AUSTRALIAN POWER GENERATION TECHNOLOGY REPORT

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Australian Government
Australian Renewable Energy Agency

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Department of Industry and Science

Office of the Chief Economist

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EXECUTIVE SUMMARY

This report provides a sound foundation for evaluating our electricity future.

It is critical for policymakers, power industry professionals and the energy sector more broadly to have a high-quality, up-to-date dataset on power generation technologies in order to make informed decisions about Australia's electricity sector.

This report provides an unbiased, technology-neutral review of a broad range of generation technologies, their capabilities and their costs for 2015 and out to 2030. Rather than making predictions about which generation sources will contribute to Australian electricity grids in future, it instead provides the information needed to understand what they could look like and how much they might cost.

This is the most in-depth study of its kind to date. The project consulted leaders from industry, government, consumer groups and industry associations and worked closely with consultants, modellers and developers.

The report provides all the building blocks needed to accurately and quantitatively explore and evaluate a range of possible technological futures. These datasets will underpin most power industry modelling studies in Australia over the next few years, help investors make important decisions and assist policymakers to guide Australia towards reliable and sustainable electricity supply.

The datasets are backed up and elucidated by a broad range of supporting information, including information on:

» how Australia's electricity grids operate

» the status of carbon dioxide (CO_2) capture, transport and storage

» the role and development of energy storage systems

» an in-depth assessment of the Callide oxyfuel technology demonstration project in Queensland.

An industry-led project

This report resulted from the combined efforts of a broad cross-section of industry participants, including project developers, technology experts and international consultants. This includes international industry leader Electric Power Research Institute (EPRI), which led the technology and current costs review; CSIRO, which developed projections of future capital costs; leading consultants; and government, academic and industry experts on a range of topics. The Australian Power Generation Technology Assessment Reference Group, a diverse group made up of 45 organisations, participated and contributed markedly to this study.

To help determine current capital and operating costs, developers and operators shared confidential data about their costs of project development. Building on that information, this report provides robust figures for the costs of constructing and operating new power plants in Australia.

The focus of this report

This Australian cost of electricity study provides credible technology cost and performance data for 2015 to 2030. It contains data 'building blocks' for policymakers, power professionals and the energy sector to use for policy and investment decisions and for further modelling of Australian electricity generation options. For a wide range of technologies, the study includes current and projected capital costs, operation and maintenance costs, and detailed performance data.

The study did not attempt to forecast the likely future make-up of the generation suite used in Australia in 2030 scenarios. This report is not designed to be used for choosing a 'winning' technology, but as a source of data as an input to further modelling and assessment work.

The future of Australia's electricity grids

The role of Australia's various electricity grids is to deliver safe, environmentally acceptable and reliable power, at an acceptable cost.

When and how electricity is produced, transmitted and distributed to consumers and how it is consumed may be very different in the future, but will require a mix of generation technologies, each playing a different role. No single technology or class of technologies can efficiently and effectively supply 100% of our energy needs.

Australia's electricity grid is changing

Both the supply and the demand side of Australia's electricity sector are undergoing significant transformation. Australia has a broad range of new technologies that can supply our future electricity generation needs, ranging from low- to zero-emissions fossil-fuel generators through to the use of CCS and to utility-scale renewable generation. Many consumers can already choose self-generation (particularly rooftop solar PV), and with rapidly developing energy storage technologies will be able to shift their electricity demand to more opportune times throughout the day. The global push for lower emissions to address climate change will continue to accelerate both the introduction of new technologies and advances in existing technologies.

Operating the grid is complex

Electricity grids are complex systems, and the largest machines ever developed by humans. Grid operators must constantly balance supply and demand by rapidly and flexibly adjusting the output of power stations, by electricity demand-management techniques, by using energy storage to smooth demand, or any combination of the three. They must also ensure that the failure of any one component (a power station or power line) does not disrupt the rest of the network. In Australia, this places constraints on the generation mix and supporting technologies.

No single technology can supply all our energy needs

Transforming Australian electricity grids is not simply a matter of choosing one technology and using it to replace our entire existing supply. As with our current grid, we need combinations of technologies that can allow supply to match demand or shift demand to times when it can be met.

Intermittent renewables do not necessarily follow changes in load (demand) across the day, as their output depends on local weather patterns, but traditional coal- and gas-fired baseload (continuously operating) generators are also being challenged to operate more flexibly. Some technologies, such as peaking generators, will continue be used infrequently, as they are now, and provide significant value despite their high LCOEs.

Electricity market design in Australia is intended to motivate generators to deliver electricity at the lowest possible prices, reflecting their actual cost of production. Future generation combinations can thus be determined by evaluating prices across the day and year, and then investigating different combinations of supply to determine the lowest cost technology mix that still manages other constraints (such as the reliability of supply and environmental considerations). Australian electricity markets will continue to provide ongoing opportunities to invest in advanced new-generation technologies to replace or displace current-generation power plants.

Not all Australian grids are the same

In addition to different demand and supply profiles, which drive different combinations of technologies, different grids in Australia have specific requirements. For example, in smaller grids such as the Northern Territory's, flexible generation is highly valuable because it can respond quickly to changes in load or the failure of a generator, potentially avoiding the need to shed load. Larger interconnected grids, such as the National Electricity Market in eastern Australia and the Wholesale Electricity Market in Western Australia, are more resilient because of their larger volume and diversity of generation and load, but will need continued careful management to respond to an increasingly diverse generation mix.

Grid planners need to continue to ensure the availability of sufficient capacity for year-round supply, the flexibility needed to meet both surges in demand and unexpected outages of generation, redundancy in both power stations and the transmission and distribution grids, and the availability of the frequency control and network support services that are needed for a functioning grid. Failure to address these requirements increases the risk that a single outage will lead to a cascade of failures and widespread blackouts.

Future electricity grids worldwide will be more diverse than in the past, as the large base of generation and major industrial demand connected to high-voltage networks becomes increasingly integrated with small embedded generators and customer loads in low-voltage distribution networks (Figure E1).

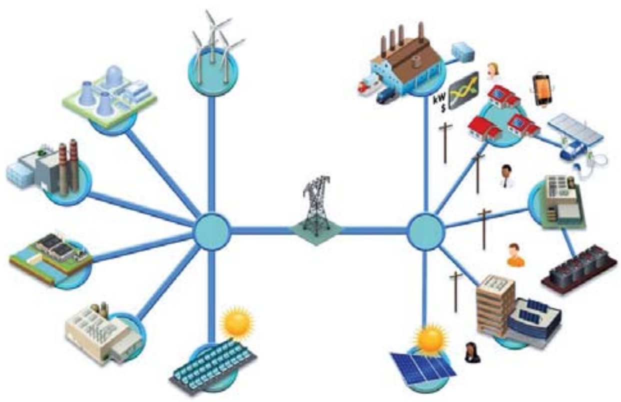


Figure E1: A highly integrated future grid. Source: EPRI, The integrated grid: realising the value of central and distributed energy resources, EPRI product ID 3002004103.

Comparing our technology options

This report presents a set of important 'building blocks' that enable different generation technologies to be compared on a common basis. It provides industry, government and consumers with the tools needed to evaluate all relevant factors related to cost (both capital and operating costs) and performance (including carbon emissions, water usage and capacity factors).

Figure E2 shows the *levelised cost of electricity* (LCOE) for a range of technologies if they were to be built in Australia today, under today's conditions. The LCOE captures the average cost of producing electricity from a technology over its entire life, given assumptions about how the generator will operate. It allows the comparison of technologies with very different cost profiles, such as solar photovoltaic (PV) (high upfront cost, but very low running costs) and gas-fired generators (moderate upfront cost, but ongoing fuel and operation costs).

THE COST OF GENERATION IN 2015

No single technology is optimal across all metrics, so the ideal grid should include a mix of technologies.

Of the renewable technologies, wind power has the lowest LCOE in 2015.

Of the fossil-fuel technologies, natural gas combined cycle and supercritical coal-fired generation have the lowest LCOEs.

All new technologies have significantly higher LCOEs than the current Australian grid average wholesale price.

A levelised cost does not capture the total cost of operating an electricity grid. For that reason, the LCOE and current electricity pool prices are not comparable, as LCOE covers long-run costs but pool prices often do not.

The LCOE of a technology is the average cost of producing electricity from that technology over its entire life, given assumptions about how the power station will operate; it is the cost of power as delivered to the plant boundary. Table E1 shows typical inputs to LCOEs for a range of generation technologies used in Australia.

A levelised cost does not capture the total cost of operating an electricity grid. For that reason, the LCOE and current electricity pool prices are not comparable, as LCOE covers long-run costs but pool prices often do not.

Recognising the limits of the current LCOE methodology, CSIRO has begun research to develop an extended methodology so that technologies can be compared on a more 'like for like' basis. The initial focus of the research is to determine how to take into account the costs of integrating intermittent renewables into the electricity system.

However, LCOEs allow comparisons of technologies with very different cost profiles, such as solar PV versus gas- or coal-fired generation.

Table E1: LCOE input values

Financial assumptions	Values
Nominal cost of equity (% p.a.)	11.5
Nominal cost of debt (% p.a.)	8.0
Percentage debt (%)	70.0
Inflation (% p.a.)	2.5
Company tax rate (% p.a.)	30
Property tax / insurance (% p.a.)	2.0
Analysis year	2015
Currency	$A
Asset book life (years)	30
Asset book life—wind only (years)	20
Fuel costs	
Brown coal ($/GJ)	1–1.75
Black coal ($/GJ)	2–4
Natural gas ($/GJ)	5–8
Diesel ($/GJ)	20–22

Straight-line tax life depreciation was assumed for this Australian study. The tax life for fossil fuel, nuclear and solar plants was assumed to be 30 years, and for a wind plant 20 years. These tax lives are consistent with the depreciation guidelines from the Australian Taxation Office.[1]

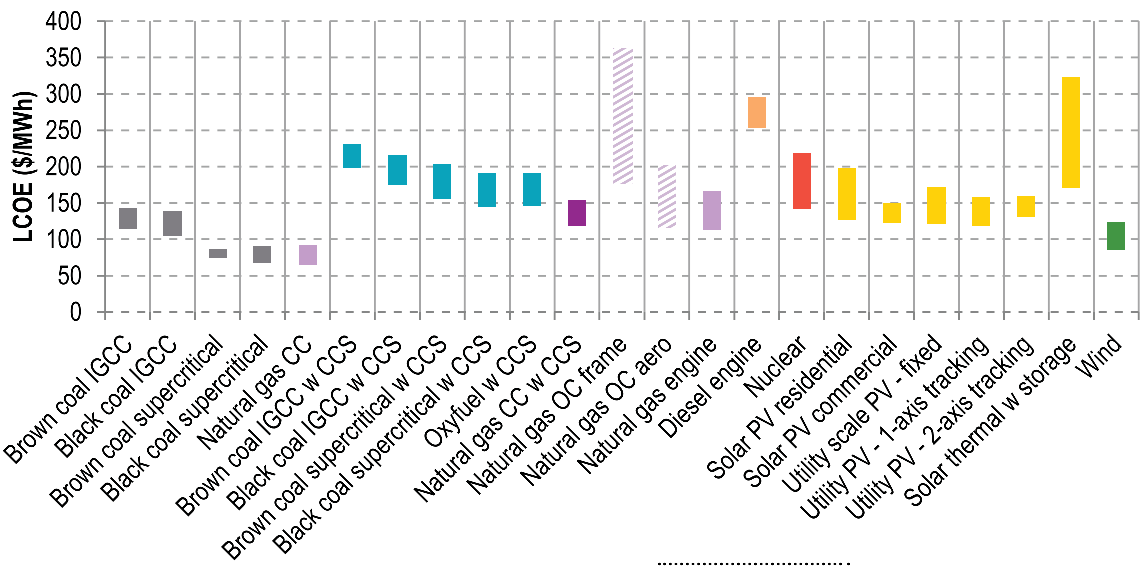


Figure E2: 2015 Levelised cost of electricity ($/MWh)

1 Taxation ruling TR 2015/2, https://www.ato.gov.au/law/view/document?LocID=%22ITD%2FEF20151%22&PiT=99991231235958

The spread of costs for each technology reflects a range of project-specific factors that can affect the costs. This includes the cost of bringing fuel to the plant, the local wind or solar resource levels, and site-specific factors that affect construction costs. The cost of new hydropower generation was not assessed, as it is unlikely that new large-scale hydropower projects will be deployed in Australia.[2]

Key trends in 2015

Wind power

Wind generation is the lowest cost renewable low-emissions technology currently available.

Commercial and utility-scale solar PV

For utility-scale solar PV, the lowest LCOE can be obtained from using single-axis tracking (panels that track the sun from east to west on a single pivot point), although this is site-specific.

Commercial rooftop PV systems have an LCOE comparable to those of utility-scale PV systems.

Residential solar PV

Residential solar PV systems, backed by various incentives, are already price competitive, as they compete at the retail level. This sector is expected to continue growing in market share beyond 2030.

Lowest cost traditional baseload technologies

Natural gas combined cycle and supercritical pulverised coal (both black and brown) plants have the lowest LCOEs of the technologies covered in the study.

Combined cycle gas with CCS

Natural gas combined cycle with CCS is the lowest cost baseload low-emissions fossil-fuel technology. While CCS technologies are not very mature, coal with CCS is more slightly mature than gas with CCS.

Retrofitting coal plants with CCS

It is technically feasible to retrofit post-combustion carbon capture (PCC) to wet- or dry-cooled black coal power plants. The LCOE for a PCC-retrofitted plant is less than for a new dry-cooled black coal supercritical plant with PCC.

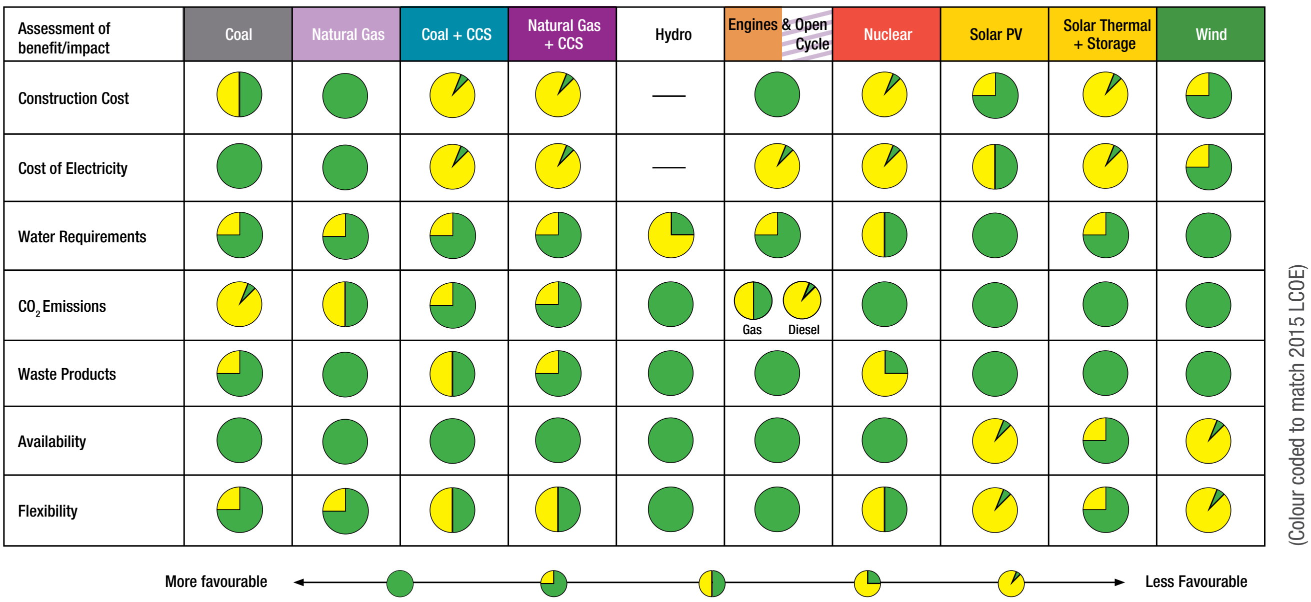
Nuclear power

Nuclear power costs are comparable to those of coal with CCS, but the costs are predicated on the development of a mature nuclear industry in Australia. The *Environment Protection and Biodiversity Conservation Act 1999* currently prohibits the development of nuclear power in Australia.

The advantages and disadvantages of each technology

Beyond the range of costs considered above, each technology has operational advantages and limitations that must be considered. Designers of reliable power systems must take all the attributes listed in Table E2 into account, as well as the integration of combinations of low-cost generation and flexible generation and emissions reduction obligations.

Table E2: Electricity technology comparisons



[2] The focus of current hydropower investment in Australia is on the refurbishment and modernisation of existing assets and in some cases the addition of mini- and micro-hydro units to waterways. The costs of refurbishments and small hydro are too site-specific for inclusion in this study.

FUTURE COST REDUCTIONS BY 2030

All new low- and zero-emissions technologies are projected to reduce in cost by 2030. In general, the more mature the technology, the less opportunity for further cost reductions.

The scope of cost reduction for a given technology depends heavily on the global take-up of that technology, along with learning-by-doing in local projects.

The overall ranking of LCOEs for technologies in 2030 is not projected to change from 2015, but there is likely to be convergence in LCOEs across most technologies.

Just as critical as assessing the current market is understanding of technology costs and capabilities are likely to go in the future. The scope and rate of technology improvements, whether incremental or breakthrough, depend on how much of each technology is deployed—which itself depends on the technology cost—so iterative modelling is needed.

Because all technologies used in Australia are also deployed globally, it is the global deployment levels that will drive technology and manufacturing cost breakthroughs. To capture these learning-by-doing effects, this study used GALLM, a global and local model from the CSIRO, informed by data from EPRI and industry partners (Figure E3). GALLM considers learning curves for each technology in a global context and projects future costs under various scenarios. A key input is the current development status of the technology: more mature technologies are less likely to experience future cost reductions.

EPRI has also conducted a separate assessment of each technology to identify explicit cost reductions achievable through focused R&D for each component. Both approaches have merit: the component-based approach identifies readily achievable cost savings, while the learning curve approach captures the more significant cost reductions that have been observed historically for many emerging technologies.

This study's findings on costs to 2030 include the following.

Solar PV

Solar PV capital costs are projected to reduce by 35–50%. As more solar PV plants are built, the cost of PV modules will continue to decline due to mass production. Other system costs and inverter costs are also expected to decrease over time. In laboratories, researchers are continuing to develop new PV configurations that promise to increase cell and module efficiency.

Solar thermal

Solar thermal capital costs may halve, depending on the volume of global installations.

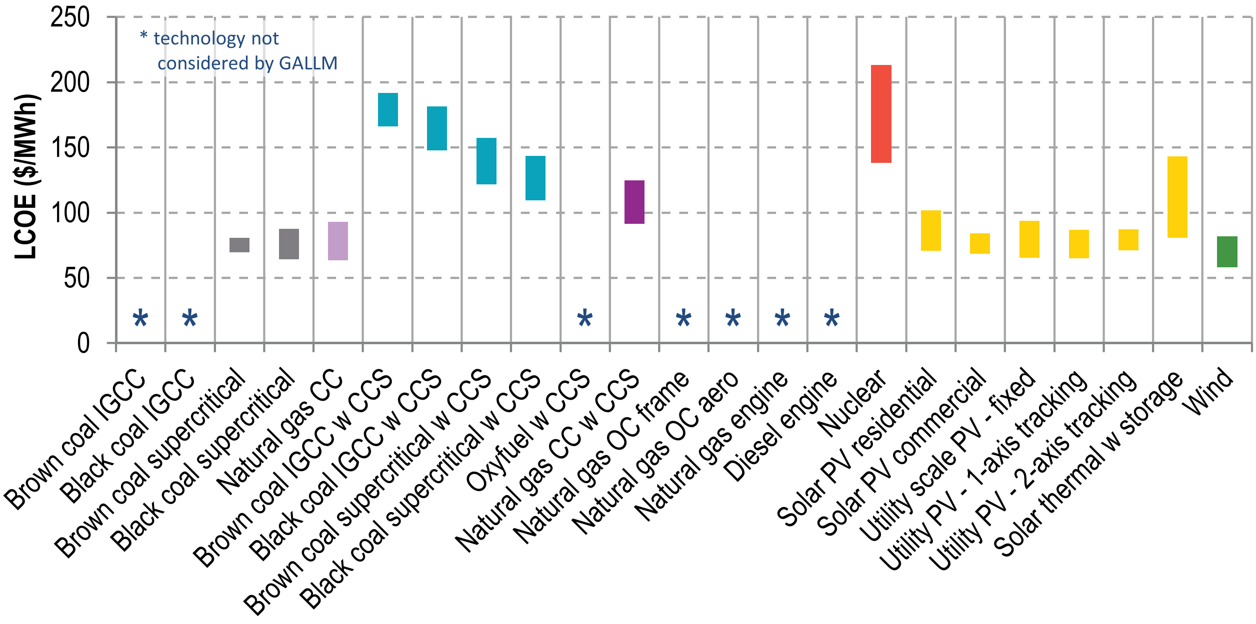


Figure E3: 2030 Levelised cost of electricity ($/MWh)

Note: LCOE assumptions are as in Table E2, except for natural gas pricing, which is $6–10/GJ.

CCS plant

CCS plant capital costs are projected to reduce by 30–50%, which translates into a reduction in levelised cost of 10–25% when operating costs are taken into account. There are likely to be improvements in both base plant efficiency and capture technology. However, if there is a lack of deployment at the global level this may inhibit learning by doing and therefore not lead to reductions in costs for CCS.

Combined cycle gas

Combined cycle gas generation is projected to become the cheapest fossil-fuel traditional baseload technology. Natural gas combined cycle plants are likely to benefit from higher firing temperatures, leading to increased efficiencies and reduced capital costs. It is projected that these developments will be used to reduce the cost and improve the performance of integrated gasification combined cycle units.

Changes to LCOE rankings caused by pricing carbon emissions

To examine the effect of pricing carbon emissions on the LCOE ranking, the study applied a carbon price to 2015 LCOEs.

In the base case studied in this report, fossil-fuel technologies are the lowest cost generators, being lower than wind and significantly lower than solar PV. In order to alter the LCOE ranking of carbon-emitting technologies, a sensitivity analysis on pricing carbon emissions was conducted (Figure E4).

The sensitivity cases showed that a high carbon price is currently required to significantly change the ranking of low-emissions generation technologies:

» Wind is competitive with supercritical coal with a $30/tCO_{2-e}$ price on CO_2 emissions.

» Solar PV is competitive with supercritical coal with a $70/tCO_{2-e}$ price.

» Supercritical coal with and without CCS are equivalent with a $130/ tCO_{2-e}$ price.

This situation is likely to change by 2030.

Supporting technologies

In addition to the generation technologies, a range of supporting technologies may create new opportunities to deliver an even more efficient and lower emissions grid. The costs and capabilities of this infrastructure should be considered when designing an integrated grid.

ENERGY STORAGE

Energy storage systems allow better matching between load and generation. Storage can act:

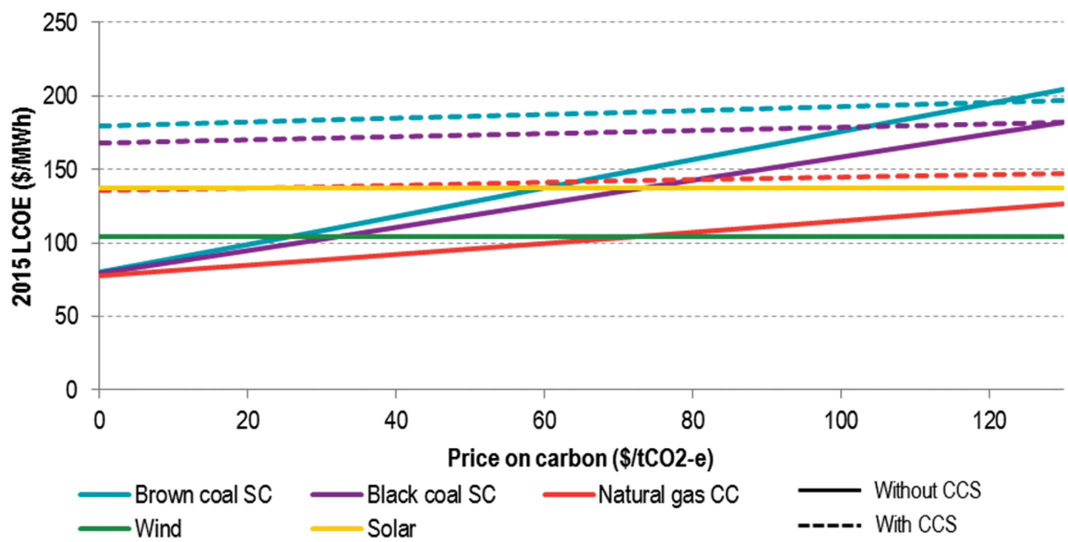
» as an alternative to peaking generation, by providing energy into the grid at peak times

» to support traditional baseload generators, by smoothing demand across the day

» to support variable renewables, by shifting production to match the system load.

The initial adoption of energy storage is likely to provide multiple benefits to the grid, such as peak shaving, the deferral of capital expenditure, provision of frequency control and network support, and energy trading in 'behind the meter' applications.

Figure E4: LCOE sensitivity to emissions pricing



Energy storage systems can be used to reduce peak demand and hence network expenditure, manage demand to shift load to more opportune times, and provide flexibility to grid operators. In many cases, storage can provide more than one service, increasing its potential value and hence its economic viability.

There is currently significant investment in a range of storage technologies, particularly battery technologies, which have already seen significant cost reductions over recent years. Recent modelling from the CSIRO using the GALLM learning curve model suggests that battery costs could halve again by 2030, leading to new market opportunities, particularly in behind-the-meter residential and commercial applications and in network support roles.

However, due to unavoidable inefficiencies in charging and discharging storage systems, a high take-up of such systems would increase the total consumption of energy in the system. When evaluating potential future systems, these costs need to be considered as part of the total cost of operating a grid.

TRANSMISSION AND DISTRIBUTION NETWORKS

The distribution and transmission network is the backbone that enables generators and consumers of power to trade with each other, even over long distances.

The various Australian grids have been developed over decades, and new grid developments are only undertaken if the benefits are demonstrated. The opportunity to expand a grid is further limited by regulatory constraints on the system.

The LCOEs for all technologies are calculated at the generator's boundary, with no allowances for the cost of connection to the grid. Larger projects (above about 100 MW) typically connect to high-voltage transmission grids; smaller projects (under 100 MW) typically connect to low-voltage distribution systems.

The cost and practicalities of connecting to a grid play an important role in determining which projects, and technologies, will be built. New power lines cost from about $0.4 million/km for distribution lines capable of connecting 10–100 MW projects to upwards of $1 million/km for transmission lines capable of supporting projects above 100 MW. While siting new power stations close to the existing grid reduces connection costs, it potentially reduces technology options.

To use the full output of low-utilisation generators (such as intermittent renewables or peaking gas plants), network connections must be built to the peak capacity, even though they might be used for only 20–40% of the time on average. Because connection costs have to be paid by the developer, this precludes all but short lines connecting to the existing grid without increasing an installed project's LCOE. Traditional baseload generators may justify longer connections to the grid.

CARBON DIOXIDE TRANSPORT AND STORAGE

To facilitate the implementation of CCS in Australia, one or more CO_2 transport and storage networks need to be developed.

The cost for transport and storage of CO_2 (excluding owner's and risk-adjusted costs) from power plants in Australia is likely to vary from \$5–14/t CO_2 to almost \$70/t CO_2. Variations in factors such as operating conditions, engineering assumptions, material costs, topography and geological characteristics may lead to different costs. The integrated design of capture systems, transport routes, operating conditions and injection strategies may lead to lower costs.

CCS is an enabling technology for reducing emissions from large stationary sources of CO_2, such as power plants and other industrial plants. The implementation of CCS requires a CO_2 transport and storage network involving pipelines, booster pumps, wells, storage site facilities and storage site monitoring. Such a network does not currently exist in Australia.

The lowest projected cost for transport and storage from power plants in Australia (\$5–14/t CO_2) is for cases involving a short transport distance to sites with good storage characteristics. The highest projected cost (up to \$70/t CO_2) is for cases involving transport over long distances to storage formations with poorer characteristics.

Variations in industry activity, exchange rates, macroeconomic cycles and owner's costs all have a significant effect on estimated CCS costs. Other major factors affecting the costs are related to variability in storage site characteristics (especially for larger and longer term injection of CO_2) and the incorporation of trade-offs in pipeline network design and storage site design. In a dynamic operating environment in which the amount of CO_2 for injection increases over time, accounting for these trade-offs becomes even more critical.

AUSTRALIAN OXYFUEL TECHNOLOGY DEMONSTRATION

The Callide Oxyfuel Project demonstrated the feasibility of oxyfuel combustion for over 10,000 hours in Australia's largest low-emissions coal plant demonstration.

Oxyfuel technology is one of the prospective technologies applicable for CCS. It involves turning air into oxygen before combustion in boilers that use pulverised coal. This facilitates the removal of CO_2 from the boiler after combustion.

- Key highlights from the project included the following:
- The project demonstrated ramp-rates under oxyfuel conditions that are equivalent to those for air-fired operations.
- It achieved a 50% load factor turndown, demonstrating the operational flexibility of an oxyfuel boiler.
- A CO_2 purity offtake of greater than 99.9% was achieved.
- The project also achieved the nearly complete capture of sulphur dioxide, nitrogen oxides, trace metals and particulates.

AUTHOR'S RESPONSIBILITIES

Work commenced on 6 July 2015 and was completed on 16 November 2015. Therefore, the Report does not take into account events or circumstances arising after 16 November 2015. The Report's authors take no responsibility to update the Report.

The Report's modelling considers only a single set of input assumptions which should not be considered entirely exhaustive. Modelling inherently requires assumptions about future behaviours and market interactions, which may result in forecasts that deviate from actual events. There will usually be differences between estimated and actual results, because events and circumstances frequently do not occur as expected, and those differences may be material. The authors of the Report take no responsibility for the modelling presented to be considered as a definitive account.

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