015 (later 2020)**

Australia's G8 projects

Australia did not build full-scale projects by 2015, as promised by the Australian Coal Association. The one full-scale project under construction, Gorgon Gas Project, is four years behind schedule and now expected in the first half of 2019.[37]

In 2010, the Global CCS Institute identified seven large-scale CCS projects that could meet the G8 criteria, including being operational by 2020 or earlier. It also indicated that Australia had committed to build three to five large-scale CCS projects by 2020.

Those projects were:[38]

1. **Coolimba Power Project:** A proposal to build a 400–450 MW coal-fired power plant in Western Australia, capturing 2 Mtpa. It was scheduled to be operational by 2015.
2. **Wandoan Power IGCC CCS Project:** A proposal to build a 400 MW IGCC[39] power plant in Queensland, capturing 2.5 Mtpa. It was scheduled to be operational by 2015 but was cancelled in 2013.[40]
3. **CarbonNet CCS Project:** A proposal to build a range of CO2 capture facilities in Victoria, capturing 4–10 Mtpa. It was planned to be operational between 2015 and 2019. As of November 2018, it has been moved back to an operation date

[37] Milne (2017) *Carbon hiccup for Chevron with 5 million-tonne greenhouse gas problem at Gorgon LNG plant*, https://thewest.com.au/business/oil-gas/carbon-hiccup-for-chevron-with-5-million-tonne-greenhouse-gas-problem-at-gorgon-lng-plant-ng-b88694565z

[38] Global CCS Institute (2010) *The status of CCS projects: Interim report 2010,* p 6, Appendix A, http://hub.globalccsinstitute.com/sites/default/files/publications/5686/status-ccs-projects-interim-report-2010.pdf

[39] "IGCC" refers to "integrated gasification combined cycle" technology, a form of power generation that turns coal into gas and burns the gas.

[40] Queensland Government (2018) *Projects discontinued or on hold,* https://www.statedevelopment.qld.gov.au/assessments-and-approvals/discontinued-eis-projects.html

of "2020s", a reduced capture of 1–5 Mtpa and a capture type of "under evaluation".[41]

4. **The Collie South West Hub Project:** A proposal to build a range of CO2 capture facilities in Western Australia, capturing 2.5–7.5 Mtpa. It was planned to be operational by 2015. As of November 2018, it has been moved back to an operation date of 2025 and a reduced capture of 2.5 Mtpa.[42]
5. **ZeroGen Commercial Scale Project:** A proposal to build a 400 MW IGCC plant in Queensland, capturing 2 Mtpa. It was planned to be operational by 2015, but it was cancelled in 2011.[43]
6. **Browse LNG Development:** A proposal to build an LNG plant in Western Australia, capturing 3 Mtpa. It was planned to be operational by 2017 but the project no longer appears as a current project in the Global CCS Institute database.[44]
7. **Gorgon Carbon Dioxide Injection Project:** A proposal to build an LNG processing plant in Western Australia, capturing 3.4 Mtpa. It was planned to be operational in 2014, but the CCS component is now only expected to be operational in 2019. Since the project began in 2016, it is estimated to have released 5.5 to 8 million tonnes of CO2 that would have been sequestered if the CCS technology were functioning.

CarbonNet and the South West Hub Project are the two CCS Flagships projects, discussed below in reference to the CCS Flagships' target.

Australia's CCS Flagships projects

Neither of the CCS Flagships programs were complete by the initial target date of 2015.

It is also unlikely that either CCS project will be complete by the revised target date of 2020.

In 2016, Energy Networks Australia wrote that:

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[41] Global CCS Institute (2018) *Large-scale CCS facilities,* http://www.globalccsinstitute.com/projects/large-scale-ccs-projects

[42] Global CCS Institute (2018) *Large-scale CCS facilities,* http://www.globalccsinstitute.com/projects/large-scale-ccs-projects

[43] Queensland Government (2018) *ZeroGen Project,* https://www.statedevelopment.qld.gov.au/assessments-and-approvals/zerogen-project.html

[44] Global CCS Institute (2018) *Large-scale CCS facilities,* http://www.globalccsinstitute.com/projects/large-scale-ccs-projects

> It is unclear whether [the two CCS projects] can achieve this timeframe, as progress on both projects has been slow.[45]

Since then, there has been no indication that the projects are now on track.[46]

Australia's pathway to accelerated deployment of CCS

Australia has no commercial-scale CCS at its power plants, and no plans to build any. As such, it will not meet the 10,000 GWh in 2020 target.

Coal

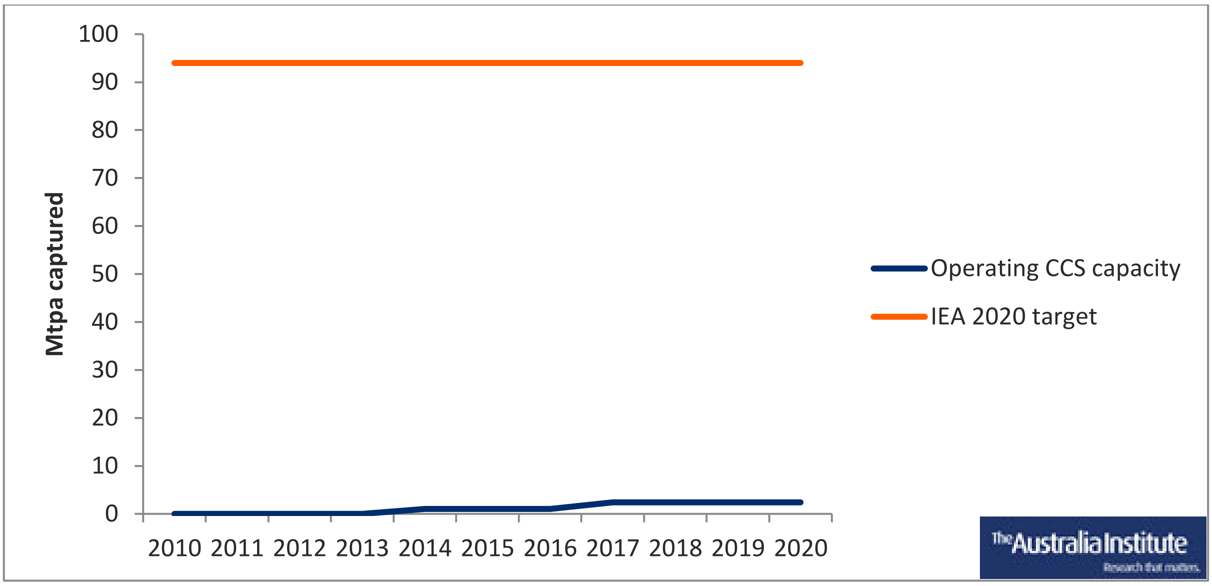
Figure 8 shows coal's performance against the initial IEA target of 94 Mtpa captured by 2020. It shows 2.4 Mtpa captured in 2020, or 3% of the target. This reflects the Boundary Dam Power Station project coming online in 2014 and the Petra Nova project operating from 2017. This estimate is optimistic because Boundary Dam is operating significantly below capacity.

There are no other projects in the pipeline that could be complete by 2020.

[45] Van Puyvelde (2016) *What about Carbon Capture and Storage?*, http://www.energynetworks.com.au/news/energy-insider/what-about-carbon-capture-and-storage#_ftn1

[46] See for example: WA Department of Industry, Innovation and Science (2015) *Carbon Capture and Storage Flagship South West Hub Project: Review report*, https://industry.gov.au/resource/LowEmissionsFossilFuelTech/Documents/CCS-western-australian-south-west-hub-project-review-report.pdf; Victoria Earth Resources (n.d.) *The CarbonNet Project*, http://earthresources.vic.gov.au/earth-resources/victorias-earth-resources/carbon-storage/the-carbonnet-project

Figure 8: Coal-with-CCS, operating and target



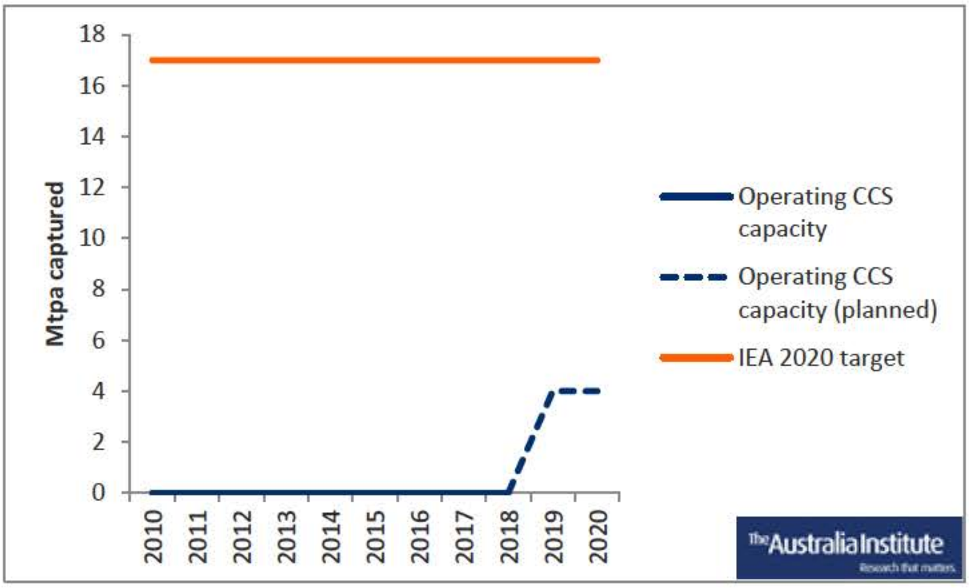
Source: Global CCS Institute (2018) *Large-scale CCS facilities,* http://www.globalccsinstitute.com/projects/large-scale-ccs-projects

OECD Pacific

Figure 9 shows the OECD Pacific's performance against the initial IEA target of 17 Mtpa captured by 2020. If the Gorgon Gas Project comes online in 2019, as is now planned (it has been delayed multiple times), then the OECD Pacific will have one project capturing 4 Mtpa, or less than a quarter of its target.

There are no other projects in the pipeline expected to be complete by 2020.

Figure 9: CCS in the OECD Pacific, operating, planned and target



Source: Global CCS Institute (2018) *Large-scale CCS facilities,* http://www.globalccsinstitute.com/projects/large-scale-ccs-projects

EU power projects

The European Union built none of its power projects by its target date of 2015, and has not built any since, despite spending "at least" EUR 587 million on at least 63 CCS projects.[47]

As of 2017:

> The two projects currently operating storage in the European Economic Area, Sleipner and Snøhvit, are located in Norway.[48]

Norway is not in the European Union.

There are not even any *plans* for such plants:

> European utilities Uniper and Engie in June [2017] announced they were walking away from a Dutch CCS project known as ROAD ... ROAD is the last proposal standing for a large-scale coal or gas power CCS project in Europe. Its

[47] Teffer (2017) *After spending €587 million, EU has zero CO2 storage plants,* https://euobserver.com/investigations/139257

[48] Kapetaki and Scowcroft (2017) *Overview of Carbon Capture and Storage (CCS) Demonstration Project Business Models: Risks and Enablers on the Two Sides of the Atlantic*, https://www.sciencedirect.com/science/article/pii/S1876610217320180#bib0010

> demise followed cancellation of CCS funding in Britain, ending prospects for a European commercial-scale demonstration power plant.[49]

There is still some room for industrial CCS, with a few such projects under consideration.[50]

[49] Wynn (2017) *The carbon-capture dream is dying,* http://energypost.eu/the-carbon-capture-dream-is-dying/

[50] Wynn (2017) *The carbon-capture dream is dying,* http://energypost.eu/the-carbon-capture-dream-is-dying/

Conclusion

The IPCC said in 2000 that by 2020 CCS would have the potential to capture between 2,600 and 4,900 Mtpa of CO2.

CCS will not have the potential to capture 2,600 Mtpa of CO2 by 2020.

The G8 said in 2008 that the world will need to build 20 new large-scale CCS projects by 2020 to enable the broad deployment of CCS.

The world will not build 20 new CCS projects by 2020.

The IEA said in 2009 that the world will need to build 100 large-scale CCS projects capturing 255 Mtpa by 2020 to make CCS a viable technology.

The world will not build 100 large-scale projects by 2020; it will not capture 255 Mtpa.

In 2013, the IEA revised its target to 34 large-scale projects capturing 50 Mtpa by 2020.

The world will not build 34 large-scale projects by 2020; it will not capture 50 Mtpa.

The IEA said in 2017 that CCS would have to capture 400 Mtpa by 2025 to be doing its bit to keeping global warming below 2 degrees Celsius.

CCS will not capture 400 Mtpa by 2025.

The Australian Coal Association said we would have large-scale projects by 2015.

Australia did not complete any large-scale projects by 2015.

Australia's CCS storage projects were meant to be completed by 2015, then 2020.

Our storage projects were not completed by 2015; they will not be completed by 2020.

The EU was going to demonstrate CCS viability by building 12 power projects by 2015.

The EU did not build any power projects.

Carbon capture and storage has missed every target that involved getting projects up and running, and it is on track to miss every future target. The sector has never delivered.

Appendix

PROJECTS OPERATING BEFORE G8 TARGET SET

Number counting towards G8 target: 0 (not new projects)

Number counting towards IEA target: 6

Table 2: Table of projects

Name	Operating by	Capacity (Mtpa)	Type	Notes
Terrell Natural Gas Processing Plant	1972	0.4-0.5	EOR	Possibly below G8 target of 0.5 Mtpa
Enid Fertilizer	1982	0.7	EOR	
Shute Creek Gas Processing Plant	1986	7	EOR	
Sleipner CO2 Storage	1996	1	Pure	
Great Plains Synfuels Plant and Weyburn-Midale	2000	3	EOR	
Snøhvit CO2 Storage	2008[51]	0.7	Pure	

Source: Global CCS Institute (2018) *Large-scale CCS facilities,* http://www.globalccsinstitute.com/projects/large-scale-ccs-projects

[51] Operating by March 2008, before the G8 target was set in July 2008: IEA and CSLF (2010) *Carbon capture and storage: Progress and next steps,* p 5, http://hub.globalccsinstitute.com/sites/default/files/publications/5701/iea-cslf-report-muskoka-2010-g8-summit.pdf; Leblond (2008) *Gaz de France receives first LNG from Snohvit,* https://www.ogj.com/articles/2008/03/gaz-de-france-receives-first-lng-from-snohvit.html; Van Noorden (2009) *Australia launches carbon capture institute,* https://www.nature.com/news/2009/090417/full/news.2009.372.html

NEW PROJECTS OPERATIONAL SINCE G8 TARGET SET

Number counting towards G8 target: 11 (Boundary Dam storing below target)

Number counting towards IEA target: 12 (more generous definition of "large-scale" than G8)

Table 3: Table of projects

Name	Operating by	Capacity (Mtpa)	Type	Notes
Century Plant	2010	8.4	EOR	
Air Products Steam Methane Reformer	2013	1	EOR	
Coffeyville Gasification Plant	2013	1	EOR	
Lost Cabin Gas Plant	2013	0.9	EOR	
Petrobras Santos Basin Pre-Salt Oil Field CCS	2013	1	EOR	
Boundary Dam Power Station	2014	1	EOR	Actual storage below G8 target of 1 Mtpa; coal project
Quest	2015	1	Pure	
Uthmaniyah CO2-EOR Demonstration	2015	0.8	EOR	
Abu Dhabi CCS	2016	0.8	EOR	
Illinois Industrial Carbon Capture and Storage	2017	1	Pure	
Petra Nova Carbon Capture	2017	1.4	EOR	Coal project
CNPC Jilin Oil Field CO2 EOR	2018	0.6	EOR	

Source: Global CCS Institute (2018) *Large-scale CCS facilities,* http://www.globalccsinstitute.com/projects/large-scale-ccs-projects

PROJECTS UNDER CONSTRUCTION

Number counting towards G8 target: 2–3 (if built; note that Alberta Carbon Trunk Line – Agrium actual storage may be below G8 target too, and/or may more properly count as a single project with the Alberta Carbon Trunk Line – Sturgeon Refinery for G8 purposes)

Number counting towards IEA target: 5 (if built; more generous definition of "large-scale" than G8)

Beyond 2020: There are no further projects under construction with operation dates after 2020. There are some identified as being in a more preliminary state.

Table 4: Table of projects

Name	Operating by	Capacity (Mtpa)	Type	Notes
Gorgon Gas Project	2019	3.4-4.0	Pure	Australian project
Alberta Carbon Trunk Line – Agrium	2019	0.3-0.6	EOR	Actual storage may be below G8 target of 0.5 Mtpa; both Alberta projects may count as one for G8 target
Alberta Carbon Trunk Line – Sturgeon Refinery	2019	1.2-1.4	EOR	Both Alberta projects may count as one for G8 target
Sinopec Qilu Petrochemical CCS	2019	0.4	EOR	Below G8 target of 0.5 Mtpa
Yanchang Integrated CCS Demonstration	2020	0.4	EOR	Below G8 target of 0.5 Mtpa

Source: Global CCS Institute (2018) *Large-scale CCS facilities,* http://www.globalccsinstitute.com/projects/large-scale-ccs-projects

Note: "Operating by" is the Global CCS Institute's prediction. For example, the Gorgon Gas Project is now only expected by 2019.