SOUTH AUSTRALIAN FUEL AND TECHNOLOGY REPORT

SOUTH AUSTRALIAN ADVISORY FUNCTIONS

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AUSTRALIAN ENERGY MARKET OPERATOR

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Purpose

The purpose of this publication is to provide information about fuel, resources, and power generation technology related to the energy industry in South Australia.

AEMO publishes this South Australian Fuel and Technology Report in accordance with its additional advisory functions under section 50B of the National Electricity Law. This publication is based on information available to AEMO as at 28 February 2017, although AEMO has endeavoured to incorporate more recent information where practical.

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Acknowledgement

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EXECUTIVE SUMMARY

The electricity generation mix in South Australia has changed in the past year, notably through the end of coal-fired generation and the increase to the Heywood Interconnector capability, and now relies on three key resources: wind, solar and gas.

Renewable generators now represent approximately 43% of South Australia's local installed capacity (2,297 megawatts (MW)), with gas-fuelled and liquid-fuelled thermal generators providing the other 57% share (2,987 MW). Energy supplied by Northern Power Station in the 2015−16 financial year is now largely being provided from Victoria via the Heywood and Murraylink interconnectors.

Following South Australia's Black System event on 28 September 2016, imports from Victoria are reduced when the inertia of the South Australian power system is low. This helps protect the system against high rates of change of frequency (RoCoF) associated with the non-credible loss of Heywood Interconnector, which could occur as a consequence of multiple contingencies in Victoria or South Australia. By limiting imports, more gas-powered generation (GPG) within South Australia is dispatched to provide the minimal level of thermal generation required to maintain security of electricity supply.

This increased dependence on GPG to maintain system security in South Australia comes at a time when gas production is in decline and gas prices are rising. The 2017 *Gas Statement of Opportunities* (GSOO) projects that GPG will be constrained from 2018–19 in South Australia, Victoria, and New South Wales unless gas production increases, or new gas supplies are developed.

Resources for power generation

- Natural gas in South Australia is sourced from Queensland, Victoria, and the Cooper and Eromanga basins. The cost of production is increasing, as the geological challenges of gas extraction are compromising gas well deliverability.
- South Australia's superior access to high mean wind speed sites has contributed to the region having the highest penetration of wind generation nationally to date. Since 2011–12, 392 MW of onshore wind farms has been developed, with a total of 1,595 MW now installed in the region.
- Sunlight is an abundant natural resource in South Australia. Overall South Australian rooftop photovoltaic (PV) generation increased by 131% from 294 MW in 2011–12 to 679 MW in 2015–16.
- There is development interest in a diverse mix of resources and technologies for future generation in South Australia, including wind, large-scale solar PV and solar thermal, bioenergy, pumped hydro storage, gas, carbon capture and storage, and grid-scale storage.

The technology frontier – comparative costs of new generation

AEMO has conducted a comparative cost assessment of different generation technologies for South Australia, based on a levelised cost of electricity (LCOE) calculation, summarised in Table 1.

- Natural gas-fuelled combined cycle gas turbines (CCGTs) remain the lowest cost new generation regardless of mode of operation (continuous or more peaking), but new entrant costs are higher than the current wholesale electricity price in South Australia. Using constant generation at nearly fully capacity (83% capacity factor), and gas prices of between $6.80 a gigajoule (GJ) and $8.50/GJ, AEMO estimates a CCGT would require an average electricity price of around $83 a megawatt hour (MWh) to cover its investment and operating costs. This is 34% higher than South Australia's time-weighted average price ($61.81/MWh) in 2015–16.
- At capacity factors below 8%, natural gas-fuelled open cycle gas turbine (OCGTs) have lower LCOE than CCGTs making OCGTs suitable to support electric power peaking load.
- For renewable generation technologies, wind remains the cheapest resource, with an LCOE of around $85/MWh (assuming a capacity factor of 42%). The LCOE for large-scale solar PV technologies, such as solar PV with dual-axis tracking, has dropped noticeably in the last two

years from $3,869/kW in 2015 to $2,810/kW in 2017, largely driven by substantial falls in capital cost. This reduction has been due to mass production, increase of market competition, and optimised system configurations.

- The LCOE for the cheapest renewable generation technology is now similar to the LCOE for thermal generation, although the value of the two generation sources is not directly comparable, due to the intermittent nature of wind generation.

Table 1 Minimum LCOEs of natural gas, wind, and solar PV technologies

Technology	Minimum LCOE ($/MWh)	Assumed maximum capacity factor (%)
Combined cycle gas turbine (CCGT)	83	83
Wind	85	42
Solar PV (single-axis tracking (SAT))	90	28
Solar PV (fixed flat PV (FFP))	96	22
Solar PV (dual-axis tracking (DAT))	98	32
Open cycle gas turbine (OCGT)*	218	10

* The calculated minimum LCOE of OCGT is more than twice the value of CCGT mainly due to lower plant efficiency and lower assumed maximum capacity factor.

Technology developments and projects

- As at 28 February 2017, South Australia had:
  - 102.4 MW committed and up to 3,109.4 MW publicly announced wind projects, in addition to 1,595 MW existing capacity.
  - Up to 945 MW of large-scale solar projects publicly announced in the region.
  - Four publicly announced projects for CCGT, OCGT, biomass, and diesel-fuelled technologies with up to 823.8 MW of total capacity.
  - Up to 200 MW publicly announced pumped hydro storage project.
- The high level of non-synchronous generation exposes South Australia to a high RoCoF associated with the non-credible loss of the Heywood Interconnector, which could occur as a consequence of multiple contingencies in Victoria or South Australia. Following South Australia's Black System event on 28 September 2016, additional RoCoF constraint equations have been implemented in the National Electricity Market (NEM) Dispatch Engine (NEMDE) to reduce imports from Victoria when the inertia of the South Australian power system is low.
- Potential solutions to existing and future challenges related to the penetration level of non-synchronous generation include the installation of synchronous condensers, storage, RoCoF protection devices, and new interconnectors.[1]
- The 2016 Heywood Interconnector upgrade increased the maximum transfer capability in both directions from 460 MW to 650 MW. AEMO has forecast that additional interconnection for South Australia with eastern States may provide positive net market benefits.[2] ElectraNet is currently investigating the development of interconnector and non-network solutions as part of its Energy Transformation Regulatory Investment Test for Transmission (RIT-T).[3]

[1] AEMO. *Future Power System Security Program Progress Report.* Published: August 2016. Available at: http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability/FPSSP-Reports-and-Analysis.

[2] See AEMO's 2016 *National Transmission Network Development Plan* (NTNDP). Available at: http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/National-Transmission-Network-Development-Plan.

[3] ElectraNet. *Regulatory Investment Test for Transmission (RIT-T)*. Available: https://www.electranet.com.au/what-we-do/network/regulatory-investment-test/ Viewed: 30 January 2017.

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1. INTRODUCTION

The 2017 *South Australian Fuel and Technology Report* (SAFTR) provides an overview of fuel resources and technology developments relevant to the South Australian energy industry.

The report outlines:

- The range of fuel resources as well as power generation and supporting technologies available in South Australia now and in the future.
- The comparative costs of power generation technologies in South Australia and the National Electricity Market (NEM).
- Where there are no related developments in the region, information about innovations in the NEM, Western Australia, or other countries that may present potential technology prospects in South Australia.

Unless otherwise referenced in this report:

- The status of generation projects in South Australia are drawn from AEMO's *Generation Information* webpage[4], which reports information on the capacity of existing, withdrawn, committed, and proposed generation projects in the NEM. The information reported on this webpage is collected from NEM generators via a web-based online system.
- Generation technology costs are sourced from the 2015 *Australian Power Generation Technology Report*.[5]
- All costs are in 2016 real dollars.

The report is published biennially starting from 2015.

[4] AEMO. *Generation Information.* February 2017. Available: http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Generation-information.

[5] AEMO. *2016 NTNDP Database*. Available: http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/National-Transmission-Network-Development-Plan/NTNDP-database.

2. GENERATION AND FUEL USE

2.1 Electricity capacity and generation

The electricity generation sector in South Australia is a mix of thermal gas-powered generation (GPG) and a geographically diverse collection of large-scale wind farms.

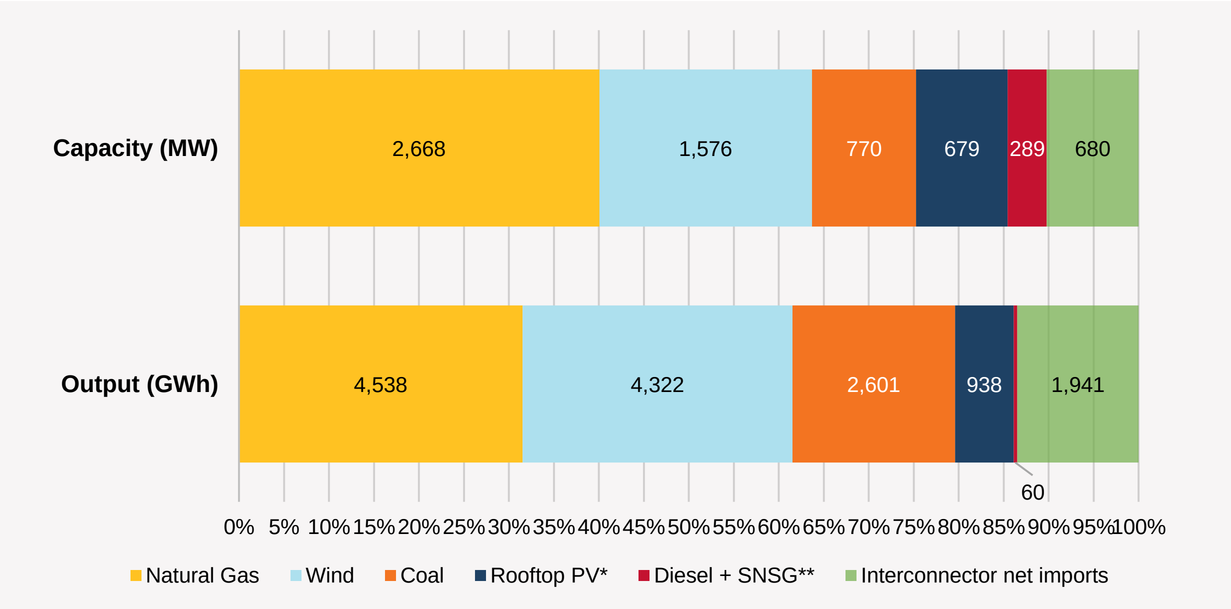
While no large-scale solar photovoltaic (PV) generators are installed currently, in 2015–16 the state produced approximately 938 gigawatt hours (GWh) of electricity, or 7% of total generation including net imports, from small-scale distributed rooftop PV systems.

In the same financial year, South Australian customers also consumed around 1,941 GWh (13% of total generation including net imports) of electricity that was generated in neighbouring regions of the NEM, imported via interconnectors connecting South Australia with Victoria (the Heywood and Murraylink interconnectors).

Figure 1 presents the fuel mix of registered capacity and generation output in 2015–16.

- The first bar shows that GPG has the highest capacity share, with approximately 40% of total registered capacity and combined nominal import capacity. Wind capacity is the next highest, with approximately 24% of total registered capacity and combined nominal import capacity.
- The second bar shows actual energy output, and highlights natural gas and wind as the two biggest sources of generation, supplying 32% and 30% of total generation output (including net imports) respectively.

Figure 1 South Australian registered capacity and generation output in 2015–16



* Rooftop PV installations are not registered with AEMO, but are included here given their material contribution to generation. Estimates are from the 2016 National Electricity Forecasting Report (NEFR).
** Diesel + SNSG includes small and large diesel, and small landfill methane and hydro generating systems.
Note: Generation (other than SNSG) and imports are taken from 5-minute averages of as-generated SCADA metering.

In May 2016, the supply mix of South Australia changed when Northern (530 MW) and Playford[6] (240 MW) power stations closed, marking the end of coal generation in the region.

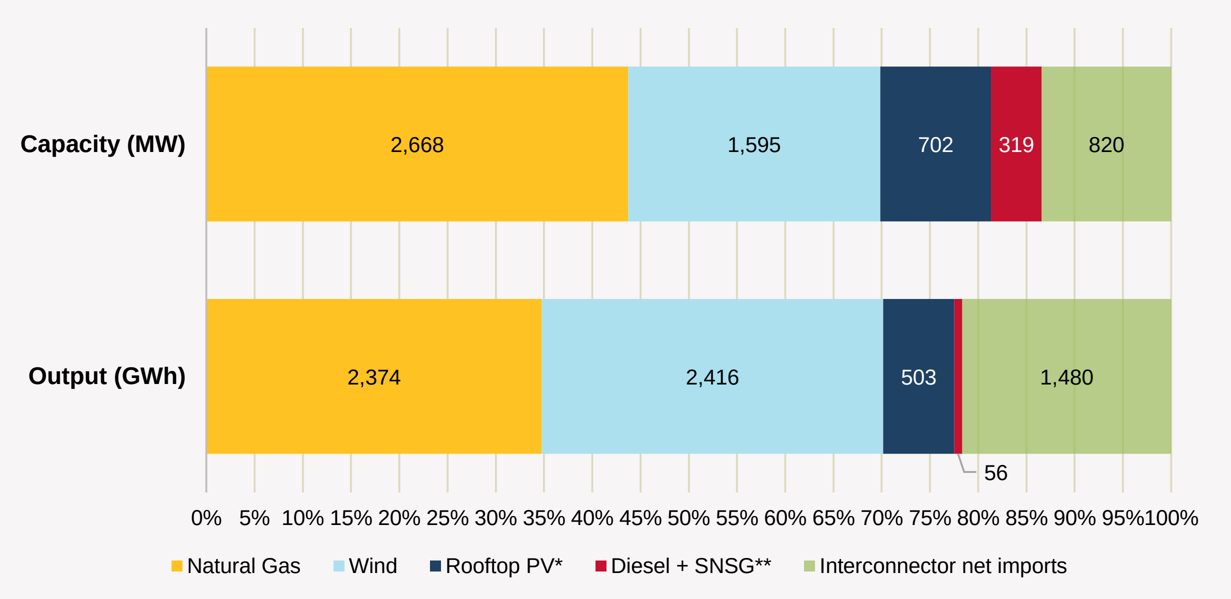
The withdrawal of coal-powered generation has led to an increased reliance on local GPG and imports from Victoria for supply adequacy and system security of the region.

[6] Playford was mothballed in 2011–12 and never brought back into service.

The withdrawal of one unit of Pelican Point Power Station (239 MW) since April 2015 puts further reliance on imports from Victoria for supply adequacy, particularly at times of low wind output in South Australia. While the second Pelican Point unit has been made available at various times throughout the period since April 2015, currently the capacity is not available to meet peak demand when required in the normal dispatch process.

Following the closure of coal generation, the capacity share of natural gas and wind became 44% and 26% respectively. The generation share of natural gas and wind reached approximately 35% each (see Figure 2) for the six month period from July 2016 to December 2016. Net imports comprised more one fifth of the total electricity consumption in the region (22%) in the same period.

Figure 2 South Australian registered capacity and generation output in July – December 2016



* Rooftop PV installations are not registered with AEMO, but are included here given their material contribution to generation. Estimates are from the 2016 NEFR.
** Diesel + SNSG includes estimates for small and large diesel, small biomass, small hydro and small gas cogeneration generating systems. SNSG generation and capacity is only included in the Diesel + SNSG category, even if it also falls into another listed category.
Note: Generation (other than SNSG) and imports is taken from 5-minute SCADA snapshots.

The list of existing generators by fuel type in South Australia as at 28 February 2017 is provided in Table 2.

Detailed analysis of the region's historical generation and interconnector flows can be found in AEMO's 2016 *South Australian Historical Market Information Report* (SAHMIR).[7]

[7] AEMO. *South Australian Historical Market Information Report*. August 2016. Available: https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/South-Australian-Advisory-Functions.

Table 2 List of existing generators by fuel type in South Australia as at 28 February 2017

Fuel type	Power station	Installed capacity (MW)
Natural gas (supplied via pipeline)	Dry Creek GT	156
	Hallett GT	228.3
	Ladbroke Grove	80
	Mintaro GT	90
	Osborne	180
	Pelican Point*	478
	Quarantine	224
	Torrens Island A	480
	Torrens Island B	800
Wind	Clements Gap	56.7
	Hallett 4 North Brown Hill	132.3
	Hallett 5 The Bluff WF	52.5
	Hallett Stage 1 Brown Hill	94.5
	Hallett Stage 2 Hallett Hill	71.4
	Hornsdale Wind Farm Stage 1	102.4
	Lake Bonney 2 Wind Farm	159
	Lake Bonney 3 Wind Farm	39
	Snowtown	98.7
	Snowtown S2	270
	Waterloo	130.8
	Canunda	46
	Cathedral Rocks	66
	Lake Bonney 1 Wind Farm	80.5
	Mt Millar	70
	Starfish Hill	34.5
	Wattle Point	90.75
Diesel	Angaston	50
	Lonsdale	20.7
	Port Lincoln GT	73.5
	Port Stanvac 1	57.6
	Snuggery	63
	Blue Lake Milling Power Plant	0.505
	Tatiara Meats	0.5
Landfill methane / landfill gas	Pedler Creek	3.09
	Wingfield 1	4.1
	Wingfield 2	4.1
Sewerage / waste water	Bolivar Waste Water Treatment	10
Water	Terminal Storage Mini Hydro	2.5

* Pelican Point Power Station has reduced capacity of 239 MW from 1 April 2015.

2.2 South Australian generation update

For planning purposes, AEMO categorises new generation and transmission projects into classes of certainty based on progression against five commitment criteria.[8] These criteria focus on whether or not the proponent has:

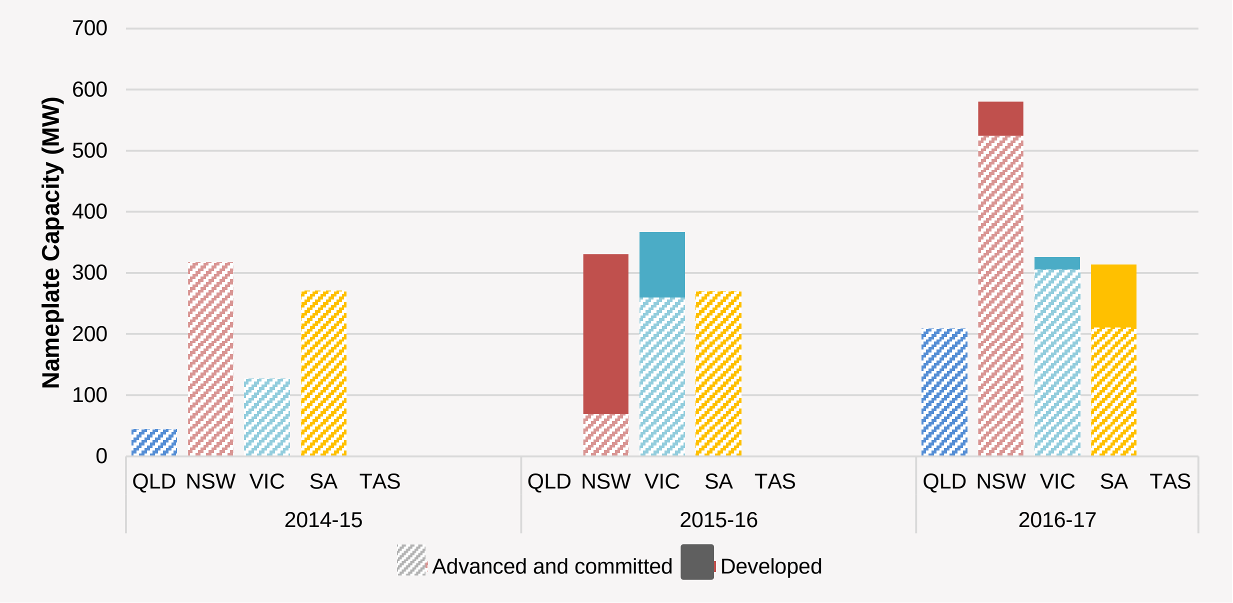
- Acquired land.
- Contracted supply for major components of plant and equipment.
- Obtained all required planning consents.
- Executed financial contracts.
- Finalised a construction date.

AEMO considers a project to be committed (that is, certain to proceed with known timing) if it satisfies all five commitment criteria. An advanced project is one that satisfies at least three, but not all, of the commitment criteria. If fewer than three criteria are satisfied, the project is classed as a proposal.

AEMO has observed that fewer South Australian projects appear to be actively progressing to the committed and/or advanced planning stages in the last two years, as shown in Figure 3.

Development delays can be caused by numerous factors, including competition from projects in other states. Hornsdale Wind Farm Stage 2 (102.4 MW) is currently the only committed project in South Australia according to AEMO's criteria, having secured tariff revenue through the Australian Capital Territory (ACT) renewable energy auctions.

Figure 3 Advanced, committed, and developed capacities in the NEM regions from 2014–15 to 2016–17



Note: The Hornsdale Wind Farm was listed as 270 MW in 2014–15 and subsequently split into three stages in 2016–17: Stage 1 (102.4 MW), Stage 2 (102.4 MW), and Stage 3 (109 MW).

[8] AEMO. *Market Modelling Methodology and Input Assumptions.* December 2016. Available: http://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/NTNDP/2016/Dec/Market-Modelling-Methodology-And-Input-Assumptions.pdf.

Table 3 lists AEMO's current identified projects in South Australia. Further details are provided in the technology review in Chapter 4, where appropriate.

Table 3 Summary of South Australian generation projects and network investments

Project status	Technology	Description
Committed	Wind	Hornsdale Wind Farm Stage 2 (102.4 MW)
Publicly announced new generation projects (proposals)	Wind	Wind projects with a total capacity up to 3,109.4 MW: • Barn Hill Wind Farm (124–186 MW) • Carmodys Hill Wind Farm (140 MW) • Ceres Project Wind Farm (up to 670 MW) • Exmoor Wind Farm (144 MW) • Hornsdale Wind Farm Stage 3 (109 MW) • Keyneton Wind Farm (105 MW) • Kongorong Wind Farm (100–240 MW) • Kulpara Wind Farm (60–150 MW) • Lincoln Gap Wind Farm (212.4 MW) • Palmer Wind Farm (309 MW) • Port Augusta Renewable Energy Park - Wind Farm (200 MW) • Stony Gap Wind Farm (119 MW) • Willogoleche Wind Farm (95–125 MW) • Woakwine Wind Farm (400 MW)
	Gas	Gas projects with a combined capacity of 780 MW: • Pelican Point S2 Power Station (320 MW) • Leigh Creek Energy Project (460 MW)
	Solar*	Solar projects with overall capacity up to 945 MW: • Aurora Solar Energy (110 MW) • Bungala Solar Power (220 MW) • Kingfisher Solar Storage (120 MW) • Port Augusta Renewable Energy Park - Solar (175 MW) • Port Augusta Solar (220 MW) • Tailem Bend - Solar (100 MW)
	Biomass	• Yorke Peninsula Biomass (15 MW)
	Diesel	• Tailem Bend - Diesel (28.8 MW)
	Pumped hydro storage	• Spencer Gulf Pumped Hydro Storage (100–200 MW)
Potential new interconnection**	Network investment	• A new 275 kilovolt (kV) link from Tailem Bend (SA) to Horsham (VIC), with a new 275 kV single circuit line from Tailem Bend to Tungkillo (SA), to provide increased interconnection (325 MW) from 2021, or • New 275 kV link between Darlington Point (NSW) and Robertstown (SA) to provide increased interconnection (325 MW) from 2021, or • Augmentation of QNI and VIC-NSW interconnectors

* Includes both solar thermal with storage, and solar PV projects.
** AEMO. *National Transmission Network Development Plan*. December 2016. Available: https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/National-Transmission-Network-Development-Plan.

The Hornsdale Wind Farm Stage 2 commenced commissioning on 21 February 2017, but at the time of publication of this report was not yet fully operational.

3. RESOURCE AVAILABILITY

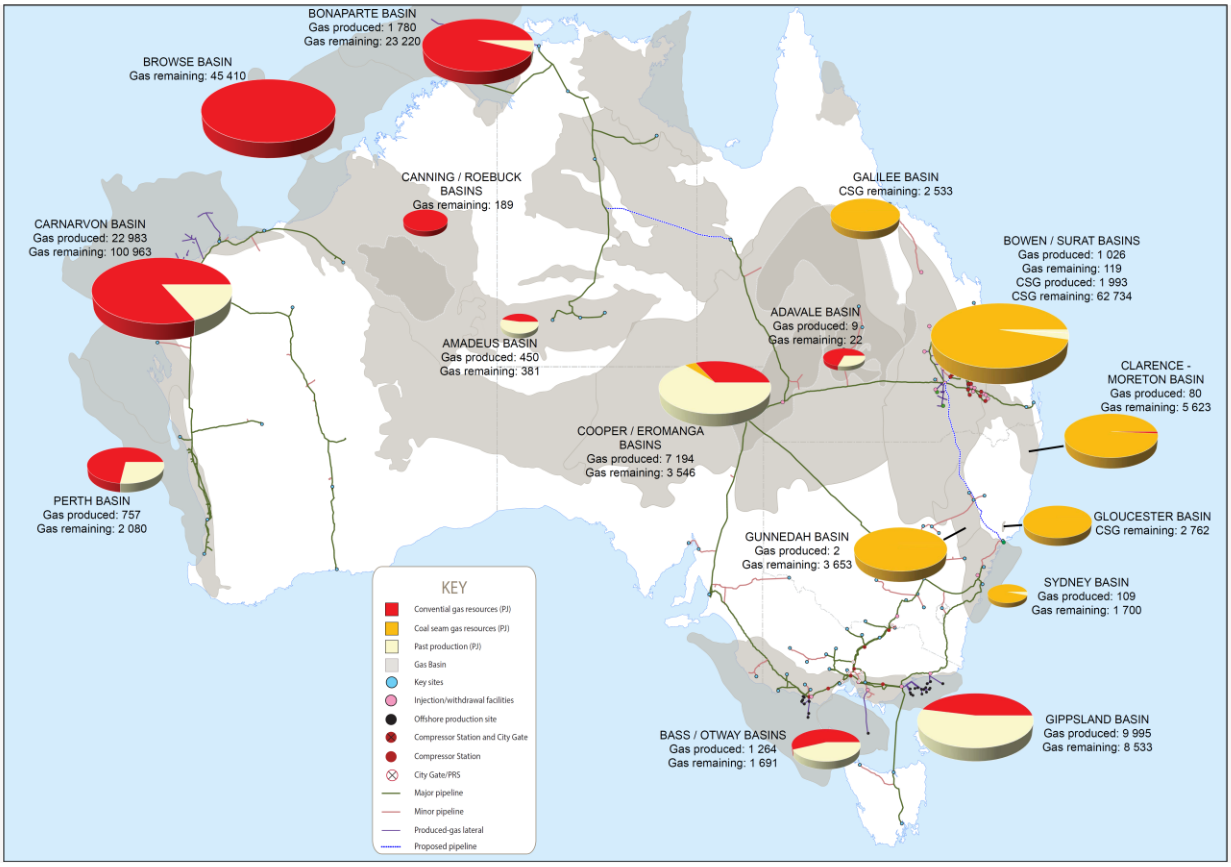
3.1 Natural gas

Availability

South Australia has traditionally sourced natural gas from the Cooper and Eromanga basins.[9] The LNG export market has now changed domestic contract dynamics, such that the Cooper and Eromanga basins are now supplying most of their gas for LNG export. The majority of South Australia's gas supply is therefore currently sourced from Queensland and Victoria via an interconnected pipeline network.

Figure 4 shows the identified natural gas and coal seam gas (CSG) resources in Australia. Figure 5 shows major natural gas producing basins and gas transmission infrastructure in Australia's east and south-east.

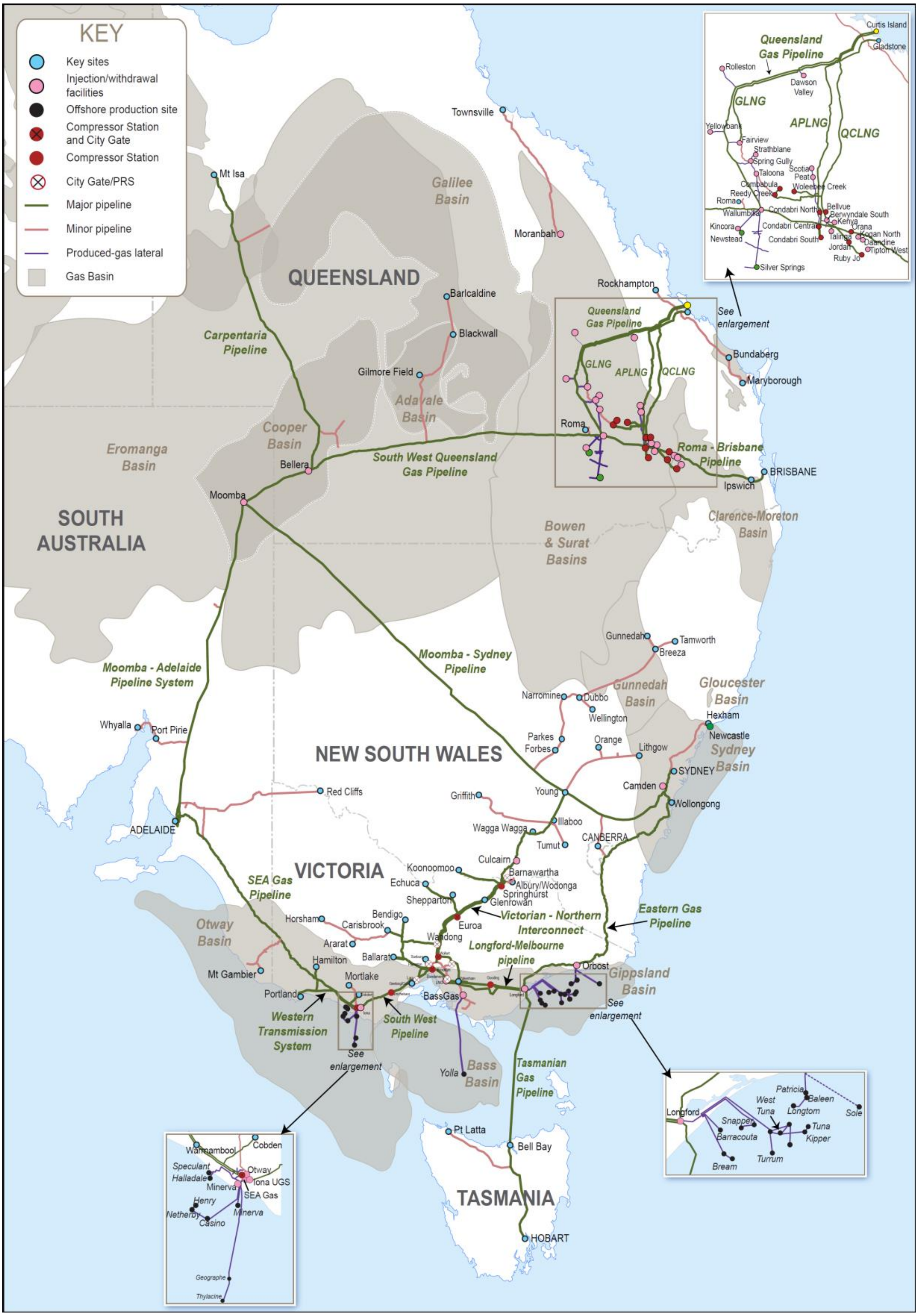
Figure 4 Australian identified natural gas and CSG resources, and annual production



Note: Values of gas reserve and production are based on © Commonwealth of Australia (Geoscience Australia) 2016. *Gas*. Available: *http://www.ga.gov.au/aera/gas*.

9 The Cooper and Eromanga basins span South Australia, New South Wales, and Queensland, and the point of gas extraction may not necessarily be in South Australia.

Figure 5 Gas producing basins and infrastructure



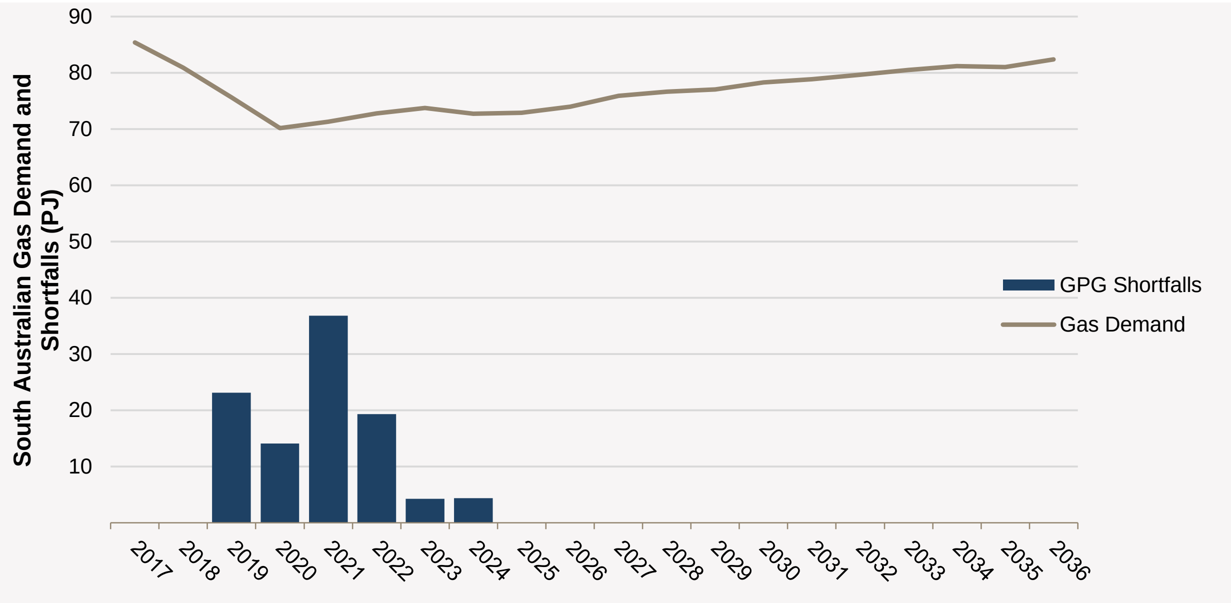
As at 31 December 2015, eastern and south-eastern Australian proven plus probable (2P) natural gas reserves[10] totalled 47,815 petajoules (PJ), but production is in decline.

Based on advice from gas producers, domestic gas production across eastern and south-eastern Australia is forecast to decline by 122 PJ over the next five years, from 600 PJ in 2017 to 478 PJ in 2021. Domestic production decline is most apparent in offshore Victoria, where production is forecast to reduce by 155 PJ (or 38%) over this period.

The 2017 *Gas Statement of Opportunities*[11] (GSOO) projects that declining gas production may result in insufficient gas to meet projected demand by GPG between 2019 and 2021 across South Australia, Victoria, and New South Wales. To meet electricity supply needs, the NEM requires either increases in gas production to fuel GPG, or a rapid implementation of alternative non-gas electricity generation sources.

Figure 6 shows forecast annual GPG consumption and shortfalls in South Australia from AEMO's 2017 GSOO. Future GPG forecasts are highly uncertain and depend on future generation mix, climate change policies, transmission constraints, and electricity demand. This GPG forecast assumed additional new renewable generation is developed to support the large-scale renewable energy target (LRET) by 2020, and Pelican Point Power Station's mothballed unit returns to service after 2020 to support emissions reduction objectives. It also assumed an electricity demand response to projected electricity price rises following the closure of Hazelwood Power Station by April 2017. It does not, however, include any GPG impact of additional rate of change of frequency (RoCoF) constraint equations implemented in the NEM Dispatch Engine (NEMDE) following the Black System event in South Australia on 28 September 2016. The forecast is therefore considered a conservative estimate of potential future GPG demand in the region.

Figure 6 South Australian total annual GPG gas consumption forecast and projected gas shortfalls



[10] 2P is considered the best estimate of commercially recoverable reserves. See glossary for definitions of reserve and resource classification.

[11] AEMO. *Gas Statement of Opportunities*. March 2017. Available: http://www.aemo.com.au/Gas/National-planning-and-forecasting/Gas-Statement-of-Opportunities.

South Australian gas demand

Historically, at least 50% of South Australian gas demand is used to fuel GPG. Table 4 summarises the total annual South Australian natural gas consumption, and the percentage used for electricity generation (GPG), from 2013 to 2016.

Table 4 South Australian gas consumption 2013–16

Calendar year	Calculation	Total gas consumption (PJ)	Gas used for electricity generation (GPG)	
			(PJ)	Percent of total
2013	Actual	97	58	60%
2014	Actual	86	49	57%
2015	Actual	78	43	55%
2016	Actual	75	39	51%

* Data from AEMO, *National Electricity & Gas Forecasting* dynamic interface. Available: http://forecasting.aemo.com.au/. Viewed: 20 December 2016.
Note: To access the South Australian data, please go to http://forecasting.aemo.com.au/, click Gas on the ribbon menu, and use the Filter button to select South Australia.

Current developments

AEMO understands gas producers are continuing to investigate additional gas supply opportunities in South Australia. Based on the advice of the Department of State Development – Energy Resources Division (DSD-ERD), 261 exploration wells and 148 appraisal/development wells have been drilled in the Cooper Basin from January 2002 to May 2016. Most of the exploration wells that targeted oil discovered both oil and gas.[12]

A recent report, however, suggests that the rate of exploration and development of oil and gas wells drilled across Australia has nearly halved since 2014.[13] Whether the recent decline in exploration and development in South Australia represents a trend is unclear.

Unconventional gas

Gas exploration in Australia has focused on potential unconventional reservoirs since late 2011. These resources are yet to be demonstrated to be economically viable.

Core Energy Group[14] has identified exploration of five unconventional prospects in the Cooper Basin, based on the 2012 *Roadmap for Unconventional Gas Projects in South Australia*:

- Basin Centred Gas (shale, siltstone, tight sandstone).
- Roseneath–Epsilon–Murteree (shale, siltstone, tight sandstone).
- Permian Coal (source rock).
- Patchawarra Coaly Shale (source rock).
- Deep Coal Seam Gas.

In July 2016, the U.S. Geological Survey completed an assessment of the technically recoverable, unconventional gas resources in the Cooper Basin. A total of 29.784 multi-trillion cubic feet (TCF) of

[12] Core Energy Group © 2016. *Cooper-Eromanga Basin Outlook 2035*. October 2016. Commissioned by the South Australian Department of State Development's Energy Resource Division. Available: http://petroleum.statedevelopment.sa.gov.au/__data/assets/pdf_file/0005/283919/Core_Energy_-_Cooper-Eromanga_Basin_Outlook_-_Final_-_Oct2016.pdf. Viewed: 20 December 2016.
[13] © 2017 EnergyQuest™ EnergyQuarterly™. Media Release. *Oil-Gas Exploration Rates Hit Decade Record Lows on Back of Oil Price Collapse*. 9 March 2016. Available: http://www.energyquest.com.au/uploads/docs/australian_oilgas_exploration_hits_decade_record_lows_as_low_oil_price_impacts__energyquest_9mar_2016.pdf. Viewed: 28 February 2017.
[14] Core Energy Group © 2016. *Cooper-Eromanga Basin Outlook 2035*. October 2016.

gas was estimated.[15] The TCF potential of each of these prospects has yet to be fully tested as a precedent to development. Chevron withdrew from a major venture formed by the South Australian Cooper Basin Joint Venture (SACB JV) in early 2015, while the pre-existing licence holders are still exploring high graded prospects.

In December 2016, the Department of State Development presented the timeline and process for the preparation of the second edition of the *Roadmap for Oil and Gas in South Australia*. The roadmap is scheduled to be launched in December 2017.[16]

South Australian gas policy

Fracture stimulation (fracking) is a specialised extraction technology to extract oil and gas from an unconventional reservoir. The DSD-ERD reported that fracking has been demonstrated to be safe and without harm to social, natural or economic environments in more than 800 wells in the Cooper Basin. However, the DSD will not permit fracking in the south-east of South Australia unless a proponent can demonstrate that all risks that will adversely affect other users of the land will be avoided, and all concerns from potentially affected stakeholders have been adequately addressed, under the consultation requirements in the *Petroleum and Geothermal Energy Acts, 2000* (PGE Act). As at 25 October 2016, there was no fracking activity nor proposal made to the government.[17]

In September 2016 the South Australian Government announced it will commit $24 million in grants with the aim of incentivising companies to extract more gas and supply it to the South Australian market. The State Government's Plan for Accelerating Exploration (PACE) Gas fund specifically aims to help source more gas supply for local GPG.

Infrastructure

South Australia sources natural gas delivered through an interconnected pipeline network from Victoria, New South Wales, and Queensland, as well as from the Cooper Basin. Table 5 lists the major gas pipelines that supply natural gas to South Australian consumers.

Table 5 Major gas pipelines relating to South Australia*

Gas pipeline	Length (km)	Year of first gas flow	Capacity reported (TJ/d)**
South West Queensland Pipeline* **	937	1996	384 (West), 340 (East)
Moomba to Adelaide Pipeline	1,185	1969	209 (South), 85 (North)
Moomba to Sydney Pipeline	2,030	1998	439 (South-East), 381 (North-West)
South East Australia Gas Pipeline	680	2004	314

* Data from AEMO. *Natural Gas Services Bulletin Board*. Available: http://gbb.aemo.com.au/Reports/Standing%20Capacities.aspx. Viewed: 20 December 2016.
** Reported capacity from Gas Bulletin Board as at December 2016, viewed January 2017. Summer and winter seasonal capacities may vary.
*** Includes the Queensland – South Australia – New South Wales (QSN) Link.

As shown in Figure 5 (page 14), gas can flow from Queensland to South Australia via South West Queensland Pipeline (SWQP) and the Moomba processing facility. Gas supplied from offshore Victoria can be delivered to South Australia either:

- Directly along the South East Australia Gas Pipeline (SEA Gas), or

[15] Schenk, C.J., Tennyson, M.E., Mercier, T.J., Klett, T.R., Finn, T.M., Le, P.A., Brownfield, M.E., Gaswirth, S.B., Marra, K.R., Hawkins, S.J., and Leathers-Miller, H.M., 2016, *Assessment of continuous oil and gas resources of the Cooper Basin, Australia*, 2016: U.S. Geological Survey Fact Sheet 2016–3050, 2 p.. Available: http://dx.doi.org/10.3133/fs20163050. Viewed: 30 January 2017.

[16] Government of South Australia. Department of State Development. *Second Edition of the Roadmap – Roadmap for Oil and Gas in SA*. Available: http://petroleum.statedevelopment.sa.gov.au/__data/assets/pdf_file/0004/286150/20161201_-_Plans_for_update_of_the_Roadmap_-_Elinor_Alexander.pdf. Viewed: 30 January 2017.

[17] Government of South Australia. Department of State Development. *Gas and Oil in Unconventional Reservoirs in the South East of South Australia*. Available: http://www.petroleum.statedevelopment.sa.gov.au/__data/assets/pdf_file/0008/267191/FAQ_-_South_East_Gas_and_Oil_in_Unconventional_Reservoirs_25_October_2016.pdf. Viewed: 30 January 2017.

- Via multiple pipelines in an anti-clockwise direction through the Victoria – New South Wales Interconnector, the Moomba to Sydney Pipeline (MSP), and then south along the Moomba to Adelaide Pipeline System (MAPS).

Current operation levels

Due to the increasing demand for LNG exports, the pattern of gas flow across east and south-eastern Australia has changed to be generally towards Gladstone in Queensland (for example, both the MAPS and the MSP registered reverse flow capability (ability to flow towards Moomba) on the Gas Bulletin Board (GBB) in 2015).[18]

The projected decline in production, particularly in Victoria, is also forecast to impact the pattern of gas flow to supply South Australian demand, with less flow forecast on the SEA Gas pipeline and more reliance on the MAPS.

The SEA Gas pipeline is supplied directly from fields that are processed at the Port Campbell processing facility (such as Otway and Minerva) or from the Iona Underground Gas Storage facility. Forecast production in offshore Victoria is declining, and supply into South Australia via the SEA Gas pipeline will become more reliant on supply from the Longford Gas Plant via the South West Pipeline (SWP). The projected SWP flows for 2017 onwards, as discussed in the 2017 *Victorian Gas Planning Report* (VGPR)[19], are expected to be constrained from November to April. This pipeline constraint will subsequently impact flows on the SEA Gas pipeline to South Australia, as any flows on SWP will be prioritised towards refilling Iona Underground Storage which supports peak winter demand in Victoria.

This increases South Australia's reliance on gas supplies from the Cooper–Eromanga Basins via the MAPS to meet annual consumption and maximum daily demand. Flows along the MAPS routinely reach maximum capacity during high GPG demand days in winter.

Future projections

Further information on gas adequacy, and on potential opportunities for infrastructure investment or reserves development under a range of future scenarios, is available in the 2017 GSOO.

3.2 Liquid fuel

Australia's liquid fuel supply is maintained by domestic refineries, import terminals, and storage facilities. The fuels are distributed through a complex transport system and retail supply arrangements. The discussion of liquid fuel in this section focuses on conventional crude oil and refined products.

Availability

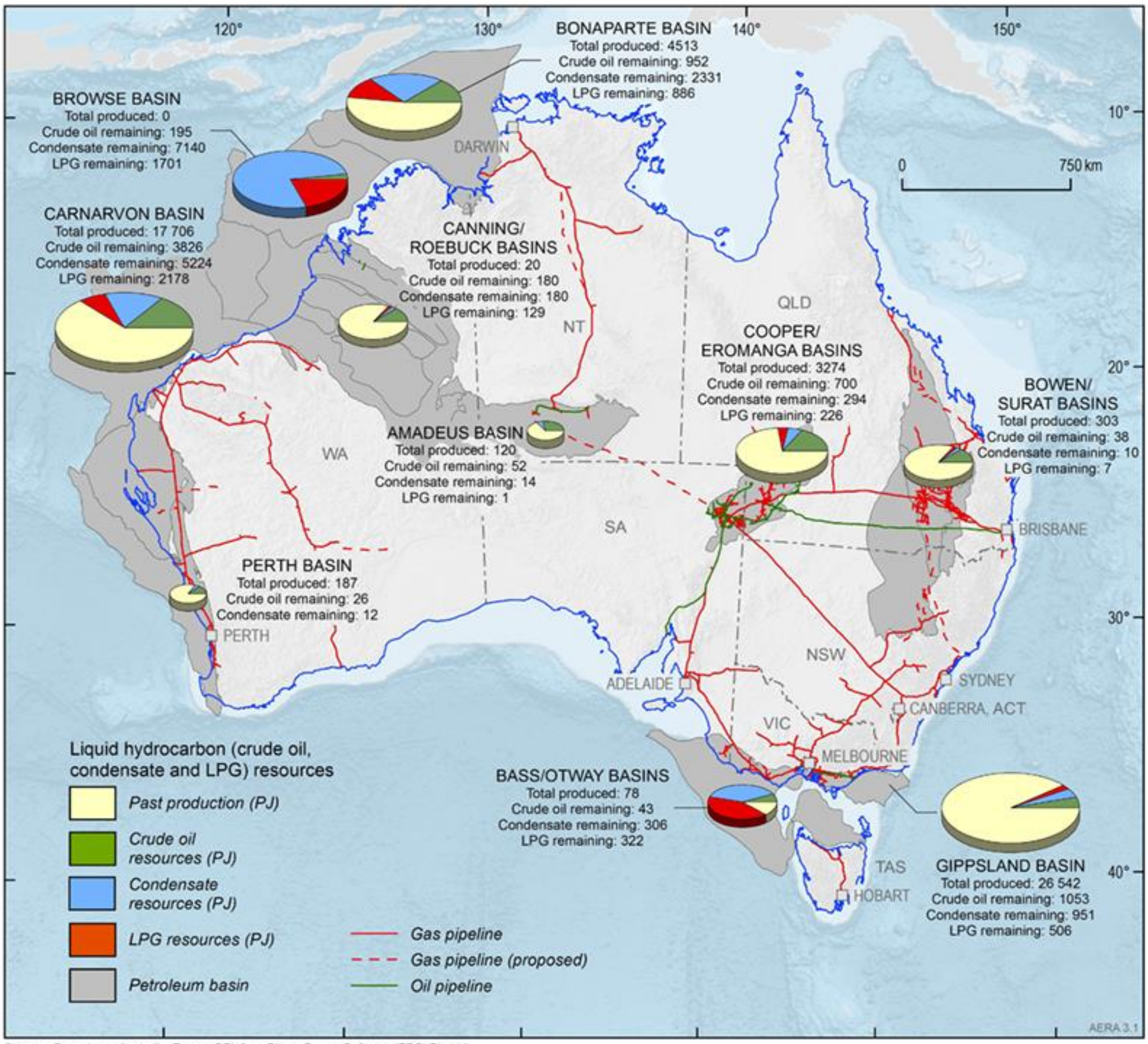
South Australia has limited domestic supply of crude oil (700 PJ), condensate (294 PJ), and liquefied petroleum gas (LPG) (226 PJ) recorded in the Cooper and Eromanga Basins, as shown in Figure 7. In addition, a prospective supply of shale oil of 3,340 PJ is estimated in Eromanga Basin that could potentially supply the future oil requirement in the region.[20]

[18] AEMO. *Natural Gas Services Bulletin Board*. Available: http://gbb.aemo.com.au/Reports/Standing%20Capacities.aspx. Viewed: 20 December 2016.

[19] AEMO. *Victorian Gas Planning Report*. March 2017. Available: http://www.aemo.com.au/Gas/National-planning-and-forecasting/Victorian-Gas-Planning-Report.

[20] © Commonwealth of Australia (Geoscience Australia) 2016. *Oil*. Available: http://www.ga.gov.au/aera/oil. Viewed: 20 December 2016.

Figure 7 Australian oil deposits[21]



Source: Geoscience Australia, Encom GPinfo, a Pitney Bowes Software (PBS) Pty Ltd.
Whilst all care is taken in the compilation of the field outlines by PBS, no warranty is provided re the accuracy or completeness of the information, and it is the responsibility of the Customer to ensure, by independent means, that those parts of the information used by it are correct before any reliance is placed on them. Accurate at July 2015.

Current developments

Senex Energy Limited (Senex) has announced its current drilling program in the Cooper Basin. Phase 1 involves drilling of two wells to increase the overall oil recovery of the Worrior and Spitfire fields while utilising their existing surface facilities. Drilling of the two wells commenced in December 2016 and was successful. Phase 2 includes oil exploration prospects, with the first two wells located in Sparta and Hoplite fields scheduled to be drilled in early 2017. If the drilling campaign is successful, Senex intends to proceed with multiple follow-up prospects it has identified.[22, 23]

[21] © Commonwealth of Australia (Geoscience Australia) 2016. *Oil*. Available: http://www.ga.gov.au/aera/oil. Viewed: 20 December 2016.
[22] Petroleum Exploration Society of Australia. *Senex Announces Cooper Basin Drilling Program*. 7 December 2016. Available: https://www.pesa.com.au/senex-announces-cooper-basin-drilling-program/. Viewed: 20 December 2016.
[23] Senex Energy Limited. *Quarterly Report. Q2 FY17*. December 2016. Available: http://www.senexenergy.com.au/wp-content/uploads/2017/01/2017-01-25-December-Quarterly-Report-FINAL.pdf. Viewed: 30 January 2017.

Infrastructure

Liquid fuel is typically transported from suppliers to consumers via oil pipelines.

Port Bonython fuel terminal, the largest diesel fuel storage facility in South Australia, was commissioned in May 2016. The terminal is located approximately 25 kilometres north of Whyalla and 80 kilometres south of Port Augusta. The $80 million project, which includes a 5.2 km pipeline, can supply three tanks with 81 million litres storage capacity to support the regional supply requirement in South Australia.[24]

3.3 Wind

Availability

Southern South Australia is one of the areas with the strongest widespread wind resource in Australia, based on two independent studies conducted by the Australian Government and the Massachusetts Institute of Technology (MIT) Joint Program on the Science and Policy of Global Change.

The combined results of the two mappings recorded an estimated wind speed ranging from 6.4 to 7.8 metres per second (m/s) in south-east South Australia.[25]

The findings of the MIT Joint Program suggest that the wind resource in southern South Australia has relatively high variability and a moderate level of intermittency. According to the research, areas with moderate to high wind intermittency are characterised by very low anticoincidence.[26] This indicates that wind generators in southern South Australia tend to be correlated in their output and aggregating turbine output from wind farms in this location is less likely to provide steady power.[27]

AEMO's 2016 *South Australian Renewable Energy Report* (SARER) observed that South Australia's wind generation variation differs by geographical area (mid-north, south-east, and coastal peninsula), and larger fluctuations (though less frequent) do exist.[28] Among the areas, south-east has the highest wind generation variation.

Figure 8 shows the comparison of mean wind speed (m/s) at an 80 metre turbine hub height across Australia from each of the two independent studies. The figures show that, with the exception of parts of Tasmania, South Australia has superior access to high mean wind speeds compared to other NEM regions. This has contributed to South Australia having the highest penetration of wind farms nationally to date.

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[24] Petro Diamond Australia. *Port Bonython Fuel Terminal.* Available: http://www.petrodiamond.com.au/port-bonython-fuel-terminal/. Viewed: 20 December 2016.

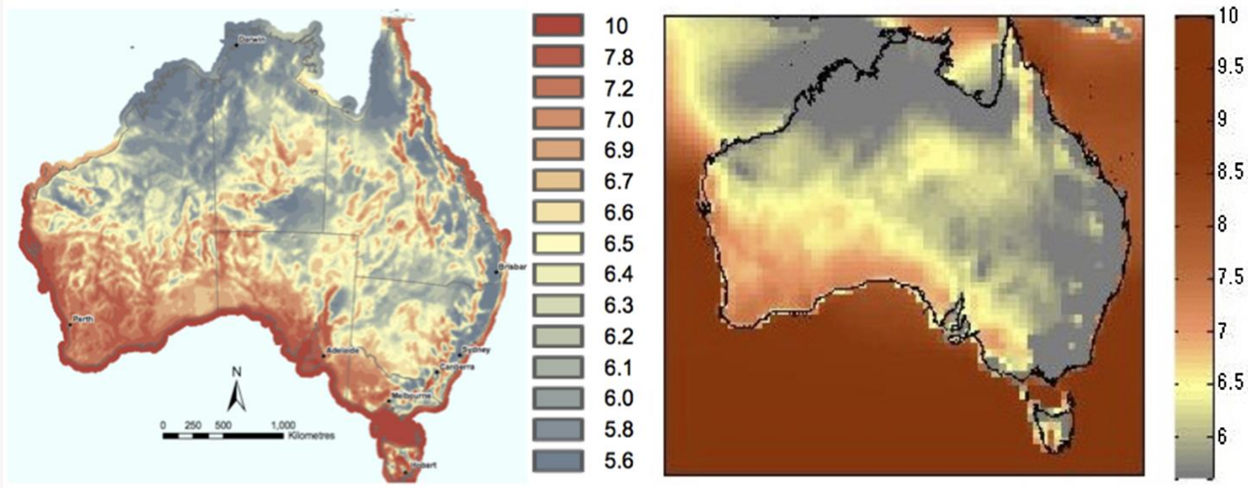
[25] The mapping of wind speed was referenced at 80 metre hub height.

[26] The occurrence of one event without the simultaneous occurrence of another.

[27] © 2014 Hallgren, Gunturu, and Schlosser. The MIT Joint Program on the Science and Policy of Global Change. Massachusetts Institute of Technology. *The Potential of Wind Power Resource in Australia: A New Perspective. July 2014*. Available: https://globalchange.mit.edu/sites/default/files/MITJPSPGC_Reprint_14-14_1.pdf. Viewed: 20 December 2016.

[28] AEMO. *South Australian Renewable Energy Report*. August 2016 Available: https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/South-Australian-Advisory-Functions.

Figure 8 Comparison of mean wind speed (m/s) at an 80 m turbine hub height across Australia[29]



(a) Map developed by the Australian Government in 2008, and (b) Map constructed from the MERRA data of MIT Joint Program on the Science and Policy of Global Change in 2014.

3.4 Solar

Availability

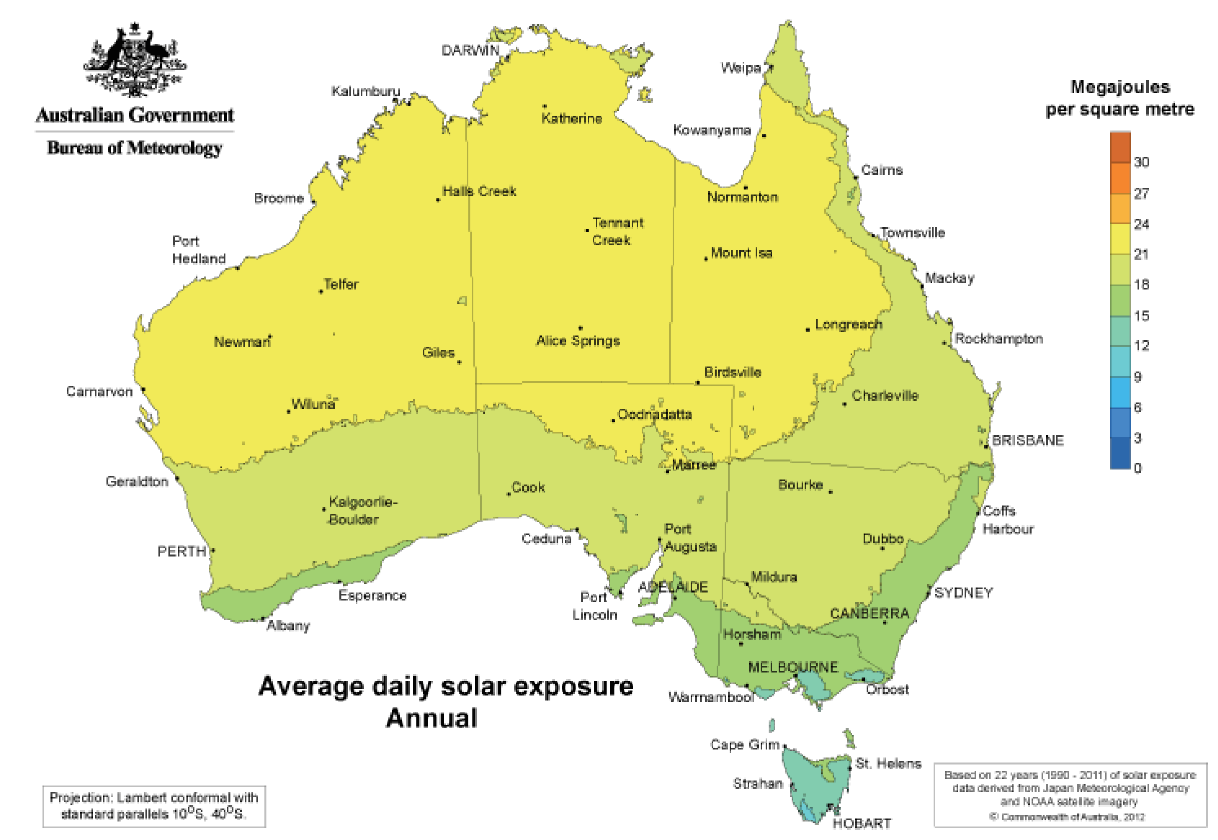
South Australia has an abundance of high quality sites for residential-, commercial-, and industrial-scale solar generation facilities. This is illustrated in Figure 9, which shows the average daily global solar exposure over Australia annually from 1990 to 2011.

In South Australia, the total solar energy for a day ranges from 15 to 24 megajoules per square metre (MJ/m^2) with increasing solar exposure for northern sites across the state.[30] South Australia's western positioning (relative to the rest of the NEM) also provides increased value, as solar generation will more likely be available later in the day as evening peak demands occur throughout the eastern regions of the NEM.

[29] © 2014 Hallgren, Gunturu, and Schlosser. The MIT Joint Program on the Science and Policy of Global Change. Massachusetts Institute of Technology. *The Potential of Wind Power Resource in Australia: A New Perspective. July 2014*. Available: https://globalchange.mit.edu/sites/default/files/MITJPSPGC_Reprint_14-14_1.pdf. Viewed: 20 December 2016.

[30] © Commonwealth of Australia 2016. Bureau of Meteorology. *Average daily solar exposure*. Available: http://www.bom.gov.au/jsp/ncc/climate_averages/solar-exposure/index.jsp. Viewed: 20 December 2016.

Figure 9 Average daily global solar exposure over Australia[31]



Current developments

In 2014, AEMO established the Australian Solar Energy Forecasting System (ASEFS), designed to produce solar generation forecast for large solar power stations and small-scale distributed PV systems.

The objective of ASEFS is to improve the accuracy of the forecasting processes in the NEM. It has two phases:

- Phase 1 involved the production forecast for large solar power stations, with registered capacity of at least 30 MW. It commenced operation on 30 May 2014.
- Phase 2 forecast output for small-scale distributed PV systems, with capacity less than 100 kW. This phase became fully operational on 30 March 2016.[32]

Developments of grid-connected large-scale solar projects are provided in Chapter 4.

31 © Commonwealth of Australia 2016. Bureau of Meteorology. *Average daily solar exposure*. Available: http://www.bom.gov.au/jsp/ncc/climate_averages/solar-exposure/index.jsp. Viewed: 20 December 2016.

32 AEMO. Solar and Wind Energy Forecasting. *Australian Solar Energy Forecasting System.* Available: http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Solar-and-wind-energy-forecasting#phase2.Viewed: 20 December 2016.

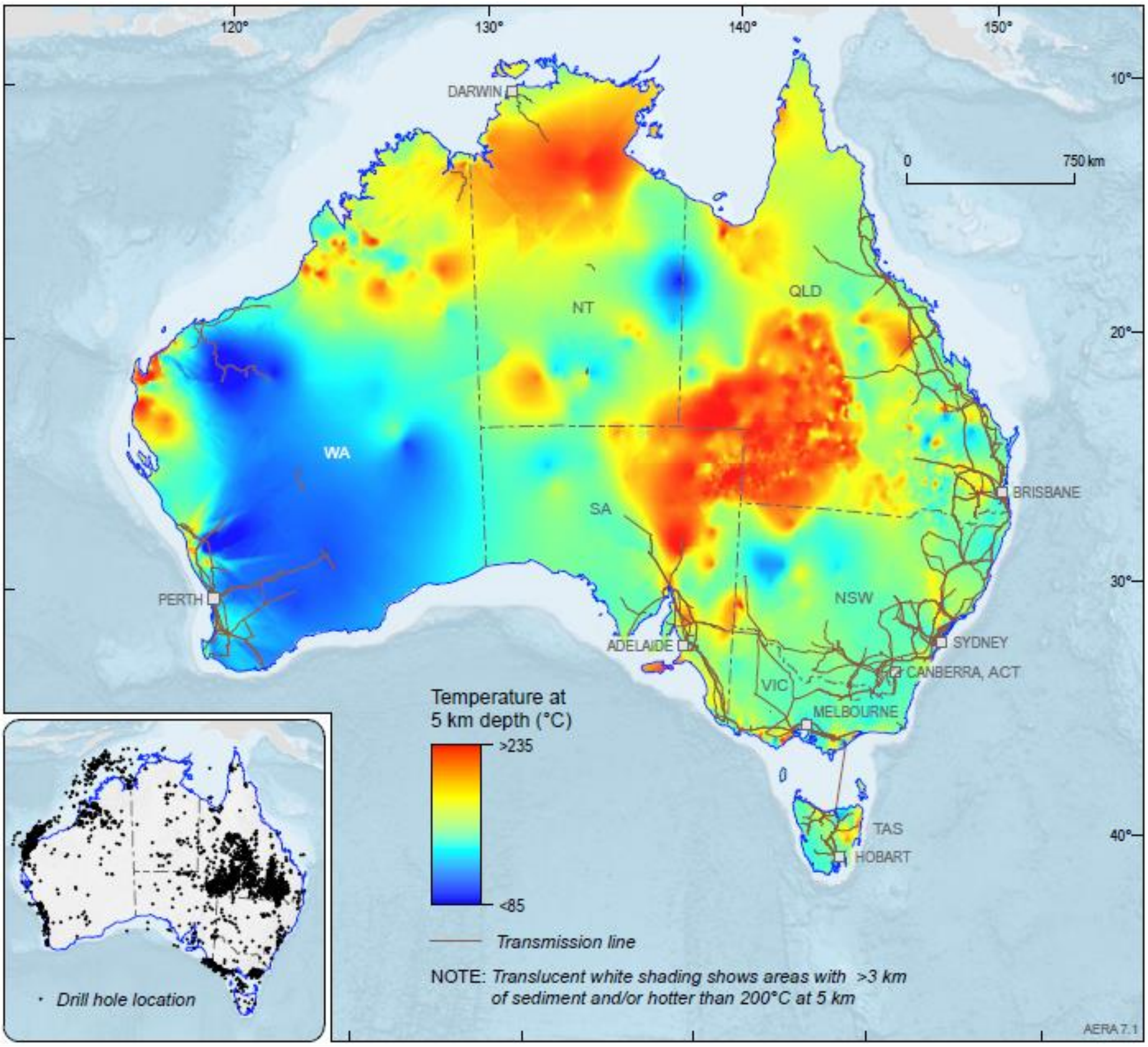
3.5 Geothermal

Availability

Geothermal resources for electricity generation are still at the early development stage in Australia, due to the country's lack of active volcanism.[33] As such, geothermal developments in Australia will require deeper drilling to access sufficient temperatures to provide electricity generation capabilities.

Figure 10 shows the presence of higher temperature (at least 200 ºC at around 5 km depth) and lower temperature geothermal resources in South Australia.

Figure 10 Predicted temperature of geothermal resources at 5 km depth[34]



Based on bottom-hole temperature measurements in more than 5,000 petroleum and water boreholes.

33 Bendall, B. and Goldstein, B.A. IEA Geothermal. *Australia Country Report*. 2015. Available: http://iea-gia.org/wp-content/uploads/2014/12/Australia-country-report-IEAGIA-2015-1.pdf. Viewed: 20 December 2016.

34 © Commonwealth of Australia (Geoscience Australia) 2014. Department of Industry. Bureau of Resources and Energy Economics. *Australian Energy Resource Assessment*. Second Edition. 2014. Available: https://industry.gov.au/Office-of-the-Chief-Economist/Publications/Documents/GA21797.pdf. Viewed: 20 December 2016.

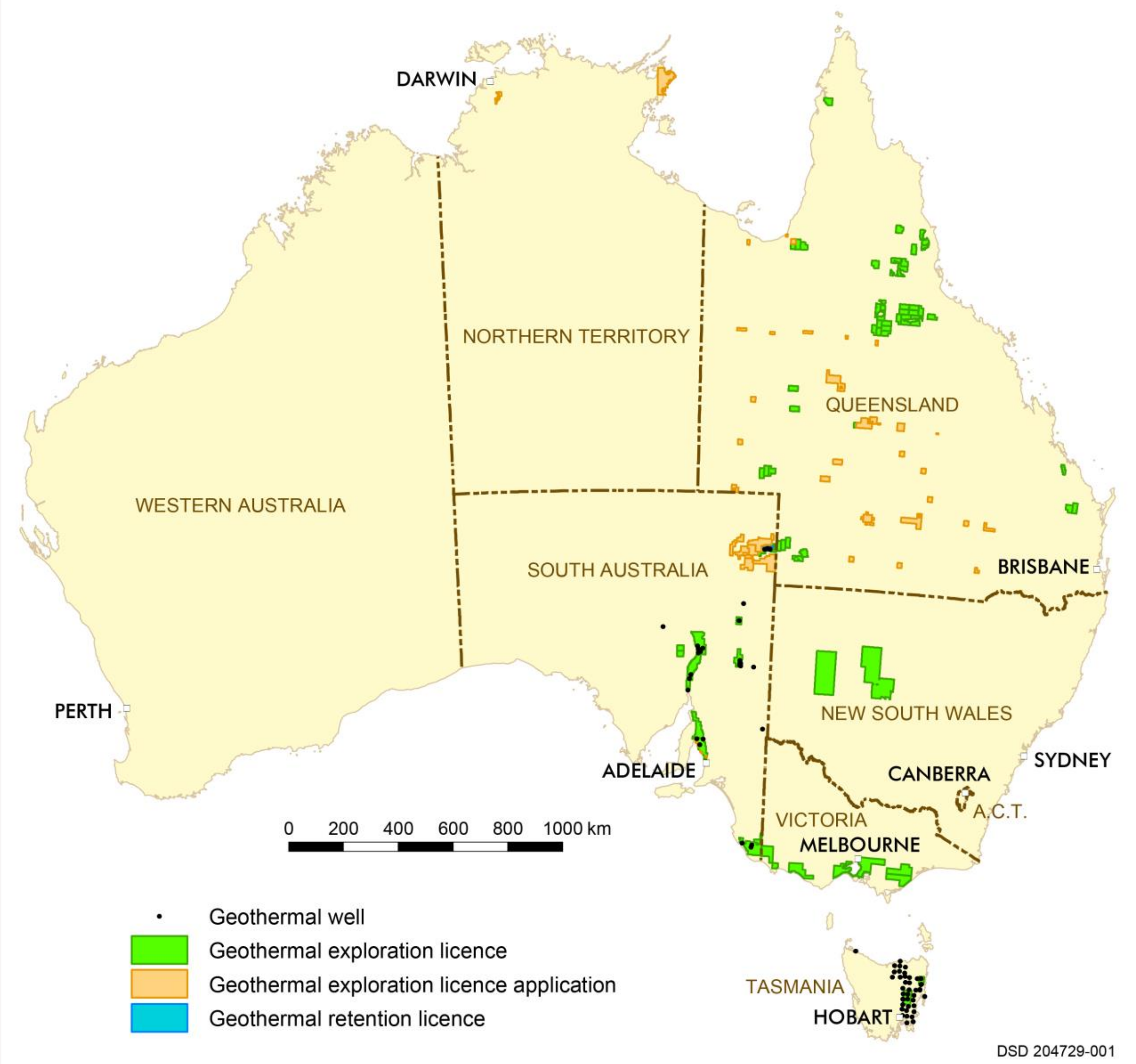
Current developments

To date, the Australian geothermal industry remains largely at a pre-competitive exploration stage. It faces two challenges:

- To prove the resource.
- To prove the ability of the technologies to generate sustainable amounts of usable energy at a commercially viable cost.

As at 31 December 2016, 21 companies had applied for 96 license areas to progress proof-of-concept of technology projects (see Figure 11).[35]

Figure 11 Australian geothermal licences, applications and gazettal areas as at 31 December 2016



[35] Data provided by the Department of State Development – Energy Resources Division, Government of South Australia.

3.6 Biomass and waste-to-energy

Availability

South Australia has untapped existing and potential resources of bioenergy, based on a 2015 investigation conducted by Jacobs Group (Australia). Feedstocks as source of bio-energy in South Australia can be categorised into five groups, as shown in Table 6.[36]

Table 6 Feedstock groupings in South Australia

Feedstock	Constituents
Agricultural waste	• Livestock manure • Abattoir waste solids • Other processing plants • Crop and food residues from harvesting and processing
Horticultural waste	• Vegetables & fruit • Shells, pips, trees
Energy crops	• Canola • Planted mallee • Woody weeds • Planted fast growing foods (annual and perennial) • Algae
Forest residues	• Plantation forests • Saw mills residues • Manufactured wood plant residues
Municipal waste	• Green organics, paper, timber • Processed food

The quantities of the existing and potential bioenergy sources for all feedstocks in South Australia, from Jacobs' report, are summarised in Table 7 and Table 8.

The locations of existing feedstocks are illustrated in Figure 12. The locations to grow purpose-grown biomass crops such as algae, arundo donax, and corn, as well as their potential growing areas in South Australia, are also in Jacobs' report.[37]

Table 7 Existing bio-energy materials in South Australia

Material	Actual Tonnes (t) / Volume (m3) or Nos.	Calorific Value (MJ/ kg or MJ/No.)	Moisture Content (%)	Comment
Timber	984,000 tpa	7.7	50	
Poultry	30,310,000 chickens	96		Slurry
Broadacre	154,000 tpa	14	15	
Pigs	225,000 pigs	1,580		Slurry
Horticulture	112,500 tpa	10	50	
Livestock	15,200 cows	3,240		Slurry
Dairy	80,000 cows	3,240		Slurry

[36] Jacobs Group (Australia) Pty Limited. *A Bio-energy Roadmap for South Australia. Renewables SA. Jacobs Report*. 5 August 2015. Available: http://www.renewablessa.sa.gov.au/files/a-bioenergy-roadmap-for-south-australia--report--version-1-appendix-a-removed.pdf. Viewed: 20 December 2016. (Commissioned by RenewablesSA)

[37] Jacobs Group (Australia) Pty Limited. *A Bio-energy Roadmap for South Australia*, 5 August 2015.

Table 8 Prospective bioenergy feedstocks in South Australia

Feedstock	Potential Yields (Mtpa)	Calorific Value (MJ/ kg)	Moisture Content (%)
Arundo Donax	93	7.6	50
Woody weeds	150	7.7	50
Mallee	23	7.7	50
Cumbungie	4.2	10.7	35
Corn / Maize	1.5	6.2	55
Phragmities	4.2	11.7	30
Acacia Saligna	5.7	8.2	50
Brassica Juncea	1.2	6.0	50

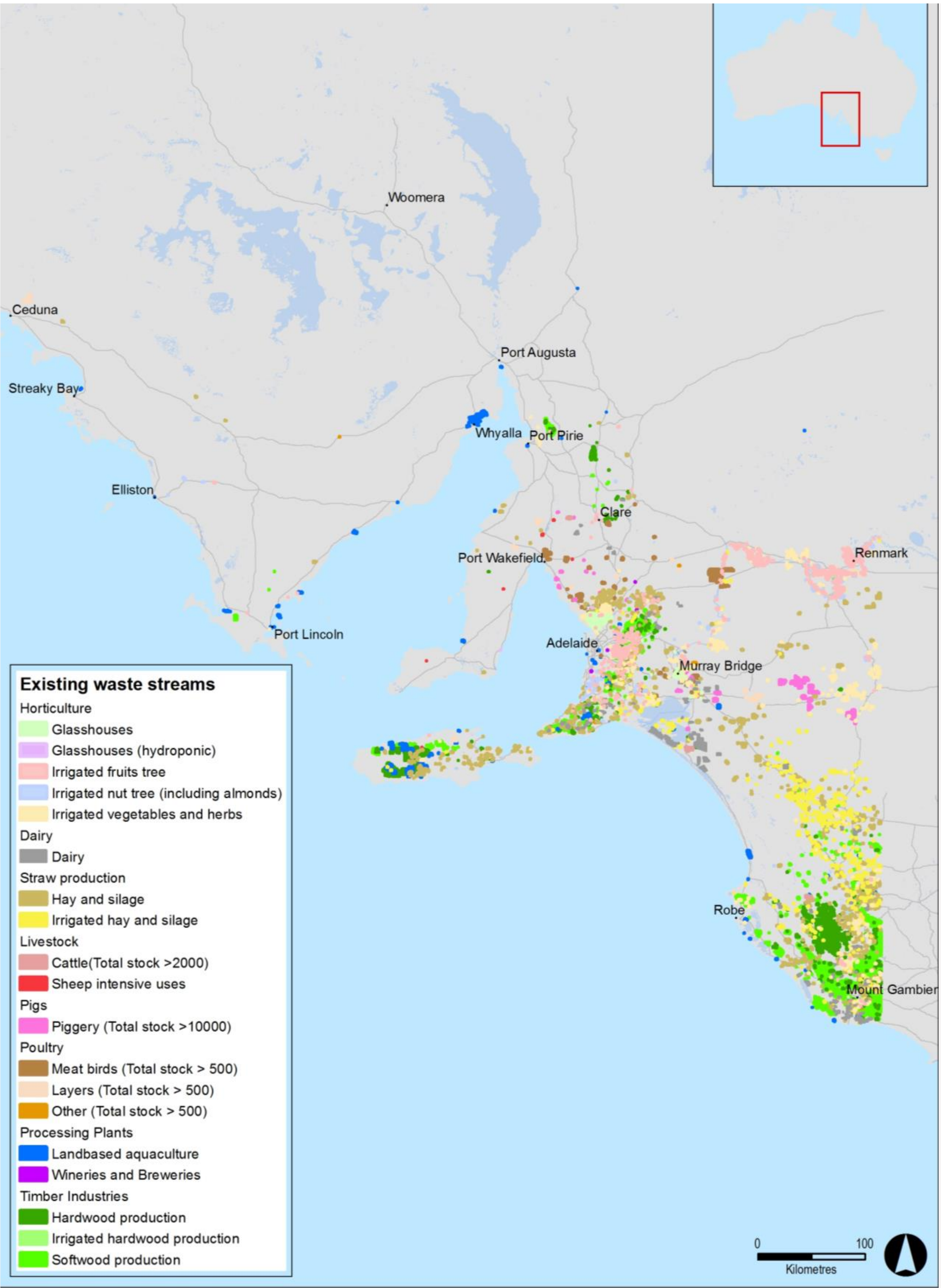
Current developments

The Yorke Peninsula Biomass Project is listed under the new development projects in South Australia (see Section 4.6). The project is estimated to deliver 10–20 MW by July 2018.

The business model of the project will involve a feedstock supply agreement between Yorke Biomass Energy Pty Ltd (YBE) and Yorke Biomass Supply (YBS), with YBE as the project owner and YBS as the feedstock supplier. YBS, which is owned by straw aggregators and individual farmers, will deliver approximately 120,000 tonnes of biomass per year within a 50 km radius of Ardrossan.[38]

[38] Yorke Biomass Energy Pty Ltd. *Yorke Biomass Energy Project*. 26 May 2016. Presentation during Bioenergy Roadmap Stage 2 - Industry Forums hosted by RenewablesSA . Available: http://www.renewablessa.sa.gov.au/files/160625-terry-kallis--yorke-biomass-energy-project.pdf. Viewed: 20 December 2016.

Figure 12 Summary of existing feedstocks by location in South Australia

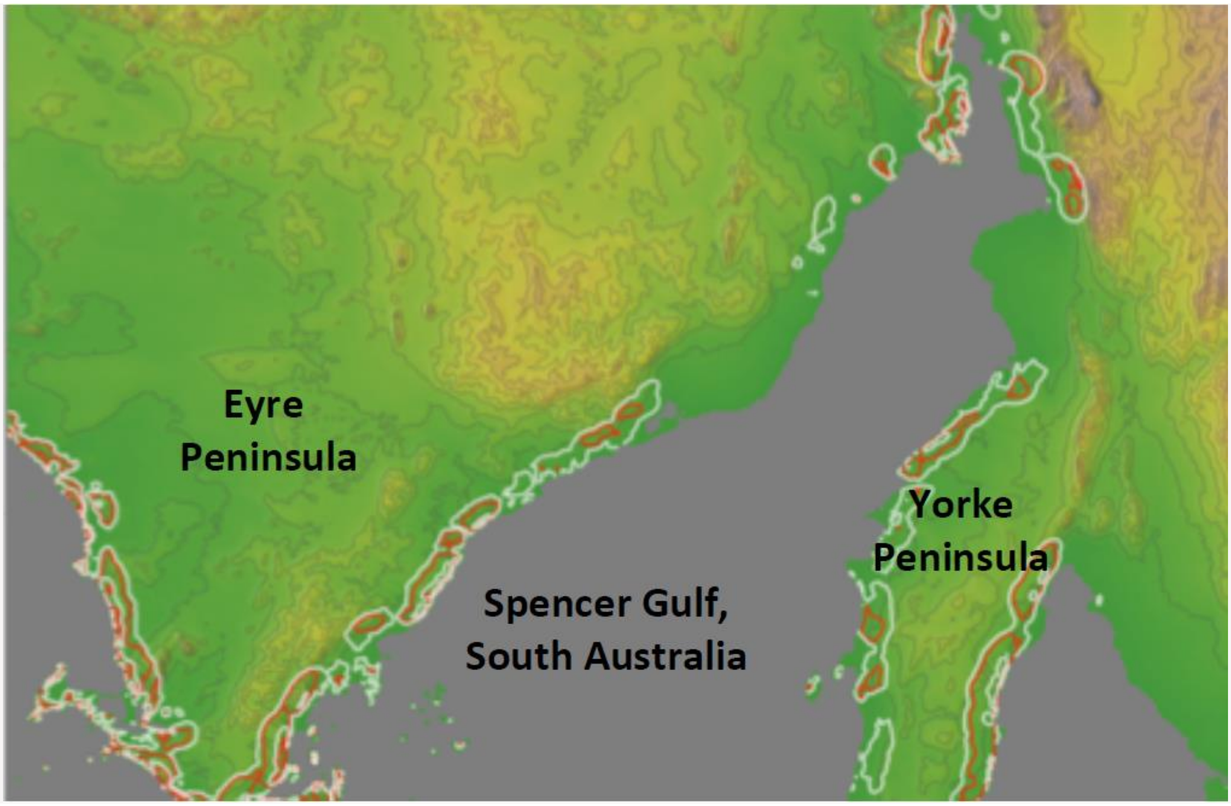


3.7 Hydro

Availability

There is potential in South Australia for man-made seawater reservoirs (knows as turkey-nests) along the coasts of the Eyre and Yorke Peninsulas in the Spencer Gulf region. These reservoirs could be potential sites for pumped hydroelectric storage (PHS) in South Australia. Figure 13 shows the potential PHS sites marked with white and red contours in the region.

Figure 13 Potential PHS sites in South Australia



Source: Hearps, P., Dargaville, R., McConnell, D., Sandiford, M., Forcey, T., and Seligman, P.. *Opportunities for Pumped Hydro Storage in Australia*. 27 February 2014. Available: http://energy.unimelb.edu.au/research/energy-systems/energy-storage-liquid-air-and-pumped-hydro/research/opportunities-for-pumped-hydro-energy-storage-in-australia2. Viewed: 30 January 2017.

Current developments

In 2 November 2016, the Australian Renewable Energy Agency (ARENA) announced that it will be funding the Australian National University (ANU) to map the potential short-term off-river pumped hydro energy storage (STORES) sites in Australia. With $449,000 of funding provided by ARENA, ANU will partner with ElectraNet and VTara Energy Group for the study. The research is expected to finish in June 2018.[39, 40]

[39] © Commonwealth of Australia. ARENA. Old dog, new tricks: the oldest form of clean energy could be key to increasing renewables in our national grid. 2 November 2016. Available: https://arena.gov.au/media/old-dog-new-tricks-oldest-form-clean-energy-key-increasing-renewables-national-grid/. Viewed: 4 January 2017.

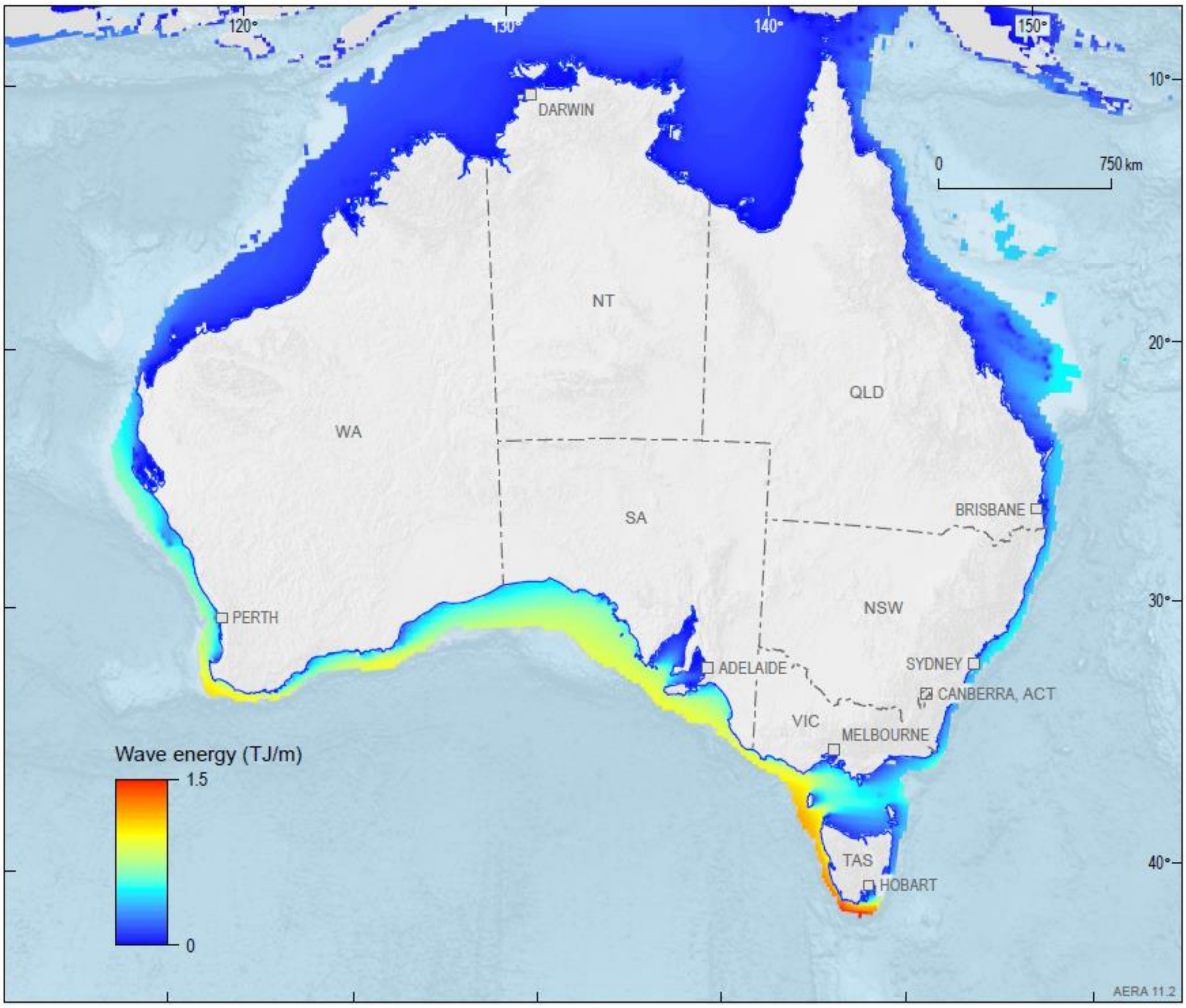
[40] Australian National University. *Hydro may boost share of renewables in electricity grid*. 2 November 2016. Available: http://www.anu.edu.au/news/all-news/hydro-may-boost-share-of-renewables-in-electricity-grid. Viewed: 4 January 2017.

3.8 Ocean

Availability

Australian ocean energy resources can be categorised into tidal energy, wave energy, and ocean thermal energy. The southern half of the Australian continental shelf has excellent wave energy resources. South Australia is one of the states with the best wave energy resources, as shown in Figure 14. There are locations indicating that an average wave power in water depths less than or equal to 300 metres (m) can reach a total annual wave energy delivery of 1.1 terajoules per meter (TJ/m).[41] The average power density is estimated at 40–60 kilowatts per metre (kW/m).[42]

Figure 14 Australian total annual wave energy (TJ/m)



Based on less than 300 m water depth.
© IRENA 2014. *Wave Energy Technology Brief.* June 2014. Available: http://www.irena.org/documentdownloads/publications/wave-energy_v4_web.pdf. Viewed: 20 December 2016.

[41] © Commonwealth of Australia (Geoscience Australia) 2014. Department of Industry. Bureau of Resources and Energy Economics. *Australian Energy Resource Assessment*. Second Edition. 2014. Available: https://industry.gov.au/Office-of-the-Chief-Economist/Publications/Documents/GA21797.pdf. Viewed: 20 Dec 2016.

[42] © IRENA 2014. *Wave Energy Technology Brief.* June 2014. Available: http://www.irena.org/documentdownloads/publications/wave-energy_v4_web.pdf. Viewed: 20 December 2016.

Current developments

There are no current developments for ocean energy in South Australia, reflecting the less developed stage of this technology.

3.9 Coal

Availability

As at December 2015, South Australia had economic demonstrated resources (EDR) estimated at 18,584 PJ of coal, comprising 65% black coal and 35% brown coal. The region has total inferred resources (INF) of roughly 311,595 PJ of coal, comprising 50% black coal and 50% brown coal, as shown in Table 9.[43]

Table 9 South Australian coal resources

Basin	Coal type	EDR (Mt)	INF (Mt)	Total (Mt)	EDR (PJ)	INF (PJ)	Total (PJ)	Longitude	Latitude	Basin GJ/t
Arckaringa Basin	Black	623	9,292	9,915	9,471	141,234	150,704	134.45	-28.29	15.2
Leigh Creek	Black	135	317	452	2,700	6,336	9,036	138.42	-30.48	20.0
Saint Vincent Basin	Black	0	560	560	0	8,504	8,504	137.76	-34.14	15.2
Eucla Basin	Brown	513	1,746	2,259	6,413	21,825	28,238	128.61	-32.06	12.5
Murray Basin	Brown	0	13,523	13,523	0	133,696	133,696	142.74	-35.94	9.9
Total		**1,271**	**25,437**	**26,708**	**18,584**	**311,595**	**330,178**			

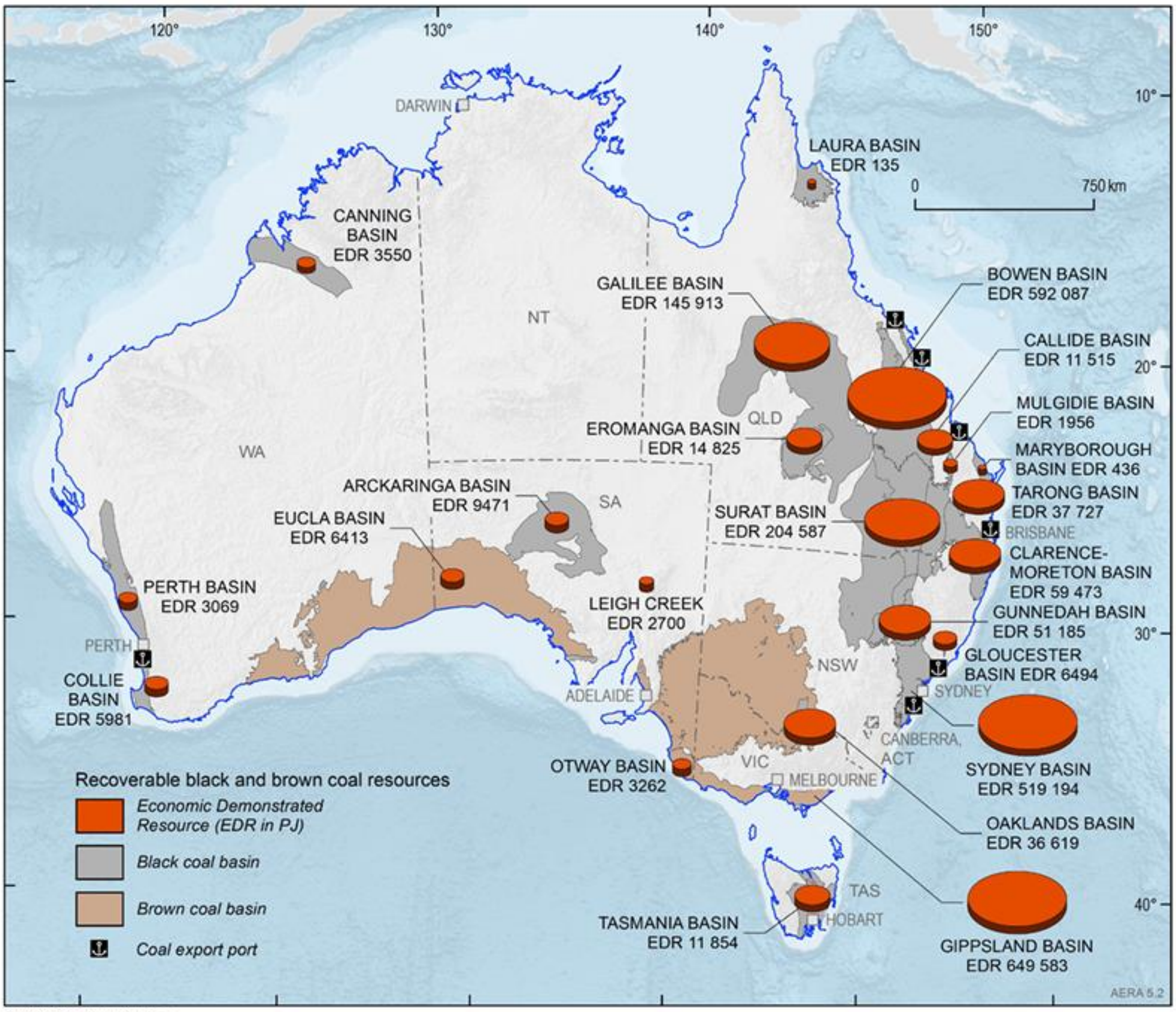
Figure 15 shows identified EDR coal sites in Australia, with Queensland, New South Wales, and Victoria having the largest deposits.[44] In South Australia, coal deposits are located in five basins, namely, Arckaringa, Eucla, Leigh Creek, Murray, and Saint Vincent basins. Leigh Creek has the only coal mine that operated in the region, but the coal mine closed in May 2016.

Current development

By December 2016, there has not been any announcement of intended exploration of the coal resource in South Australia.

[43] © Commonwealth of Australia (Geoscience Australia) 2016. *Coal*. Available: http://www.ga.gov.au/aera/coal. Viewed: 20 December 2016.
[44] © Commonwealth of Australia (Geoscience Australia) 2016. *Coal*. Available: http://www.ga.gov.au/aera/coal. Viewed: 20 December 2016.

Figure 15 Australian coal deposits



Source: Geoscience Australia

4. TECHNOLOGY REVIEW

A range of new and emerging electricity generation technologies have the potential to be commercially viable over the next 30 years. A number of supporting technologies may also create new opportunities to address potential operational challenges in the power system.

This chapter reviews different generation and supporting technologies and their relevance to South Australia. Detailed descriptions of each generation technology and sub-categories are included in each section.

Table 10 provides a summary of the development interest[45] by technology in each NEM region. In the table, the development interest is marked with a check symbol while lack of interest is represented by a cross symbol. It highlights that a relatively diverse range of technologies and fuel sources are being explored in South Australia.

Table 10 Development interest by technology in NEM regions

Technology	Development interest				
	QLD	NSW	SA	TAS	VIC
Gas generation	✓	✓	✓	×	✓
Wind farms	✓	✓	✓	✓	✓
Large-scale solar PV	✓	✓	✓	×	✓
Solar thermal	×	×	✓	×	×
Geothermal	×	×	×	×	×
Bioenergy	✓	✓	✓	×	×
Hydroelectricity (including PHS)	✓	×	✓	×	×
Ocean	×	×	×	×	✓
Coal-fired generation	×	×	×	×	×
Carbon capture and storage	✓	×	✓	×	✓
Integrated gasification combined cycle	×	×	×	×	×
Grid-scale storage	✓	✓	✓	×	✓

4.1 Gas generation

Background

A gas or combustion turbine is typically an axial flow rotary engine with a combustion chamber located between an upstream compressor and a downstream turbine.

A traditional open cycle gas turbine (OCGT) compresses air in a gas compressor, then adds energy to the compressed air by combusting liquid or gaseous fuel in the combustor, producing power to drive the turbine rotor.

A combined cycle gas turbine (CCGT) uses the exhaust heat from one or several OCGT units to generate steam in a relatively conventional boiler to drive a steam turbine. This use of “waste” heat increases the output from the generating unit for the same amount of fuel, increasing overall plant efficiency.

The best available OCGT technology can achieve around 40% efficiency – where efficiency refers to the energy generated per unit of energy input - and the best available CCGT technology can achieve

45 Development interest refers to the committed, advanced, and publicly announced projects with capacity greater than 0 MW in the AEMO Generation Information webpage.

approximately 50% efficiency.[46] Actual achievable efficiencies scale proportionally with installed capacity, with smaller units being less efficient than larger units.

Another gas-fuelled generation technology is sub-critical steam turbine. Unlike OCGT and CCGT, which use gas combustion directly to produce power, a sub-critical steam turbine applies gas combustion to power a steam turbine that generates electricity.

Applications

OCGTs, CCGTs, and sub-critical steam turbines are mature technologies, which are already commercially available and operating, and can be designed to operate with almost all forms of liquid and gaseous fuels. Technology improvements are targeted at efficiency gains, focusing mainly on operating at higher firing temperatures and high-pressure ratios.

As at 28 February 2017, South Australia has a total registered capacity of 778.3 MW of OCGT, 658 MW of CCGT, and 1,280 MW of sub-critical steam turbine generation (details in Table 11).

Table 11 Gas-fired generation technologies in South Australia as at 28 February 2017

Power station	Installed capacity (MW)	Technology type
Dry Creek GT	156	OCGT
Hallett GT	228.3	
Ladbroke Grove	80	
Mintaro GT	90	
Quarantine	224	
Osborne	180	CCGT
Pelican Point*	478	
Torrens Island A	480	Sub-critical steam turbine**
Torrens Island B	800	

* Pelican Point Power Station has reduced capacity of 239 MW from 1 April 2015.
** Torrens Island A and B power stations (1,280 MW) are classified steam sub-critical in AEMO's Generation Information webpage.

Recent developments

CCGT units can have carbon capture and storage (CCS) technology fitted, but no large-scale demonstrations have been achieved to date.[47] The 2015 APGTR suggests that thermal efficiency reduction of about 8% is expected when applying CCS technology to a CCGT.

OCGTs are cheaper to build, but also have lower plant efficiencies than CCGTs. This results in OCGTs typically being used to support electric power peaking load, and therefore operating at lower capacity factors (7.5–20%) than CCGTs (up to 85%).[48]

Table 12 lists the publicly announced OCGT and CCGT projects in South Australia. The development of a new gas-fired power station near Port Augusta[49] is being considered.

Table 12 Publicly announced OCGT and CCGT in South Australia as at 28 February 2017

Power station	Nameplate capacity (MW)	Technology type	Fuel type
Pelican Point S2	320	OCGT	Natural gas pipeline
Leigh Creek Energy project	460	CCGT	Coal seam methane

[46] © 2015 Electric Power Research Institute, Inc. *Australian Power Generation Technology Report*. 2015. Available: http://www.co2crc.com.au/wp-content/uploads/2016/04/LCOE_Report_final_web.pdf. Viewed: 4 January 2017.
[47] © OECD/IEA 2016. *Tracking Clean Energy Progress 2016.* Available: http://www.iea.org/publications/freepublications/publication/TrackingCleanEnergyProgress2016.pdf. Viewed: 20 December 2016.
[48] © 2015 Electric Power Research Institute, Inc. *Australian Power Generation Technology Report*. 2015. Available: http://www.co2crc.com.au/wp-content/uploads/2016/04/LCOE_Report_final_web.pdf. Viewed: 4 January 2017.
[49] © The Advertiser. *Chinese firm Powerchina planning $350 million gas-fired power station near Port Augusta*. Available: http://www.adelaidenow.com.au/news/south-australia/chinese-firm-powerchina-planning-350-million-gasfired-power-station-near-port-augusta/news-story/4b836c02d9166c55f1140b67e013d893. Viewed: 30 January 2017.

In South Australia, the Pelican Point CCGT power station reduced its capacity to half from 1 April 2015.[50] As outlined in AEMO's November 2016 *Electricity Statement of Opportunities Update*, the return to full operation of the Pelican Point Power Station is possible in the short to medium term, as a market response to the closure of the Hazelwood Power Station.[51] AEMO expects this would be a decision largely driven by gas prices and available pipeline capacity.

4.2 Wind farms

Background

Wind power harnesses flowing air to drive wind turbine blades, which, in turn, drive a generating turbine. In typical large-scale applications, the output from multiple generating units is aggregated, and the generation plant collectively is termed a "wind farm".

Wind generation technology is one of the most mature renewable energy technologies available, and can be expected to continue to develop and increase overall generation efficiency. Likely improvements include stronger and lighter materials for larger and lighter blades, and increased electrical efficiency. The trend of the past two decades of developing larger turbines (in terms of their rated megawatt output capacity) is also likely to continue and help lower per kilowatt costs. The wind turbine's maximum theoretical power efficiency is about 59.3%.[52]

Applications

South Australia has the greatest penetration of wind generation in Australia, with the total registered capacity of wind farms reaching 1,595 MW as at 28 February 2017. In 2015–16, wind energy in South Australia supplied 4,322 GWh[53] of electricity, 35% of the region's total generation.[54] For a detailed analysis of wind generation performance in South Australia, see the *South Australian Renewable Energy Report* (SAER) published by AEMO in 2016.[55]

Recent developments

As at 28 February 2017, South Australia has one committed wind project (102.4 MW Hornsdale Wind Farm Stage 2), and 14 publicly announced wind projects with up to 3,109.4 MW total capacity.

The current Large-scale Renewable Energy Target (LRET), the Victorian Renewable Energy Target (VRET), and the 2015 Paris agreement (COP21 commitment) are forecast in the 2016 NTNDP to drive replacement of coal generation with wind, PV, and GPG. The 2016 NTNDP projected new installations of 9.4 GW of wind generation in South Australia may be required by 2036 in the Neutral (considered the most likely) demand growth scenario.[56]

4.3 Solar PV

Background

Solar photovoltaic (PV) technologies convert sunlight directly into electricity, using semiconductor materials that produce electric current when exposed to light.

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50 AEMO. *Generation Information.* February 2017. Available: http://www.aemo.com.au/Electricity/Planning/Related-Information/Generation-Information.

51 AEMO. *Electricity Statement of Opportunities Update*, November 2016. Available at: http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/NEM-Electricity-Statement-of-Opportunities.

52 US DOE. NREL. *Modelling of the UAE Wind Turbine for Refinement of FAST_AD NREL/TP-500-34755.* Dec 2003. Available: http://www.nrel.gov/docs/fy04osti/34755.pdf. Viewed: 4 January 2017.

53 This includes scheduled and non-scheduled generation.

54 AEMO. *South Australian Generation Forecasts*. December 2016. Available: https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/South-Australian-Advisory-Functions.

55 AEMO. *South Australian Renewable Energy Report*. August 2016 Available: https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/South-Australian-Advisory-Functions.

56 AEMO. *National Transmission Network Development Plan*. December 2016. Available: https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/National-Transmission-Network-Development-Plan.

Inverters are another key component of most solar PV systems. Similar to wind technologies, inverters convert the generated DC power to AC power for connection to the electricity grid or a facility's electrical wiring.

PV technology uses solid-state devices called solar PV cells. There are a range of different types of PV cells, including crystalline silicon cell, thin film, multi-junction cell, and single-junction cell. The two main types are crystalline silicon cell and thin film.[57]

PV technology can be installed as a fixed flat plate (FFP) on roofs, as a large field array with no moving parts. It can also be mounted on tracking devices that constantly change the panel's orientation to maximise exposure to the sun (optimising on either a single or dual axis). Single-axis tracking (SAT) devices deliver around 30% more annual electricity output than fixed flat plates, and dual-axis trackers (DAT) can deliver up to about 10% more output than single-axis trackers, although there are associated increases in auxiliary loads to operate the tracking devices.

One of the most mature emerging technologies is Concentrating Photovoltaics (CPV).[58] These systems consist of concentrators (lenses, reflection, or refraction systems) that focus sunlight onto highly efficient PV cells. Systems with high concentration factors require adequate heat dissipation and must use highly accurate optics and sun-tracking technologies.

Another area of research is organic solar cells based on active, organic layers.[59] Their manufacturing and material costs are quite low compared to other technologies, but cell efficiency and longevity is yet to be proven as commercially viable, apart from niche applications.

As PV technology only produces useful energy output when there is enough sunlight, its average output over time is limited. An integrated battery storage system is one way to overcome this problem. Section 5 discusses recent developments in battery storage systems.

Applications

Solar PV installations are generally categorised into:

- Residential and commercial installations (rooftop PV).
- Larger-scale solar farms, which are typically connected to the transmission grid and incorporate aggregated PV collector arrays to give higher output capacity.

Tracking technologies (single-axis or dual-axis) are often deployed to further increase the total generation output across the day, although tracking does introduce a relatively small auxiliary load.

Rooftop PV

Australia has seen rapid growth in residential and commercial rooftop PV installation,s from 23 MW in 2008 to over 4,300 MW in 2016. In 2015–2016, over one million individual installations were estimated to generate over 5,000 GWh, or 3% of the NEM's annual operational electricity consumption.[60]

The 2016 *National Electricity Forecasting Report* (NEFR)[61] projected further increases in rooftop PV installed capacity in South Australia over the next 20 years:

- Nationally, AEMO projects effective installed capacity[62] of rooftop PV to be 4,939 MW by 2016–17 (generating 5,648 GWh) rising to 19,049 MW by 2035–36 (generating 25,442 GWh).

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57 © 2015 Electric Power Research Institute, Inc. *Australian Power Generation Technology Report*. 2015. Available: http://www.co2crc.com.au/wp-content/uploads/2016/04/LCOE_Report_final_web.pdf. Viewed: 4 January 2017.

58 © IEA-ETSAP and IRENA 2013. *Solar Photovoltaics Technology Brief* (E11 – January 2013). Available: http://www.irena.org/DocumentDownloads/Publications/IRENA-ETSAP%20Tech%20Brief%20E11%20Solar%20PV.pdf. Viewed: 4 January 2017.

59 © IEA-ETSAP and IRENA 2013. *Solar Photovoltaics Technology Brief* (E11 – January 2013).

60 AEMO and University of Melbourne. *Rooftop PV Model Technical Report*. 22 July 2016. Available: https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/National-Electricity-Forecasting-Report.

61 AEMO. *National Electricity Forecasting Report.* June 2016. Available: https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/National-Electricity-Forecasting-Report.

62 Effective installed capacity takes into account the fact that PV panels degrade over time by applying an annual degradation factor to the projected installed capacity.

- Projections for effective installed capacity in South Australia are 718 MW (15% of projected NEM rooftop PV) by 2016–17 (generating 924 GWh), rising to 1,942 MW (10% of the projected NEM rooftop PV) by 2035–36 (generating 2,730 GWh).

State-based PV feed-in tariffs have been reduced or discontinued in recent years. The South Australian feed-in scheme closed to new entrants on 30 September 2013, although new customers are still eligible for the minimum retailer payment.[63] The Federal Government's small-scale Renewable Energy Scheme also creates Small-scale Technology Certificates (STCs) for the energy produced by eligible systems, which can reduce new system costs for customers. In Victoria, solar PV feed-in tariff decreased from 6.2 cents/kWh in 2015 to 5 cents/kWh in 2016. From 1 July 2017, the tariff will increase to 11.3 cents/kWh as set by the Essential Services Commission on 28 February 2017.[64]

Integrated battery storage systems are an emerging technology for residential and commercial rooftop PV systems, with several battery storage solutions currently emerging in the market. The 2016 NEFR projected the installed capacity of integrated PV and storage systems to be:

- 24 MW across the NEM and 1 MW in South Australia by 2016–17.
- 3,783 MW across the NEM and 517 MW in South Australia by 2035–36.

Adelaide City Council has been offering financial incentives for PV and energy storage system installations from 11 October 2016, which could accelerate installations in the area.[65]

Large-scale PV farms

Many large-scale PV farms are established worldwide, with several more planned or under construction. Australia has several small-scale PV farms, but none in South Australia.

ARENA is assisting large-scale PV development by providing funding for selected projects. The latest round of funding ($92 million) is supporting approximately 480 MW of new large-scale PV generation, although none of the projects successful in the auction process are located in South Australia.[66] Some large-scale solar projects are being considered in South Australian locations such as Port Augusta, Leigh Creek, Roxby Downs, Whyalla, and Woomera.[67, 68, 69]

Recent developments

In August 2016, DP Energy was granted Development Approval to build a hybrid solar and wind plant with total installed capacity of up to 375 MW, on land situated on the coastal plain south-east of Port Augusta, South Australia. The project would include approximately 400 hectares of solar PV arrays and 59 wind turbines.[70, 71]

Retailers are also offering commercial arrangements for residential PV, requiring no upfront investment, but instead a pay-as-you-go Power Purchase Agreement (PPA). Some offers can also be combined with battery storage systems.[72] In February 2017, Origin Energy signed a PPA with the Bungara Solar

63 Government of South Australia. Department of State Development. *Minimum Retailer Payment*. Available: http://www.sa.gov.au/topics/water-energy-and-environment/energy/energy-supply-and-sources/renewable-energy-sources/solar-energy/solar-photovoltaic-systems/solar-feed-in-scheme#minimum. 4 January 2017.

64 © Renew Economy 2017. *Victoria solar feed-in tariff more than doubles to 11.3 c/kWh.* 28 February 2017. Available: http://reneweconomy.com.au/victoria-solar-feed-in-tariff-more-than-doubles-to-11-3ckwh-87581/. Viewed: 28 February 2017.

65 Adelaide City Council. *Sustainability Incentives Scheme*. Available: http://www.adelaidecitycouncil.com/your-council/funding/sustainable-city-incentives-scheme/. Viewed 4 January 2017.

66 © Commonwealth of Australia. ARENA. *Large-scale solar photovoltaics – competitive round*. Available: https://arena.gov.au/programs/advancing-renewables-program/large-scale-solar-pv/. Viewed: 4 January 2017.

67 © Renew Economy 2017. *SolarReserve aims to build 6 solar power plants in South Australia*. 13 September 2016. Available: http://reneweconomy.com.au/solarreserve-aims-build-6-solar-tower-power-plants-south-australia-29236/. Viewed: 4 January 2017.

68 © Renew Economy 2017. *World's biggest solar + storage projects planned for Australia*. 19 July 2016. Available: http://reneweconomy.com.au/worlds-biggest-solar-storage-projects-planned-australia-95528/. Viewed: 4 January 2017.

69 The Advertiser. *Revealed: Proposal for $1.2 bn solar thermal power at Port Augusta*. 3 June 2016. Available: http://www.adelaidenow.com.au/news/south-australia/revealed-proposal-for-12bn-solar-thermal-power-plant-at-port-augusta/news-story/58e18b826e4ecedfb57a9d11dc5fe7ba. Viewed: 4 January 2017.

70 © 2016 DP Energy. Australia: Port Augusta Renewable Energy Park – South Australia. Available: http://www.dpenergy.com/hybrid/port-augusta-renewable-energy-park/. Viewed: 31 January 2017.

71 © Renew Economy 2017. *Port Augusta 375MW solar and wind energy park approved for development*. Available: http://reneweconomy.com.au/port-augusta-375mw-solar-wind-energy-park-approved-development-82044/. Viewed: 31 January 2017.

72 BNEF. Bloomberg Energy Finance. *Residential solar: Too cheap to finance?* (Private report provided to AEMO.)

Project, a 300 MW single-axis tracking solar PV power plant in Port Augusta.[73] The project's application for development was submitted in September 2016.[74]

In May 2016, AECOM analysed the financial merit of connecting solar plants to existing wind farms. The results showed that:

- Western Australia appeared to be more attractive than the NEM-connected wind farms, due to superior solar resource and higher market prices.
- The next best performing states were South Australia and New South Wales, followed by Victoria and Tasmania.
- Queensland was excluded in the study, due to missing data from existing wind farms.[75]

For larger-scale PV, a trend seen in New South Wales and Queensland is co-location of solar and wind farms to increase utilisation of network connection assets. In some cases, this includes battery storage. The proposed development projects include 10–11 MW Gullen Solar Farm[76] and 20 MW White Rock Solar Farm[77] in New South Wales, to be co-located with the existing wind farms in the region. There have been no publicly announced co-location projects in South Australia as at 28 February 2017.

SA Power Networks is also conducting a trial of combined PV and battery storage systems, deploying about 100 Tesla Energy and Samsung batteries in the suburb of Salisbury to test whether such installations could avoid the need to build additional distribution network infrastructure.[78]

4.4 Solar thermal

Background

Solar thermal electricity generation technologies use the sun's heat to produce steam (directly or indirectly). The sun's heat energy is reflected by mirrored surfaces and concentrated onto receiving mechanisms. The high temperature is harnessed by passing a working fluid (such as water, molten salt, or synthetic oil) through a focal point (or tubes, depending on the design).

The heated fluid can generate steam either directly (if the fluid is water) or indirectly (by using a heat exchanger). Finally, steam turbines use the steam to generate electricity.

Several solar thermal technologies are available to reflect and concentrate solar radiation onto a working fluid. The three types considered in this report are chosen for their relevance to Australia and their technological maturity.

They are:

- Parabolic trough (PT): This concentrates reflected solar radiation onto a focal receiver tube that runs the length of a mirrored trough.
- Central receiver (CR, also known as solar tower): This uses numerous, flat, sun-tracking mirrors to focus solar radiation onto a focal point, called the central receiver, usually mounted in a tower.
- Compact linear fresnel (CLF): This is similar to PT, using a focal receiver tube, but instead of a trough, has linear arrays of moveable mirrors to focus solar radiation.

Some solar thermal systems can also store the heat energy before it is used to produce steam. This allows the plant to continue producing electricity even when sunlight is unavailable or below ideal radiation levels.

[73] © Renew Economy 2017. *Origin signs up for 200MW solar plant in S.A, as PPA prices tumble*. Available: http://reneweconomy.com.au/origin-signs-up-for-200mw-solar-plant-in-s-a-as-ppa-prices-tumble-86240/. Viewed: 20 February 2017.

[74] © Renew Economy 2017. *Former coal boss seeks approval for 300MW solar plant in Port Augusta*. Available: http://reneweconomy.com.au/former-coal-boss-seeks-approval-for-300mw-solar-plant-in-port-augusta-60879/. Viewed: 4 January 2017.

[75] © AECOM Australia Pty Ltd (AECOM). *Co-location Investigation.* 15 March 2016. Available: https://arena.gov.au/wp-content/uploads/2016/03/AECOM-Wind-solar-Co-location-Study-1.pdf. Viewed: 4 January 2017. (Commissioned by ARENA.)

[76] © 2017 Gullen Solar Farm. *Gullen Solar Farm*. http://www.gullensolarfarm.com/, Viewed: 30 January 2017.

[77] © 2017 White Rock Wind Farm. *News Updates. Proposed Development of White Rock Solar Farm*. February 2016. http://www.whiterockwindfarm.com/news/, Viewed: 30 January 2017.

[78] © 2016 SA Power Networks. *SA Power Networks to conduct nation-leading trial of combined solar and batteries*. 19 May 2016. Available: http://www.sapowernetworks.com.au/. Viewed: 4 January 2017.

Solar thermal hybrid

A solar/coal hybrid plant uses solar thermal technology to increase the steam energy powering a turbine at a traditional coal-fired power station. In practical terms, steam for the turbine is powered by burning coal and, when available, also by concentrating solar radiation.

Integrated solar combined cycle (ISCC) technology uses solar thermal technology to increase the steam energy used in the steam turbine stage of a CCGT plant. In practical terms, steam for the second stage turbine is powered by the heat recovered from the gas turbine exhaust and, when available, also by concentrated solar radiation.

These solar thermal additions to coal- or gas-fired plant increase fuel efficiency and reduce greenhouse gas emissions per megawatt of electricity generated.

Applications

The largest solar thermal power plant in the world is the Ivanpah project, a 377 MW solar tower system that has been operating in the United States of America (USA) since 2013.[79] The Crescent Dunes project, also in the USA, applies solar tower and molten salt storage technologies to generate 110 MW of power with 10 hours of full load storage.[80]

Parabolic trough installations are another type of solar thermal system that have been deployed in the USA since the 1980s, and the Solana Power Plant in Arizona (installed in 2013) has a rated output of 280 MW with six hours of molten salt storage.[81]

Liddell coal-fired power station in New South Wales applies a 9.3 MW linear Fresnel system to pre-heat boiler feedwater to produce high quality steam for use in existing power stations.

There is currently no solar thermal plant installed in South Australia.

Kogan Creek solar boost project was intended to demonstrate the hybridisation of solar thermal and coal-fired generation using a 44 MW linear Fresnel system. The project, however, was closed on 8 March 2016 after the withdrawal from the project of AREVA (the technology proponent and Engineering, Procurement, and Construction (EPC) contractor).[82, 83]

Australia's largest solar thermal research hub is the CSIRO's National Solar Energy Centre in Newcastle, New South Wales. This is an international research facility to develop and commercialise solar thermal energy technologies, such as solar air turbines.[84]

Recent developments

In 2014, Alinta Energy performed a feasibility study into the viability of a solar thermal plant at Port Augusta, jointly funded by Alinta Energy, ARENA, and the South Australian Government. The project did not progress, as the plant was not commercially viable due to high capital costs.[85]

Nonetheless, there remains great interest in such a project, particularly following the closures of the Northern and Playford B power stations in 2016. Solar Reserve and Solastor Australia are both considering solar thermal projects in the area, with capacities of 110 MW and 100 MW respectively.

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79 © 2015 BrightSource Energy, Inc. BrightSource Energy. *Ivanpah*. Available: http://www.brightsourceenergy.com/ivanpah-solar-project#.WFx6x7J9600. Viewed: 4 January 2017.

80 © 2017 SolarReserve, LLC. *Crescent Dunes*. Available: http://www.solarreserve.com/en/global-projects/csp/crescent-dunes. Viewed: 4 January 2017.

81 © 2017 IDG Communications, Inc. Computerworld from IDG. *U.S. flips switch on massive solar power array that also stores electricity*. Available: http://www.computerworld.com/article/2485916/emerging-technology/u-s--flips-switch-on-massive-solar-power-array-that-also-stores-electricity.html. Viewed: 4 January 2017.

82 © Commonwealth of Australia. ARENA. *Kogan Creek Solar Boost project*. Available: https://arena.gov.au/project/kogan-creek-solar-boost-project/. Viewed: 4 January 2017.

83 © Renew Economy 2017. "Why Australia should not abandon world-leading solar boost technology", 1 April 2016. Available: http://reneweconomy.com.au/kogan-creek-solar-boost-should-be-completed-29923/. Viewed: 4 January 2017.

84 © CSIRO Australia 2017. *Solar thermal*. Available: http://csiro.au/en/Research/EF/Areas/Solar/Solar-thermal. Viewed: 4 January 2017.

85 © Commonwealth of Australia. ARENA. *Port Augusta Solar Thermal Generation Feasibility Study:* Available at https://arena.gov.au/project/port-augusta-solar-thermal-feasibility-study/. Viewed: 4 January 2017.

4.5 Geothermal

Background

Geothermal energy is derived from heat found within the earth. The resources can be classified in three categories:

- Conventional hydrothermal systems (volcanogenic or magmatic).
- Unconventional hydrothermal systems (hot sedimentary aquifers (HSA), amagmatic).
- Enhanced geothermal systems (EGS, also known as Engineered Geothermal Systems or 'hot rocks').

Australia does not have the wet, high-temperature geothermal environments found in volcanically active countries, such as New Zealand. Australia's hydrothermal systems are not hot enough or under enough pressure to produce large amounts of steam (such as used in dry steam and flash geothermal systems).

HSA and EGS are the only available resources in Australia:

- EGS involves harnessing stored underground heat using mining technology to circulate fluid through geothermally heated rocks in a natural or artificially stimulated underground cavity, and using conventional generation techniques to generate power from the hot fluid when it returns to the surface. EGS is sometimes referred to as hot dry rock or hot fractured rock.
  - Once the system is in place, water is injected into hot granite rock underground. Heat extracted from the rock is transferred to a secondary or working fluid and is then recirculated and pumped back down the injection well.
- HSA involves reservoirs in which rainwater that has been absorbed into the ground is heated by hot rocks. The temperature of these rocks typically increases with depth. Rainwater collects in porous rocks between two impermeable sedimentary layers creating an aquifer from which hot fluid can be extracted by drilling.
  - The key to HSA research and development is finding shallow systems to reduce development costs and allow use of proven hydrothermal systems and supporting technology. HSA can be exploited by more conventional geothermal technology.

Potential Australian developers seek areas with a high heat gradient that can be generated from the radioactive decay of naturally occurring potassium, thorium, and uranium isotopes in the earth's crust. Exploiting most Australian geothermal resources requires a dual-fluid cycle power generation system.[86] This system passes geothermally heated water or hot geo-liquid through a heat exchanger, where it transfers heat to a secondary liquid (the working fluid) with a much lower boiling point than water. The working fluid boils to a vapour and is expanded through a turbine connected to a generating unit that produces electricity.

Geothermal site development requires consideration and evaluation of several factors, such as site geography, geology, reservoir size, geothermal temperature, and plant type. Cost is affected not only by power plant size and design, but also geothermal resource temperature and pressure, steam, impurity and salt content, and well depth.

Barriers

EGS is not yet a commercially viable technology, although small systems have been established overseas. The same plant and drilling technologies can be used as for hydrothermal plants (which are considered commercial), but cost, injection, working fluid recovery, and depth remain significant issues.

Operational uncertainties involving the resistance of the reservoir to flow, thermal drawdown over time, and water loss have also made commercial development uncertain. Lower-cost resource assessment and drilling technologies are required to make EGS commercially viable.

[86] Some texts refer to this as "binary cycle" power generation.

HSA is also not yet commercially proven in Australia but the technology is in production elsewhere. It is considered less risky than EGS, as it uses a conventional low-temperature dual-fluid cycle, involves shallower drilling, and does not require resource stimulation. Several potential sedimentary basins that may have lower exploration, drilling, and reservoir risks have been identified in Australia, however there has been little success with HSA so far.

The advance of EGS technologies in Australia will benefit from ongoing development of rock-fracturing technologies worldwide, driven by the exploitation of shale gas reserves. One factor that may impede geothermal power's development in Australia is that many identified potential geothermal resources are located far from major load centres or electricity transmission infrastructure.

Applications

Birdsville, Queensland has the only working geothermal power station in Australia. The binary plant[87] is rated to 120 kW and has 40 kW parasitic losses[88]. The power station uses a low temperature geothermal resource, drawing water at 98 ºC from a 1.28 km deep production well in the Great Artesian Basin.[89]

Recent developments

Several developers have sought to drill geothermal exploration or production wells in Australia, but have yet to begin any commercial developments.

In South Australia, Geodynamics' Innamincka project,[90] in the Cooper Basin, focused on developing electricity generated from EGS. In 2013, the 1 MW Habanero Pilot Plant was successfully operated for 160 days. Although Geodynamics publicly announced additional developments, such as utilising geothermal energy to provide process heat for natural gas development, a decision was made in 2016 not to proceed with the project as it was not financially viable.[91]

In March 2016, Ergon Energy, owner of the Birdsville geothermal plant, announced it had plans to expand the existing installed capacity to between 150 and 200 kW, to displace up to 80% of diesel energy.[92]

4.6 Bioenergy

Background

Bioenergy refers to energy extraction from biomass fuels (sometimes the generation technology is also referred to as "biomass").

Current commercially viable technologies include:

- Combustion or gasification to produce heat, steam, or gases for generation.
- Conversion to biofuels, such as bio-diesel or ethanol for transport or energy production.
- Landfill extraction or anaerobic digestion of sewage or animal waste to produce gas for generation.

The type of biomass fuel and plant location dictate the power generation technology used. In Australia, the main biomass power generation technologies are spark ignition reciprocating engines and subcritical steam turbines.

[87] A closed-loop system with two separate sections: the geothermal fluid loop and the power cycle.
[88] Refers to auxilliary loads such as fans, pumps, and gas extraction system.
[89] Government of South Australia, Department of State Development. *Current use in Australia*. Available: http://geothermal.statedevelopment.sa.gov.au/ageg/geothermal_basics/current_use. Viewed: 4 January 2017.
[90] Government of South Australia. Department of State Development. *Status of Geothermal Licence Activity*. Available: http://geothermal.statedevelopment.sa.gov.au/ageg/status_of_geothermal_licence_activity. Viewed: 4 January 2017.
[91] © Commonwealth of Australia. ARENA. *Cooper Basin Enhanced Geothermal Systems Heat and Power Development*. Available: https://arena.gov.au/project/cooper-basin-enhanced-geothermal-systems-heat-and-power-development/. Viewed: 4 January 2017.
[92] © Ergon Energy 2017. *Ergon to upgrade Birdsville geothermal plant* Available: https://www.ergon.com.au/about-us/news-hub/talking-energy/electricity-industry/ergon-to-upgrade-birdsville-geothermal-plant. Viewed: 4 January 2017

Fuel

Key challenges in biomass include fuel gathering and transportation, low or seasonal yields, relatively high moisture content, low density, modest thermal content, and a rarely homogenous or free-flowing form. Many biomass projects are linked with production or primary industries where materials that can be used as fuels are already gathered for another purpose.

Applications

Statistics from the Clean Energy Council for 2015provide a useful perspective[93] on Australia's use of biomass resources:

- Bioenergy currently supplies 1.3% (3,200 GWh) of Australia's electricity generation, and contributes to approximately 9.1% of renewable energy generation.
- The biggest bioenergy projects in Australia (see Table 13 below) have capacities ranging from 30 to 68 MW. Most of them are bagasse cogeneration at sugar mills in Queensland.

Table 13 Largest bioenergy projects

Technology	State	Owner	Location	Commission year	Capacity (MW)
Bagasse cogeneration	QLD	Sucrogen	Pioneer II	2005	68
Black liquor	VIC	Australian Paper	Maryvale	1976–89	54.5
Bagasse cogeneration	QLD	Sucrogen	Invicta	1976–96	50.5
Bagasse cogeneration	QLD	Mackay Sugar Ltd	Racecource	2013	38
Bagasse cogeneration	NSW	Capital Dynamics	Broadwater II	2009	30

In South Australia:

- The registered capacity of bioenergy plants amounts to 21 MW, about 1% of the region's total renewable capacity.
- The bioenergy fuel capacity mix was 52% landfill gas and 48% sewage treatment, all operating using spark ignition reciprocating engines.

Recent developments

In South Australia, the publicly announced Yorke Peninsula Biomass Project would operate using straw-fuelled biomass technology with a spark ignition reciprocating engine. The project is estimated to deliver 10–20 MW capacity to local customers connected to 33 kilovolts (kV) network or below from Ardrossan.[94]

4.7 Hydroelectricity

Background

Hydroelectric generation uses the power of pressurised, flowing water to spin a turbine connected to a generating unit. The amount of electricity generated depends on the height of the water above the turbine, and the volume of water flowing through it. Large hydroelectric power stations ensure maximum value is extracted from the water[95] in water storage dams. These dams may have been built for other purposes, such as for irrigation or drinking water.

[93] © Clean Energy Council. Clean Energy Council. *Clean Energy Australia Report 2015.* Available: http://www.cleanenergycouncil.org.au/policy-advocacy/reports/clean-energy-australia-report.html. Viewed: 4 January 2017.

[94] Yorke Biomass Energy Pty Ltd. *Yorke Biomass Energy Project*. 26 May 2016. Available: http://www.renewablessa.sa.gov.au/files/160625-terry-kallis--yorke-biomass-energy-project.pdf. Viewed: 20 December 2016. (Presentation during Bioenergy Roadmap Stage 2 - Industry Forums hosted by RenewablesSA.)

[95] © Clean Energy Council 2014. *Hydroelectricity.* Available: http://www.cleanenergycouncil.org.au/technologies/hydroelectricity.html. Viewed: 4 January 2017.

Current applications

In 2015, hydroelectricity generated 40.1% of total renewable energy in Australia. This was equivalent to 5.9% of the total electricity generated in the country.[96]

As at 28 February 2017, NEM's hydroelectricity stations have a combined registered capacity of 7,976.1 MW. South Australia has only one hydro plant currently registered as a non-scheduled generating unit – the 2.5 MW Terminal Storage Mini Hydro.

Recent developments

The 2015 APGTR stated that the development of new large-scale hydropower projects in Australia is unlikely. Current hydropower investment concentrates on the refurbishment and modernisation of existing assets as well as the addition of mini- and micro-units to waterways. The potential for new hydro plants across the NEM is limited, but there is strong interest in pumped storage. The developments in pumped hydro storage are presented in Section 5.

4.8 Ocean (wave) energy extraction

Background

Wave energy extraction converts ocean wave motion into electrical energy. Several devices are being explored and use a variety of ways to mechanically interact with ocean waves, under or on the water surface.

Wave power energy technologies include[97]:

- Attenuator devices that generally have long floating structures absorbing energy by the attenuation of the devices' movements due to wave motion.
- Overtopping devices that focus wave surges to force water into a raised storage reservoir (that can then be used for hydroelectric generation).
- Oscillating water columns (OWC), to generate electricity via an air turbine powered by wave motion pushing a column of air up and down.
- Point absorbers, to exploit the buoyancy of objects in response to wave motion.
- Oscillating wave surge converter (OWSC), to extract energy from the surge motion of waves, generally near the shore.

With these and other wave technology types, there are many construction and design possibilities. The exact means of transferring the wave energy to electricity are also open to a variety of engineering designs.

Compared with other technologies such as wind and solar, wave energy is more spatially concentrated, which makes it an attractive option. However, the technology is still in the research and early development phase.

Applications

Despite the excellent wave conditions in Australia, as discussed in Section 3.8, the development of wave energy is still at an early stage.

Other than the unsuccessful attempt to commercially demonstrate wave energy using the 1 MW Oceanlinx unit in 2014[98], there has been no development in South Australia. Several wave energy projects have been commissioned in other states. By June 2016, the Australian total installed capacity

[96] © Clean Energy Council 2017. *Clean Energy Australia Report 2015*. Available: http://www.cleanenergycouncil.org.au/policy-advocacy/reports/clean-energy-australia-report.html. Viewed: 4 January 2017.

[97] © Clean Energy Council 2014. *Hydroelectricity.* Available: http://www.cleanenergycouncil.org.au/technologies/marine-energy.html. Viewed: 4 January 2017.

[98] © Commonwealth of Australia. ARENA. *Oceanlinx 1 MW Commercial Wave Demonstrator.* Available: https://arena.gov.au/project/oceanlinx-1mw-commercial-wave-energy-demonstrator/. Viewed: 30 January 2017.

of wave energy was 1.25 MW, with the additional planned installation of 3 MW by 2020 after the completion of Carnegie Wave Energy project in Western Australia.[99]

Key wave energy projects commissioned included:

- The Perth Wave Energy Project. Led by Carnegie Wave Energy, this is the world's first commercial-scale wave energy array which provides both renewable electricity and desalinated water.[100] In early 2015, two CETO 5 units were added to the project, enabling a total generation capacity up to 720 kW.[101]
- BioPower Systems. In late 2015 it completed the deployment of its 250 kW bioWAVE pilot unit, off the coast of Port Fairy in south-west Victoria. The project was initiated in 2012 with a total project value of $21,000,000.[102]

Recent developments

As at 28 February 2017, there are no publicly announced ocean (wave) projects in South Australia.

On 10 December 2016, Carnegie Wave Energy announced its successful trial of three buoys near Perth that provided power to a nearby naval base on Garden Island using a wave energy system for over 14,000 hours in total.[103] The Garden Island project with the next generation 1 MW CETO 6 unit is expected to be fully operational in 2017.[104]

4.9 Coal-fired generation

Background

In a pulverised coal boiler system, coal is crushed into a fine powder, fed into a boiler and burned. The resulting heat generates steam that is expanded through a steam turbine to produce electricity. The pressure and temperature of the steam at the turbine inlet and just prior to entering the condenser determines the relative generation plant efficiency.

This can be classified into:

- Sub-critical (16.5 MPa, 565 ºC).
- Supercritical (at least 24.8 MPa, 565–585 ºC).
- Ultra-supercritical (at least 24.8 MPa, 593–621 ºC).
- Advanced ultra-supercritical (at least 34.5 MPa, 677 ºC and above).

Supercritical and ultra-supercritical technologies are also known as high-efficiency, low-emissions technologies.[105]

Sub-critical units are capable of about 38% maximum net thermal efficiency while supercritical units are capable of 41%. Ultra-supercritical units are capable of 42% maximum net thermal efficiency. Advanced ultra-supercritical units are capable of at least 42% net thermal efficiency.[106]

[99] © 2016 Property of Ernst & Young et Associés. *Ocean energies, moving towards competitiveness: a market overview.* Available: https://arena.gov.au/files/2016/10/1605SG797-Etude-Seanergy-lowres.pdf. Viewed: 4 January 2017.
[100] © Commonwealth of Australia. ARENA. *Perth Wave Energy Project*. Available: https://arena.gov.au/project/perth-wave-energy-project/. Viewed: 4 January 2017.
[101] © Clean Energy Council 2017. *Marine energy*. Available: http://www.cleanenergycouncil.org.au/technologies/marine-energy.html. Viewed: 4 January 2017.
[102] © Commonwealth of Australia. ARENA. *bioWAVE Ocean Pilot at Port Fairy*. https://arena.gov.au/project/biowave-ocean-pilot-at-port-fairy/ Viewed: 4 January 2017.
[103] © 2016 Singapore Press Holdings Ltd. The Strait Times. *Underwater wave energy system operates for over 12 months in ground-breaking project.* 10 December 2016. Available: https://carnegiewave.com/wp-content/uploads/2016/12/Clean-energy-breakthrough-buoys-hopes-in-Australia-Australia_NZ-News-Top-Stories-The-Straits-Times.pdf. Viewed: 4 January 2017.
[104] © Clean Energy Council 2017. *Clean Energy Australia Report 2015.* Available: http://www.cleanenergycouncil.org.au/policy-advocacy/reports/clean-energy-australia-report.html. Viewed: 4 January 2017.
[105] © 2015 Electric Power Research Institute, Inc. *Australian Power Generation Technology Report*. 2015. Available: http://www.co2crc.com.au/wp-content/uploads/2016/04/LCOE_Report_final_web.pdf. Viewed: 4 January 2017.
[106] © 2015 Electric Power Research Institute, Inc. *Australian Power Generation Technology Report*. 2015. Available: http://www.co2crc.com.au/wp-content/uploads/2016/04/LCOE_Report_final_web.pdf. Viewed: 4 January 2017.

The type of coal used also affects efficiency. Brown coal deposits, which are found mostly in Victoria, have a high moisture content and require drying before combustion, reducing overall cycle efficiency. Black coal from Australia's eastern regions does not require drying prior to combustion.

Applications

Coal generation currently generates 40% of global electricity and contributes 30% of energy-related carbon emissions globally.[107]

In Australia, about 50% of installed generation capacity in the NEM is coal-fired as at 28 February 2017. Five subcritical units in Queensland comprise about 11% (5,270 MW) of this capacity, while the rest is supercritical units (2,946 MW).

In South Australia, all coal generation has now been withdrawn following the retirement of the Northern and Playford B power stations in 2016.

Recent developments

As at 28 February 2017, there are no new developments of coal-fired projects in South Australia.

The World Coal Association is driving a program to increase the average global efficiency rate of coal-fired power plants from 33% to 40%, a measure that could cut carbon emissions by two gigatonnes (Gt) per annum worldwide. The key to achieving this is breakthroughs in:

- High efficiency, low emission (HELE) coal-fired power plants.
- Ultra-supercritical plants which have been deployed commercially in Denmark, Germany, and Japan.[108]

In Australia, there has been renewed political interest in HELE coal-fired technologies. The Federal government is considering issuing a ministerial directive to the Clean Energy Finance Corporation (CEFC) to invest in clean coal projects to ensure energy security while transitioning to a low-emissions future.[109]

4.10 Carbon capture and storage

Background

Carbon capture and storage (CCS) is an enabling technology for reducing CO_2 emissions produced from the use of fossil fuels in electricity generation.[110] This technology involves separation of CO_2 from other gases produced at power plants, compression and transport of CO_2 to suitable storage sites, and injection of CO_2 captured to permanently remove it from the atmosphere.[111]

Depending on the power plant, carbon capture can take place through several processes, including:

- Pre-combustion: removes CO_2 before it is burned as part of the gasification process.
- Post-combustion: removes CO_2 from the flue gas after combustion by a separation method, such as using a liquid solvent.
- Oxyfuel (also known as oxy-firing combustion or oxy-combustion): burns the fuel in pure or enriched oxygen to create a flue gas composed mainly of CO_2 and water.

[107] © OECD/IEA 2016. *20 Years of Carbon Capture and Storage. Accelerating Future Deployment.* Available: http://www.iea.org/publications/freepublications/publication/20YearsofCarbonCaptureandStorage_WEB.pdf. Viewed: 4 January 2016.

[108] © 2017 World Coal Association. *High efficiency low emission coal*. Available: https://www.worldcoal.org/reducing-co2-emissions/high-efficiency-low-emission-coal. Viewed 4 January 2017.

[109] News Limited Copyright © 2017. "Clean Energy Finance Corporation could fund 'clean coal' power stations". Available: http://www.news.com.au/national/politics/clean-energy-finance-corporation-could-fund-clean-coal-power-stations/news-story/2002d56f68109945a33c1b57130e1339. Viewed: 20 February 2017.

[110] © 2015 Electric Power Research Institute, Inc. *Australian Power Generation Technology Report*. 2015. Available: http://www.co2crc.com.au/wp-content/uploads/2016/04/LCOE_Report_final_web.pdf. Viewed: 4 January 2017.

[111] Global CCS Institute. *Understanding CCS*. Available: http://www.globalccsinstitute.com/understanding-ccs/how-ccs-works-storage. Viewed: 30 January 2017.

Post combustion capture and oxy-firing[112] are both suitable for retro-fitting to existing pulverised coal generation.

Pipelines are the most common method of transporting large amount of CO_2 captured. Transport using trucks and ships are alternative options for small quantities.[113]

Several storage possibilities are proposed for CO_2 captured in CCS processes. These are:

- Geological storage (or geo-sequestration): CO_2 is injected and (ideally) permanently trapped in underground geological formations such as depleted oil and gas fields, deep unusable water formations, and un-mineable coal seams.
- Ocean storage: CO_2 is injected into deep oceans where it dissolves and becomes part of the global carbon cycle; relative cost and potential adverse environmental effects suggest this method might not be pursued.[114]
- Mineral storage (or mineral carbonation): CO_2 is reacted with metal oxides to produce stable carbonates. This mimics relatively slow natural processes. However, useful implementations must prove to be economically and environmentally viable.[115]

Although carbon capture has been demonstrated at pilot scale and in a number of large-scale industrial processes, more research and commercial-scale demonstration projects are required to lower the overall costs of CCS systems.[116]

Applications

The 2016 International Energy Agency (IEA) report on *20 Years of Carbon Capture and Storage* stated that the COP21 commitment will increase the need for carbon capture and storage (CCS). Although CCS is one of the technology solutions capable of delivering material reductions from fossil fuel use in power generation and industrial processes, only around USD 2.8 billion (of the total USD 30 billion in public funding announcements) was invested in large-scale CCS projects globally between 2007 and 2014.[117]

Most CCS systems for power generation around the world are classed as demonstration, prototype, or research and development. As at 28 February 2017, the Global CCS Institute database shows two operational large-scale CCS project in the power sector worldwide:

- Boundary Dam Unit 3 plant in Saskatchewan, Canada (Carbon Dioxide (CO_2) capture capacity of approximately 1 million tonnes per annum (Mtpa)).
- Petra Nova Carbon Capture Project (CO_2 capture capacity of approximately 1.4 Mtpa).[118]

The Otway Project in Victoria is the first CO_2 capture demonstration project in Australia, and is one of the world's largest CO_2 storage laboratories.[119] In the experiment conducted in 2011, CO_2-rich natural gas comprising 80% CO_2 and 20% methane was extracted, compressed, and transported via a 2.5 km pipeline to the Otway Project Site. The test proved that CO_2 storage in depleted gas fields was safe and effective, and that the structures of the project could store significant amounts of CO_2.[120]

[112] Oxy-firing can be considered a technology in its own right.
[113] Global CCS Institute. *Understanding CCS*. Available: http://www.globalccsinstitute.com/understanding-ccs/how-ccs-works-storage. Viewed: 30 January 2017.
[114] © GreenFacts 2001–2016 GreenFacts®. *CO2 Capture and Storage 6. Could CO2 be stored in the deep ocean?* Available: http://www.greenfacts.org/en/co2-capture-storage/l-3/6-ocean-storage-co2.htm. Viewed 4 January 2017.
[115] Goldberg, Chen, O'Connor, Walters, and Ziock. *CO_2 Mineral Sequestration Studies in US.* Available: https://www.netl.doe.gov/publications/proceedings/01/carbon_seq/6c1.pdf. Viewed: 4 January 2017.
[116] Global CCS Institute. *Understanding CCS*. Available: http://www.globalccsinstitute.com/understanding-ccs/how-ccs-works-storage. Viewed: 30 January 2017.
[117] © OECD/IEA 2016. *20 Years of Carbon Capture and Storage. Accelerating Future Deployment.* Available: http://www.iea.org/publications/freepublications/publication/20YearsofCarbonCaptureandStorage_WEB.pdf. Viewed: 4 January 2016.
[118] Global CCS Institute. *Large Scale CCS Projects.* 2017. Available: https://www.globalccsinstitute.com/projects/large-scale-ccs-projects. Viewed: 28 February 2017.
[119] Global CCS Institute. *CO2CRC Otway Project.* Available: http://www.globalccsinstitute.com/projects/co2crc-otway-project. Viewed: 4 January 2017.
[120] © Government of Western Australia. Department of Mines and Petroleum. Community & Education. Carbon Capture and Storage. CCS around the world. *Otway Project Fact Sheet*. January 2014. Available: http://www.dmp.wa.gov.au/Documents/Community-Education/Otway_Project.pdf. Viewed: 4 January 2017.

The Callide Oxyfuel Project in Queensland demonstrated oxy-firing and CO_2 capture at the Callide A power station in 2014. The benefits observed from the demonstration were increased boiler combustion efficiency, greater than 50% reduction in stack nitrogen oxides (NO_x) mass emission rates, and almost complete removal of all toxic gaseous emissions.[121]

Recent developments

Based on the 2015 APGTR, natural gas CCGT with CCS is the lowest cost new-build baseload low-emissions fossil-fuel technology. The report stated that while CCS technologies are not very mature, coal with CCS is slightly more mature than gas with CCS.

In South Australia, AGL Energy Limited and Air Liquide announced in 2015 that they have partnered to recover CO_2 at the Torrens Island Power Station site in Adelaide. The CO_2 recovery plant is estimated to capture and purify up to 0.05 Mtpa of CO_2 emissions per year.[122, 123] The date for implementation of this project is not yet known.

On 15 February 2017, The University of Queensland and Gamma Energy Technology released *A Roadmap for Carbon Capture and Storage in Australia*, outlining a way forward for CCS deployment in Australia.[124]

4.11 Integrated gasification combined cycle

Background

Coal gasification converts coal into “syngas” (hydrogen, carbon monoxide, water, CO_2, and methane) by oxidising or burning it under high temperatures and pressures with oxygen and steam. The resulting gas stream is burnt in a conventional CCGT.

In integrated gasification combined cycle (IGCC) technology, heat recovery in the gasification unit is integrated with the combined cycle of the plant. [125] IGCC provides a mechanism for using a low cost fuel, such as coal, in a high-efficiency power generation cycle, such as a CCGT. While it uses more energy, overall cycle efficiency is still greater than a conventional pulverised coal-fired power plant, and can be combined with CCS technologies.

Applications

Integrated gasification combined cycle (IGCC) generation technology is still developing, with a limited number of manufacturers offering commercial plants. Only a few full-scale IGCC plants are operational globally. The National Energy Technology Laboratory (NETL) has identified four pioneering gasification plants around the world[126]:

- 313 MW Tampa Electric IGCC Project in Florida, USA.
- 292 MW Wabash River Coal Gasification Repowering Project in Indiana, USA.
- 253 MW Willem Alexander IGCC Plant in the Netherlands.
- 330 MW ELCOGAS IGCC Plant in Spain.

[121] Dr. Spero. Oxyfuel Technologies Pty Ltd. *Callide Oxyfuel Project – Lessons Learned.* May 2014. Available: http://hub.globalccsinstitute.com/sites/default/files/publications/157873/callide-oxyfuel-project-lessons-learned.pdf. Viewed: 4 January 2017. (Supported by Global CCS Institute.)

[122] AGL Energy Limited. Media Centre. *AGL and Air Liquide partner to reduce carbon emissions*. 4 June 2015. Available: https://www.agl.com.au/about-agl/media-centre/article-list/2015/june/agl-and-air-liquide-partner-to-reduce-carbon-emissions. Viewed: 4 January 2017.

[123] © Air Liquide 2017. *It's Happening Now in Australia*. Available: https://www.airliquide.com/australia. Viewed: 4 January 2017.

[124] Greig, C., Bongers, G., Stott, C., and Byrom, S. *Energy Security and Prosperity in Australia. A Roadmap for Carbon Capture & Storage*. Available: http://www.powerfactbook.com/media-categories/media-releases. Viewed: 17 February 2017.

[125] © 2015 Electric Power Research Institute, Inc. *Australian Power Generation Technology Report*. 2015. Available: http://www.co2crc.com.au/wp-content/uploads/2016/04/LCOE_Report_final_web.pdf. Viewed: 4 January 2017.

[126] US DOE. NETL. *IGCC Project Examples*. Available: https://www.netl.doe.gov/research/coal/energy-systems/gasification/gasifipedia/project-examples#nine. Viewed: 4 January 2017.

In Australia, the Wandoan Power Consortium conducted a pre-feasibility study in 2010 to assess the viability of an IGCC power station with carbon capture. One of the key findings was that GE Energy's technology for an IGCC plant with 90% CO_2 capture is technically viable and could be deployed in Queensland at industrial scale.[127] In 2012, the ZeroGen Pre-feasibility Study reviewed a potential IGCC plant with CCS in Queensland and found that new industrial-scale, low-emissions coal generation plants that incorporate CCS are not currently economic.[128]

Recent developments

As at 28 February 2017, there are no publicly announced IGCC power plant projects at any development stage in Australia.

Internationally, as at June 2016, the NETL database has recorded 13 active gasification projects globally, two in the USA and 11 outside the USA.[129] The 582 MW Kemper County Energy Facility[130] in Mississippi, USA, is a leading example of IGCC with carbon capture, however the project is behind schedule and subject to billion dollar cost blowouts.[131]

[127] © 2011 Wandoan Power Consortium. *Wandoan Power Project Pre-feasibility Study Knowledge Sharing Report*. June 2011. Available: http://hub.globalccsinstitute.com/sites/default/files/publications/20586/wandoan-power-project-pre-feasibility-study-knowledge-sharing-report.pdf. Viewed: 4 January 2017.

[128] © The University of Queensland. Garnett, Greig, and Oettinger. The University of Queensland. *Zerogen IGCC with CSS. A Case History*. 2014. Available: https://energy.uq.edu.au/files/1084/ZeroGen.pdf. Viewed: 4 January 2017.

[129] US DOE. NETL. *Gasification Plant Databases*. Available: http://www.netl.doe.gov/research/coal/energy-systems/gasification/gasification-plant-databases. Viewed: 4 January 2017.

[130] © 2014 Mississippi Power. *Kemper County Energy Facility*. Available: http://mississippipowernews.com/kemper-county-energy-facility/. Viewed: 4 January 2017.

[131] IEEE, Spectrum *Kemper County and the Perils of Clean Coal Technology* http://spectrum.ieee.org/energywise/energy/fossil-fuels/kemper-county-and-the-perils-of-clean-coal-technology Viewed 3 March 2017.

5. STORAGE

Background

For energy commodities like oil, gas, and coal, storage is an integral part of the supply chain, providing a buffer to help balance supply and demand over a few days, weeks, months or even a year. The absence of cost-effective electricity storage (other than hydro storage) means supply is constantly being adjusted to meet demand across the entire grid at any given time. The increasing penetration of both wind and solar PV, which are inherently intermittent and have strong daily and seasonal variations, is expected to further complicate the balancing challenge by adding more variability to the supply and demand side.

According to the IEA's 2016 *Tracking Clean Energy Progress* report, electricity storage technologies are expected to play a significant role in achieving the 2 °C scenario goal of the COP21 commitment. They have the capability to provide flexibility to energy systems by complementing the potential integration of intermittent renewables and distributed generation and enhancing management of the electricity grid.[132]

Applications

Storage technologies can play a diverse range of roles in the electricity market. Their potential applications vary depending on location in the grid, as summarised in Table 14.[133, 134, 135]

[132] © OECD/IEA 2016. *Tracking Clean Energy Progress 2016.* Available: http://www.iea.org/publications/freepublications/publication/TrackingCleanEnergyProgress2016.pdf. Viewed: 20 December 2016.
[133] © OECD/IEA 2014. *Energy Technology Perspectives 2014. Harnessing Electricity's Potential.* Available: https://www.iea.org/publications/freepublications/publication/EnergyTechnologyPerspectives2014.pdf. Viewed: 4 January 2017.
[134] Sandia National Laboratories. *DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA.* July 2013. Available: https://energy.gov/sites/prod/files/2013/08/f2/ElecStorageHndbk2013.pdf. Viewed: 4 January 2017.
[135] © 2015 Electric Power Research Institute, Inc. *Australian Power Generation Technology Report*. 2015. Available: http://www.co2crc.com.au/wp-content/uploads/2016/04/LCOE_Report_final_web.pdf. Viewed: 4 January 2017.

Table 14 Applications for electricity storage

	Application	Description
Generation	Seasonal storage	Storage over months, based on seasonal variability on the supply and demand sides of the energy system
	Inter-seasonal or weekly storage	Storage over days or weeks, for the loss of an interconnection or supply disruption
	Arbitrage	Storage over hours, between low-price periods and high priced periods
	Large-scale wind and PV grid integration	Storage to help integration of variable renewable energy by smoothing supply variability
System operation	Frequency regulation and load following	Provision or absorption of active power to balance the supply and demand under normal conditions
	Reserve capacity	Reserve capacity to compensate for a rapid, unexpected loss in generation
	Voltage support	Provision or absorption of reactive power to maintain voltage levels
	Black start	Black start capabilities to allow electricity supply resources to restart without pulling electricity from the grid
Transmission and Distribution (T&D)	Congestion management and investment deferral	Storage technologies to relieve system congestion and defer construction of certain T&D infrastructure
	Voltage support	Provision of minimal active power to damp voltage fluctuations on the distribution system
End use	Small-scale PV integration and increased self-consumption/ tariff avoidance	Storage technologies installed at the customer level to allow energy supply from self-generation (e.g. from solar PV) to be shifted to meet the timing of demand and avoid high time-of-use charges
	Power quality	Storage technology installed at the customer level to protect customer loads from short-duration events that affect the quality of power
	Power reliability	Behind-the-meter storage to provide backup power supply
	Retail energy time shift	The battery can be charged during off-peak low-priced periods and discharge during peak high-priced periods
	Off-grid	Compact storage to supply power to consumers not connected to electric grid

Storage technologies

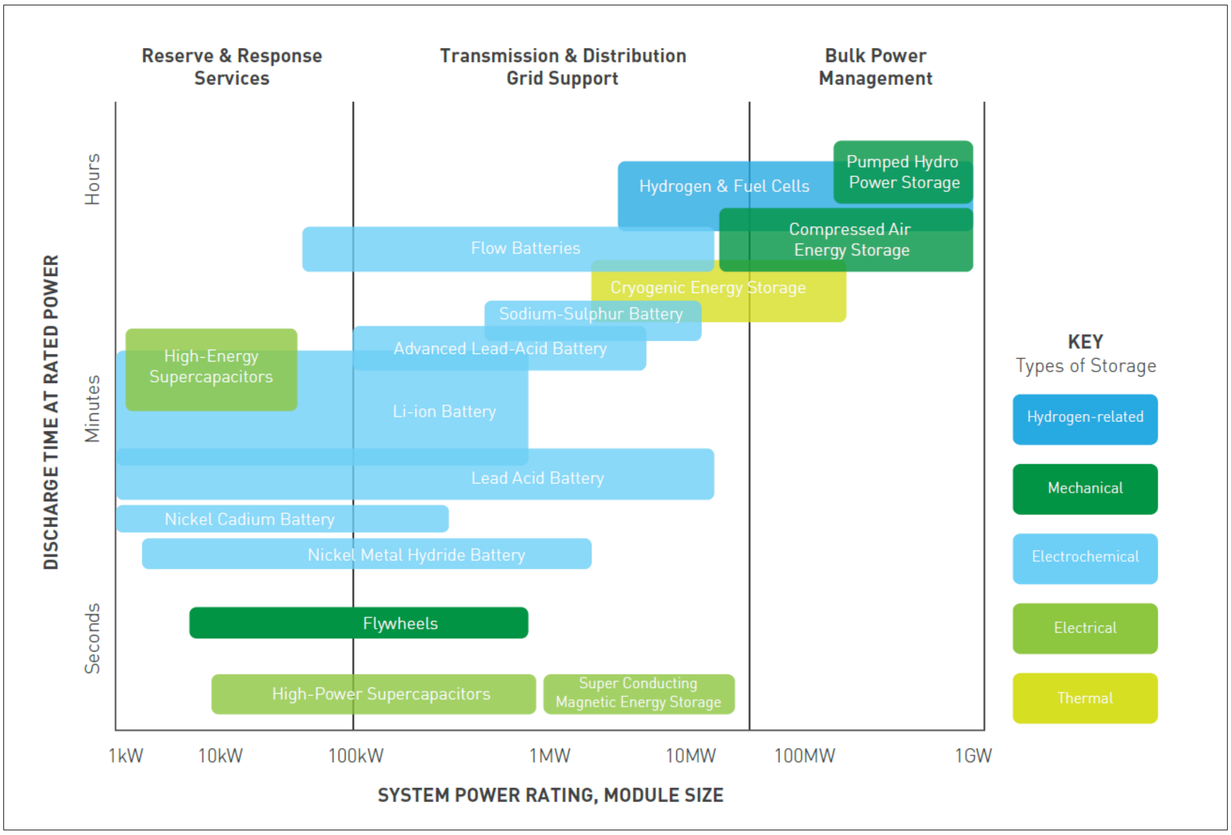
Different energy storage technologies can be considered for providing a range of electric grid services, and can be mapped according to two key characteristics: power rating and discharge time.

Figure 16 indicates pumped hydro and compressed air energy storage (CAES) are candidates for bulk energy services, which are suitable technologies for large-scale power (approximately 100–1,000 MW) and longer-term storage (hours to weeks).

Technologies such as flywheels and high-power supercapacitors can support load shifting and power quality at lower power (around 10 kW–1 MW) and short-term storage (seconds to minutes).

Being modular and scalable, electrochemical batteries such as Lithium-ion (Li-ion) are capable of helping maintain the power quality at small-scale power (approximately 1–100 kW) and medium-term storage (minutes to hours).

Figure 16 Positioning of energy storage technologies



Source: The Centre for Low Carbon Futures 2012. *Pathways for energy storage in the UK*. 27 March 2012. Available: http://www.lowcarbonfutures.org/sites/default/files/Pathways%20for%20Energy%20Storage%20in%20the%20UK.pdf.

The brief descriptions of energy storage technologies provided in Table 15 are adapted from information provided in the *IEA Energy Technology Perspectives*[136], 2015 APGTR, and the *U.S. Department of Energy Electricity Storage Handbook.*[137]

136 © OECD/IEA 2014. *Energy Technology Perspectives 2014. Harnessing Electricity's Potential.* Available: https://www.iea.org/publications/freepublications/publication/EnergyTechnologyPerspectives2014.pdf. Viewed: 4 January 2017.

137 Sandia National Laboratories. *DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA.* July 2013. Available: https://energy.gov/sites/prod/files/2013/08/f2/ElecStorageHndbk2013.pdf. Viewed: 4 January 2017.

Table 15 List of energy storage technologies

Technology	Description
Pumped hydro energy storage (PHS)	PHS plants comprise a low and high water reservoir. Water is pumped using electricity up to the high reservoir. The stored energy can be transformed back into electricity by letting the water fall from the high reservoir to drive a turbine. PHS is a mature technology used widely on a large commercial scale. Topology is the main limitation for new-build, expansion or reservoir hydro upgrades. Costs also vary widely, depending on the specific location and works required.
Hydrogen (H_2)	Electricity is stored as hydrogen by driving an electrolyser that produces hydrogen from air and water. Stored hydrogen can consequently power a fuel cell or combustion turbine and so be reconverted into electricity. Total cycle efficiency is low due to the many conversion steps: electrolyser (efficiency 60%), hydrogen storage (90%), and CCGT (50%) – the final efficiency is less than 32%.
Compressed air energy storage (CAES)	CAES involves compressing and storing air, either in geological underground voids (e.g. salt caverns) or designated above-ground vessels. Electricity is transformed into thermal and mechanical energy as hot pressurised air. Later, the compressed air is heated by burning natural gas and then expanded in a gas turbine to generate electricity. The process of compressing air for storage generates heat. Heat exchangers, underground pipes, and above-ground storage vessels could make CAES projects independent of geology and improve efficiencies, but will cost more.
Flywheel (FW)	Flywheels are powered by electricity and can store electrical energy as rotating inertia. The discharging process transforms the flywheel movement back into electricity through a generator with efficiencies of between 90% and 95%.
Super-capacitors (SC)	Super-capacitors store small electricity quantities in an electric field between two capacitor plates. At present, only limited grid installations exist.
Superconducting magnetic energy storage (SMES)	SMES systems store energy in a magnetic field produced by a coil with multiple windings. They operate at very low temperature to minimise resistance.
Battery storage	Batteries can store electricity as electrochemical energy. A diverse set of battery technologies exist today, listed below.
Lithium-based (Li-ion)	Li-ion batteries, due to their high-energy density, are already used for many small power stationary applications.
Lead-acid (LA)	LA batteries are a mature technology used mainly as starters in automobiles and are the current leader in the industrial battery sector (e.g. uninterruptable power source and off-grid). The innovation potential is relatively small: limited lifetime and low energy density are major drawbacks.
Sodium-sulphur (NaS)	NaS batteries are most suited for daily operation. They need to be kept at high operational temperature (250 ºC to 350 ºC), which can be maintained from the heat released by chemical reactions combined with efficient cell isolation.
Sodium-nickel-chloride ($NaNiCl_2$)	$NaNiCl_2$ batteries are high-temperature battery devices similar to NaS. In charging the battery, salt (NaCl) and Nickel (Ni) are converted into Nickel-Chloride ($NiCl_2$) and molten sodium (Na). The chemical reactions are reversed in the discharging process.
Flow battery	Flow batteries are a unique category of batteries, composed of two electrolytes separated by an ion-selective membrane that allows only specific ions to pass during the charging or discharging process. The electrolyte can be stored in separate tanks and pumped into the battery as needed. Flow battery contains more parts than some other technologies but it can be fully discharged on a regular basis which allows a better lifetime.

Applications and recent developments

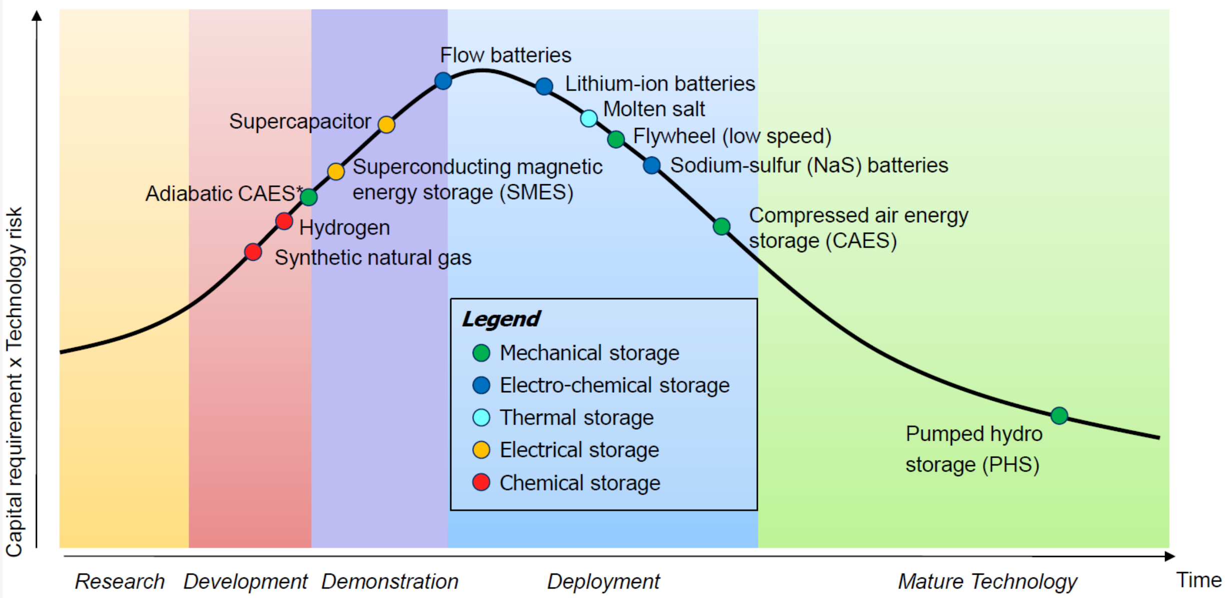
Energy storage technologies are at very different levels of maturity, with many clustered at the high capital requirement and risk stages.

This is illustrated in Figure 17, which shows PHS as the most mature storage technology. PHS continues to dominate large-scale energy storage globally, reaching 149 GW in 2015 (or 96% of the total installed capacity).[138] PHS typically has approximately 70–85% efficiency and may be expected to

[138] © OECD/IEA 2016. *Tracking Clean Energy Progress 2016.* Available: http://www.iea.org/publications/freepublications/publication/TrackingCleanEnergyProgress2016.pdf. Viewed: 20 December 2016.

operate over a 30–60 year lifetime.[139] On the other hand, technologies such as natural gas batteries, hydrogen batteries, and adiabatic CAES are at early stages of development.

Figure 17 Energy storage technology maturity curve



Source: SBC Energy Institute. *Electricity Storage*. September 2013. Available: http://www.sbcenergyinstitute.com/_/media/Files/SBC%20Energy%20Institute/SBC%20Energy%20Institute_Electricity_Storage%20Factbook_vf1.pdf

Pumped hydro storage in Australia

As at 30 September 2016, pumped hydro storage accounted for 99% of the total installed capacity of storage technologies in Australia.[140] This comprises three major large-scale pumped hydro facilities with a total combined capacity of 2,240 MW (shown in Table 16).

However, no new large-scale facilities have been installed in the last three decades.

Table 16 Australian large-scale pumped hydro storage capacity as at 28 February 2017

Power station	Region	Pump capacity (MW)
Wivenhoe	QLD	480
Shoalhaven	NSW	240
Tumut-3	NSW	600

At the Federal Government's request, the CEFC and ARENA are seeking opportunities to fund large-scale storage and other flexible capacity projects, including pumped hydro.[141] In response, a

[139] © 2013 SBC Energy Institute. *Electricity Storage.* September 2013. Available: http://www.sbcenergyinstitute.com/_/media/Files/SBC%20Energy%20Institute/SBC%20Energy%20Institute_Electricity_Storage%20Factbook_vf1.pdf. Viewed: 4 January 2017.
[140] US DOE. Office of Electricity Delivery & Energy Reliability. *DOE Global Energy Storage Database.* Available: http://www.energystorageexchange.org/projects?utf8=%E2%9C%93&technology_type_sort_eqs=&technology_type_sort_eqs_category=&country_sort_eq=Australia&state_sort_eq=South+Australia&kW=&kWh=&service_use_case_inf=&ownership_model_eq=&status_eq=&siting_eq=&order_by=&sort_order=&search_page=1&size_kw_ll=&size_kw_ul=&size_kwh_ll=&size_kwh_ul=&show_unapproved=%7B%7D. Viewed: 4 January 2017.
[141] Commonwealth of Australia. *Government supports project with potential for pumped hydro*. 16 February 2017. Available: http://www.pm.gov.au/media/2017-02-16/government-supports-project-potential-pumped-hydro. Viewed: 17 February 2017.

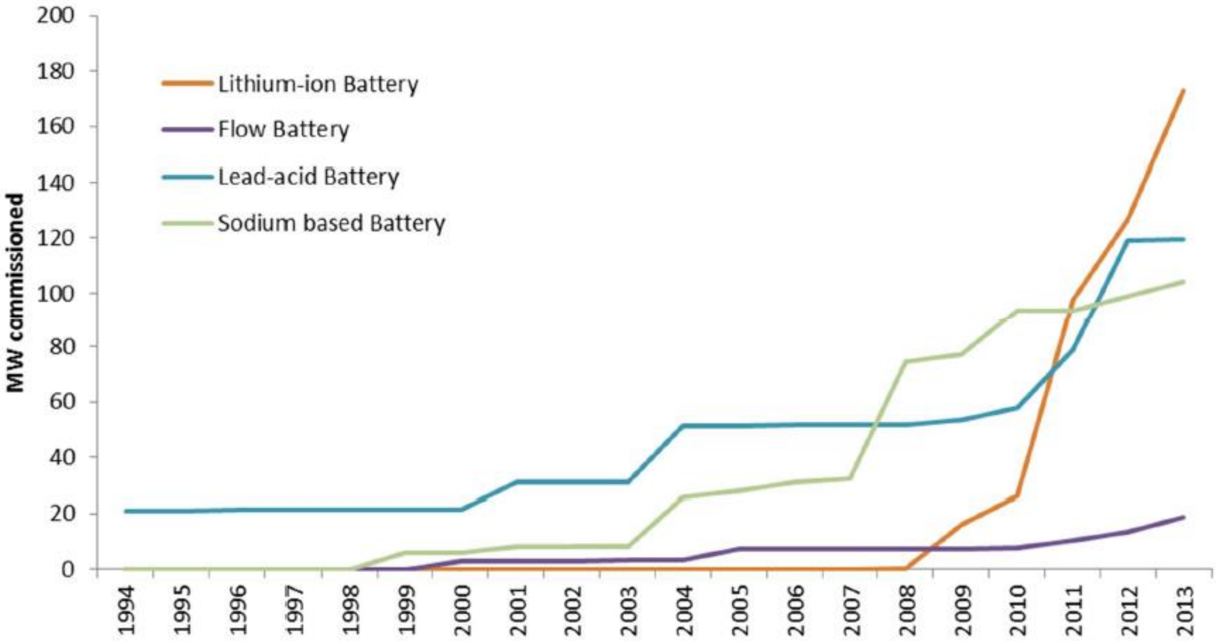
potential site for pumped hydro has been identified at Cultana on the Eyre Peninsula in South Australia, and is being further investigated by the Australian National University.[142]

On 21 February 2017, Energy Australia received a $450,000 grant from ARENA to develop a pumped hydro storage project in the Upper Spencer Gulf, South Australia.[143]

Battery storage

Battery storage has received extensive media attention recently, particularly with the high-profile launch of residential storage systems such as Tesla's Powerwall 2.[144] As Figure 18 shows, the deployment of battery storage globally has accelerated strongly since 2010, especially for the Lithium-ion technology.

Figure 18 Cumulative global capacity (MW) of battery storage[145]



As listed on the US Department of Energy database.

One of the key drivers of this strong deployment was the rapid reduction in battery technology costs. An average cost learning rate[146] of 22% of lithium-ion battery technology has been observed since 2010[147], and the International Renewable Energy Agency (IRENA) has predicted that the battery storage price will continue to fall, as Figure 19 indicates.[148]

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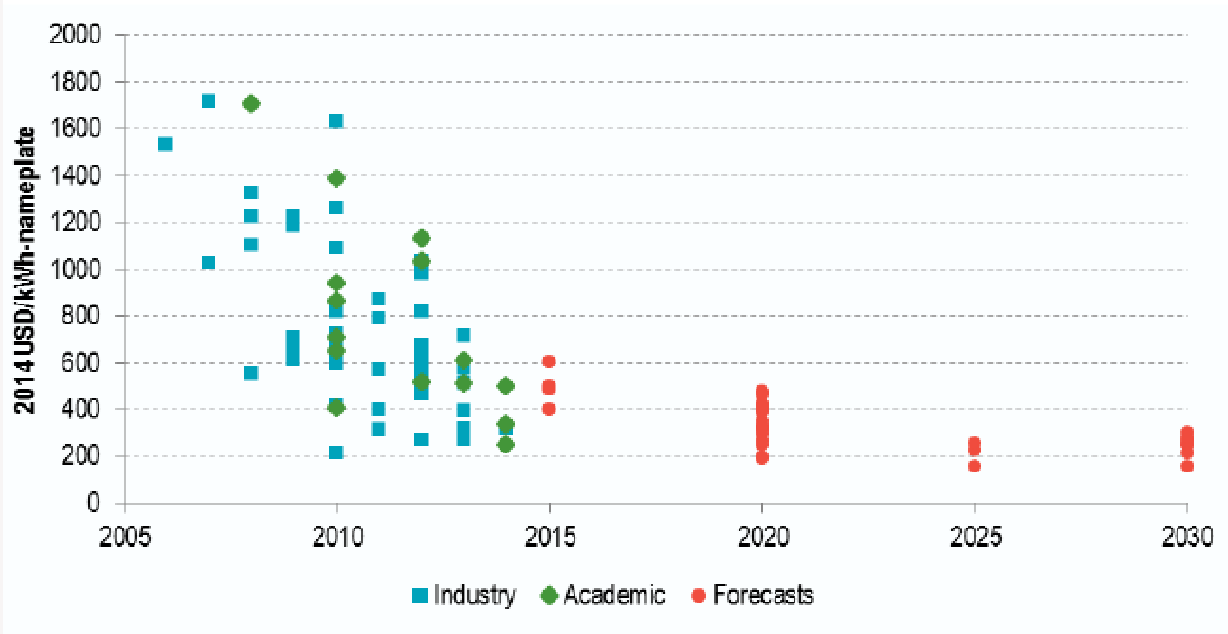
[142] Australian Energy Council. *Watery solution to power problems*. 17 February 2017. Available: https://www.energycouncil.com.au/media/7143/4-watery-solution-to-power-problems.pdf. Viewed: 20 February 2017.
[143] © ABC. *Solar power battery storage would solve SA's electricity problems, company says*. 21 February 2017. Available: http://www.abc.net.au/news/2017-02-21/solar-power-battery-storage-could-have-prevented-sa-blackout/8290304. Viewed: 21 February 2017.
[144] Tesla Motors © 2017. *Powerwall 2*. Available: https://www.tesla.com/en_AU/powerwall. Viewed: 21 December 2016.
[145] © AECOM Pty Ltd. *Energy Storage Study* (Prepared for Australian Renewable Energy Agency). 13 July 2015. Available: https://arena.gov.au/files/2015/07/AECOM-Energy-Storage-Study.pdf. Viewed: 4 January 2017. (Prepared for ARENA.)
[146] Refers in this case to the reduction in technology investment costs for every doubling of cumulative (historical) installed capacity.
[147] © OECD/IEA 2016. *Tracking Clean Energy Progress 2016.* Available: http://www.iea.org/publications/freepublications/publication/TrackingCleanEnergyProgress2016.pdf. Viewed: 20 December 2016.
[148] © IRENA 2015. *Battery Storage for Renewables: Market Status and Technology Outlook*. January 2015. Available: http://www.irena.org/DocumentDownloads/Publications/IRENA_Battery_Storage_report_2015.pdf. Viewed: 4 January 2017.

Figure 19 Historical trends in Li-ion battery costs



Source: Electric Power Research Institute, Inc. *Australian Power Generation Technology Report*. 2015. Available: http://www.co2crc.com.au/wp-content/uploads/2016/04/LCOE_Report_final_web.pdf.

Battery storage is the next emerging storage technology nearest to maturity in Australia. As at 30 September 2016, out of 44 storage projects in Australia, 28 are operational. There is one battery storage project under construction, while nine battery storage projects are announced.[149]

South Australia has three prominent battery storage projects – one operational and two under construction (listed in Table 17).[150]

Table 17 Prominent battery storage projects in South Australia

Project name	Capacity kW)	Technology type	Status	Applications
RedFlow 300 kW Adelaide	300	Flow battery	Operational	Electric bill management, electric supply reserve capacity
Kingfisher Project (Stage 1)	20,000[151]	Electro-chemical	Under construction	Renewables capacity firming, renewable energy time shift
Kingfisher Project (Stage 2)	100,000	Electro-chemical	Under construction	Renewables capacity firming, renewable energy time shift

In August 2014, the ARENA funded Phase 1 of the Energy Storage for Commercial Renewable Integration – South Australia (ESCRI-SA) project to investigate the business case for deploying energy storage device within the South Australian transmission system. The project, which was undertaken by a consortium of AGL, WorleyParsons, and ElectraNet, planned to install a 10 MW/20 MWh Lithium-ion battery storage device close to the Wattle Point Wind Farm. In December 2015, the consortium

[149] US DOE. Office of Electricity Delivery & Energy Reliability. *DOE Global Energy Storage Database.* Available: http://www.energystorageexchange.org/projects?utf8=%E2%9C%93&technology_type_sort_eqs=&technology_type_sort_eqs_category=&country_sort_eq=Australia&state_sort_eq=South+Australia&kW=&kWh=&service_use_case_inf=&ownership_model_eq=&status_eq=&siting_eq=&order_by=&sort_order=&search_page=1&size_kw_ll=&size_kw_ul=&size_kwh_ll=&size_kwh_ul=&show_unapproved=%7B%7D. Viewed: 4 January 2017.

[150] US DOE. Office of Electricity Delivery & Energy Reliability. *DOE Global Energy Storage Database.*

[151] © Lyon Group. *Kingfisher Solar Storage Project.* Available: http://www.lyoninfrastructure.com/kingfisher.html. Viewed: 6 February 2017.

reported the proposal was not currently considered profitable, but is considering a similar demonstration project in the future.[152]

Since June 2016, when the latest NEFR was published, there have been further step changes in the cost and performance of energy storage systems, for example the release of the Tesla Powerwall 2 that has double the battery capacity and smaller physical size at a cost similar to the first Powerwall.[153]

On 5 August 2016, AGL announced the launch of a $20 million virtual power plant battery demonstration project which involved constructing 1,000 centrally controlled battery storage system with individual 5kW/7 kWh storage specification in South Australia. The project is planned to deploy in three phases with the participants able to purchase a heavily discounted Sunverge battery system.[154]

Potential power system security benefits of battery storage are discussed in Chapter 6.

5.1 Electric vehicles

Background

Electric vehicles (EVs) refer to electric cars such as battery electric vehicles (BEVs), and plug-in hybrid electric vehicles (PHEVs).

A brief description of EVs from AEMO's 2015 *Emerging Technologies Information Paper* is provided in Table 18. In this paper, AEMO does not address "hybrid" EVs and other fuel-powered vehicle technologies, such as hydrogen and fuel cells.[155]

Table 18 List of battery rechargeable electric vehicles

Vehicle	Description
Battery Electric Vehicle (BEV)	BEVs are powered only by energy stored in batteries. Batteries are charged by plugging into the grid and the range of BEV is limited by the size of the battery.
Plug-in Hybrid Electric Vehicle (PHEV)	PHEVs combine an internal combustion engine (ICE) with an electric motor. Electrical battery is charged by plugging into the grid. The vehicle is primarily powered by the electric engine and after the battery is discharged, ICE will be used and the car functions much like a hybrid vehicle.

The deployment of EVs may have a strong impact on the load profile of the power generation system and the load distribution across the electricity network. There is scope to efficiently increase the utilisation of distribution networks, and therefore decrease per unit charges, if charge and discharge patterns are coordinated to avoid increasing peak loads.[156]

Applications

The IEA reported a total number of 477,000 electric car sales in 2015, corresponding to an annual growth of 70%. In the meantime, public charging infrastructure continued to grow, with the number of "slow" alternating current (AC) chargers growing from 94,000 in 2014 to 148,000 by 2015.[157]

[152] © Commonwealth of Australia. ARENA. Energy Storage for Commercial Renewable Integration - South Australian (ESCRI-SA). *Milestone 5. Phase 1 – General Project Report*. December 2015. Available: https://arena.gov.au/wp-content/uploads/2016/04/ESCRI-General-Project-Report-Phase-1.pdf. Viewed: 20 December 2016.
[153] © 2015. Off-Grid Energy Australia. *Tesla Powerwall 2*. Available: http://www.offgridenergy.com.au/tesla-powerwall/. Available: 4 January 2017.
[154] AGL Energy. ASX and Media Releases. "AGL launches world's largest solar virtual power plant battery demonstration to benefit customers", 5 August 2016. Available: https://www.agl.com.au/about-agl/media-centre/article-list/2016/august/agl-launches-world-largest-solar-virtual-power-plant. Viewed: 4 January 2017.
[155] AEMO. *Emerging Technologies Information Paper*. June 2015. Available: https://www.aemo.com.au/-/media/Files/PDF/Emerging-Technologies-Information-Paper.pdf.
[156] © OECD/IEA 2016. *Global EV Outlook 2016. Beyond one million electric cars*. Available: https://www.iea.org/publications/freepublications/publication/Global_EV_Outlook_2016.pdf. Viewed: 4 January 2017.
[157] © OECD/IEA 2016. *Tracking Clean Energy Progress 2016.* Available: http://www.iea.org/publications/freepublications/publication/TrackingCleanEnergyProgress2016.pdf. Viewed: 4 January 2017.

Table 19 provides the EV sales in each NEM region up to 30 April 2015.[158]

Table 19 Total number of electric vehicles sold by April 2015

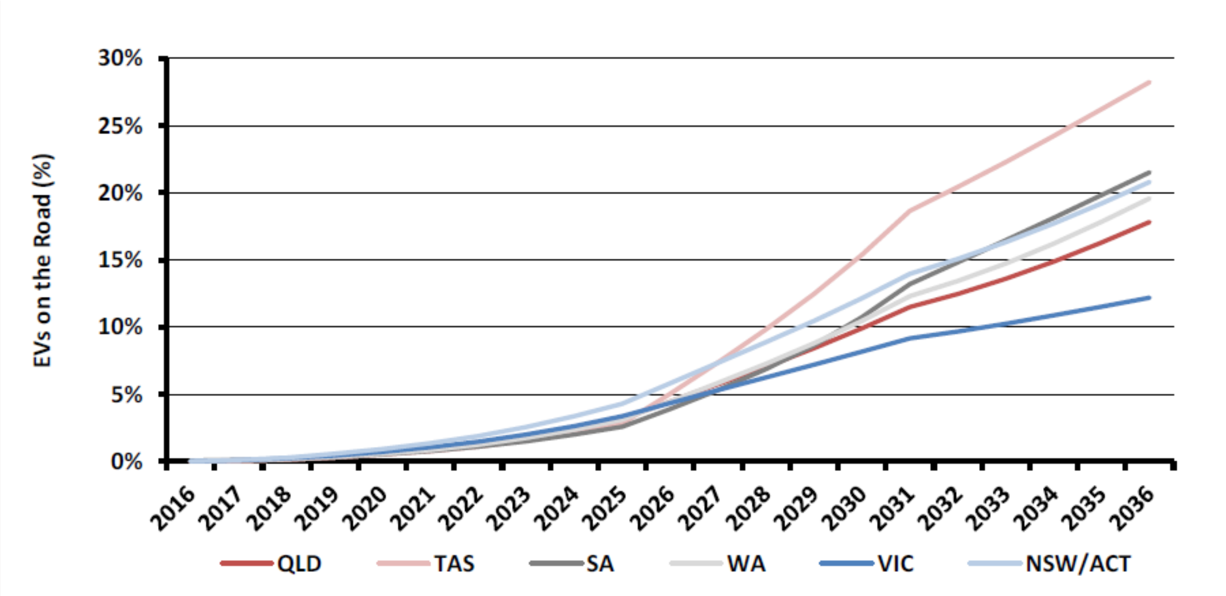
	QLD	NSW & ACT	SA	VIC	TAS	NEM
BEVs	90	170	171	268	13	712
PHEVs	204	296	376	306	15	1,197

The IEA foresees EVs being a major contributor to the goal of the COP21 commitment in the power sector, noting that the utilisation of EVs only results in net CO_2 savings if vehicle charging patterns make use of low emission technologies or encourage a decarbonised grid.[159]

In Australia, EVs comprised up to 0.2% of annual vehicle sales in 2015. In 2016, AEMO's *Electric Vehicles Insights Report*[160] highlighted total EV (both BEV and PHEV) sales projections in the NEM of up to 276,800 vehicles per annum by 2036. The total vehicles on the road in the NEM are forecast to reach over 2.85 million by 2036. AEMO projects the percentage to increase, assuming decline in costs, increased availability and capacity of new EV models, and government and industry support. Growth in uptake of electric vehicles may remain constrained until a fuller product/style range is available and public charging infrastructure is developed.[161]

In South Australia, the EV uptake is projected to reach approximately 237,290 (21.5%) by 2036, as shown in Figure 20. South Australia is projected to have relatively higher EV uptake compared to other NEM regions (except Tasmania).

Figure 20 Forecast electric vehicle uptake in the NEM regions



[158] AEMO. *Emerging Technologies Information Paper*. June 2015.
[159] © OECD/IEA 2016. *Global EV Outlook 2016. Beyond one million electric cars*. Available: https://www.iea.org/publications/freepublications/publication/Global_EV_Outlook_2016.pdf. Viewed: 4 January 2017.
[160] AEMO and Energeia. *Electric Vehicles*. August 2016. Available: https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/NEFR/2016/AEMO-insights_EV_24-Aug.pdf. Viewed: 4 January 2017.
[161] AEMO and Energeia. *Electric Vehicles*. August 2016.

Recent developments

As part of the Adelaide Sustainable City Incentive Scheme, the Adelaide City Council has announced it will roll out at least 40 EV charging stations throughout the city by the end of 2017, in addition to the four charging points it currently has in two CBD car parks. The Council will provide up to $5,000 for each EV charging point as part of the scheme.[162] The scheme requires that the EV charging system must to be connected within the electrical installation, located immediately adjacent to the parking space where an EV will be parked, a permanent fixture to the premises, and cannot be removed without prior consent of council for a period of five years from the date of the payment of the rebate.[163]

In November 2016, the building of two electric buses was announced as part of the State Government's Northern Economic Plan in South Australia.[164]

[162] Adelaide City Council. *City of Adelaide leading the way in support from electric vehicles*. 23 October 2016. Available: http://www.adelaidecitycouncil.com/media-centre/media-releases/city-of-adelaide-leading-the-way-in-support-for-electric-vehicles. Viewed: 4 January 2017.

[163] Adelaide City Council. *Adelaide Sustainable City Incentive Scheme*. Available: http://www.adelaidecitycouncil.com/assets/documents/FORM-incentives-rebates-electric-vehicle-charging-system.pdf. Viewed: 4 January 2017.

[164] © 2017 Australian Electric Vehicle Association Incorporated SA Branch. Announcement from Transit Australia Group. *The Advertiser News dated 29 November 2016. Wheels on the bus to north are rolling on.* Available: http://aevasa.kestar.com.au/. Viewed: 4 January 2017.

6. SUPPORTING TECHNOLOGIES

"Supporting technologies" refers to a high-level potential solution to existing and future power system security challenges related to high penetration levels of non-synchronous generation across the NEM.

Background

Generation technologies such as coal, gas, and hydro are "synchronous" generators[165] providing inertia to the power system and dampening the deviation of system frequency. Inertia helps to slow the rate of change of frequency (RoCoF) of the grid. In comparison, technologies such as wind and solar typically connect via inverter technologies. They are non-synchronous generators that do not provide inertia, because they are coupled to the network via power electronic devices.

The NEM is evolving, with large-scale, centrally-dispatched synchronous generation progressively being displaced by large-scale intermittent generation as well as distributed intermittent generation.

In August 2016, AEMO's Future Power System Security (FPSS) program identified four emerging technical challenges related to the displacement of synchronous generation by non-synchronous generation that required immediate investigation[166]:

1. Frequency control – a reduction in conventional synchronous plant results in less inertia available in the power system. This in turns reduces frequency stability, which results in a higher RoCoF following a supply demand imbalance. High RoCoF levels make it increasingly difficult to manage frequency disturbances, because the system must act more rapidly to arrest the frequency change and maintain the frequency standard. If the RoCoF level is unacceptably high, it can result in a cascading trip of load or generation.
2. Management of extreme power system conditions – a power system with high RoCoF is more susceptible to extreme power system conditions, particularly during non-credible separation events between South Australia and Victoria. Additional or improved emergency frequency control schemes may be required to mitigate a black system in these situations.
3. Visibility of the power system – increasing amounts of distributed energy resources (DER) such as rooftop PV, battery storage systems, home energy management systems, dynamic pricing models, and other advances in technology can have a material impact on the dynamic behaviour of the power system. The market operator's ability to dispatch utility-scale generation will be affected due to the loss of market visibility.
4. System strength – a reduction in system strength as the generation mix changes can affect the ability of new generation to connect to the network, compromise the effectiveness of protection systems, and result in greater difficulty in maintaining stable voltages.

These challenges are initially more acute in South Australia due to the combination of its generation mix and its single synchronous AC interconnector with the rest of the NEM.

The FPSS Progress Report noted that as at June 2016, South Australia has the highest penetration of non-synchronous generation in the NEM (see Table 20).

[165] See glossary for definition of synchronous generation.
[166] AEMO. *Future Power System Security Program Progress Report*, August 2016. Available: https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability/-/media/823E457AEA5E43BE83DDD56767126BF2.ashx.

Table 20 Installed generation capacity in the NEM in terms of physical attributes as at June 2016

Generation capacity (MW) (% of total)	Queensland	New South Wales	Victoria	South Australia	Tasmania
Synchronous (registered)	12,459 (89%)	15,416 (88%)	11,050 (83%)	2,999 (58%)	2,672 (87%)
Non-synchronous (registered)	12 (0.1%)	897 (5%)	1,230 (9%)	1,473 (29%)	308 (10%)
Non-synchronous (distributed)	1,585 (11%)	1,301 (7%)	957 (7%)	683 (13%)	97 (3%)
Interconnection	Double-circuit AC interconnection NSW-Qld				
	3 cable DC connection NSW–Qld				
		5 AC lines connecting NSW-Vic			
			Double-circuit AC connection Vic-SA		
			DC connection Vic-SA		
			DC connection Vic–Tas		DC connection Vic–Tas

Similar challenges could subsequently emerge in other regions that are vulnerable to separation from the remainder of the NEM, that is, Tasmania and Queensland. As the system evolves, these challenges could become more prevalent in other NEM regions.

Table 21, also from the August 2016 FPSS Progress Report, provides a high-level summary of potential technical solutions that could address the current challenges for frequency control and system strength. The technical solutions discussed in this section include synchronous condensers, RoCoF protection devices, and new interconnections. Storage technologies such as flywheels and batteries are discussed in Section 4.5.

Table 21 Summary of potential technical solutions for the identified challenges

Technical solution	Frequency control (including extreme power system conditions)			System strength
	High RoCoF	Insufficient FCAS*	UFLS*/OFGS* operation (high RoCoF)	
Synchronous condenser with or without flywheels (These can be new or retrofitted to existing / retiring plant.)	✓		✓	✓
Synchronous generation / storage (Either new entrants or existing plant)	✓		✓	✓
Batteries and other inverter-connected **storage** providing ancillary services	✓	✓		Uncertain
Wind generation providing ancillary services	✓	✓		Uncertain
PV and other inverter-connected generation providing ancillary services	✓	✓		Uncertain
Demand management providing broader ancillary services	✓	✓		
Change **protection systems** to operate in weaker systems				✓
Allow frequency to deviate more	Uncertain	Uncertain	Uncertain	
Adjust **RoCoF protection** settings	Uncertain		Uncertain	
Maintain **local ancillary services** in areas that could island	Partial			
New **AC interconnectors**	Partial	Partial	Partial	
New **HVDC interconnectors**		Partial		
Frequency controller on existing HVDC	Partial	Partial	Partial	
Optimise Contingency FCAS requirements		Partial		
Optimise Regulation FCAS requirements		Partial		

* FCAS – Frequency control ancillary services, UFLS – Under-frequency load shedding, OFGS – Over-frequency generation shedding

Synchronous condensers

A synchronous condenser is a synchronous electrical machine operated as a motor to provide reactive power to the transmission network.

While they do not generate active power, synchronous condensers are a source of inertia. They complement distributed and intermittent renewable generation by offering essential network services such as inertia with an immediate and dynamic response to improve network stability and security.[167]

FACTS devices

Flexible Alternating Current Transmission System (FACTS) devices, such as Dynamic Voltage Regulation System (D-VAR), Static Synchronous Compensator (STATCOM), Static Var Compensator (SVC), and Series Compensation (SC), are considered RoCoF protection devices. They are used for the dynamic control of voltage, impedance, and phase angle of high voltage AC transmission lines by supplying reactive power to the grid.

Another advantage of FACTS devices is they can assist in mitigating some of the fault ride through and voltage control functions that are inherently issues with renewables.[168]

[167] AEMO and DGA Consulting. *International Review of Frequency Control Adaptation*. Version 1. 14 October 2016.
[168] AEMO and DGA Consulting. *International Review of Frequency Control Adaptation*. Version 1. 14 October 2016.

New interconnections

New interconnections via AC or High Voltage Direct Current (HVDC) interconnectors are non-synchronous technologies that can alleviate high RoCoF. This solution as also helps to reduce the risk of electrical separation from the rest of the NEM.

AEMO's 2016 NTNDP study found that potential interconnection options may deliver fuel cost savings by improving utilisation of renewable generation and reducing reliance on higher-cost gas generation.[169]

Applications

Existing synchronous plant (gas- and diesel-fired generation) is presently being dispatched in South Australia to manage a number of the power system security challenges. While effective, the long-term costs of this approach may make it unsustainable, particularly as gas prices increase and gas supplies tighten.

Most wind farms in South Australia have Dynamic Voltage Regulation System (D-VARs) installed, which is a FACTS device to manage voltage. These devices assist with local voltage control, but do not directly address issues related to low system strength.

Synchronous condensers are a well-established technology, however they are not particularly widespread in the NEM. Most synchronous condensers have either been retired or are close to retirement, and were traditionally used for voltage control, rather than inertia and fault level contributions.

Musselroe Wind Farm[170] in Tasmania is one of the few examples of modern synchronous condensers being installed to provide local fault contribution and assistance with fault ride through.

Recent developments

Following the South Australia Black System event on 28 September 2016 [171][172], additional constraint equations have been implemented in NEMDE to limit RoCoF, under South Australian regulations.

ElectraNet is currently progressing the *South Australian Energy Transformation Regulatory Investment Test –Transmission* (RIT-T)[173], which explores increased interconnection (and alternatives) to facilitate South Australia's energy transformation, while improving system security and helping lower electricity prices.

There are a number of trial and prototype utility-scale battery systems proposed or operating in South Australia. The final report of Phase 1 ESCRI-SA project (see Section 5) suggested a potential Phase 2 demonstration project of a 10 MW/20 MWh energy storage device at the Dalrymple substation (or Wattle Point Wind Farm).[174]

The Phase 2 work will test the potential of energy storage to provide:

- Frequency control services and black-start capability.
- Peak load management and/or deferral of potential transmission capital upgrades.[175]

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[169] AEMO *2016 NTNDP Database*. December 2016. Available: http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/National-Transmission-Network-Development-Plan/NTNDP-database.

[170] © Hydro-Electric Corporation 2017. *Musselroe Wind Farm*. Available: http://www.hydro.com.au/energy/our-power-stations/wind-power/musselroe-wind-farm. Viewed: 4 January 2017.

[171] AEMO. P*reliminary operating incident report into the South Australian state-wide power outage*. 5 October 2016. Available: https://www.aemo.com.au/Media-Centre/Media-Statement-South-Australia-Interim-Report.

[172] AEMO. *Update to preliminary operating incident report into the South Australian state-wide power outage*. 19 October 2016. Available: https://www.aemo.com.au/Media-Centre/Update-to-report-into-SA-state-wide-power-outage.

[173] ElectraNet. *South Australian Energy Transformation*. Available: https://www.electranet.com.au/projects/south-australian-energy-transformation/. Viewed: 4 January 2017.

[174] © Commonwealth of Australia. ARENA. Energy Storage for Commercial Renewable Integration - South Australian (ESCRI-SA). *Milestone 5. Phase 1 – General Project Report*. December 2015. Available: https://arena.gov.au/wp-content/uploads/2016/04/ESCRI-General-Project-Report-Phase-1.pdf. Viewed: 20 December 2016.

[175] © Commonwealth of Australia. ARENA. *Energy Storage for Commercial Renewable Integration*. Available: https://arena.gov.au/project/energy-storage-for-commercial-renewable-integration/, Viewed: 4 January 2017.

The design of the demonstration project was reconfigured as a 30 MW/8 MWh energy storage device and is being presented to ARENA for funding support.[176]

In September 2016, a South Australian company successfully tested a prototype of a thermal energy storage system (TESS), which stores energy by heating and melting containers full of silicon. The trial confirmed that the TESS is capable of storing and supplying hundreds of MW of electricity, making the technology suitable for load shifting of wind farms and gas-fired generators. The company announced its plan to develop the first large-scale commercial systems over the next two years.[177]

The potential for residential battery systems to be aggregated and provide non-network solutions is also being considered.[178] Discussion on battery storage is presented in Chapter 5.

[176] ElectraNet. *South Australian Transmission Annual Planning Report 2016 Overview*. July 2016. Available: https://www.electranet.com.au/wp-content/uploads/report/2016/08/20160730-Report-2016TransmissionAnnualPlanningReportOverview.pdf. Viewed: 4 January 2017.
[177] © Renew Economy 2017. *SA-made silicon energy storage system "ready to close grid gap"*. 9 December 2016. Available: http://reneweconomy.com.au/sa-made-silicon-energy-storage-system-ready-close-grid-gap-23607/. Viewed: 28 February 2017.
[178] AEMO. *South Australian Energy Transformation*. 13 February 2017. Available: https://www.aemo.com.au/-/media/Files/PDF/Response-of-Existing-PV-Inverters-to-Frequency-Disturbances-V20.pdf.

7. LEVELISED COST OF ELECTRICITY FOR NEW GENERATION

The levelised cost of electricity (LCOE) is often cited as a convenient summary measure of the overall competitiveness of different generating technologies. It represents the per megawatt hour (MWh) sent-out[179] cost (in real dollars) of building and operating a generating plant, over an assumed financial life and duty cycle.

Key inputs to calculating LCOE include capital costs, fuel costs, fixed and variable operations and maintenance costs, financing costs, and an assumed utilisation rate for each plant type.

The 2017 LCOEs presented in this chapter are calculated without any uplift associated with an explicit price on emissions. A sensitivity study of LCOE with an emissions cost, or ‘carbon price’, can be found in Appendix B.

AEMO periodically reviews all costs associated with new generation technologies. AEMO’s latest planning assumptions for technology costs are largely based on the 2015 APGTR. The report was developed in consultation with leaders from industry, government, consumer groups, and industry associations, and provides a range of forecast generation technology costs up to 2030.

Full details on cost assumptions for each technology are available in the 2016 NTNDP Database.[180]

Renewable generation

The rapid decline in the cost of renewable technology such as large-scale solar PV in recent years is expected to continue as production expands and technology matures.

Table 22 summarises LCOE and equivalent CO_2 emissions for the range of renewable technologies considered in this report. The LCOE methodology and input assumptions and emission calculations are provided in Appendix A.

Key observations include:

- Wind generation remains the lowest cost renewable technology at around $85/MWh at sites providing capacity factors of 42%. (Sites at lower capacity factors are provided in Figure 21.)
- Solar PV has seen the greatest LCOE reduction since the 2015 SAFTR, mostly as a result of substantial decreases in capital costs due to mass production, increase of market competition, and optimised system configuration. Rising confidence in the technology also contributed to the reduction of finance costs[181], which was reflected in lower weighted average cost of capital (WACC) in this review.[182] For example, the capital cost of solar PV with dual-axis tracking (DAT) reduced from $3,869/kW (2015 SAFTR) to $2,810/kW (2017 SAFTR), a reduction of approximately 27%. The assumed 2017 WACC was 6.79%, compared to 10% in the 2015 SAFTR.

For completeness and to allow comparison, renewable technologies considered in the 2015 SAFTR have been included in Table 22. Geothermal and wave technologies are not included, as they are not yet proven to be economically viable in Australia.

[179] Sent-out means measured at the generator connection point, representing energy supplied to the market, excluding auxiliary loads (energy used by the generator).
[180] AEMO. *2016 NTNDP Database.* Available http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/National-Transmission-Network-Development-Plan/NTNDP-database.
[181] ARENA. *Project proposals show shrinking cost of big solar.* Available https://arena.gov.au/media/project-proposals-show-shrinking-cost-big-solar/. Viewed: 7 February 2017.
[182] Bloomberg New Energy Outlook. Available: https://www.bloomberg.com/company/new-energy-outlook/. Viewed: 20 December 2016.

Table 22 LCOE and emissions comparison across renewable technologies

Technology	Fuel type	2017 Assumed maximum capacity factor (%)	2015		2017	
			Emissions ($kgCO_2$-e/MWh)	Minimum LCOE ($/MWh)**	Emissions ($kgCO_2$-e/MWh)	Minimum LCOE ($/MWh)
Wind	Wind	42	-	101	-	85
Solar PV (SAT)	Solar	28	-	186	-	90
Solar PV (FFP)	Solar	22	-	152	-	96
Solar PV (DAT)	Solar	32	-	244	-	98
Biomass	Biomass	70	23	121	23	120
Solar thermal (Central receiver (CR) with storage)	Solar	52	-	222	-	137
Solar thermal (Compact linear fresnel (CLF))	Solar	23	-	289		N/A*
Solar thermal (Parabolic trough (PT) with storage))	Solar	42	-	299		N/A*

* Updated technology cost projections were not available for these technologies in the 2015 *Australian Power Generation Technology Report*.
** Numbers differ from those reported in the 2015 SAFTR due to consumer price indices (CPI) escalation to 2016 real dollars.

Non-renewables

LCOE and CO_2 equivalent emissions for non-renewable generation technologies are summarised in Table 23.

Calculations for South Australia incorporate regional fuel cost estimates (where applicable), while NEM calculations use the lowest fuel costs from any region (including South Australia).

Key observations include:

- CCGT remained the cheapest new generation technology. Assuming near continuous operation at full capacity, it would need to receive at least $83/MWh in South Australia on average over the year to recover costs, assuming an average gas price of $8.07/GJ. If operating less frequently, a new CCGT would need to receive a higher average electricity price to be profitable. Although there has been an increase of capital and fuel costs in CCGT, the LCOEs between 2015 and 2017 remained the same due to a lower assumed WACC and maximum capacity factor.
- The LCOE values for OCGT have increased in South Australia, mainly driven by the assumed decline in foreign exchange rate increasing capital cost. The assumed 2017 capital cost for OCGT was $1,120/kW while the 2015 cost was $738/kW.
- The LCOE values for supercritical coal-fired technology except brown coal without CCS have increased, due to higher assumptions for capital and fuel costs as well as the WACC. The assumed 2017 WACC, which reflects risk premium attached to supercritical coal generation at present, is 12.94% while the 2015 WACC was 10%.

For completeness and to allow comparison, non-renewable technologies considered in the 2015 SAFTR have been included in Table 23.

Table 23 LCOE and emissions comparison across non-renewable technologies

Technology	Fuel type	2017 Assumed fuel cost ($/GJ)	2017 Assumed maximum capacity factor (%)	Region	2015		2017	
					Emissions ($kgCO_2$-e/MWh)	Minimum LCOE ($/MWh)*	Emissions ($kgCO_2$-e/MWh)	Minimum LCOE ($/MWh)
Combined cycle (CCGT)	Gas	8.07	83	SA	478	83	470	83
				NEM	405	74	444	70
Supercritical (SCPC)	Black coal	1.32	83	SA				
				NEM	827	73	812	81
Supercritical (SCPC)	Brown coal	0.43	83	SA				
				NEM	1,213	93	1,193	91
Combined cycle (CCGT with CCS)	Gas	8.07	83	SA			150	118
				NEM	97	117	131	116
Supercritical (SCPC with CCS)	Black coal	1.32	83	SA				
				NEM	134	143	131	185
Supercritical (SCPC with CCS)	Brown coal	0.43	83	SA				
				NEM	175	172	169	198
Open Cycle (OCGT)	Gas	10.66	10	SA	699	209	688	218
				NEM	592	199	582	198

* Numbers differ from those reported in the 2015 SAFTR due to consumer price indices (CPI) escalation to 2016 real dollars.

The difference in the calculated LCOEs between 2015 and 2017 (see Table 22 and Table 23) are driven by a combination of assumptions variations such as the WACC, fuel price, capital cost, plant economic life, maximum capacity factor, and carbon price. A comparison of LCOE calculation assumptions between 2015 and 2017 is included in Appendix A.

LCOE estimates for storage

The LCOE estimates for storage technologies are provided in Table 24. The calculations do not include the costs of charging/pumping the storage systems ready for re-use, and as such, the LCOEs are likely to be underestimated. Care must therefore be taken when interpreting any comparison with other technologies. As the appropriate charging cost depends on operational and/or commercial decisions made by the operator, it is not appropriate to estimate a generic charging cost in this context.

The value of storage will vary depending on the application, as the technology could be deployed to provide daily generation, peak capacity support, grid support services and others. To evaluate the true potential, storage performance and cost must be measured against the dispatchable thermal power plants, demand response, power grid interconnections, or innovations which storage seeks to displace.

Table 24 LCOE and emissions comparison across storage technologies

Technology	Fuel type	Assumed maximum capacity factor (%)	2015		2017	
			CO_2 emissions ($kgCO_2$-e/MWh)	Minimum LCOE ($/MWh sent out)*	CO_2 emissions ($kgCO_2$-e/MWh)	Minimum LCOE ($/MWh sent out)
Pumped hydro storage	Hydro	20	-	205	-	161
Grid battery storage	Battery	20	-	300	-	216

* Numbers differ from those reported in the 2015 SAFTR due to consumer price indices (CPI) escalation to 2016 real dollars.

LCOE by capacity factor

The LCOE varies according to several factors, including the plant's expected capacity factor.

For wind farms and solar (both PV and thermal), capacity factors depend on wind and solar resources. Although resources vary by site, suggested maximum capacity factors of 42% for the best wind sites and 32% for the best solar PV sites (with tracking systems in place) from the 2015 APGTR are used in the LCOE calculation.

However, production of each technology will likely occur at different times of the day, as solar is confined to daytime periods and wind operation may be higher overnight (at many sites). The investment decision, therefore, must consider not only the cost of developing the various technologies, but the value derived from the energy produced and/or capacity provided at the times the resource is most likely to be available.

Gas, coal, geothermal, and solar storage technologies have higher potential capacity factors, but may operate flexibly, operating at lower capacity factors to target only higher price periods to maximise profitability.

LCOE values are presented in Figure 21 and Figure 22 across a range of capacity factors that apply to each technology, based on resource availability for South Australia and the NEM. For example, if wind generation is able to achieve a capacity factor of 35%, the South Australian estimated LCOE for that generator would be $101.3/MWh sent out.

Figure 21 South Australian LCOE versus capacity factor

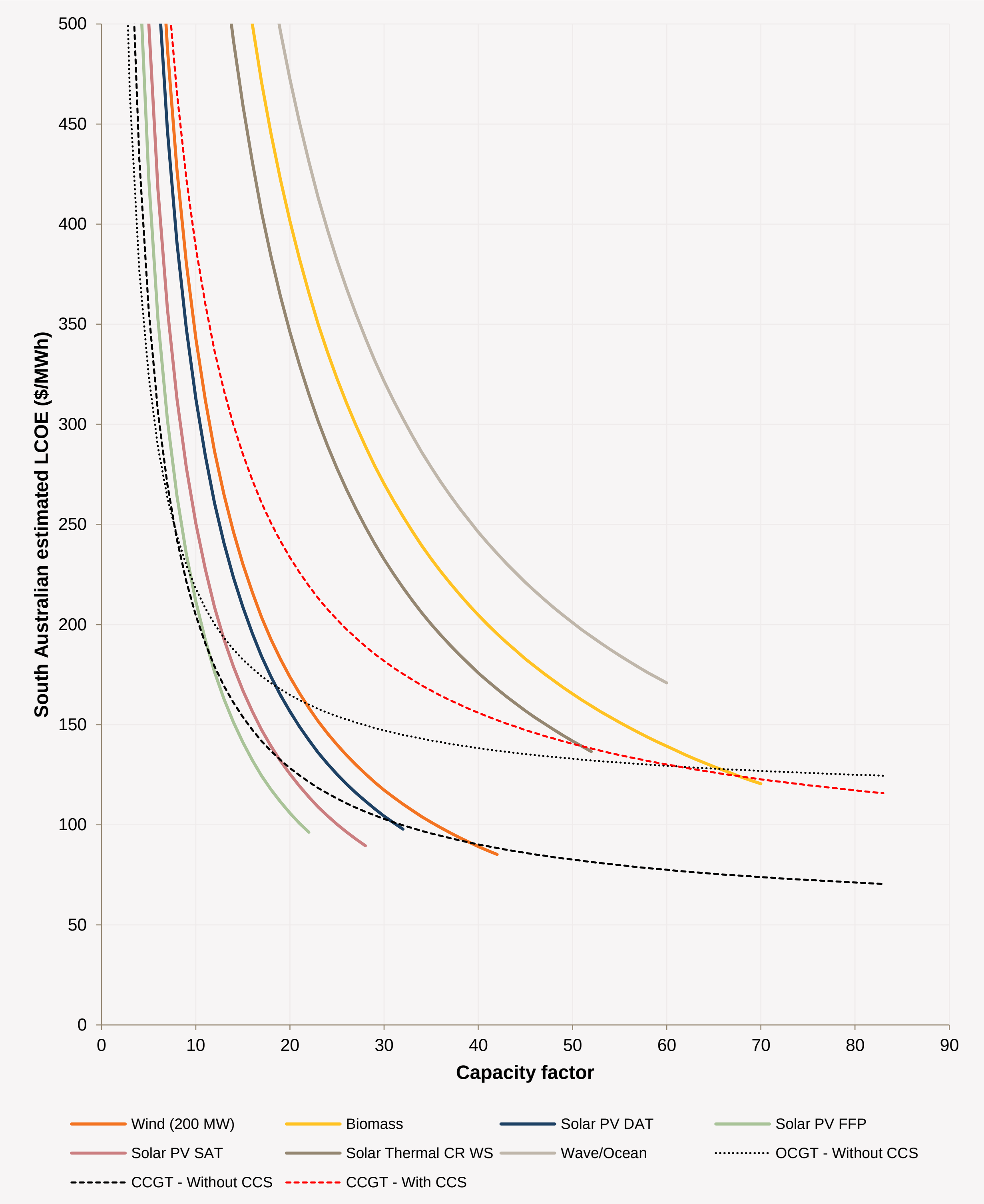
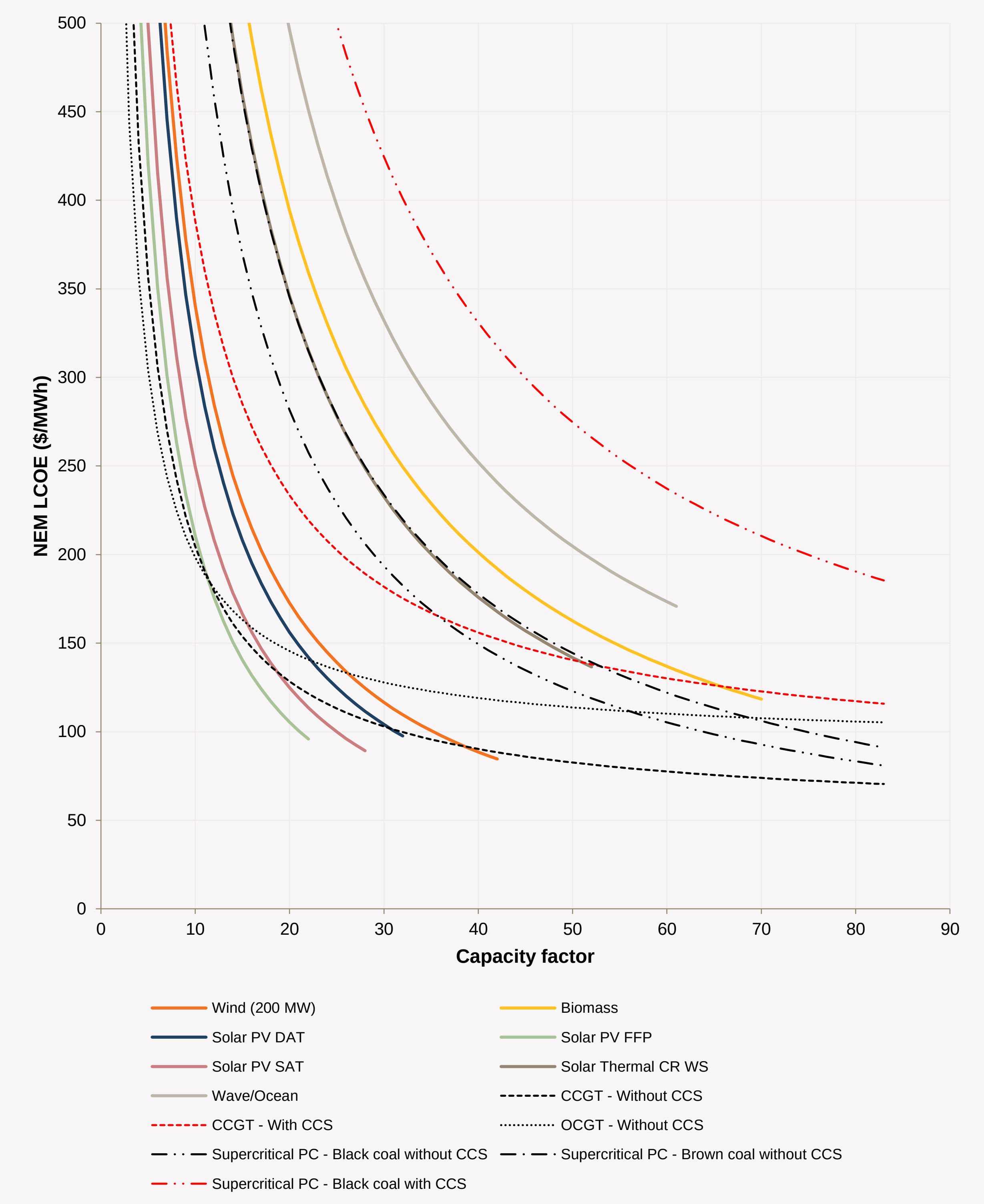


Figure 22 NEM LCOE versus capacity factor



Technology cost frontier

A technology frontier curve comprises segments of the LCOE curves for different technologies, and represents the minimum cost technology in each segment. It is useful for identifying the most potentially cost-effective technologies for a particular capacity factor and the likely revenue required.

The most cost-effective technologies by capacity factor are shown in Table 25, assuming no carbon price.

It should be noted that, for renewable generation, a simple comparison of cost-effectiveness is not necessarily a good indicator of the value of development. Availability at times of highest value in the NEM should also be considered. For example, while sites offering low capacity factor wind resources may come at a higher levelised cost, if the correlation of the resource is much higher with peak demands it may provide greater value than other sites offering higher capacity factors.

Table 25 Generation technology frontier

Generation	Generation technology at frontier	
	South Australia	NEM (including South Australia)
Non-renewables	OCGT without CCS: up to 7% capacity factor	OCGT without CCS: up to 10% capacity factor
	CCGT without CCS: from 8% capacity factor	CCGT without CCS: from 11% capacity factor
Renewables	Solar PV: up to 32% capacity factor	Solar PV: up to 32% capacity factor
	Wind: from 33% to 42% capacity factor	Wind: from 33% to 42% capacity factor

Emissions

Figure 23 and Figure 24 summarise the emissions value and corresponding LCOE across generation technologies applying for South Australia and the NEM.

Figure 23 South Australia emissions at minimum LCOE

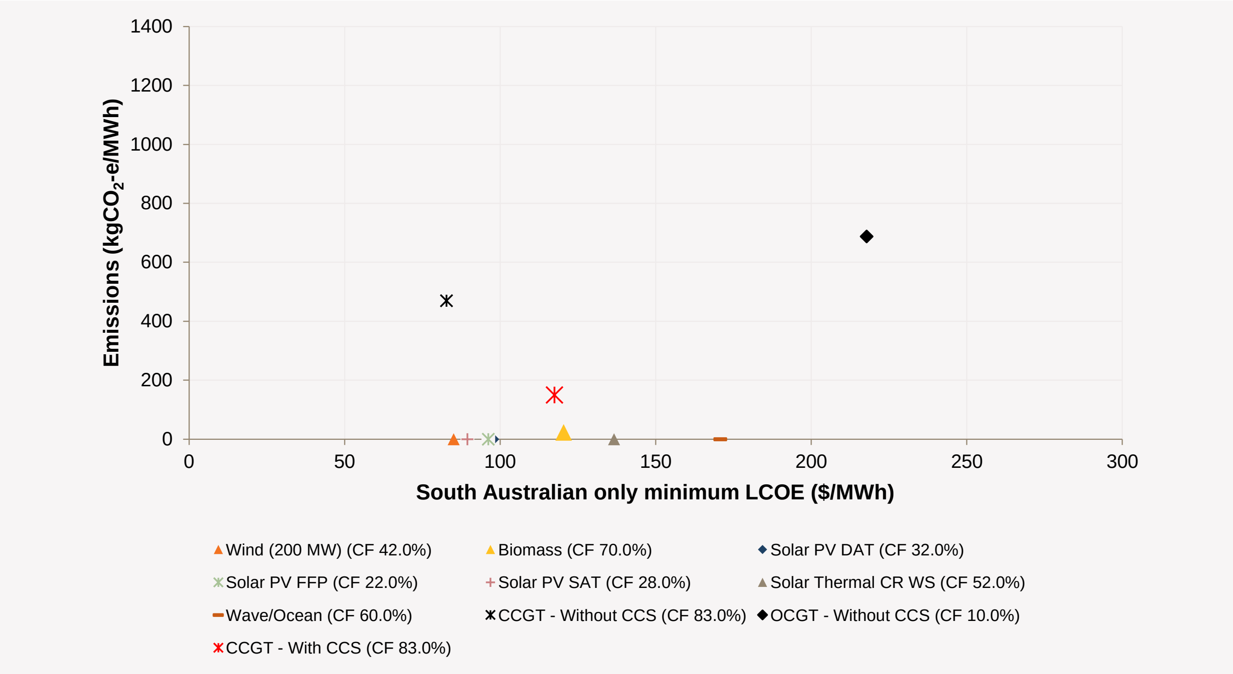
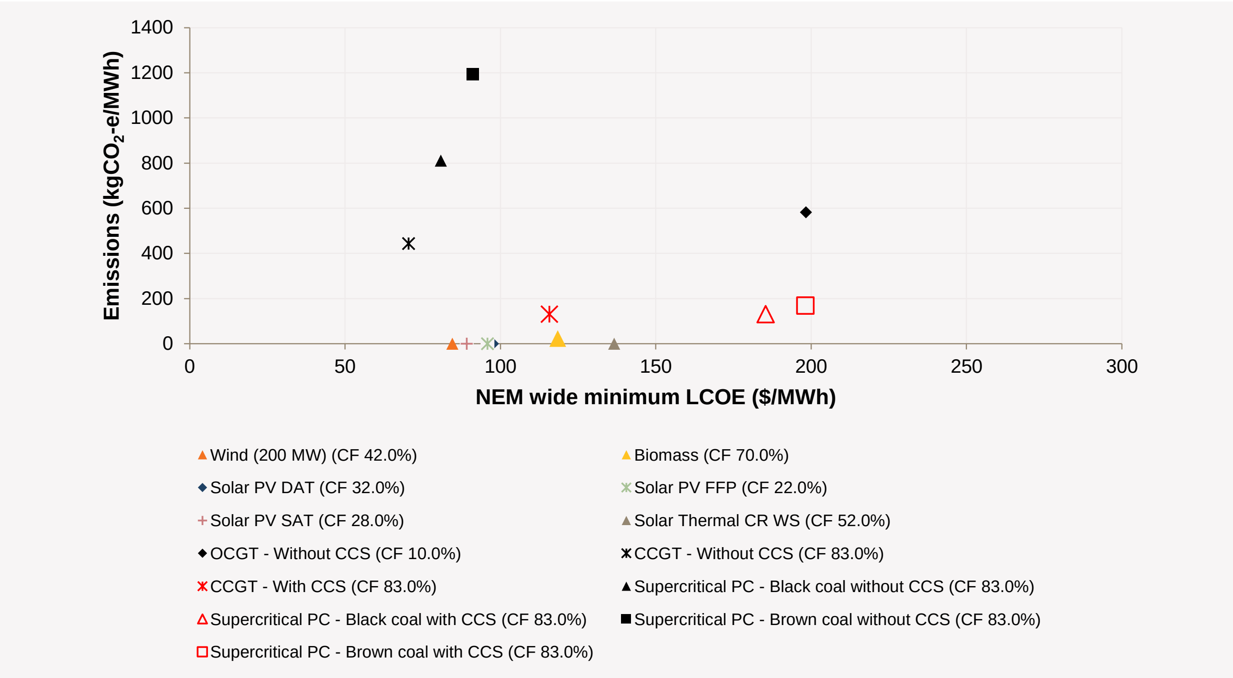


Figure 24 NEM emissions at minimum LCOE



APPENDIX A. LCOE METHODOLOGY

Assumptions

LCOE and emission calculations are based on the following assumptions:

- All technology is built "overnight" at the start of the 2016–17 financial year. In this study, the assumed WACC for each technology is based on 2016 NTNDP input assumptions.[183]
- Outlook period varies depending on the assumed economic life of the technology.[184] Capacity factors for various technologies ranged from 0% through to a maximum set by resource availability or plant availability (set to 83% assuming downtime for maintenance and unplanned outages). Values were sourced from the 2015 APGTR and 2015 SAFTR.[185]
- The calculation is specific for a given capacity factor. For renewable generators, the capacity factor will vary by location depending on the local resource typically available over a year. The values used in this assessment represent the maximum likely values for plant in South Australia and the NEM.
- Capital costs[186], fixed operating and maintenance costs, variable operating and maintenance costs, fugitive emissions, combustion emissions, fuel cost, thermal efficiency, and WACC assumptions are sourced from the 2016 NTNDP input assumptions.[187] The values of the WACC used in the 2016 NTNDP was based from 2015 *Bloomberg New Energy Outlook.*[188] Emissions captured and sequestration costs are sourced from the 2014 *Fuel and Technology Cost Report* prepared for AEMO by ACIL Allen Consulting.[189]
- The 2015 costs are converted to 2016 real dollars. The escalation factor[190] used is derived from the consumer price indices (CPI) of the Australian Bureau of Statistics.[191]

LCOE methodology

The formula used to calculate LCOE values in this report is consistent with that presented by the Bureau of Resources and Energy Economics (BREE) in Section 2.4 of the 2012 *Australian Energy Technology Assessment*.[192]

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

where:

- I_t = Investment expenditure in the year t
- M_t = Operations and maintenance expenditure in the year t
- F_t = Fuel expenditure in the year t
- E_t = Electricity generation in the year t

183 AEMO. *2016 NTNDP Database*. December 2016. Available: http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/National-Transmission-Network-Development-Plan/NTNDP-database. Viewed: 4 January 2017.

184 AEMO. *2016 NTNDP Database*. December 2016.

185 AEMO. *2015 South Australian Fuel and Technology Report*. Available: https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/South-Australian-Advisory-Functions. Viewed: 20 December 2016.

186 Assumed capital cost for 'solar thermal central receiver with storage' is based on the estimates of project proponents.

187 AEMO. *2016 NTNDP Database*. December 2016.

188 Bloomberg New Energy Outlook. Available: https://www.bloomberg.com/company/new-energy-outlook/. Viewed: 20 December 2016.

189 © ACIL Allen Consulting 2014. *Fuel and Technology Cost Final Report.* 10 June 2014. Available: http://www.aemo.com.au/-/media/Files/PDF/Fuel_and_Technology_Cost_Review_Report_ACIL_Allen.pdf. Viewed: 4 January 2017.

190 Escalation factor = March 2016 CPI/ March 2014 CPI = 107/105.1 = 1.02.

191 © Commonwealth of Australia. Australian Bureau of Statistics. *Consumer Price Index, Australia.* Available: http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/6401.0Dec%202016?OpenDocument. Viewed: 28 February 2017.

192 © Commonwealth of Australia 2012. *Australian Energy Technology Assessments 2012.* Available: https://industry.gov.au/Office-of-the-Chief-Economist/Publications/Documents/aeta/australian_energy_technology_assessment.pdf. Viewed: 4 January 2017.

- r = Discount Rate
- n = Amortisation period
- In terms of the equation for M_t, a subtle modification is needed regarding the variable emissions, given that AEMO is modelling both combustion emission factors and fugitive emission factors. The carbon price component of M_t is calculated from the "non-captured combustion emissions plus all fugitive emissions", whereas the "sequestration costs" component of M_t is calculated from the captured combustion emissions.
- For this report, the LCOE is calculated with a zero carbon price. In this formula therefore, a carbon price does not affect the LCOE, although the costs of sequestration do apply, where applicable. Appendix B presents LCOE calculations including an assumed carbon price for comparison.
- For the LCOE versus capacity factor plots, no data is plotted beyond the maximum typical capacity factor for that technology. This presents a fairer comparison between technologies.

Emissions and carbon pricing

Emissions values calculated in this report are as kilograms of equivalent CO_2 produced per MWh of electricity generated. Equivalent carbon dioxide (CO_2-e) is a way of representing the greenhouse gases produced by a power generation process in a comparable form, regardless of technology. It represents the amount of CO_2 that would have the same greenhouse gas effect as whatever greenhouse gases are actually produced.

Emissions are based on the following calculation:

$$Emissions = \frac{\left(F + C \times \left(1 - \frac{E}{100}\right)\right) \times 3.6}{\left(\frac{T}{100}\right)} \text{ (kgCO}_2\text{-e/MWh)}$$

where:

- F = fugitive emissions factor (kgCO_2-e/GJ)
- C = combustion emissions factor (kgCO_2-e/GJ)
- E = emissions captured (%)
- T = thermal efficiency (%)
- 3.6 is a constant (GJ/MWh)

Special considerations:

- Capacity factors chosen for any given technology are typical values that would be indicative of those found in practice. Values were sourced from the 2015 APGTR and 2015 SAFTR.[193]
- The emissions presented for a given technology is the value for a plant constructed in the location with the minimum LCOE value across the geographical area being examined, that is, across the entire NEM or across South Australia.
- Emission costs are influenced by the price for carbon. Given the repeal of the carbon pricing legislation in July 2014, this has changed from the last publication of this report. Carbon pricing in this report is set to zero. Appendix B presents LCOE calculations including an assumed carbon price for comparison.

[193] AEMO. *2015 South Australian Fuel and Technology Report*. Available: https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/South-Australian-Advisory-Functions. Viewed: 20 December 2016.

Table 26 Input assumptions of each technology

Technology	2015			2017		
	WACC (%)	Economic life (years)	Assumed capacity factor (%)	WACC (%)	Economic life (years)	Assumed capacity factor (%)
Wind (200 MW)	10	30	43	7.09	20	42
Biomass	10	30	70	9.42	30	70
Solar PV (FFP)	10	30	21	6.79	25	22
Solar PV (SAT)	10	30	21	6.79	25	28
Solar PV (DAT)	10	30	21	6.79	25	32
Solar thermal (CLF)	10	30	23			
Solar thermal (CR with storage)	10	30	42	6.79	25	52
Solar thermal (PT with storage)	10	30	42			
Open Cycle (OCGT)	10	30	10	7.03	30	10
Combined cycle (CCGT)	10	30	83	7.43	40	83
Combined cycle (CCGT with CCS)	10	30	83	7.43	40	83
Supercritical (SCPC)	10	30	83	12.94	50	83
Supercritical (SCPC with CCS)	10	30	83	12.94	50	83
Pumped Hydro	10	30	20	8.5	60	20
Storage	10	30	20	8.5	15	20

Table 27 LCOE and emissions input data – renewable

Technology	2015							2017						
	Capital costs ($/kW)	Fuel Costs ($/GJ)*	VOM ($/MWh)	FOM costs ($/kW/yr)	Combustion Emission Factor (kg CO_2e/GJ)	Emissions captured (%)	Thermal efficiency (%)**	Capital costs ($/kW)	Fuel Costs ($/GJ)*	VOM ($/MWh)	FOM costs ($/kW/yr)	Combustion Emission Factor (kg CO_2e/GJ)	Emissions captured (%)	Thermal efficiency (%)**
Renewable														
Wind (200 MW)	2,596	-	15.3	45.8	-	-	100	2,650	-	15	45	-	-	100
Biomass	5,294	-	8.1	127.3	-	-	28	5,500	-	8	125	-	-	28
Solar PV (FFP)	2,392	-	-	25.5	-	-	100	1,920	-	-	25	-	-	100
Solar PV (SAT)	2,952	-	-	30.5	-	-	100	2,260	-	-	30	-	-	100
Solar PV (DAT)	3,869	-	-	39.7	-	-	100	2,810	-	-	39	-	-	100
Solar thermal (CLF)	4,581	-	15.5	65.2	-	-	100							
Solar thermal (CR with storage)	6,821	-	5.8	73.3	-	-	100	6,230	-	5.7	72	-	-	100
Solar thermal (PT with storage)	9,265	-	11.6	74.3	-	-	100							
Storage														
Pumped hydro storage	3,258	-	5.1	5.1	-	-	100	3,130	-	5	5	-	-	100
Grid battery	4,581	-	6.1	30.5	-	-	100	2,810	-	6	30	-	-	100

* Fuel costs may vary by location. Representative value indicated either South Australian value or lowest in NEM.
** Sent out HHV (Higher Heating Value).

Table 28 LCOE and emissions input data – non-renewable

Technology	2015							2017						
	Capital costs ($/kW)	Fuel Costs ($/GJ)*	VOM ($/MWh)	FOM costs ($/kW/yr)	Combustion Emission Factor (kg CO_2e/GJ)	Emissions captured (%)	Thermal efficiency (%)**	Capital costs ($/kW)	Fuel Costs ($/GJ)*	VOM ($/MWh)	FOM costs ($/kW/yr)	Combustion Emission Factor (kg CO_2e/GJ)	Emissions captured (%)	Thermal efficiency (%)**
Non-renewable														
Open cycle gas turbine (OCGT)	738	6	10.2	4.1	57	-	35	1,120	10.07	10	4	54	-	35
Combined cycle gas turbine (CCGT)	1,112	4	7.1	10.2	57	-	51	1,590	8.07	7	10	54	-	52
Combined cycle gas turbine (CCGT with CCS)	2,993	4	12.2	17.3	57	85	44	3,220	8.07	12	17	54	85	45
Supercritical brown coal (SCPC)	4,465	0.4	5.1	66.7	97	-	29	4,020	0.43	5	65.5	97	-	29
Supercritical brown coal (SCPC with CCS)	8,427	0.4	11.2	98.2	97	90	21	8,530	0.43	11	96.5	97	90	22
Supercritical black coal (SCPC)	2,932	1.6	4.1	51.4	91	-	42	3,210	1.32	4	50.5	93	-	42
Supercritical black coal (SCPC with CCS)	5,485	1.6	9.2	74.5	91	90	31	7,050	1.32	9	73.2	93	90	32

* Fuel costs may vary by location. Representative value indicated either South Australian value or lowest in NEM.
** Sent out HHV (Higher Heating Value).

APPENDIX B. LCOE SENSITIVITY WITH CARBON PRICE

This section presents the calculated LCOEs across a range of capacity factors that apply to each technology based on resource availability for South Australia and the NEM with an assumed carbon price. The assumed carbon price is zero until 2020–21. Beyond 2020-21 a carbon price of $25/tonne is applied, linearly increasing to $50/tonne in 2030.[194] The carbon price is held constant in real terms beyond 2030. This carbon price trajectory is consistent with that calculated for the 2016 NEFR[195].

These calculations are provided for information purposes only, and do not represent any expectation of emissions policy pricing carbon emissions explicitly for electricity generation.

Table 29 2017 minimum LCOE with carbon price in South Australia

Technology	Minimum LCOE ($/MWh)	
	South Australia	NEM
Wind (200 MW) (CF 42.0%)	85	85
Solar PV SAT (CF 28.0%)	90	89
Solar PV FFP (CF 22.0%)	96	96
CCGT - Without CCS (CF 83.0%)	97	83
Solar PV DAT (CF 32.0%)	98	98
Biomass (CF 70.0%)	121	119
CCGT - With CCS (CF 83.0%)	122	120
Solar Thermal CR WS (CF 52.0%)	137	137
OCGT - Without CCS (CF 10.0%)	238	215
Supercritical PC - Black coal without CCS (CF 83.0%)		99
Supercritical PC - Brown coal without CCS (CF 83.0%)		118
Supercritical PC - Black coal with CCS (CF 83.0%)		188
Supercritical PC - Brown coal with CCS (CF 83.0%)		202

[195] AEMO. *National Electricity Forecasting Report.* June 2016. Available: https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/National-Electricity-Forecasting-Report.

MEASURES AND ABBREVIATIONS

Units of measure

Abbreviation	Unit of measure
$/MWh	Australian dollar per megawatt hour
GJ	gigajoule
Gt	gigatonne
GWh	gigawatt hour
Hz	hertz
kgCO_2-e/GJ	kilogram of carbon dioxide equivalent (CO_2-e) emissions per gigajoule (of fuel)
kgCO2-e/MWh	kilogram of CO_2-e emissions per megawatt hour (of electricity)
kV	kilovolts
kW	kilowatt
kW/m	kilowatt per metre
m	metre
m/s	Metre per second
MJ/kg	megajoule per kilogram
MJ/m^2	megajoule per square metre
MPa	megapascal
Mtpa	Million tonnes per annum
MW	megawatt
MWh	megawatt hour
PJ	petajoule
TCF	trillion cubic feet
TJ/a	terajoule per annum
TJ/d	terajoule per day
TJ/m	terajoule per metre

Abbreviations

Abbreviation	Expanded name
ABARE	Australian Bureau of Agricultural and Resource Economics
AC	Alternating current
ACT	Australian Capital Territory
AECOM	AECOM Australia Pty Ltd
AEMO	Australian Energy Market Operator
AETA	Australian Energy Technology Assessment
APGTR	Australian Power Generation and Technology Report
ANU	Australian National University
ARENA	Australian Renewable Energy Agency
ASEFS	Australian Solar Energy Forecasting System
AWEFS	Australian Wind Energy Forecasting System
BCG	Basin Centred Gas

Abbreviation	Expanded name
BEV	Battery electric vehicle
BREE	Bureau of Resources and Energy Economics
CAES	Compressed air energy storage
CAGR	Compound annual growth rate
CCGT	Combined cycle gas turbine
CCS	Carbon capture and storage
CLF	Compact linear fresnel
CO_2	Carbon dioxide
CO_2	Equivalent carbon dioxide
CPV	Concentrating photovoltaics
CR	Central receiver
CSG	Coal seam gas
CSIRO	Commonwealth Scientific and Industrial Research Organisation
D-VARS	Dynamic Voltage Regulation System
DMITRE	South Australian Department for Manufacturing, Innovation, Trade, Resources and Energy
EDR	Economic demonstrated resources
EGS	Enhanced Geothermal System
EPC	Engineering, Procurement, and Construction
ESCRI	Energy Storage for Commercial Renewable Integration
ESOO	Electricity Statement of Opportunities
ETSAP	Energy Technology Systems Analysis Program
EV	Electric vehicle
FACTS	Flexible Alternating Current Transmission System
FPSS	Future Power System Security
GBB	Gas Bulletin Board
GPG	Gas-powered generation
GSOO	Gas Statement of Opportunities
HELE	High efficiency, low emission
HHV	Higher heating value
HSA	Hot sedimentary aquifer
HVDC	High Voltage Direct Current
IEA	International Energy Agency
IEA-ETSAP	International Energy Agency - Energy Technology Systems Analysis Program
IGCC	Integrated gasification combined cycle
INF	Inferred resources
IRENA	International Renewable Energy Agency
ISCC	Integrated solar combined cycle
LCOE	Levelised cost of electricity
LGC	Large-scale Generation Certificates
LI	Large industrial
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
LRET	Large-scale Renewable Energy Target
MAP	Moomba to Adelaide Pipeline
MIT	Massachusetts Institute of Technology

Abbreviation	Expanded name
MM	Mass market
MMBBL	Million barrels
MMLI	Mass market and large industrial
MSP	Moomba to Sydney Pipeline
NEFR	National Electricity Forecasting Report
NEM	National Electricity Market
NETL	National Energy Technology Laboratory
NGFR	National Gas Forecasting Report
NREL	National Renewable Energy Laboratory
NTNDP	National Transmission Network Development Plan
OCGT	Open cycle gas turbine
OWC	Oscillating water columns
OWSC	Oscillating wave surge converter
PC	Pulverised coal
PHEV	Plug-in hybrid electric vehicles
PHS	Pumped hydro storage
PJ	Petajoules
PPA	Power Purchase Agreement
PT	Parabolic trough
PV	photovoltaic
QLD	Queensland
QSN	Queensland – South Australia – New South Wales
REM	Roseneath-Epsilon-Murteree
RET	Renewable Energy Target
RoCoF	Rate of change of frequency
SA	South Australia
SAAF	South Australian Advisory Functions
SACB JV	South Australian Cooper Basin Joint Venture
SAFTR	South Australian Fuel and Technology Report
SC	Series Compensation
SEAGas	South East Australia Gas Pipeline
SMES	Superconducting magnetic energy storage
SNSG	Small non-scheduled generation
SRES	Small-scale Renewable Energy Scheme
STATCOM	Static Synchronous Compensator
STC	Small-scale Technology Certificate
STE	Solar Thermal Energy
STORES	Short-Term Off-River pumped hydro energy Storage
SVC	Static Var Compensator
SWQ	South West Queensland
SWQ JV	South West Queensland Joint Ventures
SWQP	South West Queensland Pipeline
UK	United Kingdom
USA	United States of America
US DOE	United States Department of Energy

Abbreviation	Expanded name
VIC	Victoria
VRET	Victorian Renewable Energy Target
WA	Western Australia
WACC	Weighted average cost of capital
YBE	Yorke Biomass Energy Pty Ltd
YBS	Yorke Biomass Supply

GLOSSARY

Term	Definition
1P reserves	Estimated quantity of gas that is reasonably certain to be recoverable in future under existing economic and operating conditions. A low-side estimate also known as proved gas reserves.
2C contingent resources	Best estimate of contingent resources.
2P reserves	The sum of proved-plus-probable estimates of gas resources. The best estimate of commercially recoverable reserves. Often used as the basis for reports to share markets, gas contracts, and project economic justification.
3C contingent resources	High estimate of contingent resources.
3P reserves	The sum of proved, probable, and possible estimates of gas reserves.
Advanced projects	Projects that satisfy at least three, but not all of the commitment criteria, and for which commissioning timing is in doubt.
Anticoincidence	The occurrence of one event without the simultaneous occurrence of another.
Basin	A geological formation that may contain coal, oil, and gas.
Coal seam gas (CSG)	Gas found in coal seams that cannot be economically produced using conventional oil and gas industry techniques. Also referred to in other industry sources as coal seam methane (CSM) or coal bed methane (CBM).
Committed projects	Projects that will proceed, with known timing, and satisfying all five of AEMO's commitment criteria.
Contingent resources	Resources that are not yet considered commercially recoverable. Technological or business hurdles need to be cleared before these resources can be considered economically justified for development.
Conventional gas	Gas that is produced using traditional oil and gas industry practices. See also coal seam gas (CSG) and unconventional gas.
COP21 commitment	This refers to Australia's commitment at the 21st Conference of Paris to reduce greenhouse gas emissions, and is also known as the 2015 Paris agreement. The Council of Australian Governments (CoAG) has recommended the NTNDP assume a 26% to 28% emissions reduction below 2005 levels by 2030. This assessment assumed that the resultant trajectory of emissions reduction is continued between 2030 and 2036.
Domestic gas	Gas used for residences, businesses, and electricity generation. This comprises the mass market, large industrial, and GPG market segments, excluding gas demand for LNG export.
Gas Bulletin Board	A website (www.gasbb.com.au) managed by AEMO that provides information about major interconnected gas processing facilities, gas transmission pipelines, gas storage facilities, and demand centres in eastern and south-eastern Australia. Also known as the National Gas Market Bulletin Board or simply the Bulletin Board.
Gas-powered generation (GPG)	The generation of electricity using gas as a fuel for turbines, boilers, or engines.
Global solar exposure	This refers to the total amount of solar energy falling on a horizontal surface.
Large industrial (market segment)	A segment of the eastern and south-eastern Australian gas market involving businesses that consume more than 10 TJ/a.
Large-scale Renewable Energy Target (LRET)	See 'National Renewable Energy Target scheme'.
Learning rate	This refers in this case to the reduction in technology investment costs for every doubling of cumulative (historical) installed capacity.
Liquefied natural gas (LNG)	Natural gas that has been converted into liquid form for ease of storage or transport.
Market segments	To develop gas demand projections, gas consumers are grouped into domestic market segments (mass market, large industrial, and GPG) and gas demand for LNG export.
Mass market (market segment)	A segment of the eastern and south-eastern Australian gas market involving residential users and businesses that consume less than 10 TJ/a.
National Electricity Market	The wholesale market for electricity supply in Queensland, New South Wales (including the Australian Capital Territory), Victoria, South Australia, and Tasmania.

Term	Definition
National Renewable Energy Target scheme	The national Renewable Energy Target (RET) scheme, commenced in January 2010, aims to meet a renewable energy target of 20% by 2020. Like its predecessor, the Mandatory Renewable Energy Target (MRET), the national RET scheme requires electricity retailers to source a proportion of their electricity from renewable sources developed after 1997. The national RET scheme is currently structured in two parts: • The Small-scale Renewable Energy Scheme (SRES) is a fixed price, unlimited-quantity scheme available only to small-scale technologies (such as solar water heating) and is being implemented via Small-scale Technology Certificates (STC). • The LRET is being implemented via LGCs, and targets 33,000 GWh of renewable energy by 2020.
Possible reserves	Estimated quantities that have a chance of being discovered under favourable circumstances. Possible, proved, and probable reserves added together make up 3P reserves.
Probable reserves	Estimated quantities of gas that have a reasonable probability of being produced under existing economic and operating conditions. Proved and probable reserves added together make up 2P reserves.
Production	When used in the context of defining gas reserves, gas that has already been recovered and produced.
Prospective resources	Gas volumes estimated to be recoverable from a prospective reservoir that has not yet been drilled. These estimates are therefore based on less direct evidence.
Proved plus probable	See 2P reserves.
Proved reserves	An estimated quantity of gas that is reasonably certain to be recoverable in the future under existing economic and operating conditions. Also known as 1P reserves.
Reserves	Gas resources that are considered to be commercially recoverable and have been approved or justified for commercial development.
Reservoir	In geology, a naturally occurring storage area that traps and holds oil or gas (or both).
Resources (for gas)	See contingent resources and prospective resources.
Shale gas	Gas found in shale layers that cannot be economically produced using conventional oil and gas industry techniques. See unconventional gas.
Storage facility	Facilities that store gas for use at times of high demand.
Synchronous generation	This refers to generation whose operation is tightly 'synchronised' to the operating frequency of the power system. For example, in a power system operating at a normal frequency of exactly 50 Hertz (Hz), or 50 cycles per second, the rotating parts of most synchronous generating units (such as the turbine and rotor) connected to the power system will be spinning in step with the system frequency. Synchronous machines respond exactly in lock step to any changes to power system frequency.
Turkey-nest	This refers to man-made artificial reservoirs.
Unconventional gas	Gas found in shale layers, or tightly compacted sandstone that cannot be economically produced using conventional oil and gas industry techniques. See also coal seam gas (CSG) and conventional gas. Unless otherwise indicated, unconventional gas includes CSG, shale and tight gas.
Victorian Renewable Energy Target (VRET)	A Victorian Government target for renewable generation to produce 25% of total electricity in Victoria by 2020 and 40% by 2025.