SOUTH AUSTRALIAN FUEL AND TECHNOLOGY REPORT

SOUTH AUSTRALIAN ADVISORY FUNCTIONS

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IMPORTANT NOTICE

Purpose

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This report provides information about fuel, resources, and power generation technology related to the energy industry in South Australia.

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Acknowledgement

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EXECUTIVE SUMMARY

The 2015 South Australian Fuel and Technology Report outlines the range of fuel resources and power generation technologies available in South Australia now and in the future, and their comparative future costs. It details energy projects being developed in the state, and explores how new technologies are being integrated, particularly in the evolving area of renewable energy generation.

South Australia's changing generation fuel mix

South Australia has abundant renewable and non-renewable fuel resources. Non-renewable resources have traditionally provided the bulk of South Australia's energy use, with 61% of electricity generation sourced from natural gas and coal in 2013–14. However, this is down from 82% in 2009–10, highlighting the transformation currently underway towards an increasing share for renewable generation and a greater reliance on imports.

South Australia's location and connection within the National Electricity Market (NEM) provides both opportunities and challenges for local generation.

Imports and exports:

- The Heywood and Murraylink interconnectors give South Australia access to the NEM, allowing both imports and exports based on the cost of generation, subject to network limitations. There has been increasing net-energy flow from Victoria into South Australia in recent years, with a compound annual growth rate (CAGR) of 28% over the period 2009–10 to 2013–14.
- The 2016 Heywood interconnector upgrade will further increase import and export flow capacity, benefiting consumers in both states, but is likely to further increase net imports and reduce local generation.

Non-renewable generation:

- Local coal resources for electricity generation are modest compared with other parts of Australia, but are adequate to supply existing coal generation in South Australia until its expected end of life in 2030.
- Natural gas, supplied through two key pipelines that connect the state with the eastern and south-eastern Australian gas network, is under increasing cost pressure as producers seek higher prices when east coast liquefied natural gas (LNG) exports begin from Gladstone, Queensland. While there are currently sufficient gas resources across the network to meet projected gas consumption until at least 2030, price increases are likely to reduce existing natural gas power generation levels.

Renewable generation

- Renewable resources are plentiful and form the largest growing component of the South Australian fuel mix. Renewable energy generation, particularly wind, is attracting the greatest interest from potential investors but is being driven by the large scale renewable energy target (LRET) scheme currently under review. Investment in residential solar photovoltaic (PV) systems also continues to rise, reducing overall consumption and peak demand profiles for South Australia.
- South Australia has the most installed wind generation capacity in Australia. High average wind speeds near the coast, in the hinterlands, and in near-coastal waters provide potential for further wind generation investment, on- and off-shore. Overall, 3,107 MW of publicly announced wind projects are earmarked for South Australia, although exactly how much will be built is uncertain and largely depends on the future of the LRET.
- Sunlight is an abundant natural resource in South Australia. While embedded rooftop PV installation in South Australia generated 704 gigawatt hours (GWh) during 2013–14 (18% of Australia's total PV output), large-scale grid connected solar generation is limited in South Australia, with only one project announced to date. However, sizeable cost reductions for PV could see large-scale PV reach parity with wind in the near future.

The technology frontier – comparative costs of new generation

AEMO has assessed the comparative costs of a range of generation technologies for South Australia and the NEM), based on calculating the levelised cost of electricity (LCOE) incorporating estimated capital costs and likely future fuel costs.

- Gas remains the lowest cost new generation for South Australia, based on projected costs over a 30-year plant life, and including recent gas price increases and the carbon price repeal. This applies across the board for peak, intermittent, and base-load generation. For the NEM as a whole, however, new black coal generation has the lowest LCOE for base-load generation.
- For new renewable generation, with investment dependent on LRET, wind generation has the lowest LCOE. Grid connected PV (fixed flat plate) has however seen a substantial drop in capital costs in recent years and is becoming more cost competitive with wind generation.

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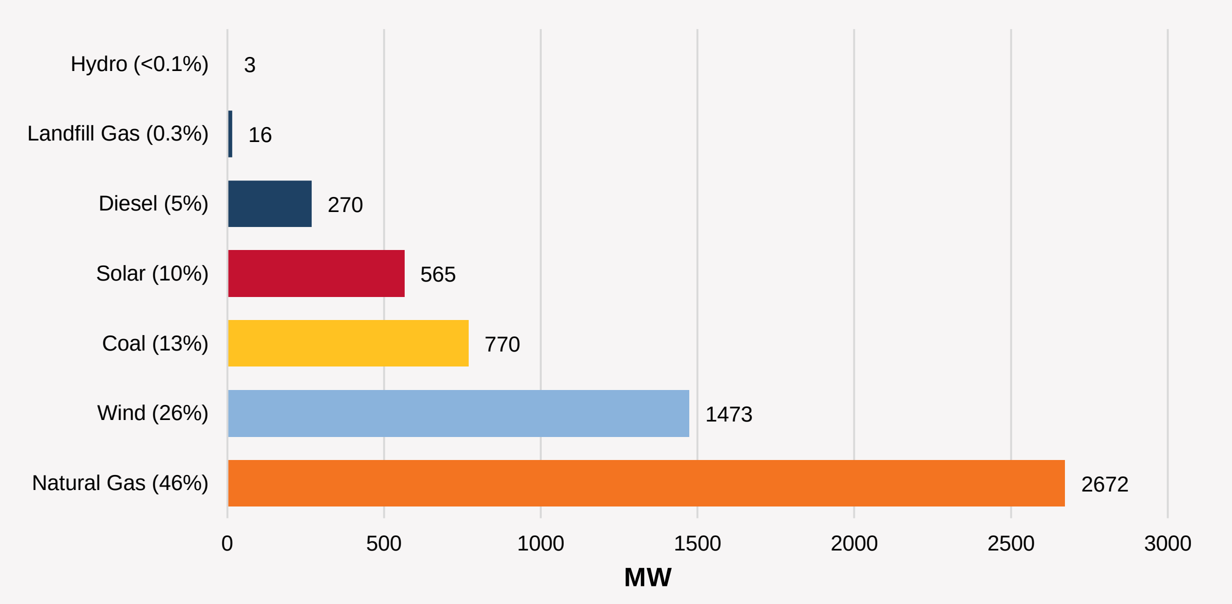
1.1 Electricity capacity mix

Since the commissioning of the 270 MW Snowtown Stage 2 Wind Farm in June 2014[1], South Australian installed electricity generation capacity increased to 5,769 MW. A breakdown of installed generation capacity by fuel type is shown in Figure 1, indicating the largest sector is natural gas at 46% of installed capacity, followed by wind at 26% of installed capacity.

Further details on South Australia's generation capacity can be found at the Generation Information Page on the AEMO website.[2]

Figure 1 South Australian electricity capacity by fuel type (as of July 2014)



Note: Solar to date, is comprised exclusively of residential photovoltaic systems (PV)

While installed capacity provides electricity generation potential, actual generation depends on a range of variables including fuel costs and resource availability, maintenance and other operational costs, network constraints, overall profit opportunities for a given participant's portfolio of generation assets, and expected demand profiles.

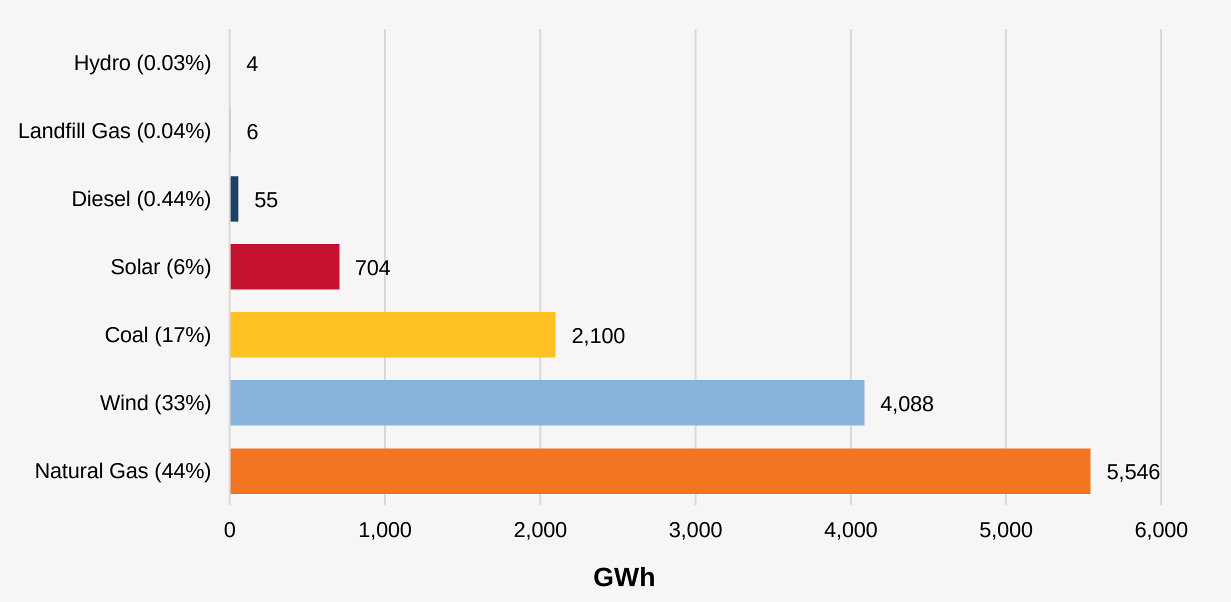
[1] Capacity for wind generation is included for a project once its output reaches 90% of its rated power. This may occur before the project is fully commissioned, as in the case for Snowtown Stage 2.

[2] AEMO *Regional generation information pages (South Australia),* August 2014. Available: http://www.aemo.com.au/Electricity/Planning/Related-Information/Generation-Information: Viewed: 1 Dec 2014.

1.2 Electricity generation mix

Annual electricity generation includes all grid-connected generation in South Australia, plus embedded generation, including an estimate of residential PV for all South Australian households. Standalone remote power systems are not included in the annual totals for South Australia in Figure 2 or imports into South Australia from other regions in the NEM.[3]

Figure 2 South Australian electricity generation share by fuel type (FY2013–14)[4]



Natural gas is the main fuel used to generate electricity in South Australia. Diesel fuel, while representing 5% of installed capacity, contributes less than 0.5% to annual energy, reflecting its high fuel cost and its use limited to high market price periods. Wind and PV have no fuel cost, but operate only intermittently when resources are available. Gas and coal operate depending on market price, although both have set run times and ramp up and down rate limitations that must be taken into account.

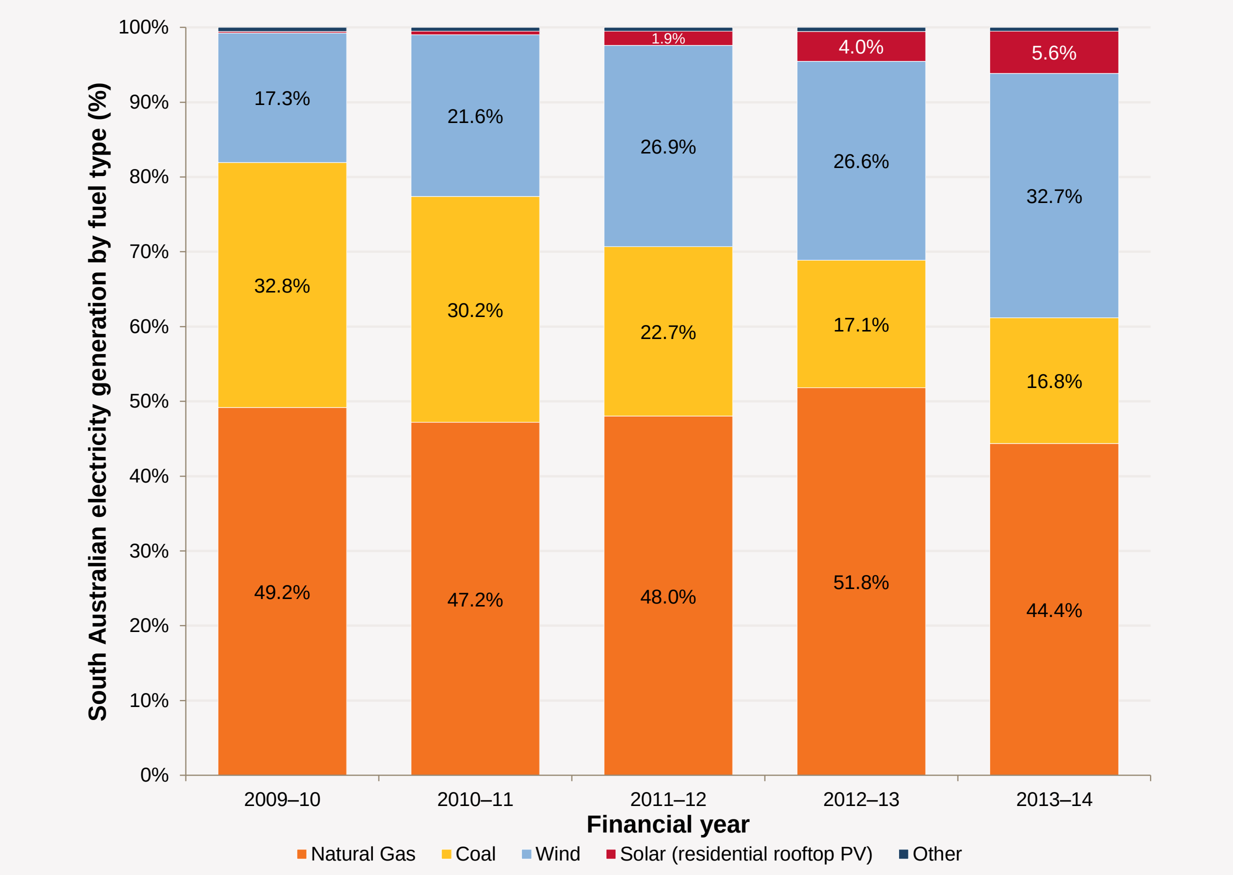
The changing generation mix

South Australia's fuel mix for generating electricity has changed in the past five years since 2009–10 as shown in Figure 3.

- Gas's share has fallen from 49.2% in 2009–10 to 44.4% in 2013–14, while coal's share has fallen from 32.8% in 2009–10 to 16.8% in 2013–14.
- Wind and residential PV has grown, with wind generation's share increasing from 17.3% in 2009–10 to 32.7% in 2013–14. Residential solar PV, starting from a much lower base of 0.2% in 2009–10, has increased to 5.6% generation share in 2013–14.[5]

[3] All generation from Snowtown Stage 2 has been included in the total for wind, including during commissioning.
[4] South Australian grid-connected generation only (excludes any remote non-NEM connected generation and imports from Victoria, includes solar residential PV generation, exports to Victoria and embedded generation). Totals may not add to 100% due to rounding.
[5] As residential PV occurs "behind the meter", it reduces network or grid supplied electricity.

Figure 3 South Australian electricity generation share by fuel type (2009–10 to 2013–14) [6]



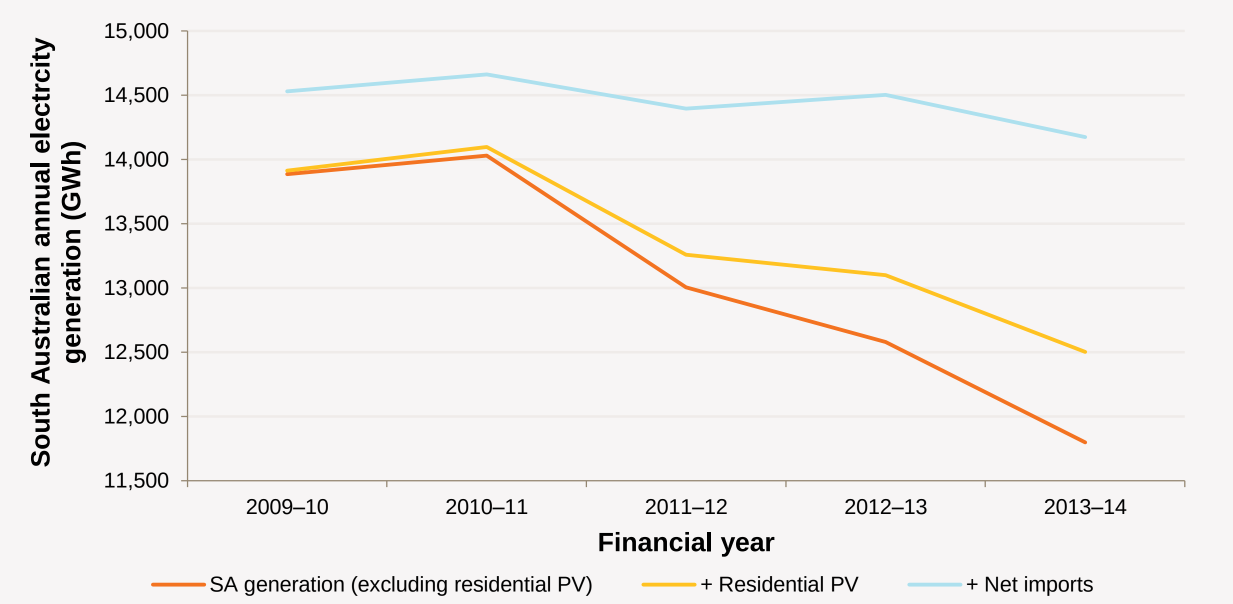
South Australian total electricity generation has also declined. This is due to the combined effects of lower consumption – due to increased residential PV, efficiency gains and response to price – and higher net imports from Victoria into South Australia.

Figure 4 summarises the South Australian grid connected generation[7], the extra generation from residential PV and net imports for five years from 2009–10 to 2013–14.

- Imports result from lower bids from outside South Australia, while exports occur when South Australian prices are lower than in other NEM regions.
- To date, net imports – combined imports and exports over the year – have resulted in a net flow from Victoria.
- Overall, net imports have increased from 618 MW in 2009–10 to 1,673 MW in 2013–14, a 28% CAGR.[8]

[6] South Australian grid-connected generation only (excludes any remote non-NEM connected generation and imports from Victoria, includes solar residential PV generation and exports to Victoria). Totals may not add up to 100% due to rounding.
[7] Includes embedded generation from diesel, hydro and landfill gas.
[8] CAGR is the Compound Annual Growth Rate, calculated in this case from 2009–10 to 2013–14.

Figure 4 South Australian generation, net imports and residential PV (2009–10 to 2013–14)



Generation mix changes and declining South Australian generation have resulted in a decrease in annual electricity generation in gigawatt hours (GWh) for both gas and coal, while wind and solar generation have increased. Table 1 provides a summary of these changes over the period 2009–10 to 2013–14.

Table 1 South Australian annual energy generation by fuel type changes (2009–10 to 2013–14)

Fuel source	% Change (from 2009–10 to 2013–14)	Compound annual growth rate (CAGR)
Coal	–55%	–18%
Natural gas	–21%	–5%
Wind	+ 53%	+14%
Solar (residential PV)	+ 2430%	+126%

A more detailed analysis of the absolute generation over time including imports and exports can be found in the 2014 South Australian Electricity Market Economics Trends Report[9] and 2014 South Australian Historical Market Information Report.[10]

[9] AEMO. *South Australian Electricity Market Economic Trends Report 2014*. Available: http://www.aemo.com.au/Electricity/Planning/South-Australian-Advisory-Functions/South-Australian-Electricity-Market-Economic-Trends-Report. Viewed: 1 Dec 2014.

[10] AEMO. *South Australian Historical Market Information Report 2014*. Available: http://www.aemo.com.au/Electricity/Planning/South-Australian-Advisory-Functions/South-Australian-Historical-Market-Information-Report. Viewed: 1 Dec 2014.

1.3 South Australian generation update

Several announced energy projects have potential to change South Australia's generation and fuel use mix. These projects cover consumers' investment decisions as well as generation assets and network investments that are tracked and updated regularly on AEMO's Generation Information webpage.[11]

However, development delays, cost increases and policy uncertainty are impacting on the development prospects and timelines of several of these projects. In particular, carbon pricing repeal and uncertainty created by the LRET review have stalled renewable generation projects. Consequently, there is a slowdown in publicly announced projects progressing to the advanced planning and/or committed stages.

Table 2 summarises current identified projects.[12] Further details are provided in the technology review in Chapter 3, where appropriate.

Table 2 South Australian new generation project summary

Project Status	Technology	Description
Committed	Network investment	The Heywood interconnector upgrade has been approved and is scheduled for commissioning in June 2016. This will allow higher electricity exports to Victoria from wind generation in South Australia, and more electricity imports from Victoria.
Publicly Announced new generation projects	Wind	Overall, 3,107 MW of new wind has been publicly announced for South Australia. However, none of this has progressed to advanced or committed status, and may be subject to delay. Overall, four projects have provided commissioning dates, with all other projects yet to be confirmed: • Investec's Hornsdale Wind Farm (270 MW) • Ratch Australia's Kongorong Wind Farm (240 MW) and the Kulpara Wind Farm (150 MW) • TrustPower Australia Palmer Wind Farm (342 MW)
	Gas	Three projects with a combined generation capacity of 720 MW have been publicly announced. Given falling demand and volatile gas prices, no projects have proceeded to advanced or committed status. • Tungkillo Powerco's Cherokee Power power station (250 MW) • Pelican Point Power Limited's Pelican Point S2 power station (320 MW) • Acquasol Infrastructure's Point Paterson power station (150 MW)
	Solar	The only grid-scale solar project publicly announced for South Australia is by Acquasol Infrastructure Pty Ltd, involving a 50 MW solar thermal plant included as part of the Point Paterson station development.
	Coal	Plans to build an integrated gasification and combined cycle (IGCC) power station as part of Altona Energy's Arckaringa Project have been publicly announced, but neither capacity nor target dates have been provided to AEMO at this stage.
	Geothermal	Three geothermal power station projects have been publicly announced for South Australia and are included on the AEMO generation information page. Given policy uncertainty, these projects have not been progressing. • Geodynamics' Innamincka power station (initial 10MW, 500MW to follow) • Petratherm Limited's Paralana project (2 x 3.5 MW) • Raya Group's Penola station (5.9 MW)
Not proceeding	Oceanic (wave)	Only one wave project has been publicly announced. Oceanlinx Limited's Port MacDonnell (1 MW) wave energy project was due to begin testing in early 2014. However, the unit was damaged beyond repair during transportation and the company was placed in receivership.[13]

11 Generation Information. Available: http://www.aemo.com.au/Electricity/Planning/Related-Information/Generation-Information. Viewed: 15 Dec 2014.

12 Projects mentioned in this report may not be included in AEMO's Planning Studies if they did not meet the "committed" status at the time of modelling for earlier AEMO reports.

13 Oceanlinx Receivership Update. Available: http://www.kordamentha.com/news/oceanlinx-receivership-update. Viewed: 16 Dec 2014.

Falling demand continues to place pressure on existing generation. Overall, three existing generation facilities have publicly announced plans to retire or reduce capacity. Table 3 summarises all announcements applying to South Australian generation.

Table 3 South Australian existing generation retirement summary

Project Status	Technology	Description
Retirements	Gas	AGL has announced that the four Torrens Island A-station generation units will be mothballed in 2017, reducing the plant's capacity by 480 MW.[14]
Capacity reduction	Gas	Pelican Point is to reduce its capacity by half (240 MW) from April 2015.[15]
On recall	Gas	Alinta Energy advises that Playford B power station (240 MW) will be available with a 90-day recall time.

[14] AGL media release 10 Dec 2014. Available: http://www.agl.com.au/about-agl/media-centre/article-list/2014/december/agl-to-mothball-south-australian-generating-units. Viewed: 15 Dec 2014.

[15] Adelaide Now, quoting a written statement from GDF Suez. Available: http://www.adelaidenow.com.au/news/south-australia/pelican-point-power-station-will-cut-more-than-half-its-generation-capacity-early-next-year-threatening-jobs/story-fni6uo1m-1226978458743. Viewed: 24 Dec 2014.

2. RESOURCE AVAILABILITY

2.1 Coal

Availability

Geoscience Australia[16] estimates that the total economically recoverable quantities of brown and black coal deposits in South Australia are modest compared with other states.

The South Australian Department of State Development publishes quantitative and qualitative estimates of South Australia's coal resources. These are presented in Table 4 and Figure 5.

Table 4 South Australian coal resources[17]

Deposit		Coal tonnage		Proximate analysis				Heat value (MJ/kg)	Impurities		
		Measured Indicated (million tonnes)	Inferred (million tonnes)	Moisture (%)	Ash (%)	Volatile manner (%)	Fixed carbon (%)		Total sulphur (%)	Chlorine (%)	Sodium-in-ash (%)
Sub-bituminous											
Arckaringa Coalfield	Wintinna	1,850	2,270	35	6	25	34	18.5	1.2	0.04	2
	East Wintinna	975	1,200	38	6	22	34	17.6	0.7	0.02	1
	Murloocoppie	-	1,450	35	7	25	33	17.6	3.1	-	2
	Westfield	140	490	35	7	25	33	17.8	3.1	-	1
Lake Phillipson		-	4,700	30	13	25	32	17.0	1	1.70	10
Leigh Creek Coalfield	Copley Basin Lobe A	11	-	37	12	20	31	15.2	2.9	-	-
	North Field Lobe C	12	-	29	22	22	27	13.3	3.0	-	-
	Telford Basin Lobe B	150	350	33	16	21	30	15.8	0.4	0.27	4
Lock		260	-	26	23	30	21	14.6	0.4	-	2
Lignite											
Northern St Vincent Basin	Bowmans	1,250	350	56	5	22	17	10.6	2.2	0.50	14
	Clinton*	340	440	53	9	18	20	9.4	1.9	-	16
	Beaufort*	255	45	-	-	-	-	-	-	-	-
	Whitwarta*	145	185	55	12	19	14	9.4	2.6	-	9
	Lochiel	585	-	61	6	19	14	9.1	1.1	0.18	6
Kingston+		985	-	53	7	22	18	10.6	1.5	0.11	6
Anna		58	-	54	11	21	14	9.9	1.8	-	2
Sedan		231	-	58	9	19	14	9.4	2.3	0.08	3
Moorlands		32	-	55	9	18	18	9.9	1.8	0.14	3

* Combined total 558 Mt (Indicated and Inferred) – Syngas 2008. <*www.syngas.com.au*>.
\+ Combined total 578.3 Mt (Measured and Indicated) – Hybrid Energy 2007. <*www.hybridenergyaustralia.com.au*>.

[16] Geoscience Australia. *Australia's Identified Mineral Resources.* Available: http://www.ga.gov.au/corporate_data/78988/78988_AIMR_2013.pdf. Viewed: 16 Dec 2014.

[17] Department of State Development, Resources and Energy Group. *Coal Deposits in South Australia*. Available: https://sarigbasis.pir.sa.gov.au/WebtopEw/ws/samref/sarig1/image/DDD/ISM23.pdf. Viewed: 16 Dec 2014.

Current development

Leigh Creek

Leigh Creek, 567 km north of Adelaide, has the only operating coal mine in South Australia. The mine's sole use is supplying the coal-fired generating units of the Northern and Playford B power stations at Port Augusta, via a 280 km rail line.

Leigh Creek is open-cut, comprising the Copley, North Field, and Telford basins. Its sub-bituminous brown coal is lower quality than New South Wales or Queensland black coal, but higher than Victorian brown coal. The Leigh Creek mine is currently limited to the main and upper series coal seams of Lobe B in the Telford Basin, with potential to access the lower seam in the future. While there are about 150 million tonnes of inferred resources at Leigh Creek, much of this is not economically recoverable.

The 2011 Leigh Creek Life Study report[18] commissioned by AEMO, suggested that around 15 years of economically recoverable coal was left in the mine, assuming mining was extended to access the lower seam.

- This assessment correlates well with publicly reported estimates[19] by Alinta Energy, the owner of the mine and the Port Augusta power stations.
- Should the Leigh Creek coal source cease to be economic, the report suggests that viable options for supplying the Port Augusta power stations include new mine development in South Australia, and coal imports from Western Australia, New South Wales, or overseas.
- Alinta Energy is looking to extend Northern power station's life beyond 2030, potentially sourcing coal from another suitable location in South Australia if viable.[20]

Other factors contributing to the potential demand for coal in South Australia include Port Augusta power stations' changing operating regime (see AEMO's Generation Information webpage[21]) and government policy on carbon pricing mechanisms and renewable energy targets.

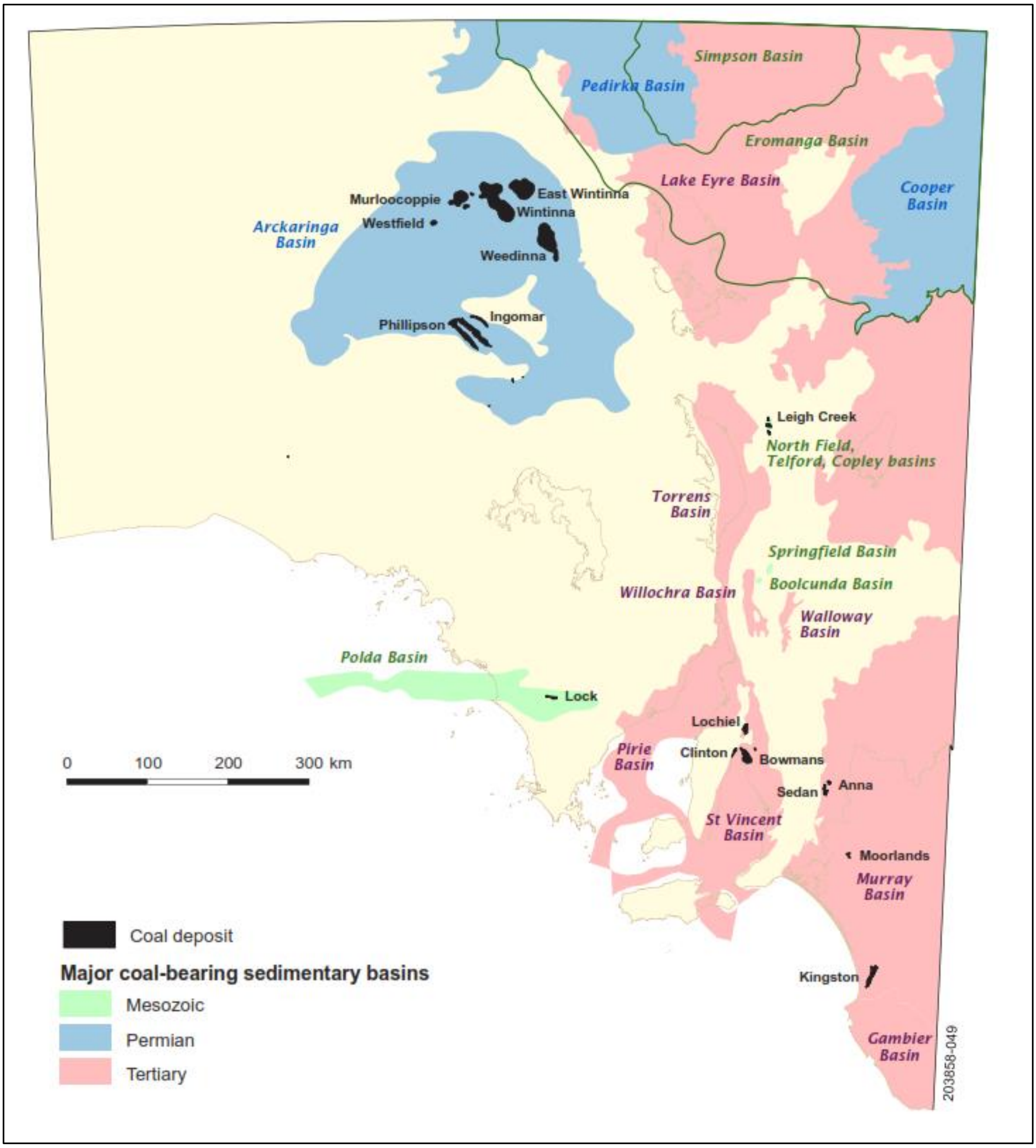
Arckaringa

The Arckaringa Project in South Australia's far north is exploring opportunities for mining the Westfield, Wintinna, and Murloocoppie coal deposits.[22] The proposed open-cut mine has the potential to produce various outputs, including some liquid fuels, industrial chemicals, and electricity generation.

Altona Energy, Sino-Aus Energy Group and Wintask Group announced a joint venture in December 2013[23], and Altona stated the Arckaringa project's product focus will be coal-to-methanol, coal chemical and synthetic gas production, due to market demand and reliance of proven technology. The initial drilling program and bankable feasibility study (BFS) is targeted for completion within two years.

18 CQ Partners. *Leigh Creek Life Study*. March 2011.
19 Adelaide Now. *Alinta seeks coal to keep power plant going.* Available: http://www.adelaidenow.com.au/business/alinta-seeks-coal-to-keep-power-plant-going/story-e6frede3-1226038658107. Viewed: 16 Dec 2014.
20 Ibid.
21 AEMO. *Generation Information.* Available: http://www.aemo.com.au/Electricity/Planning/Related-Information/Generation-Information. (Refer to the latest published workbook for SA in the Summer Scheduled Capacities and Winter Scheduled Capacities worksheets.) Viewed: 16 Dec 2014.
22 Altona Energy. *Welcome to Altona Energy*. Available: http://www.altonaenergy.com/index.php. Viewed: 16 Dec 2014.
23 Asian Oil and Gas, *Altona signs new Arckaringa joint venture* Nov 2014. Available at: http://www.aogdigital.com/component/k2/item/4390-altona-signs-new-arckaringa-joint-venture. Viewed: 8 Dec 2014.

Figure 5 South Australian coal deposits[24]



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24 Department of State Development, Resources and Energy Group. *Coal Deposits in South Australia*. Available: https://sarigbasis.pir.sa.gov.au/WebtopEw/ws/samref/sarig1/image/DDD/ISM23.pdf. Viewed: 16 Dec 2014.

2.2 Natural gas

Availability

Eastern and south-eastern Australian proven plus probable natural gas reserves (2P)[25] totalled 53,229 PJ as at 31 December 2012. Analysis indicates that commercially viable reserves are likely to satisfy projected demand for at least the next 20 years. Unless otherwise referenced, the information in this section has been sourced from AEMO[26,27,28] and Core Energy Group[29] reports. The 2015 Gas Statement of Opportunities (GSOO) will provide an update on reserves and is due for publication in March 2015.

South Australia has traditionally sourced natural gas from the Cooper and Eromanga Basins.[30] 2P reserves for the Cooper and Eromanga Basins are reported at 1,943 PJ or the equivalent of 23 years of South Australian natural gas consumption at the current rate of use.

Figure 6 illustrates major natural gas producing basins and gas transmission infrastructure in eastern and south-eastern Australia.

Current developments

Unconventional gas

A source of public information about unconventional gas exploration in South Australia is the Roadmap for Unconventional Gas Projects in South Australia report, published by the Department of State Development (formerly DMITRE).[31] Chapter 4 of the report describes the unconventional gas projects being pursued within South Australia, by basin and company. Key points include:

- At least nine unconventional gas plays are being explored in South Australia.
- Two of these are expected to be profitably developed within the next five years.
- The most advanced is in the Cooper Basin, comprising shale, tight, and deep CSG.
- The Moomba 191 shale gas well is already commercialised, having commenced production in October 2012.

The Core Energy Group reserves report[32] estimates no CSG 2P reserves for the Cooper and Eromanga basins at 31 December 2012. Total 2P CSG reserves for eastern and south-eastern Australia total 46,131 PJ. The report lists unconventional 2P reserves for the same basins (excluding CSG) as totalling 5 PJ, which comprises all such reserves in eastern and south-eastern Australia.

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25 See glossary for definitions of reserve and resource classification.

26 AEMO, *Gas Statement of Opportunities 2013*. Available: http://www.aemo.com.au/Gas/Planning/Gas-Statement-of-Opportunities. Viewed: 22 Dec 2014.

27 AEMO, *Gas Statement of Opportunities 2013*. Gas Reserves Update and Projections. Available: http://www.aemo.com.au/Gas/Planning/Gas-Statement-of-Opportunities/GSOO-2013-Gas-Reserves-Update-and-Projections. Viewed: 22 Dec 2014.

28 AEMO, *Gas Statement of Opportunities 2013* Available: http://www.aemo.com.au/Gas/Planning/~/media/Files/Other/planning/gsoo/2013/GSOO%202013%20National%20Gas%20Forecast.xlsx.ashx. Viewed: 22 Dec 2014.

29 Core Energy Group. *Current and Projected Gas Reserves and Resources for Eastern and South Eastern Australia*. Available: http://www.aemo.com.au/Gas/Planning/Gas-Statement-of-Opportunities/~/media/Files/Other/planning/gsoo/2013/Core%20Energy%20Group%20AEMO%20GSOO%202013%20Reserves%20and%20Resources%20Report.pdf.ashx. Viewed: 22 Dec 2014.

30 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.

31 DMITRE. *DMITRE Petroleum, Roadmap for unconventional gas projects in South Australia*. (See Executive Summary). Available: http://www.petroleum.dmitre.sa.gov.au/prospectivity/basin_and_province_information/unconventional_gas/unconventional_gas_interest_group/roadmap_for_unconventional_gas_projects_in_sa. Viewed: 22 Dec 2014.

32 Core Energy Group. August 2013. *Current and Projected Gas Reserves and Resources for Eastern and South Eastern Australia*. Available: http://www.aemo.com.au/Gas/Planning/Gas-Statement-of-Opportunities/~/media/Files/Other/planning/gsoo/2013/Core%20Energy%20Group%20AEMO%20GSOO%202013%20Reserves%20and%20Resources%20Report.pdf.ashx. Viewed: 22 Dec 2014.

Shale gas

Shales generally have insufficient permeability to allow substantial gas flow to a well bore, making shale gas a historically difficult resource to commercialise. However, recent advances in hydraulic fracturing technology have made extraction economically viable. Total prospective unconventional (excluding CSG) reserves and resources in the Cooper and Eromanga Basins are estimated at 159,474 PJ, as at 31 December 2012.[33]

Further progression of successful hydraulic fracturing processes in Australia were reported by Armour Energy, who reported the "first successful application of multi-stage, hydraulically stimulated, horizontal well technology in the Australian shale gas industry" at their Egilabria 2 well in Queensland.[34]

The Australian Council of Learned Academies' *Engineering Energy: Unconventional Gas Production – A study of shale gas in Australia* broadly assessed the issues that the shale gas industry faces in Australia, including technological and economic challenges.

Santos began an unconventional gas exploration program in 2004. Shale gas is currently being produced in the Cooper Basin through a joint venture between Santos, Beach Energy, and Origin Energy. Moomba 191 is a vertical shale test well and officially started production on 19 October 2012.[35] Further shale gas exploration is continuing in South Australia with participation by more than 20 joint ventures, including BG and Chevron.[36]

South Australian Demand

AEMO categorises South Australian natural gas usage into three areas: mass market (MM), large industrial (LI), and gas-powered generation (GPG). LI users are those that consume more than 10 TJ/a.

Table 5 summarises the total annual South Australian natural gas consumption and the percentage used for electricity generation (GPG).

Table 5 South Australian gas consumption 2011–14[37]

Calendar year	Calculation	Total gas consumption (PJ)	Gas used for electricity generation (GPG)	
			(PJ)	Percent of total
2011	Actual	103.8	63.0	60.7%
2012	Actual	105.2	65.6	62.4%
2013	Actual	96.8	58.3	60.2%
2014	Forecast	85.2	47.3	55.5%

33 AEMO. *Reserves update and projections accompanying database*. Available: http://www.aemo.com.au/Gas/Planning/Gas-Statement-of-Opportunities/GSOO-2013-Gas-Reserves-Update-and-Projections. Viewed: 22 Dec 2014.

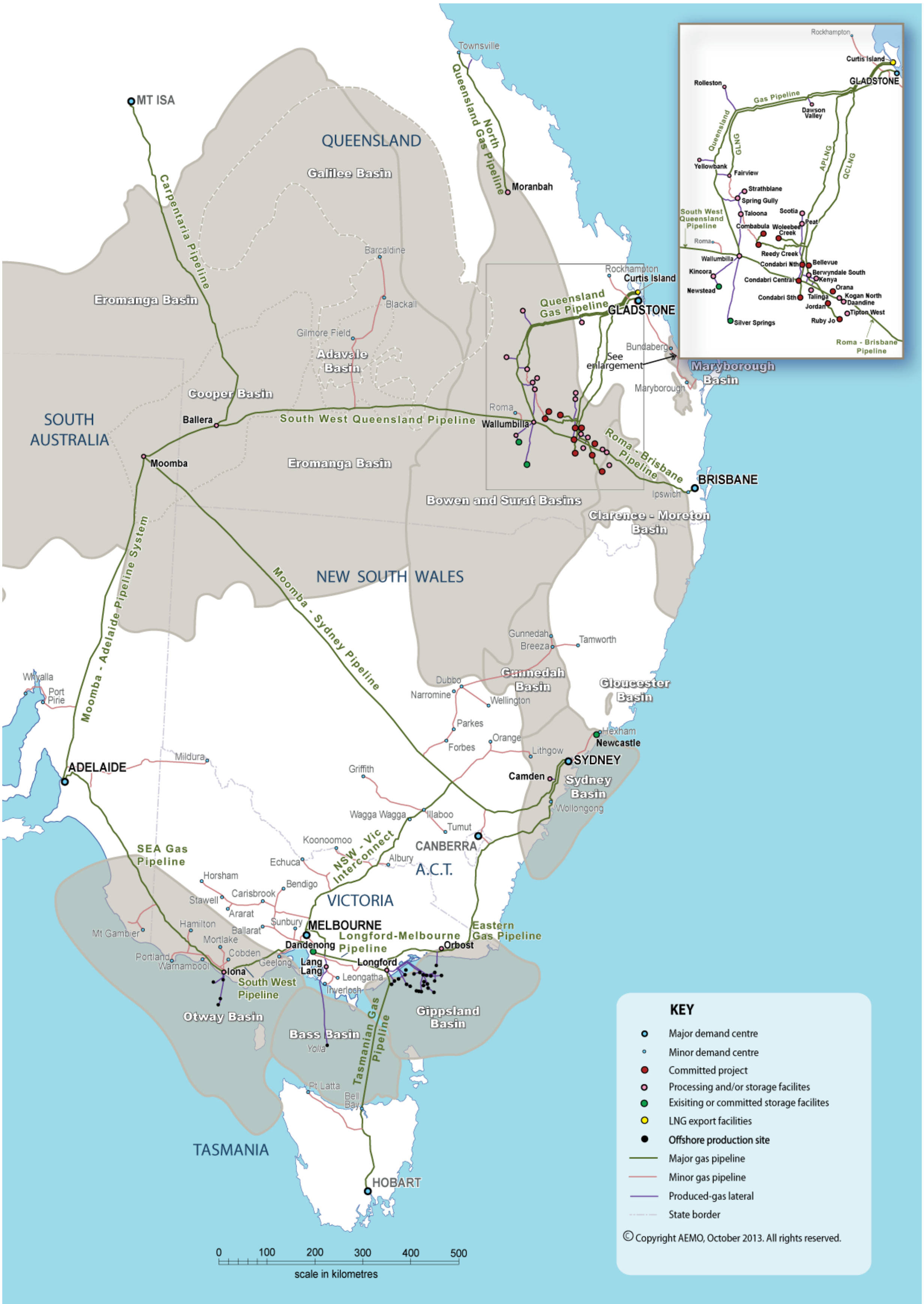
34 Armour Energy. *Egilabria 2 – First Continuous Post-Stimulation Gas Flows*. Available: http://www.armourenergy.com.au/assets/downloads/announcements/2013/nov/asx-20131104-egilabria2dw1-first-gas2surface.pdf. Viewed: 22 Dec 2014.

35 Santos. *Santos announces start of Australia's first commercial shale gas production*. Available: http://www.santos.com/Archive/NewsDetail.aspx?p=121&id=1347. Viewed: 22 Dec 2014.

36 South Australian Chamber of Mines and Energy. *Oil and Gas in South Australia*. Available: http://www.sacome.org.au/policy-and-advocacy/environment-a-social/oil-gas.html. Viewed 16 Dec 2014.

37 AEMO. *National Gas Forecast Report*. Available: http://aemo.com.au/Gas/Planning/Forecasting/National-Gas-Forecasting-Report. Viewed 16 Dec 2014.

Figure 6 Gas producing basins and infrastructure



Infrastructure

South Australia's natural gas is delivered through an interconnected pipeline network from the Cooper Basin, Victoria, and Queensland.

Gas imported from Queensland and Victoria supplements locally sourced gas. Gas producers are investigating extra conventional and unconventional gas resources in South Australia.

Table 6 lists the major gas pipelines relating to South Australia. As Figure 6 shows, gas can flow from Queensland to South Australia via the South West Queensland Pipeline (SWQP) and on to the Adelaide demand centre via the Moomba to Adelaide Pipeline System (MAPS). Gas can also be imported into South Australia from Victoria via the South East Australia Gas Pipeline (SEAGas). Gas is exported from South Australia to New South Wales via the Moomba to Sydney Pipeline (MSP).

Table 6 **Major gas pipelines relating to South Australia**[38]

Gas pipeline	Length (km)	Year of first gas flow	Capacity reported as at July 2013 (TJ/d)
South West Queensland Pipeline[a]	937	1996	385 (west), 198 (east)
Moomba to Adelaide Pipeline	1,185	1969	253
Moomba to Sydney Pipeline	2,030	1998	420
South East Australia Gas Pipeline	680	2004	314

[a] Includes the Queensland – South Australia – New South Wales (QSN) Link.

Current operation levels

For 2014 (to 15 December), South Australia exported about 66 PJ of gas via the MSP, while importing about 55 PJ via the SEA Gas pipeline. A precise measure of the gas imported through the SWQP for 2014 was not available via the Gas Bulletin Board. However, in general, gas has been flowing from east to west from Wallumbilla to support supply in the southern states. AEMO expects that direction to change when LNG exports ramp up.

In 2014, the following gas supplies were delivered to the Adelaide demand centre:

- MAPS supplied 40 PJ, operating (on average) at about 46% of full capacity (253 TJ/d), with flows ranging from 44 TJ/d to 238 TJ/d.
- SEA Gas supplied 43 PJ, operating (on average) at about 39% of full capacity (314 TJ/d), with flows ranging from 27 TJ/d to 250 TJ/d.

Together, these pipelines supplied 83 PJ of gas during 2014, as at 15 December, which is about 40% of the combined 208 PJ/year pipeline capacity.

Future projections

Further information on gas adequacy, and potential opportunities for infrastructure investment or reserves development under a range of future scenarios, will be available in the 2015 GSOO.

[38] AEMO. *Gas Facilities Database*, 29 Nov 2013. Available: http://www.aemo.com.au/Gas/Planning/Gas-Statement-of-Opportunities/~/media/Files/Other/planning/gsoo/2013/GSOO%202013%20Gas%20Facilities.xlsx.ashx. Viewed: 22 Dec 2014.

2.3 Liquid fuel

Availability

South Australia is currently estimated to have 109 million barrels (equivalent to 634 PJ) of crude oil, condensate, and LPG category one[39] conventional reserves listed in the Cooper and Eromanga Basins.[40]

Santos' Moomba plant processes crude oil and hydrocarbon liquids, and transports a mix of naphtha, crude oil, propane, and butane along a 659 km, 355 mm diameter pipeline to Port Bonython's processing plant. Most of the fractionated products are exported by ship.

LPG is the only locally used liquid hydrocarbon product produced from the Port Bonython facility.[41]

Current developments

Liquid fuels that generate electrical energy are as diverse as petrol, diesel, kerosene, liquid petroleum gas (LPG), biodiesel, and various alcohols. Australia imports more than half of its liquid fuel requirements.[42]

In the context of South Australia's electricity production requirements, some issues of importance are:

- Generation from liquid fuels is more expensive than from coal or natural gas, so generation run solely on liquid fuel is limited to peak or emergency generation and remote off-grid power systems.
- Coal-fired generating units use fuel oil to start and to temporarily maintain flame stability when changing output.
- Diesel can be used to generate electricity in gas turbines and internal combustion engines; some South Australian power stations have a diesel/gas dual-fuel capability.
- If gas supplies are restricted or contract quantities are reached, the open cycle gas turbines (OCGT) at Hallett Power Station can use diesel, and the boilers supplying Torrens Island A Power Station steam turbines can use fuel oil.

Infrastructure

Diesel infrastructure services many industry sectors, allowing grid connected power generators to benefit from a mature infrastructure and distribution network. In November 2014, BP launched a $20m expansion of its Largs North Terminal, doubling the company's diesel storage capacity.[43]

The development of Port Bonython's[44] fuel terminal project in South Australia's upper Spencer Gulf will further ensure supply and stockpiles are adequate across the state. The project to develop diesel fuel offtake, storage, and distribution facilities with potential later stages for extra storage and refining facilities, has received development approval by the South Australian Government.[45]

The project is due for completion in 2016.

[39] Category 1 comprises reserves being commercially produced, or that have been declared commercial and are awaiting production. This includes both proved and probable reserves.

[40] CORE Energy Group. *Statistical Review of Australian Energy – Quarter Ending: 30 September 2013*.

[41] SANTOS. *Port Bonython*. Available: http://www.santos.com/our-activities/eastern-australia/port-bonython.aspx. Viewed: 23 Dec 2014.

[42] Geosciences Australia. *Energy, Basics*. Available: http://www.ga.gov.au/energy/basics.html. Viewed: 22 Dec 2014.

[43] News Release – Treasurer Tom Koutsantonis, *Diesel storage doubled with $20m expansion of BPs Largs North Terminal*. Available: http://www.premier.sa.gov.au/images/news_releases/14_11Nov/bplargsnorthterminallaunch.pdf. Viewed: 8 Jan 2014.

[44] Petro Diamond Australia. *Port Bonython Fuel Terminal Project Presentation – 3-4 September 2014.* Available: http://www.gmusg.com/WSCMConfig/Presentation/Item218.pdf. Viewed 19 Dec 2014.

[45] PIRSA. *Port Bonython fuel facility.* Available: http://www.pir.sa.gov.au/regions/archived_media_releases/media_release_-asset_list_source/13012010_port_bonython_fuel_facility. Viewed: 22 Dec 2014.

2.4 Wind

Availability

South Australia's wind resources largely derive from the Roaring Forties (strong westerly winds operating between the latitudes of 40° and 49°), particularly along the coast but also extending inland. Figure 8 summarises South Australia's wind resources.

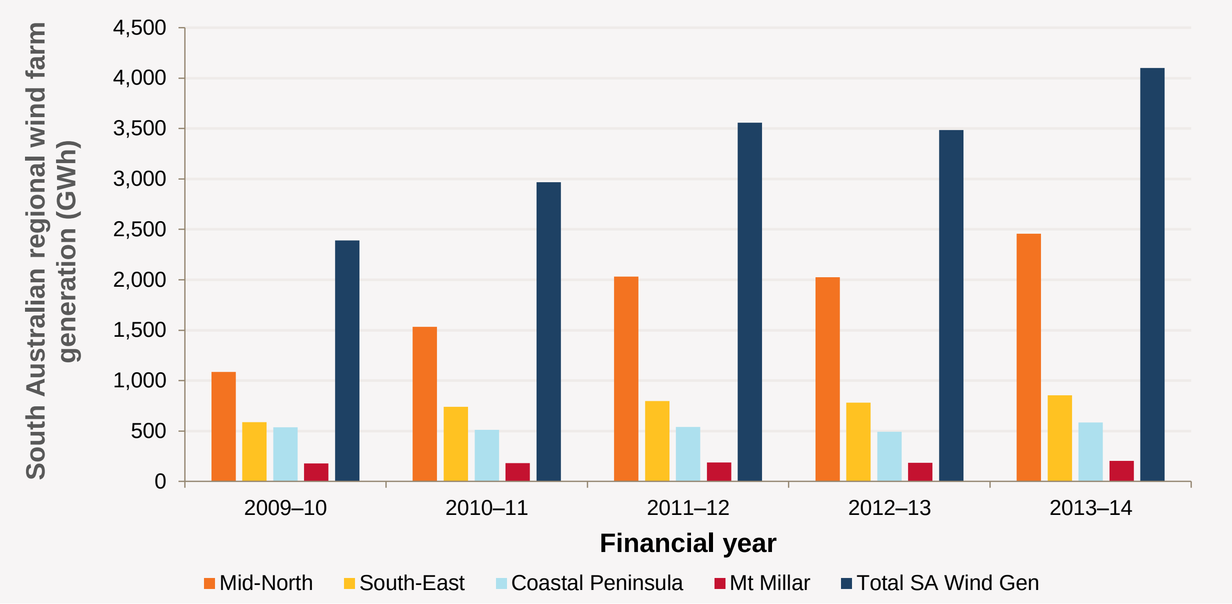
Although no off-shore wind generation projects currently exist in the NEM, on-shore wind generation continues to attract investor interest. There are over 3,107 MW of publicly announced wind developments in South Australia, with most being dependent on the LRET.[46]

Current developments

The total registered wind farm capacity in South Australia increased in June 2014 by 270 MW to reach 1,473 MW, with Snowtown Stage 2 South and North commencing operation.

The South Australia Wind Study Report[47] categorises wind farms into geographic zones: Mid-north, South-east, and Coastal Peninsula, and Mt Millar.[48] Figure 7 shows wind farm generation in each zone and for the state for 2014.

Figure 7 South Australian regional wind farm generation 2008–09 to 2013–14

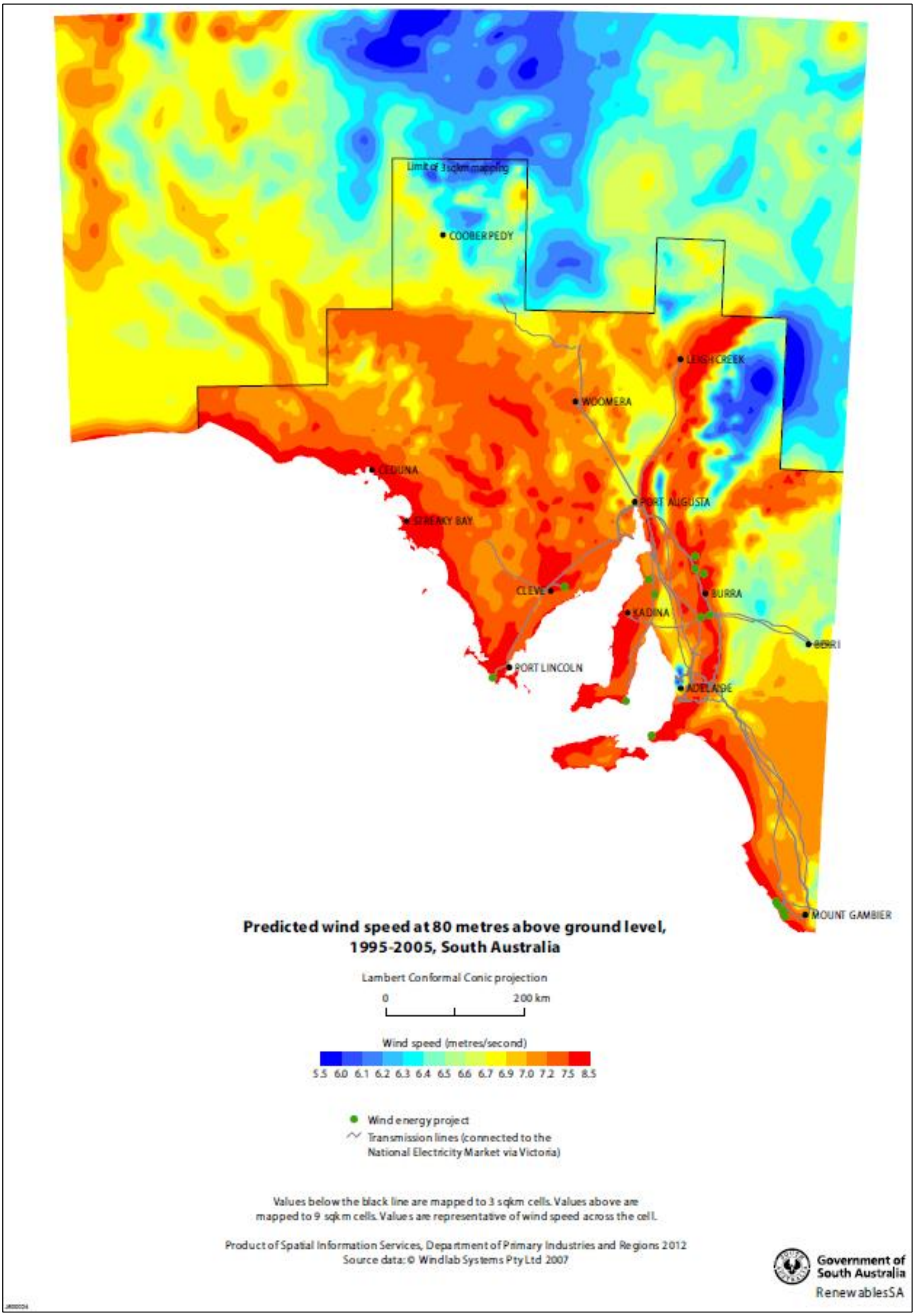


[46] AEMO. *AEMO Generation Information – SA,* Nov 15 2014*Nov*. Available: http://www.aemo.com.au/Electricity/Planning/Related-Information/Generation-Information. Viewed: 16 Dec 2014.

[47] AEMO. *2014 South Australian Wind Study Report.* Available: http://www.aemo.com.au/Electricity/Planning/South-Australian-Advisory-Functions/South-Australian-Wind-Study-Report. Viewed: 15 Dec 2014.

[48] The Coastal Peninsula region refers to the land on the tips of the peninsulas surrounding Spencer Gulf and Gulf St Vincent. The wind farms in this region are Cathedral Rocks, Starfish Hill and Wattle Point wind farms. Mt Millar wind farm is treated separately as it does not lie geographically close to the three aforementioned wind generation areas.

Figure 8 Predicted average wind speed at a height of 80 metres (South Australia)[49]



49 Renewables SA. *Renewable Energy Resource Maps*. Available: http://www.renewablessa.sa.gov.au/investor-information/resources. Viewed: 23 Dec 2014.

2.5 Solar

Availability

Sunlight is an abundant natural resource with vast potential for power generation. Figure 9 shows the average daily direct normal irradiance across South Australia.

Given that solar energy systems rely on transforming the sun's energy at or near ground level, the output varies depending on the plant's geographical location, time of day, time of year, and local weather conditions. As a result, output from solar generation varies –both large, utility-sized installations or cumulatively from domestic installations– presenting challenges where it is proposed to integrate these into electricity grids.

To facilitate increasing participation from large-scale solar generation in the NEM, the Australian Solar Energy Forecasting System (ASEFS) was developed[50] and commissioned at AEMO in May 2014.[51] AEMO will use the ASFES forecasts in dispatch and pre-dispatch processes and to more accurately adjust short term forecasts, once large-scale solar plants are commissioned.

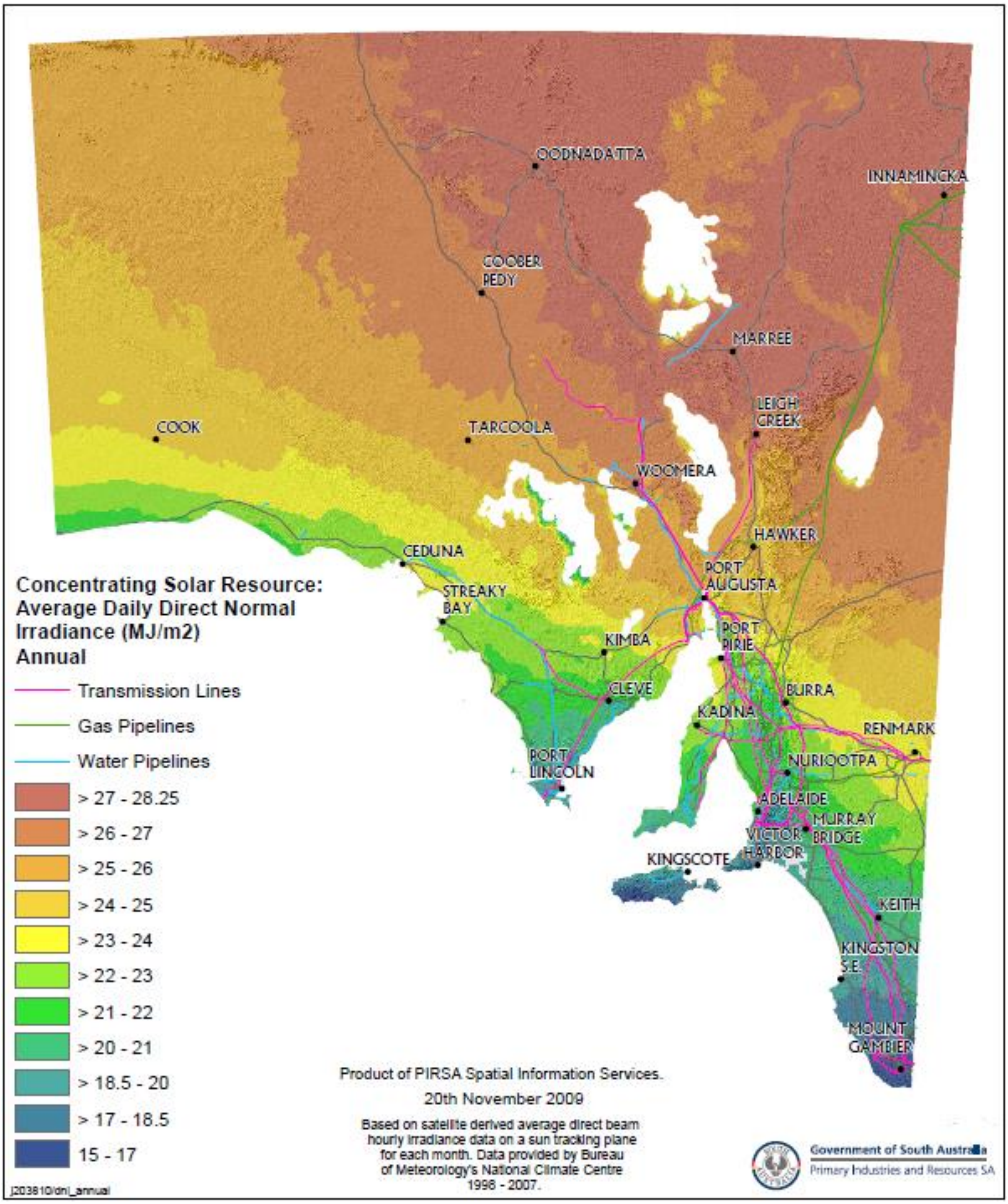
Current developments

To date, solar has largely been confined to residential PV. Grid-connected solar systems have been slow to develop with no projects yet committed for South Australia. Further details on development of grid connected solar projects (both PV and thermal) are provided in Chapter 3.

[50] CSIRO. *Australian solar energy forecasting system*. Available: http://www.csiro.au/Organisation-Structure/Flagships/Energy-Flagship/Solar-forecasting.aspx. Viewed: 23 Dec 2014.

[51] AEMO. *Energy Conversion Model for Solar Forecasting*. Available: http://www.aemo.com.au/Consultations/National-Electricity-Market/Energy-Conversion-Model-for-Solar-Forecasting. Viewed: 22 Dec 2014.

Figure 9 **Solar irradiance across South Australia**[52,53]



52 RenewablesSA. D*irect Normal Irradiance*. Available: http://www.renewablessa.sa.gov.au/investor-information/resources/direct-normal-irradiance. Viewed: 23 Dec 2014.

53 MJ/m2 means megajoules per square metre.

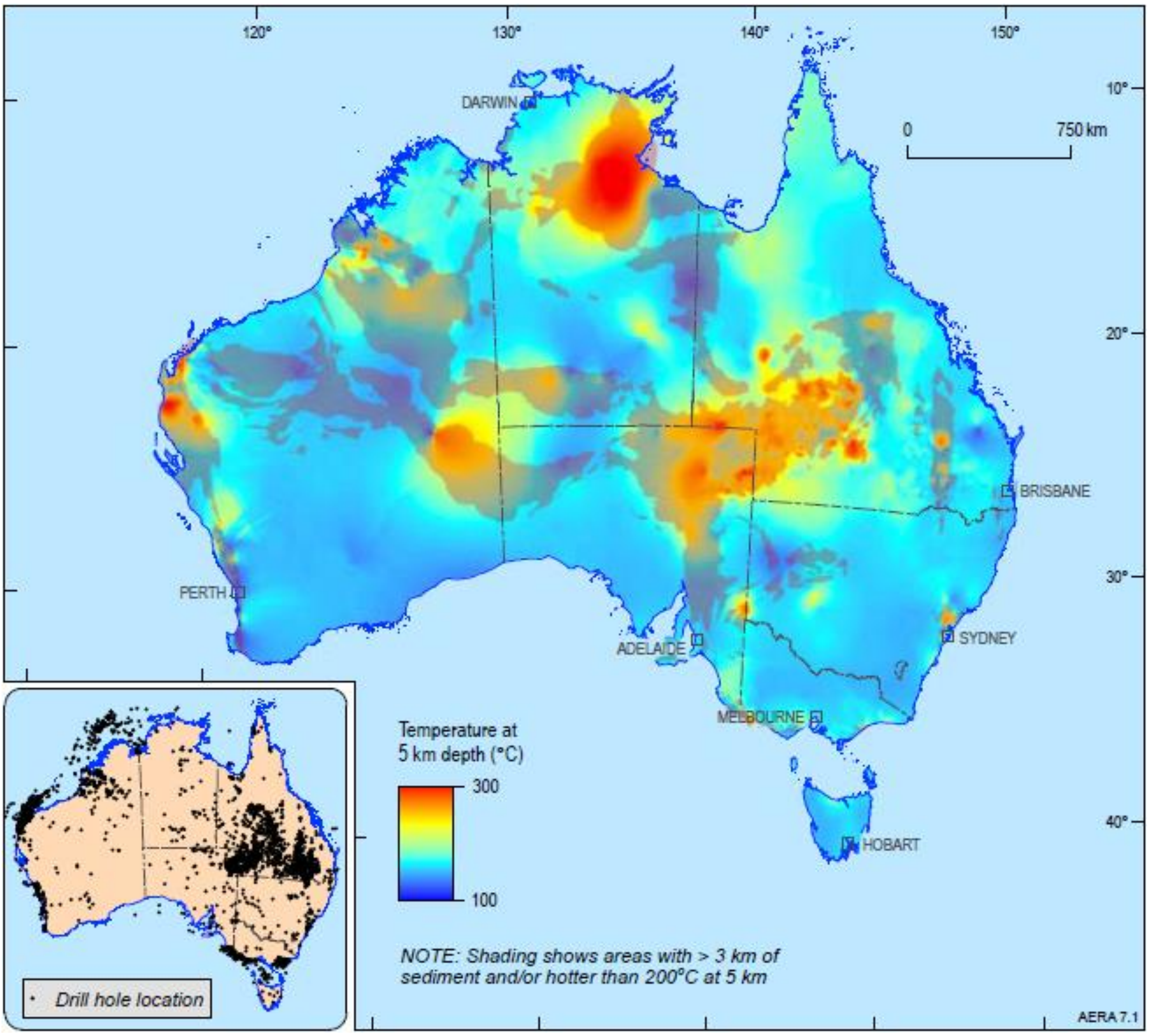
2.6 Geothermal

Availability

Australia's geothermal resources are associated with high-temperature granites, and lower-temperature geothermal resources in naturally circulating aquifers deep in sedimentary basins.

Geothermal energy can provide a constant heat source with potential to provide high capacity factor electricity supplies; however, resources are generally located far from existing electricity transmission infrastructure. Figure 10 shows the geothermal resource distribution throughout Australia.

Figure 10 Predicted temperature at a depth of five kilometres[54]



[54] Geoscience Australia and ABARE. *Australian Energy Resource Assessment* (2010, Figure 7.1). Based on data from Earth Energy Pty Ltd; AUSTHERM database; Geoscience Australia. Available: http://data.daff.gov.au/data/warehouse/pe_aera_d9aae_002/aera.pdf. Viewed: 23 Dec 2014.

2.7 Biomass and waste-to-energy

Availability

Biofuel

Energy crops, or fuel crops, are grown to produce biomass for fuel (“biofuel”), rather than for some other primary purpose (such as food or clothing). A well-known example is the cultivation of canola to produce biodiesel.

An ongoing related area of research is using algae for biofuel production. A recent study demonstrated that there is potential for algae to be converted to biofuel with higher yields than previously anticipated.[55]

Although South Australia has several potentially suitable locations for energy crop production[56], economic factors play a large part in determining a crop’s viability, as the resultant biofuel must be financially profitable. There are currently no large-scale energy crops in production in the state.

General Waste

Activities such as agriculture, forestry, and food production produce organic waste. In addition, over time general household landfill waste produces gas that contains large amounts of methane. This organic matter and gas can be used as a fuel source for heating and electricity generation.

Potential fuels for biomass generation include bagasse (processed sugar cane residue), wood waste, crop oils, sewage, agribusiness residues, and landfill gas.

Current developments

In South Australia, biomass generation is mainly fuelled by landfill gas collected from various sites around Adelaide, and sewage gas collected from some of SA Water’s sewage treatment plants.[57,58]

A related fuel source is landfill waste itself. Technologies now available use landfill waste in power generation systems; these technologies incorporate cleaning or spent fuel recovery processes.[59]

Such uses have not been exploited on a large scale in Australia, although Western Australia’s Environmental Protection Authority recently approved construction of Australia’s first “waste-to-energy” plant near Port Hedland.[60] Commercial-scale incineration in South Australia is limited to the safe destruction of medical, quarantine, and pharmaceutical wastes.[61]

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55 Oilprice.com. *Research Unlocks Algae Biofuel Potential*. Available: http://oilprice.com/Alternative-Energy/Biofuels/Research-Unlocks-Algae-Biofuel-Potential.html. Viewed: 23 Dec 2014.

56 RenewablesSA. *Renewable Energy Resource Maps, Biomass.* http://www.renewablessa.sa.gov.au/investor-information/resources#Biomass. Viewed: 23 Dec 2014.

57 AEMO. *Generation_Information_SA_20131104.xlsx*, ("Existing NS Generation" worksheet). Available: http://www.aemo.com.au/Electricity/Planning/Related-Information/~/media/Files/Other/planning/generation/2013/Generation_Information_SA_20131104.ashx. Viewed: 23 Dec 2014.

58 SA Water. *Wastewater Treatment Process.* Available: http://www.sawater.com.au/sawater/education/ourwastewatersystems/wastewater+treatment+process.htm. Viewed: 23 Dec 2014.

59 City of Oslo Waste-to-Energy Agency. *Green energy from waste.* Available: http://www.energigjenvinningsetaten.oslo.kommune.no/english/. Viewed: 23 Dec 2014.

60 PerthNow. *Waste-to-energy plant gets green tick*. Available: http://www.perthnow.com.au/news/western-australia/waste-to-energy-plant-gets-green-tick/story-fnhocxo3-1226614892477. Viewed: 23 Dec 2014.

61 EPA SA. *Environmental Info - Solid waste Incineration*. Available: http://www.epa.sa.gov.au/environmental_info/waste/solid_waste/incineration. Viewed: 23 Dec 2014.

2.8 Oceanic

Availability

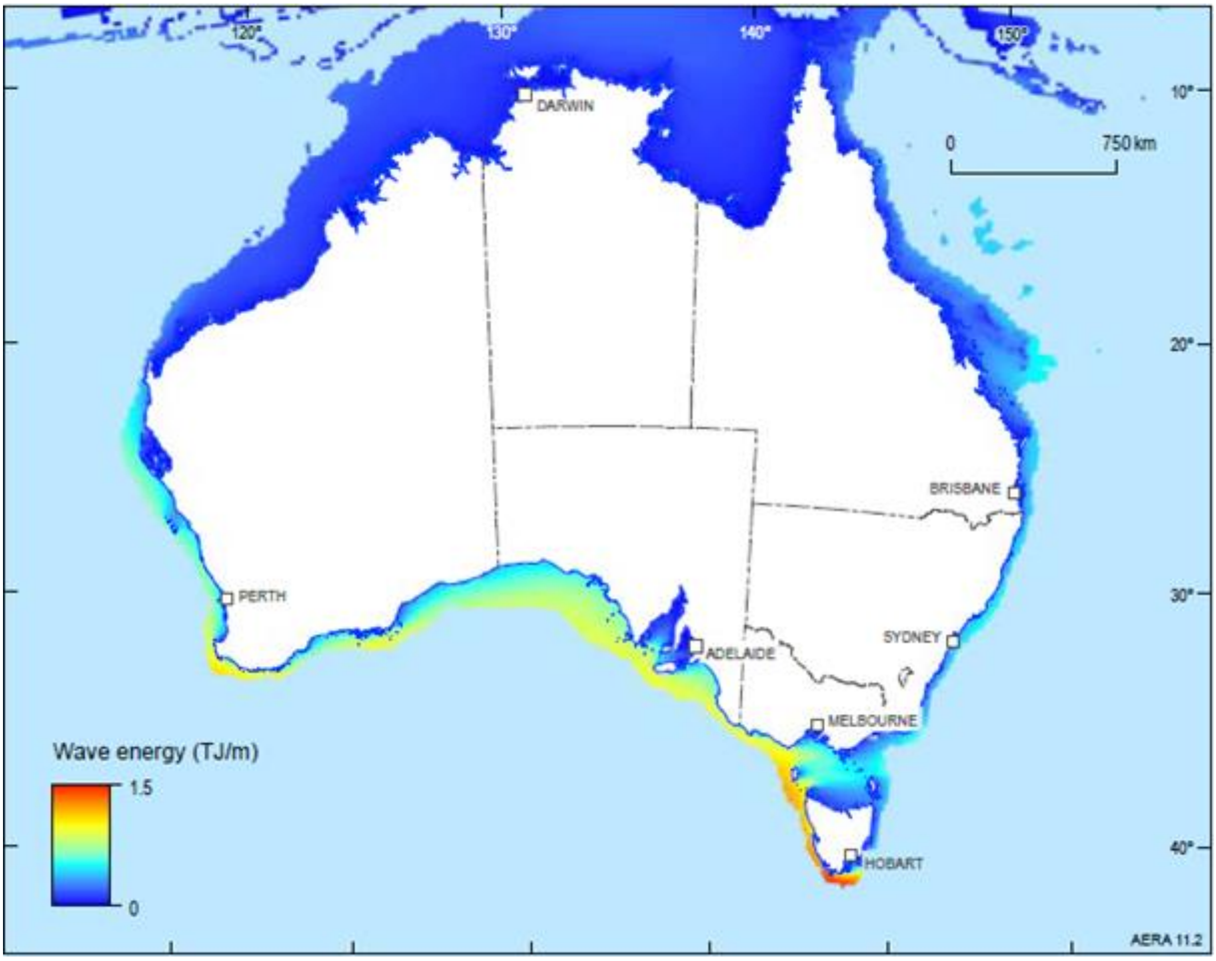
Energy from the ocean is potentially a substantial renewable energy source. Oceanic energy resources include wave, tidal, currents, and ocean thermal energy. Technologies to exploit these resources are at various stages of development.

A report by the CSIRO on ocean renewable energy[62] identified that wave energy has the potential to supply about 11% of Australia's electricity needs by 2050. However, wider environmental and social issues would need to be considered (such as marine protected areas, tourism, and aquaculture).

The focus here and in the generation technologies chapter is on wave energy, which promises the most potential for development as a power generation resource in South Australia.

Figure 11 shows Australia's total annual wave energy and illustrates that the southern half of the Australian continental shelf, along the western and southern coastlines, has high quality wave energy resources.

Figure 11 Annual wave energy on the continental shelf (at less than 300 m depth)



[62] CSIRO. *Ocean renewable energy: 2015-2050 and Ocean renewable energy brochure.* Available: http://www.csiro.au/en/Organisation-Structure/Flagships/Energy-Flagship/~/Media/BEA2D11E313C498BAD26624B0BE911F9.ashx and http://www.csiro.au/~/media/CSIROau/Flagships/Energy%20Transformed%20Flagship/ORE%20images/Ocean-renewable-energy-brochure.ashx. Viewed: 23 Dec 2014.

3. TECHNOLOGY REVIEW

A range of new and emerging electricity generation technologies have potential to be commercially viable over the next 30 years. This chapter reviews those relevant to South Australia, together with levelised cost of electricity (LCOE) estimates for technologies that apply to South Australia and the NEM.

3.1 Carbon capture and storage

Description

CCS is an optional emission-reducing adjunct to some generation technologies. The carbon capture process produces a concentrated CO_2 stream that can be compressed, transported, and stored. Depending on the power plant, carbon capture can take place through several processes, including:

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

Post combustion capture and oxy-firing[63] are both suitable for retro-fitting to existing pulverised coal generation.

Several storage possibilities are proposed for CO_2 captured in carbon capture and storage (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.[64]
- 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.[65]

Several proponents worldwide are researching ways to improve the absorption process for post-combustion carbon capture.[66] Any significant developments in available technologies, combined with advances in CO_2 compressor technology, should lower overall costs for many CCS systems. This will improve the economic viability of CCS solutions for power generation facilities.

Use

Most CCS systems for power generation around the world are classed as demonstration, prototype, or research and development, with a recent International Energy Agency (IEA) report[67] stating there are no large-scale integrated projects in the power sector, and few in industry. However, proven CCS technologies are available to the power industry and are gradually being incorporated (including the USA's Kemper County Energy Facility).

In Australia, several projects have been proposed and constructed over the last 12 years, incorporating various CCS process aspects. A recent example is a mineral carbonation pilot plant being constructed at the University of Newcastle in New South Wales and managed by Mineral Carbonation International.[68]

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63 Oxy-firing can be considered a technology in its own right.

64 GreenFacts. *CO2 Capture and Storage 6. Could CO2 be stored in the deep ocean?* Available: http://www.greenfacts.org/en/co2-capture-storage/l-2/6-ocean--storage-co2.htm. Viewed 23 Dec 2014.

65 Goldberg, Chen, O'Connor, Walters, and Ziock. *CO2 Mineral Sequestration Studies in US.* Available: http://www.netl.doe.gov/publications/proceedings/01/carbon_seq/6c1.pdf. Viewed: 23 Dec 2014.

66 IEA Greenhouse Gas R&D Programme (IEAGHG). *Evaluation of novel post-combustion CO2 capture solvent concepts.* Available: http://www.globalccsinstitute.com/publications/evaluation-novel-post-combustion-co2-capture-solvent-concepts/online/109096. Viewed: 23 Dec 2014.

67 IEA. *Tracking Clean Energy Progress 2013*. Available: http://www.iea.org/publications/freepublications/publication/TCEP_web.pdf. Viewed: 23 Dec 2014.

68 Mineral Carbonation International. *Safely locking CO2 away for good*. Available: http://mineralcarbonation.com. Viewed: 23 Dec 2014.

On a very large commercial scale, the planned geo sequestration plant for the Gorgon project in Western Australia, will capture and store CO_2 extracted from natural gas mining activities.[69] This is expected to be the largest commercial CCS project in the world when operations start in 2016, and is regulated under the *Barrow Island Act 2003*.[70]

Recent Developments

Canada opened the world's first large scale coal-fired power plant with CCS in September 2014. The 110 MW plant located in Saskatchewan at Boundary Dam cuts emissions by 90% and stores CO_2 underground.[71]

3.2 Integrated gasification and combined cycle

Description

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

Integrated gasification and combined cycle (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.

Use

IGCC power generation technology is still developing, with limited manufacturers offering commercial plants. Worldwide, only a few full-scale IGCC plants are operational. An example of a large-scale brown coal IGCC power plant with carbon capture is the Kemper County Energy Facility[72] in Mississippi, USA, which is expected to operate commercially from 2016 (delayed from 2014).

HRL Limited has successfully proven a coal drying and gasification technology known as integrated drying and gasification combined cycle (IDGCC) in Victoria's Latrobe Valley at 10 MW scale. A 600 MW Dual Gas Project[73] planned to demonstrate the technology at commercial scale is currently on hold. It would mainly use local brown coal, with natural gas as a start-up and supplementary fuel.

IDGCC and IGCC suit operation with other efficiency and emission-reduction options. For both coal IGCC and IDGCC with CCS, potential improvements are possible in the following areas:

- Improved gasifier reliability and flexibility.
- Oxygen (O_2) separation (leading to reduced costs, and better IGCC plant performance and efficiency).
- Hydrogen (H_2) turbines (to increase plant economics) and fuel cells (to improve fuel utilisation and reduce CO_2 emissions).
- Carbon capture.
- Successful demonstration of a large-scale IGCC with CCS plant.

Research is ongoing, although this technology remains expensive.

Recent Developments

In 2009, Altona Energy[74] announced the development of an IGCC power station as part of its South Australian Arckaringa Project, but has yet to confirm a commissioning date or if the project will connect to the NEM. [75]

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[69] Chevron Australia. *Gorgon | Our Businesses | Chevron Australia.* Available: http://www.chevronaustralia.com/ourbusinesses/gorgon.aspx. Viewed: 23 Dec 2014.
[70] Department of Mines and Petroleum, Government of Western Australian. Available: http://www.dmp.wa.gov.au/9525.aspx#16578. Viewed: 15 Dec 2014.
[71] Saskpower – Carbon Capture Project, Available: http://www.saskpowerccs.com/ccs-projects/boundary-dam-carbon-capture-project/carbon-capture-project/ Viewed: 15 Dec 2014.
[72] Mississippi Power. Kemper County Energy facility. Available: http://www.mississippipower.com/kemper/home.asp. Viewed: 23 Dec 2014.
[73] DualGas. *Final Report, Dual Gas Pty Ltd to Department of Primary Industries*. 30 May 2013. Available: http://www.dualgas.net.au/secure/downloadfile.asp?fileid=1001319. Viewed: 23 Dec 2014.
[74] Altona Energy. *Welcome to Altona Energy*. Available: http://www.altonaenergy.com/index.php. Viewed: 23 Dec 2014.
[75] AEMO. Generation_Information_SA_2014_Dec_10.xlsx. Available: http://www.aemo.com.au/Electricity/Planning/Related-Information/~/media/Files/Other/planning/esoo/2014/Generation_Information_SA_2014_Dec_10.ashx. Viewed: 16 Dec 2014.

3.3 Supercritical pulverised coal technology

Description

In a pulverised coal (PC) 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 divided into subcritical (at least 19.0 MPa and 535 ºC – 560 ºC) and supercritical (at least 24.8 MPa and 565 ºC – 593 ºC).

Recent improvements have seen introduction of ultra-supercritical technology operating at even higher pressures and temperatures, for example, 27.5 MPa and 605 ºC in the Yuhuan Power Plant in China.[76]

Subcritical units are capable of about 38% maximum net thermal efficiency and ultra-supercritical units are capable of 46%.[77]

The type of coal used also affects efficiency. Some brown coal deposits, such as those in the Latrobe Valley, require drying before combustion, reducing overall cycle efficiency. Leigh Creek coal and black coal from Australia's eastern regions do not require drying prior to combustion.

Use

Coal-fired power stations dominate the power industry worldwide but most plants currently use subcritical technology.[78]

In Australia, about 56% of installed generation capacity in the NEM (excluding embedded generation) is coal-fired[79]. About 11% of these are four supercritical units in Queensland.[80]

In South Australia, 12.6% of registered generation capacity (including embedded generation) is coal-fired[81], all using subcritical technology.

Recent Developments

There is continued development and testing of materials needed to achieve steam conditions of 34.5 MPa and 760 ºC, with expectations of commercial availability by 2030. The improvements deliver better thermal efficiency, and fewer CO_2 emissions per megawatt hour of electricity generated.

There are plans internationally for a commercial-scale facility with ultra-supercritical pulverised coal technology employing a steam temperature of 700 ºC by 2016.

76 Power Technology. *Yuhuan 1,000MW Ultra-Supercritical Pressure Boilers, China*. Available: http://www.power-technology.com/projects/yuhuancoal/. Viewed: 23 Dec 2014.
77 IEA. *Tracking Clean Energy Progress 2013.* Available: http://www.iea.org/publications/freepublications/publication/TCEP_web.pdf. Viewed: 23 Dec 2014.
78 Ibid.
79 AEMO. Historical generation data.
80 AEMO. *AEMO Generation Information.* Available: http://www.aemo.com.au/Electricity/Planning/Related-Information/Generation-Information. Viewed: 15 Dec 2014.
81 AEMO. *2014 South Australian Historical Market Information Report.* Available: http://www.aemo.com.au/Electricity/Planning/South-Australian-Advisory-Functions/~/media/Files/Other/planning/SAAF/SA_Historical_Market_Information_Report_July_2014.ashx. Viewed: 16 Nov 2014.

3.4 Open and combined cycle gas turbines

Description

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 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.

A technology brief published by the IEA's Energy Technology Systems Analysis Program (ETSAP)[82] lists advantages for CCGTs compared to coal-fired generating units. These are: shorter construction times, lower investment costs, lower CO_2 emissions per kilowatt-hour of electricity generated, high service flexibility. One disadvantage is higher fuel costs. CCGTs also produce relatively low non-greenhouse gas emissions such as sulphur oxides (SOx), nitrogen oxides (NOx), and particulate matter, when compared to coal-fired generation.

The best available OCGT technology can achieve around 40% efficiency and, for CCGT, in excess of 60% efficiency[83], although actual achievable efficiencies scale proportionally with installed capacity. Given this, smaller units are less efficient than larger units. By 2020, OCGT unit efficiency is expected to reach 45%, and CCGT unit efficiency is expected to reach 64%.[84]

Use

OCGTs and CCGTs are mature technologies, with development and efficiency improvements focusing mainly on operating at higher firing temperatures and high-pressure ratios.

OCGT and CCGT generation is already commercially available and operating, and can be designed to operate with almost all forms of liquid and gaseous fuels.

Recent developments

CCGT units can have CCS technology fitted, but no large-scale demonstrations have been achieved to date.[85] Modelling used for LCOE calculations in this report suggests that thermal efficiency reductions of about 6% are expected when applying CCS technology to a CCGT.

There are several publicly announced projects to build more OCGT or CCGT units in both South Australia and the NEM.[86] While OCGTs are used mainly as peaking units due to their operational flexibility, their relatively low efficiency means they are typically too expensive for base load operation. CCGTs, which have relatively high efficiency but reduced flexibility, are more suited for base load operation. For base load operation, gas powered generation is usually more expensive than coal.

Development of gas generation over coal fired generation will in large part depend on the difference in fuel costs and changes in government policy relating to CO2 emissions.

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[82] Energy Technology Systems Analysis Programme. *IEA ETSAP - Technology Brief E02 – April 2010*. Available: http://www.iea-etsap.org/Energy_Technologies/Energy_Supply/Gas-Fired_Power_Plants.asp. Viewed: 23 Dec 2014.

[83] IEA. *Tracking Clean Energy Progress 2013.* Available: http://www.iea.org/publications/freepublications/publication/TCEP_web.pdf. Viewed: 23 Dec 2014.

[84] Energy Technology Systems Analysis Programme. *IEA ETSAP - Technology Brief E02 – April 2010*. Available: http://www.iea-etsap.org/Energy_Technologies/Energy_Supply/Gas-Fired_Power_Plants.asp. Viewed: 23 Dec 2014.

[85] IEA. *Tracking Clean Energy Progress 2013.* Available: http://www.iea.org/publications/freepublications/publication/TCEP_web.pdf. Viewed: 23 Dec 2014.

[86] AEMO. Generation_Information_SA_2014_Dec_10.xlsx. Available: http://www.aemo.com.au/Electricity/Planning/Related-Information/~/media/Files/Other/planning/esoo/2014/Generation_Information_SA_2014_Dec_10.ashx. Viewed: 16 Dec 2014.

3.5 Wind

Description

Wind power harnesses flowing air to drive wind turbine blades that, in turn, drive a generating turbine. In typical large-scale applications, the output from several 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 wind farm 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%, although in practice it is limited to around 45%.[87]

Use

South Australia has the largest installed level of wind generation in Australia, with total registered capacity of wind farms reaching 1,473 MW in 2014 after Snowtown Stage 2[88] came on line.

In 2013–14, wind energy in South Australia supplied 4,088 GWh of electricity, 33% of the state's total generation. This contrasts with NEM-wide wind energy contribution of about 7,604 GWh or 3.9% of total NEM generation.[89] By international standards, South Australia has very high wind generation capacity levels.[90]

Growth in wind generation will benefit from the planned Heywood Interconnector upgrade between South Australia and Victoria, increasing use and export of wind energy from South Australia.[91] For a detailed analysis of wind generation in South Australia, see the South Australian Wind Study Report, published by AEMO each year.[92]

Recent Developments

The current Large-scale Renewable Energy Target (LRET) scheme is driving new wind generation uptake in the NEM, although uncertainty surrounding the scheme's future has stalled development in the past year. Assuming these policies continue in their current form, the 2014 Generation Expansion Plan[93] for the 2014 National Transmission Network Development Plan (NTNDP) forecasts more new wind generation to 2020.[94] New developments are extremely sensitive to the expected end date of the LRET and penalty pricing.

AEMO's recently published Wind Turbine Plant Capabilities Report[95] and Wind Integration Studies Report[96] also provide information and assumptions about future wind generation performance and operational challenges presented by high wind generation levels in the NEM.

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87 National Renewable Energy Laboratory. Dec 2003. *Modeling of the UAE Wind Turbine for Refinement of FAST_AD NREL/TP-500-34755.* Available: http://www.nrel.gov/docs/fy04osti/34755.pdf. Viewed: 23 Dec 2014.

88 AEMO. *South Australian Wind Study Report 2014*. Available: http://www.aemo.com.au/Electricity/Planning/South-Australian-Advisory-Functions/South-Australian-Wind-Study-Report. Viewed: 23 Dec 2014.

89 AEMO. 2014 *NEM Historical Generation*.

90 Ecar Energy. *Wind Integration in Electricity Grids: International Practice and Experience*. (Refer to Table 1 on page 19). Available: http://www.aemo.com.au/~/media/Files/Other/planning/0400-0049%20pdf.pdf. Viewed: 23 Dec 2014. (Commissioned by AEMO).

91 ElectraNet. *Heywood interconnector project – expanding the availability of wind energy*, Ninth Wind Energy Conference Adelaide 18 Nov 2013. Available: http://www.slideshare.net/informaoz/rainer-korte-expanding-the-availability-of-wind-energy-rainer-korte-18-nov2013. Viewed: 23 Dec 2014.

92 AEMO. *South Australian Wind Study Report 2014*. Available: http://www.aemo.com.au/Electricity/Planning/South-Australian-Advisory-Functions/South-Australian-Wind-Study-Report. Viewed: 23 Dec 2014.

93 AEMO. *2014 Generation Expansion Plan.* Available: http://aemo.com.au/Electricity/Planning/~/media/Files/Electricity/Planning/Reports/NTNDP/2014/2014%20Generation%20Expansion%20Plan.ashx. Viewed: 23 Dec 2014.

94 AEMO. *2014 National Transmission Network Development Plan*. Available: http://www.aemo.com.au/Electricity/Planning/National-Transmission-Network-Development-Plan. Viewed: 22 Dec 2014.

95 AEMO. *Wind Turbine Plant Capabilities Report*. Available: http://www.aemo.com.au/Electricity/Planning/~/media/Files/Other/planning/Wind_Turbine_Plant_Capabilities_Report.ashx. Viewed: 23 Dec 2014.

96 AEMO. *Integrating Renewable Energy – Wind Integration Studies Report.* Available: http://www.aemo.com.au/Electricity/Planning/~/media/Files/Electricity/Planning/Reports/Integrating%20Renewable%20Energy%20-%20Wind%20Integration%20Studies%20Report%202013.pdf.ashx. Viewed: 23 Dec 2014.

3.6 Solar PV

Description

Solar PV technologies convert sunlight directly into electricity using semiconductor materials that produce electric current when exposed to light. Inverters are another key component of most solar PV systems. Inverters convert the generated DC power to AC power for connection to the electricity grid or facility's electrical wiring.

PV technology can be installed as a fixed flat plate 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 devices deliver around 30% more annual electricity output than fixed flat plates, and dual-axis trackers have up to about 10% more output than single-axis trackers.

One of the most mature emerging technologies is Concentrating Photovoltaics (CPV).[97] 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.[98] 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. The University of Queensland is researching new materials and device architectures to increase organic solar cell efficiency to commercially viable levels.[99]

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 3.12 discusses recent developments in battery storage systems.

Use

PV installations are generally divided into residential and commercial installations, and larger-scale grid connected solar farms, where PV collector arrays are aggregated to give higher output capacity.

Domestic and commercial rooftop PV

Australia has seen rapid growth in residential and commercial rooftop PV installations. The 2014 National Electricity Forecasting Report (NEFR)[100] noted that uptake of rooftop PV in South Australia has been high compared to other states:

- Nationally an estimated 2,587 MW of rooftop PV capacity as at 30 June 2014 generated 3,951 GWh in 2013–14.
- South Australia has 565 MW of capacity (15% of the national rooftop PV capacity), which generated 704 GWh in 2013–14 (18% of the national rooftop PV generation). For comparison, total South Australian generation[101] represented only 6% of the NEM generation in 2013–14.

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[102]. Australia-wide Small-scale Technology Certificates (STCs) are also still available for new rooftop PV installations and can reduce new system costs for customers.

Integrated battery storage systems are an important emerging technology for residential and commercial rooftop PV systems, with several battery storage solutions currently emerging in the market.

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[97] IRENA & IEA-ETSAP. *Solar Photovoltaics Technology Brief* (E11 – January 2013). Available: http://www.irena.org/DocumentDownloads/Publications/IRENA-ETSAP%20Tech%20Brief%20E11%20Solar%20PV.pdf. Viewed: 23 Dec 2014.

[98] IRENA & IEA-ETSAP. *Solar Photovoltaics Technology Brief* (E11 – January 2013). Available: http://www.irena.org/DocumentDownloads/Publications/IRENA-ETSAP%20Tech%20Brief%20E11%20Solar%20PV.pdf. Viewed: 23 Dec 2014.

[99] ARENA. *New materials and architectures for organic solar cells.* Available: http://arena.gov.au/project/new-materials-and-architectures-for-organic-solar-cells/. Viewed: 23 Dec 2014.

[100] AEMO. *NEFR Supplementary Information 2014: Rooftop PV, 25 August 2014.* Available: http://www.aemo.com.au/Electricity/Planning/Forecasting/National-Electricity-Forecasting-Report/~/media/Files/Other/planning/NEFR/2014/2014%20Supplementary/2014_NEFR_Methodology_PV_annual_energy_and_installed_capacity_v2.ashx. Viewed: 16 Dec 2014.

[101] Including rooftop PV, large-scale thermal and renewable generation

[102] *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. Viewed 31 Dec 2014.

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. Similarly, a number of large-scale grid connected PV projects have been committed, but none in South Australia.[103]

South Australian research and development

South Australia does, however, have several solar research and development programs, including:[104]

- Shared research on solar technology between South Australia's three universities via the South Australian Renewable Energy Institute (SAREI).[105]
- Commercial investment in research at Flinders University to explore battery storage systems for next generation panels.
- Other research at Flinders University on flexible solar cells that could be cut to size from a roll and installed in unconventional places like windows and walls.

Recent Developments

PV system electricity costs are expected to continue decreasing. This is due to expected reductions in solar panel, inverter and other PV system component costs. Research continues to develop new PV configurations and variations, which promise to increase cell and module efficiency, again helping to lower electricity costs.

Several retailers also plan to offer new commercial arrangements for residential PV, requiring no upfront investment, but instead a pay-as-you-go Power Purchase Agreement (PPA). These offers have proven popular in California where they now account for half of all installations.[106]

[103] AEMO. *Regional generation information pages (2014, Dec 10 update)*. Available: http://www.aemo.com.au/Electricity/Planning/Related-Information/Generation-Information. Viewed: 23 Dec 2014.
[104] Australian Broadcasting Corporation. *Governments urged to back solar research push.* Available: http://www.abc.net.au/news/2013-11-22/solar-research-cutting-edge/5110246?&section=news. Viewed: 23 Dec 2014.
[105] Flinders University. *Flinders University Blogs - Nano News - Centre Director, Professor David Lewis talks solar energy on ABC*. Available: http://blogs.flinders.edu.au/nano-news/2013/11/27/centre-director-professor-david-lewis-talks-solar-energy-on-abc/. Viewed: 23 Dec 2014.
[106] BNEF, Bloomberg New Energy Finance *Residential solar: Too cheap to Finance?* Private report provided to AEMO.

3.7 Solar thermal

Description

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 on to 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 that use working fluids, such as molten salts, can 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.

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 combined cycle gas turbine 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.

Use

The most widely deployed and mature solar thermal type is the parabolic trough; installations have been deployed in the USA since the 1980s, and the recently commissioned Solana Power Plant in Arizona has a rated output of 280 MW with six hours of molten salt storage.[107]

Central receiver technology is less common, with the Gemasolar Plant in Spain being the first commercial-scale plant to use it. The plant has a 15-hour molten salt storage system, and a rated electrical output of 19.9 MW.

[107] Computerworld. *U.S. flips switch on massive solar power array that also stores electricity.* Available: http://www.computerworld.com/s/article/9243140/U.S._flips_switch_on_massive_solar_power_array_that_also_stores_electricity. Viewed: 23 Dec 2014.

In Australia, several solar thermal projects have been proposed including:

- A feasibility study into conversion of Collinsville Power Station from coal to hybrid solar thermal/gas.[108]
- The Kogan Creek Solar Boost project in Queensland.[109] This is a steam/coal hybrid system, where compact linear fresnel technology will be used to boost steam energy for the existing coal-fired power station. The project is being built and, when complete, is set to become the world's largest steam/coal hybrid plant of its type, with up to 44 MW of its existing electricity output capacity to be generated by the solar thermal addition.[110]
- Acquasol Infrastructure has publicly announced a 50 MW solar thermal plant to be included as part of its Point Paterson station development.

Recent Developments

Compared to the relatively quick commercial uptake of low-cost PV, progress in commercialising solar thermal has been relatively slow. The following improvements are expected over time, and should lead cheaper construction of new solar thermal plants, higher and more efficient plant output, and cheaper electricity generated:

- Increased utility market share and installed capacity.
- Increased volume of production for key equipment.
- Increased experience of manufacturers and engineers.
- Lower cost working fluids or those able to withstand higher temperatures.
- Lower cost heat storage systems.
- Better absorbing receiver tubes and steam turbine efficiencies.

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.[111]

Port Augusta solar thermal feasibility study

In January 2014, Alinta Energy announced a Feasibility Study into the viability of a solar thermal plant at Port Augusta, jointly funded by Alinta Energy, the Australian Renewable Energy Agency (ARENA) and the South Australian Government.[112] The study will include a full feasibility and technological analysis of solar thermal power generation. This includes hybridised and standalone options, at or near the Port Augusta Power Stations (Northern Power Stations 1 and 2, and Playford B Power Station).

The milestone 2 summary report, published in July 2014, marks the completion of the Options Study and Siting Study, which made the following key recommendations:[113]

- Standalone power tower technology including storage was selected as the most favourable technology option following a weighting process that considered technological maturity (and experience in operation), predictability, land use, risks to integration or operations and dual financial metrics: total installed cost and LCOE. Hybrid technology was rejected due to integration risks and lower potential generation opportunities beyond the life of current coal-fired operations.
- Alinta Energy has selected a site south-east of the Augusta Power Station to inform the remainder of the study. The location was chosen after considering proximity to a connection point (power or sub-station), environmental and heritage impacts, slope and flooding potential and land use (or ability to acquire).

Pre-feasibility work is due for delivery in early 2015, with a full feasibility study due at the end date of December 2015.

[108] Ratch, *Collinsville Solar Thermal.* Available: http://ratchaustralia.com/collinsville/collinsville_solar_thermal.html. Viewed: 16 Dec 2014.
[109] CSEnergy. *Kogan Creek Solar Boost Project.* Available: http://kogansolarboost.com.au. Viewed: 23 Dec 2014.
[110] AEMO. *2013 Electricity Statement of Opportunities.* (Revision 2, 13 Aug 2013). Refer to Note 26 in the ESOO. Available: http://www.aemo.com.au/Electricity/Planning/~/media/Files/Other/planning/esoo/2013/2013_ESOO.ashx. Viewed: 16 Dec 2014.
[111] CSIRO. *Australia's largest solar thermal research hub.* Available: http://csiro.au/Outcomes/Energy/Renewables-and-Smart-Systems/Solar-Brayton-Cycle.aspx. Viewed: 23 Dec 2014.
[112] Alinta Energy, *Port Augusta Solar Thermal Generation Feasibility Study:* Available at https://alintaenergy.com.au/about-us/power-generation/port-augusta-solar-thermal. Viewed: 31 Dec 2014.
[113] Alinta Energy, *Port Augusta Solar Thermal Generation Feasibility Study: Milestone 2 summary report*. Available: https://alintaenergy.com.au/about-us/power-generation/port-augusta-solar-thermal. Viewed 31 Dec 2014.

3.8 Geothermal

Description

Geothermal energy is derived from heat found within the earth.

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).

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.[114] This system passes geothermally heated water or hot geoliquid 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.

Systems with potential in Australia include:

- Enhanced geothermal systems[115] (EGS): This 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.
- Hot sedimentary aquifers (HSA): This 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.

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. The same plant and drilling technologies can be used as 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.

HSA is also not yet commercially proven, but 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.

[114] Some texts refer to this as "binary cycle" power generation.
[115] Enhanced Geothermal Systems are also known as Engineered Geothermal Systems.

Use

Birdsville, Queensland, has the only working geothermal power station in Australia. It is rated to 120 kW and uses a low temperature geothermal resource, drawing water at 98 ºC from a 1.28 km deep production well in the Great Artesian Basin.[116]

Recent Developments

Several developers have started drilling geothermal exploration or production wells in Australia, but have yet to begin any commercial developments. Projects in South Australia include:

- Petratherm's Paralana Geothermal Energy Project,[117] located 600 km north of Adelaide. This is a joint venture with Beach Energy involving EGS technology. Initial plans were to build a 3.75 MW commercial power plant to supply a local off-grid mine, with the long-term goal to build a 520 MW plant connected to the NEM. However, in July 2014, Petratherm's $13 million Emerging Renewables Program (ERP) Grant from the Australian Renewable Energy Agency (ARENA) lapsed.
- Raya Group (formerly Panax Geothermal) holds geothermal exploration licences in the state's south-east focusing on the Otway Basin and the state's north-east focusing on the Cooper Basin.[118] Exploration areas in the south-east are close to existing electricity transmission infrastructure. In 2010 the group's Penola Project successfully demonstrated the first use of conventional geothermal technology in Australia on the Salamander-1 well.
- Torrens Energy explored numerous sites in South Australia, including Parachilna and Port Augusta, which have good geothermal prospects for EGS technology and are in close proximity to existing electricity transmission infrastructure.[119]
- Geodynamics' Innamincka project,[120] located in the Cooper Basin, focuses on developing electricity generated from EGS. From April to October 2013, the 1 MW Habanero Pilot Plant was successfully trialled. Although Geodynamics have publically announced additional developments, recent communications at their annual general meeting indicate much of their current work on geothermal energy will be focused on direct heat use rather than electricity generation, given policy uncertainty.[121]

[116] Ergon Energy. Birdsville Organic Rankine Cycle Geothermal Power Station. Available: https://www.ergon.com.au/__data/assets/pdf_file/0008/4967/EGE0425-birdsville-geothermal-brochure-r3.pdf. Viewed: 16 Dec 2014.
[117] Petratherm. *Paralana: Overview*. Available: http://www.petratherm.com.au/projects/paralana. Viewed: 15 Dec 2014.
[118] Raya Group. *Projects: Australia*. Available: http://www.rayagroup.com.au/projects-australia.htm. Viewed: 15 Dec 2014.
[119] Torrens Energy Limited. *Projects*. Available: http://www2.torrensenergy.com/projects.html. Viewed: 15 Dec 2014.
[120] Geodynamics. *Geodynamics: Innamincka (EGS) Project*. Available: http://www.geodynamics.com.au/Our-Projects/Innamincka-Deeps.aspx. Viewed: 15 Dec 2014.
[121] Geodynamics, Chairman's Report. Available at: http://www.geodynamics.com.au/ASX-Announcements/2014.aspx. Viewed: 31 Dec 2014.

3.9 Bioenergy

Description

Bioenergy refers to energy extraction from biomass fuels (and 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.

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.

Use

Statistics from the Clean Energy Council for 2013 provide a useful perspective[122] on Australia's use of biomass resources:

- Bioenergy currently provides just over 1% (2,400 GWh) of Australia's electricity generation, and contributes to about 6.9% of renewable energy generation.
- The mix of biomass fuels used, by installed generation capacity, comprises bagasse cogeneration (62%), landfill gas (22%), black liquor[123] (9%), sewage gas (5%), food and agricultural wet waste (1%), and wood waste (1%).
- The installed capacity of bioenergy plants amounts to 778 MW, which is 5.5% of Australia's total renewable capacity.

In South Australia:

- In 2013–14, bioenergy generated less than 1% (55 GWh) of the state's electricity, and contributed to about 1.2% of renewable energy generation.
- The biomass fuel mix was nearly 100% landfill gas.
- The registered capacity of bioenergy plants amounts to 16 MW; about 1% of total renewable capacity.
- Sewage treatment plants at Bolivar and Glenelg use the gas produced to generate electricity for the plant.[124]

Recent Developments

In September 2014, Zerowaste SA published their report, *Waste Biomass Opportunities Map for the South East (SA)*. The report found that there is up to 5.5 million tonnes of accessible waste biomass per annum, although up to 3 million t/p.a. is currently committed to waste management practices involving some resource recovery or disposal for use elsewhere.[125]

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[122] Clean Energy Council. *Clean Energy Council – Bioenergy.* Available: http://www.cleanenergycouncil.org.au/technologies/bioenergy.html. Viewed: 16 Dec 2014.
[123] Black liquor is the term for a by-product created during the industrial processing of pulpwood into paper pulp.
[124] SA Water, Water Treatment Process. Available: http://www.sawater.com.au/sawater/education/ourwastewatersystems/wastewater+treatment+process.htm. Viewed: 16 Dec 2014.
[125] Available: http://www.zerowaste.sa.gov.au/resource-centre/publications. Viewed 15 Dec 2014.

3.10 Hydroelectricity

Description

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 flowing through it. Large hydroelectric power stations ensure maximum value is extracted from the water[126] in water storage dams. These dams have historically been built for other purposes, such as for irrigation or drinking water.

Use

Hydroelectricity delivers most of Australia's renewable energy through 123 operational plants with a combined installed capacity of 8.5 GW.[127] Although each plant's capacity is quite small, they can usefully limit reliance on grid-connected electricity.

South Australia has limited water resources and only operates mini and micro hydro generation. SA Water's website reports the following power plants: Hope Valley Terminal Storage (2.5 MW), Seacliff Park (0.9 MW), Winninowie Tanks (micro), and on-site use of water energy recovery devices at the Adelaide Desalination Plant.[128]

Recent Developments

Hydroelectricity is a mature technology. While no major breakthroughs have occurred in the basic machinery in recent decades, computer technology has led to significant improvements in turbine blade optimisation and operating processes. These include computer monitoring, diagnostics, protection, and control.

Most of Australia's suitable hydro sites have already been developed, so the sector's opportunity for growth is limited. In coming years, most activity in the sector will be in developing mini hydro power plants or upgrading and refurbishing existing power stations.[129]

Information about pumped hydro storage can be found in section 3.12.

[126] Clean Energy Council. *Clean Energy Council - Hydroelectricity.* Available: http://www.cleanenergycouncil.org.au/technologies/hydroelectricity.html. Viewed: 23 Dec 2014.

[127] Clean Energy Council. *Clean Energy Australia Report 2013*. Available: http://www.cleanenergycouncil.org.au/dam/cec/policy-and-advocacy/reports/2014/Clean-Energy-Australia-Report-2013.pdf. Viewed: 23 Dec 2014.

[128] SA Water. *Mini-Hydro*. Available: http://www.sawater.com.au/SAWater/Environment/SaveWater/Innovation/Mini-Hydro.htm. Viewed: 23 Dec 2014.

[129] Clean Energy Council. 2012. *Hydro Electricity Fact Sheet 1.* Available: http://www.cleanenergycouncil.org.au/dam/cec/technologies/hydroelectricity/Hydro-Fact-Sheet-An-Overview-of-Hydroelectricity-in-Australia.pdf. Viewed: 23 Dec 2014.

3.11 Ocean (wave) energy extraction

Description

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 technology types include:[130]

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

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

Wave energy conversion is still in the research and development phase. In coming years, a few commercial-scale options are expected to emerge and it is expected that the electricity generation cost from wave power will decline with future increased deployment.

Use

Around the world, deployment of commercial wave power devices is limited and is only a fraction of the renewable technology capacity installed.[131] In 2013, 18 companies were actively investigating a variety of innovative marine energy projects in Australia, using tides, currents or waves to generate electricity.[132]

Key projects in this list included the following:

- Carnegie Wave Energy has an offshore licence agreement for a potential project on the limestone coast near Port MacDonnell.[133]
- Wave Rider Energy announced in July 2013 that it had successfully completed a prototype trial of its Wave Rider™ technology in South Australian waters and is now looking to the next phase of the project to develop a pre-commercialisation plant.[134]

Recent Developments

Oceanlinx originally planned to install a 1 MW "greenWAVE" energy converter 3 km offshore at Port MacDonnell and transfer the electricity it generated to the grid via a subsea cable. However, the device was damaged beyond repair during transportation.[135] As a result, the company entered into receivership in April 2014[136], with insurance claims related to removal of the generator ongoing.[137]

[130] Clean Energy Council. *Clean Energy Council – Marine Energy.* Available: http://www.cleanenergycouncil.org.au/technologies/marine-energy.html. Viewed: 17 Dec 2014.
[131] IEA. *Tracking Clean Energy Progress 2013*. Available: http://www.iea.org/publications/freepublications/publication/TCEP_web.pdf. Viewed: 23 Dec 2014.
[132] Clean Energy Council. *Clean Energy Australia Report 2013*. Available: https://www.cleanenergycouncil.org.au/dam/cec/policy-and-advocacy/reports/2014/Clean-Energy-Australia-Report-2013.pdf. Viewed: 17 Dec 2014.
[133] Carnegie Wave Energy. *What is CETO*? Available: http://www.carnegiewave.com/index.php?url=/ceto/what-is-ceto. Viewed: 23 Dec 2014.
[134] Wave Ride Energy. 1 July 2013. *News – Wave Rider Project moves to next phase.* Available: http://www.waveriderenergy.com.au/News.html. Viewed: 23 Dec 2014.
[135] ARENA, Oceanlinx 1MW Commercial Wave Energy Demonstrator. Available: http://arena.gov.au/project/oceanlinx-1mw-commercial-wave-energy-demonstrator/. Viewed 16 Dec 2014.
[136] Oceanlinx Receivership Update, Available: http://www.kordamentha.com/news/oceanlinx-receivership-update. Viewed 16 Dec 2014.
[137] The Times on the Coast, Available: http://www.victorharbortimes.com.au/story/2469811/oceanlinx-energy-generator-at-carrickalinga-is-still-considered-unsafe/, Viewed 31 Dec 2014.

3.12 Storage

Background

Electricity is difficult to store so it differs from most other energy commodities. With oil, gas and coal, storage is an integral part of the supply chain that provides a buffer to help balance supply and demand over a few days, weeks, months or even a year. The historic absence of cost-effective electricity storage has meant that supply is constantly being adjusted to meet demand across the entire NEM 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 side.

This need to balance supply and demand carries a cost. To secure reliability, the power system is designed and built to meet the anticipated maximum peak demand, which by design is expected to occur only on relatively rare occasions.

Applications

Applications for electricity storage, which cover all aspects of generation, system operation, transmission and distribution (T&D) and end use are summarised in Table 7.

Table 7 Applications for electricity storage[138]

Location	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 intermittent renewables (e.g. wind, solar) by smoothing supply variability.
System operation	Frequency regulation	Storage to provide frequency balancing in a region under normal conditions.
	Reserve capacity	Reserve capacity for the electricity supply 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 address peak demand in order to relieve congestion points in the T&D networks and defer the need for a large investment in T&D infrastructure.
Customer	Increased self-supply	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.
	Off-grid	Storage technologies installed at the customer level to maximise consumption of self-generation (e.g. from solar PV) and potentially facilitate disconnection from the grid.

[138] Adapted from *Energy Technology Perspectives 2014*, IEA. Available: http://www.iea.org/w/bookshop/472-Energy_Technology_Perspectives_2014. Viewed: 01 Dec 2014.

Storage technologies

Not all storage technologies are suited to each application. Technical limitations (power requirements and discharge duration) and cost implications both influence any technology's suitability for a particular application.

Figure 12 from the Centre for Low Carbon futures[139] provides a conceptual guide to the range of power and discharge durations required for each application.

Figure 12 Summary of energy storage technologies

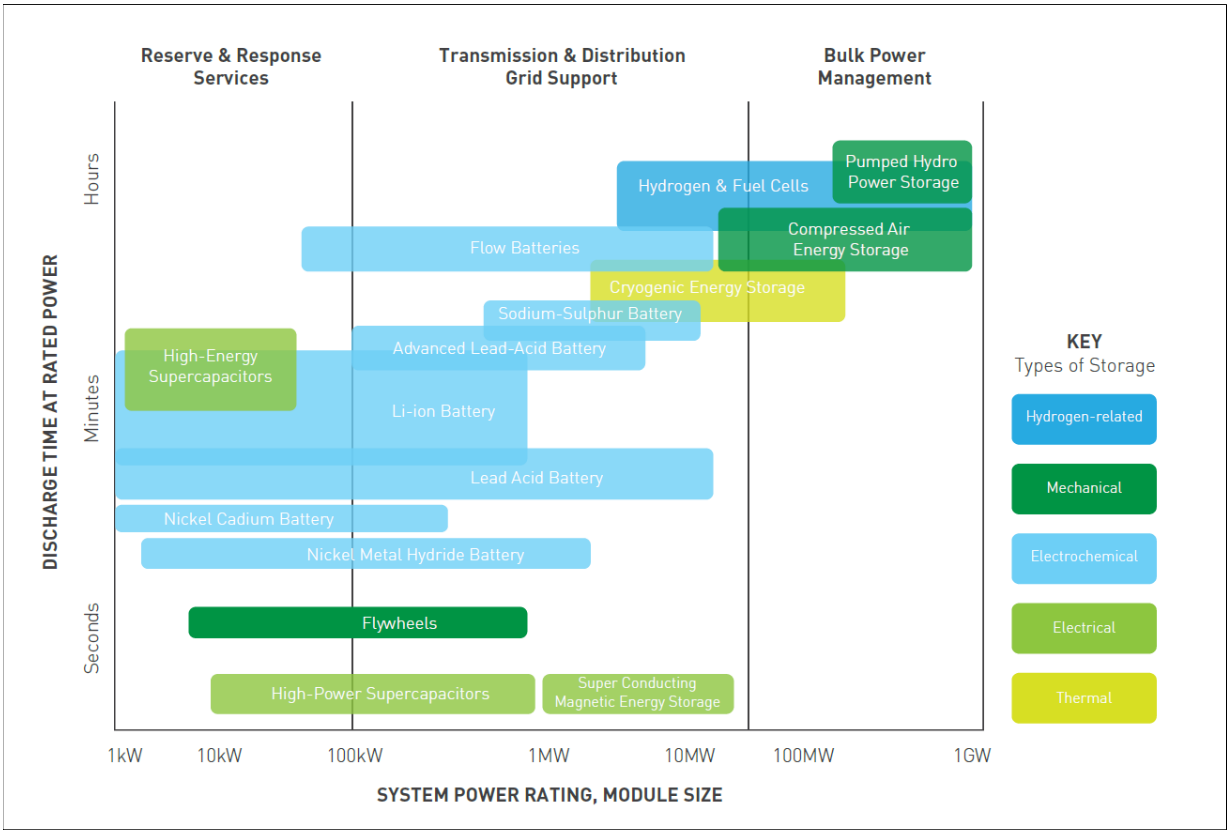


Table 8 describes each storage technology, adapted from information provided in the Department of Energy Supply handbook.[140]

[139] Centre for Low Carbon Futures, *Pathways for energy storage in the UK (2012)*. Available: http://www.lowcarbonfutures.org/sites/default/files/Pathways%20for%20Energy%20Storage%20in%20the%20UK.pdf Viewed: 15 Dec 2014.
[140] DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA (2013). Available at http://energy.gov/oe/downloads/doeepri-2013-electricity-storage-handbook-collaboration-nreca-july-2013 Viewed: 15 Dec 2014.

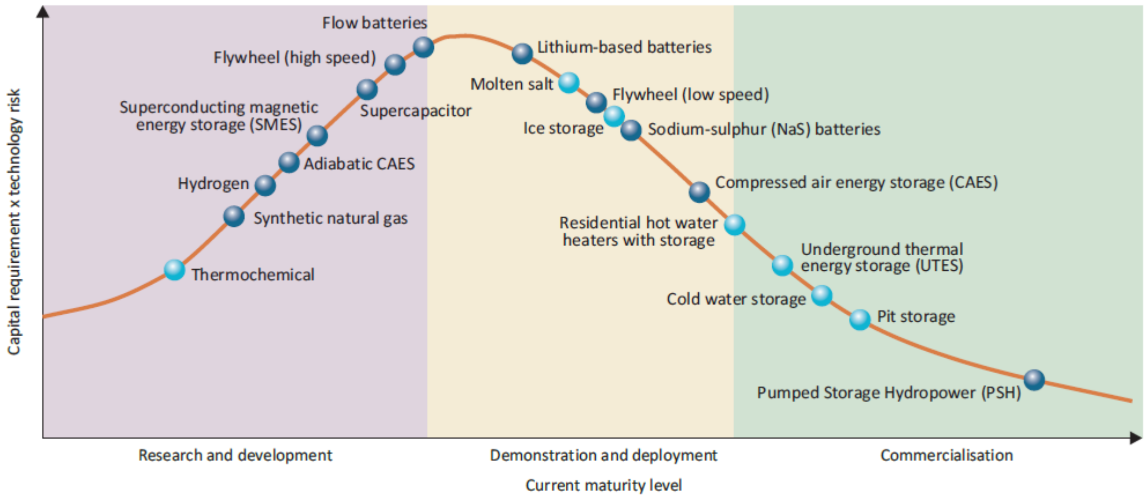
Table 8 Storage technologies

Technology	Description
Pumped hydro 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 (H2)	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 (60%) – 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.
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 °C to 350 °C), which can be maintained from the heat released by chemical reactions combined with efficient cell isolation.
Vanadium Redox Flow Battery (VRB)	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. Several chemistries can be used, but VRB appear the most mature.

Use

Pumped hydro storage (PHS) is the most common electricity storage in use worldwide, comprising over 99% of all storage in use in 2014 according to the IEA. It is also the most common storage in Australia. As indicated in Figure 13, PHS is currently the most commercially-available form of storage.

Figure 13 Maturity of energy storage technologies[141]



Source: Decourt, B. and R. Debarre (2013), "Electricity storage", *Factbook*, Schlumberger Business Consulting Energy Institute, Paris, France and Paksoy, H. (2013), "Thermal Energy Storage Today" presented at the IEA Energy Storage Technology Roadmap Stakeholder Engagement Workshop, Paris, France, 14 February.

Pumped Hydro Storage in Australia

Australia has three major large scale pumped hydro facilities with a total combined capacity of 1,340 MW, as shown in Table 9. However, no new large scale facilities have been installed in the last 30 years.

Table 9 Australian pumped hydro storage capacity (2014)

Power station	Region	Installed Capacity MW
Wivenhoe	QLD	500
Shoalhaven	NSW	240
Tumut-3	NSW	600

While no new pumped hydro storage systems have been proposed or announced, several studies have investigated its potential:

- ROAM report on Pumped Storage modelling for AEMO 100% Renewables project.[142]
- Opportunities for Pumped Hydro Energy Storage in Australia, Arup-Melbourne Energy Institute.[143]

[141] IEA 2014. *Technology Road Map – Energy Storage.* Available: http://www.iea.org/publications/freepublications/publication/technology-roadmap-energy-storage-.html. Viewed: 11 Dec 2014.
[142] Available at http://www.climatechange.gov.au/sites/climatechange/files/files/reducing-carbon/APPENDIX4-ROAM-report-on-pumped-storage.pdf. Viewed: 15 Dec 2014.
[143] Available at http://www.energy.unimelb.edu.au/files/site1/docs/39/20140227%20reduced%20.pdf. Viewed: 15 Dec 2014.

Battery storage projects in Australia

Battery storage is the next most mature emerging storage technology in Australia. Table 10 summarises current projects under development, and the battery technology in use.

Table 10 Prominent battery storage projects in Australia

Electricity storage project	Region	Capacity kW	Technology type	Primary application
Energy storage for commercial renewable integration[144]	SA	5,000 – 30,000	Electro-chemical	Renewable capacity firming[145] and power quality management
King Island renewable energy integration project[146]	TAS	3,000	Hybrid lead acid	Renewable capacity firming
Hampton wind park[147]	NSW	1,000	Hybrid lead acid	Ramping and voltage support
Lord Howe island hybrid renewable energy system[148]	NSW	400	Electro-chemical	Renewable capacity firming
King Island renewable energy expansion[149]	TAS	200	Vanadium Redox flow battery	Renewable capacity firming
Cape Barren Island hybrid system[150]	TAS	163	Electro-chemical	Renewable generation shifting
University of Queensland Global Change Institute building[151]	QLD	120	Zinc bromine flow battery	Renewable generation shifting
Transgrid iDemand project[152]	NSW	100	Lithium Polymer Battery	Maximum demand management
University of Technology	NSW	25	Zinc bromine flow battery	Renewable capacity firming
Queensland grid support for single wire earth return lines (Magellan)[153]	QLD	25	Lithium iron phosphate	Load following and voltage control

144 AGL-Arena. Available: http://arena.gov.au/project/energy-storage-for-commercial-renewable-integration/. Viewed: 17 Dec 2014
145 Renewable capacity firming is the use of storage to mitigate rapid output changes from renewable generation.
146 Hydro Tasmania. Available: http://www.kingislandrenewableenergy.com.au/. Viewed: 17 Dec 2014.
147 Ecoult. Available: http://www.ecoult.com/case-studies/hampton-wind-farm-australia-wind-smoothing/. Viewed: 17 Dec 2014.
148 ARENA (Australian Renewable Energy Agency). Available: http://arena.gov.au/project/lord-howe-island-hybrid-renewable-energy-system/. Viewed: 17 Dec 2014.
149 Hydro Tasmania. Available: http://www.kingislandrenewableenergy.com.au/history/kirex. Viewed: 17 Dec 2014.
150 ITP Power. Available: http://www.itpau.com.au/cape-barren-island-hybrid-system-power-project-department-of-families-housing-and-indigenous-affairs-fahcsia/. Viewed: 17 Dec 2014.
151 University of Queensland. Available: http://uq.rise.ws/gci/. Viewed: 17 Dec 2014.
152 Transgrid. Available: http://www.transgrid.com.au/mediaweb/articles/Pages/TransGridtakesuptheenergychallengewiththeiDemandProjectatitswesternSydneyheadquarters.aspx. Viewed: 17 Dec 2014.
153 Magellan Power. Available: http://www.magellan-power.com.au/component/virtuemart/grid-power-support-systems/gpss-swr-detail. Viewed: 17 Dec 2014.

3.13 Levelised cost of electricity for new generation

Levelised cost of electricity (LCOE) is often cited as a convenient summary measure of the overall competiveness of different generating technologies. It represents the per-kilowatt-hour sent-out 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, auxiliary load and an assumed utilisation rate for each plant type.

The investment environment

Given current consumption expectations across both South Australia and the NEM, AEMO does not anticipate that overall generation capacity will need to increase in the next ten years to meet reliability requirements. The Electricity Statement of Opportunities (ESOO) forecasts an oversupply for South Australia between 550 MW and 600 MW for 2014-15, and between 350 MW and 1,050 MW by 2023-24.[154]

The LRET provides an incentive for investment in new renewable generation. LRET, in combination with aging thermal generation plant retirements, creates the potential to change the generation capacity mix for South Australia and lower overall emissions associated with electricity generation. However, LRET policy is uncertain, increasing the risk that prospective projects will be delayed or abandoned.

To assess which projects are likely given current LCOE projections, AEMO periodically reviews all costs associated with new generation technologies. These costs are included in least-cost expansion plan modelling published in support of the annual National Transmission and Network Development Plan (NTNDP).[155]

The latest predicted costs were compiled in consultation with consultants ACIL Allen and GHD in June 2014. Full details on cost assumptions for each technology is available on 2014 Planning Assumptions.[156]

Table 11 summarises new generation technologies included in this cost projection update, based on new information provided from ACIL Allen.

Table 11 Electricity generation technologies

Technology	Fuel	Comments / variations	Costing review
Supercritical pulverised coal (SCPC)	Brown Coal	With and without CCS	2014
Supercritical pulverised coal (SCPC)	Black Coal	With and without CCS	2014
Combined Cycle Gas Turbine (CCGT)	Natural gas	With and without CCS	2014
Open Cycle Gas Turbines (OCGT)	Natural gas	Without CCS	2014
Wind – 100MW	Wind	On shore	2014
Biomass	Biomass		2014
Solar Thermal - Compact Linear Fresnel (ST CLF)	Solar	Without storage	2014
Solar Thermal – Parabolic Trough (ST PT)	Solar	With 6 hr storage	2014
Solar Thermal – Central Receiver (ST CR)	Solar	With 6 hr storage	2014
Solar Photovoltaic – Fixed Flat Plate (PV FFP)	Solar	Grid scale and connected	2014
Solar Photovoltaic – Single Axis Tracking (PV SAT)	Solar	Grid scale and connected	2014
Solar Photovoltaic – Dual Axis Tracking (PV DAT)	Solar	Grid scale and connected	2014
Wave	Oceanic		2014
Integrated solar combined cycle (ISCC)	Natural Gas / Solar	Based on ST PT with CCGT.	2014

[154] AEMO. *2014 Electricity statement of Opportunity*, available at http://www.aemo.com.au/Electricity/Planning/Electricity-Statement-of-Opportunities. Viewed: 15 Dec 2014.

[155] AEMO. *2014 National transmission and Development Plan.* Available at http://www.aemo.com.au/Electricity/Planning/National-Transmission-Network-Development-Plan. Viewed: 23 Dec 2014.

[156] AEMO. *2014 Planning assumptions.* Available http://www.aemo.com.au/Electricity/Planning/Related-Information/Planning-Assumptions. Viewed: 15 Dec 2014.

Renewables

Compared to traditional carbon-emitting generation technologies, many renewable technologies have high capital and fixed operating and maintenance costs per installed megawatt of capacity. These costs are expected to decline as technology developments continue to improve plant efficiency, and as greater economies of scale occur with increasing adoption. Cost advantages may be offset by unfavourable exchange rate movements resulting in higher capital costs and changes in policy from year to year.

Table 12 summarises LCOE and equivalent CO_2 emissions for the range of renewable technologies considered in the report. Further LCOE and emission calculations and assumptions are provided in Appendix A.

Key observations include:

- Wind generation remains the lowest cost renewable technology at $99/MWh at sites providing capacity factors of 43%. (Sites at lower capacity factors are provided in Figure 14).
- Grid connected solar PV (FFP) has seen the greatest cost reduction due to substantially lower capital costs, reducing from $3518/MWh to $2350/MWh given updated information used in modelling.
- The LCOE for biomass has risen, partly due to higher assumed fixed operation costs.
- The LCOE for wave energy is promising but is unlikely to be developed commercially until at least 2020. Costings provided in Table 12 are also based on achieving a 60% capacity factor, which has yet to be shown.

For completeness and to allow comparison, technologies considered in the 2013 South Australian Fuel and Technology Report but not updated this year, have been included.

Table 12 LCOE and emissions comparison across technologies (renewables)

Technology	Fuel type	Max Capacity factor (%)	2014		2015	
			CO_2 emissions ($kgCO_2$-e/MWh)	Minimum LCOE ($/MWh sent out)	CO_2 emissions ($kgCO_2$-e/MWh)	Minimum LCOE ($/MWh sent out)
Wind (100 MW)	Wind	43	-	99	-	99
Biomass	Biomass	70	23	100	23	119
Solar PV (FFP)	Solar	21	-	224	-	149
Solar PV (SAT)	Solar	21			-	183
Solar PV (DAT)	Solar	21			-	240
Solar thermal (CR with storage)	Solar	42	-	277	-	218
Solar thermal (CLF)	Solar	23	-	328	-	284
Solar thermal (PT with storage)	Solar	42	-	302	-	294
Wave[157]	Oceanic	60			-	147
Geothermal - HAS	Geothermal	83	-	137		
Geothermal - EGS	Geothermal	83	-	137		

157 Wave technology not expected to reach commercial development until 2020. Costing is based on achieving a 60% capacity factor which has yet to be demonstrated.

Non-renewables

LCOE values and equivalent CO_2 emissions for non-renewable generation technologies are summarised in Table 13. Calculations for South Australia incorporate regional fuel cost estimates (when applicable and where available), while NEM calculations use the lowest fuel costs from any region (including South Australia).

For completeness and to allow comparison, technologies considered in the 2013 South Australian Fuel and Technology Report, but not updated this year, have been included in Table 13.

Key observations

- Gas fuelled technology costs have improved, mainly as a result of repeal of carbon pricing and changes in fuel cost projections, with South Australian LCOEs for CCGT at $82/MWh, down from results last year of $101/MWh, and for OCGT at $205/MWh down from $240/MWh.
- Black coal SCPC without CCS has the lowest LCOE at $72/MWh, although this technology is not currently available in South Australia.
- Assumptions for CCS have increased in price, mainly due to higher storage costs with all non-renewable technologies including CCS increasing in cost.

Table 13 LCOE and emissions comparison across technologies (non-renewable)

Technology	Fuel type	Capacity factor (%)	Region	2014		2015	
				CO2 emissions (kgCO2-e/MWh)	Minimum LCOE ($/MWh sent out)	CO2 emissions (kgCO2-e/MWh)	Minimum LCOE ($/MWh sent out)
Open Cycle (OCGT)	Gas	10	SA	700	240	699	205
			NEM	700	240	592	195
Combined cycle (CCGT)	Gas	83	SA	499	101	478	82
			NEM	499	101	405	73
Combined cycle (CCGT – with CCS)	Gas	83	SA	213	140		
			NEM	213	140	97	115
Supercritical (SCPC)	Brown coal	83	SA				
			NEM			1213	91
Supercritical (SCPC – with CCS)	Brown coal	83	SA				
			NEM			175	169
Supercritical (SCPC)	Black coal	83	SA				
			NEM			827	72
Supercritical (SCPC – with CCS)	Black coal	83	SA				
			NEM	123	152	134	140
Supercritical (SCPC – with oxy combustion CCS)	Black coal	83	SA				
			NEM	22	158		
Integrated Gasification and Combined Cycle (IGCC – with CSS)	Black coal	83	SA				
			NEM	150	191		
Integrated solar combined cycle (ISCC)	Gas / Solar	83	SA	446	123	450	103
			NEM	376	112	440	92

LCOE estimates for storage

Pumped hydro and grid battery storage LCOE costs are based on the 2014 ACIL report. To evaluate the storage's true potential, storage performance and cost must be measured against the dispatchable thermal power plants, demand response, power grid interconnections or modernisation that it seeks to displace.

LCOE calculations below are based on a zero cost charge rate, achievable only if there is surplus generation priced in the market at this rate. Any extra network costs are also not included in the estimates.

Table 14 LCOE and emissions comparison across technologies (storage)

Technology	Fuel type	Max Capacity factor (%)	2015	
			CO_2 emissions ($kgCO_2$-e/MWh)	Minimum LCOE ($/MWh sent out)
Pumped hydro storage	Wind	20	-	201
Grid battery storage	Battery	20	-	295

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, capacity factors of up to 43% for the best wind sites and 23% for the best solar sites have been achieved. However, these outputs occur at different times of the day as solar is confined to daytime periods and wind averages are higher overnight.

Gas, coal, geothermal and solar storage technologies have higher potential capacity factors, but may choose to operate only during high price events to maximise profitability.

LCOE values are presented in Figure 14 and Figure 15 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 20%, then the South Australian estimated LCOE for that generator would be $195/MWh sent out.

Figure 14 South Australia LCOE versus capacity factor

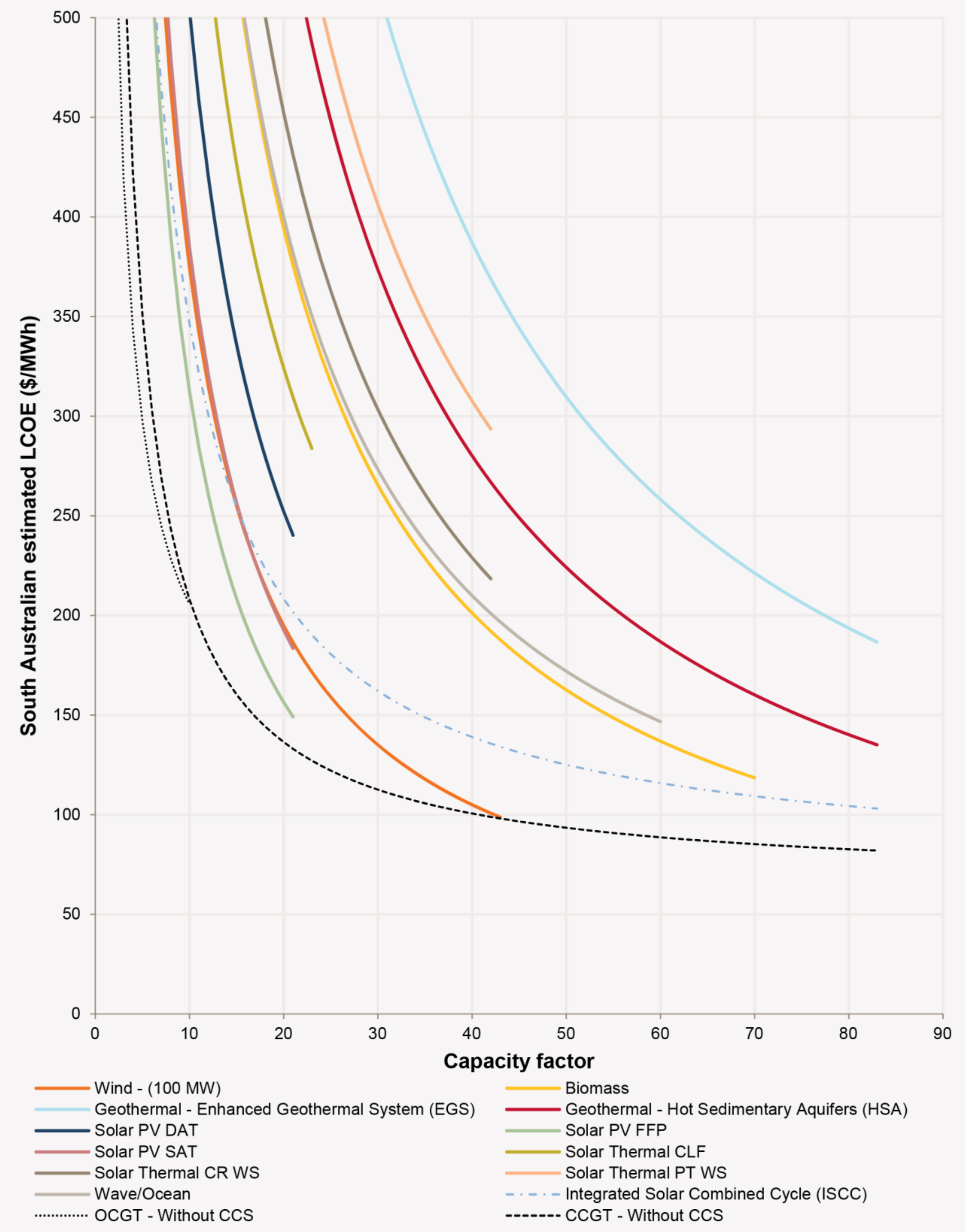
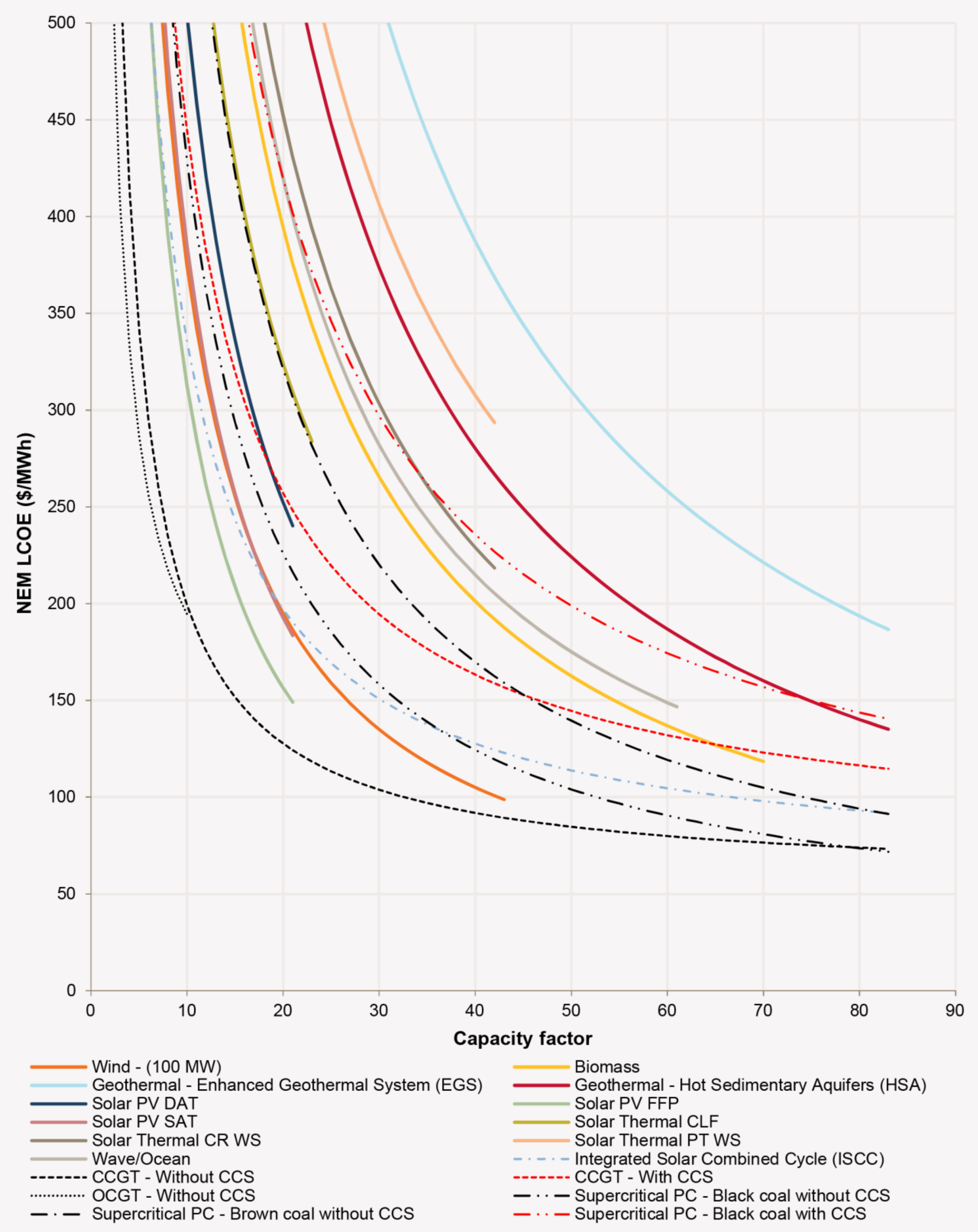


Figure 15 NEM LCOE versus capacity factor



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. This is useful for identifying the most potentially cost-effective technologies that for a particular market role (base load, intermediate, peaking), and the likely revenue required. Peaking units require maximum flexibility, allowing operation at short notice to take advantage of high market prices, but may only operate for short periods and have low capacity factors.

The most cost-efficient technologies by capacity factor are show in Table 15.

Table 15 Generation technology frontier

Load	Generation technology at frontier	
	South Australia	NEM (including South Australia)
Peaking	OCGT without CCS: up to 9% capacity factor.	OCGT without CCS: up to 9% capacity factor.
Intermediate	CCGT without CCS: from 10% to 83%[158] capacity factor.	CCGT without CCS: from 10% to 75% capacity factor.
Base-load		Super critical PC without CCS (black coal): from 75% capacity factor.

For new renewable generation, investment also depends on the LRET that fosters competition between different renewable technologies, but excludes non-renewable gas and coal. As a result:

- Overall wind generation is most economical, especially for sites where there are high capacity factors.
- Biomass is more economical when wind capacity factors approach 32%, provided biomass utilisation is high at or near 70%.
- Grid connected solar PV (fixed flat plate) has seen the largest decrease with capital costs reducing by 31% since the last technology cost review in 2012, and is now more economical than wind at sites where capacity factors are below 28%.
- Geothermal (Hot Sedimentary Aquifers) is only lower than wind at sites where wind capacity is below 25%, and only when utilisation rates of 83% for geothermal can be achieved and where no extra network costs are associated with connection to a transmission or distribution network.

[158] Maximum capacity factors for all thermal generation technologies (excluding OCGT) have been set at 83%. The actual maximum capacity factor for each technology may be greater than this, but the technology cost frontier is not impacted by this assumption.

Emissions

Figure 16 and Figure 17 summarise the emissions value and corresponding LCOE across generation technologies applying for South Australia and the NEM.

Figure 16 South Australia emissions at minimum LCOE

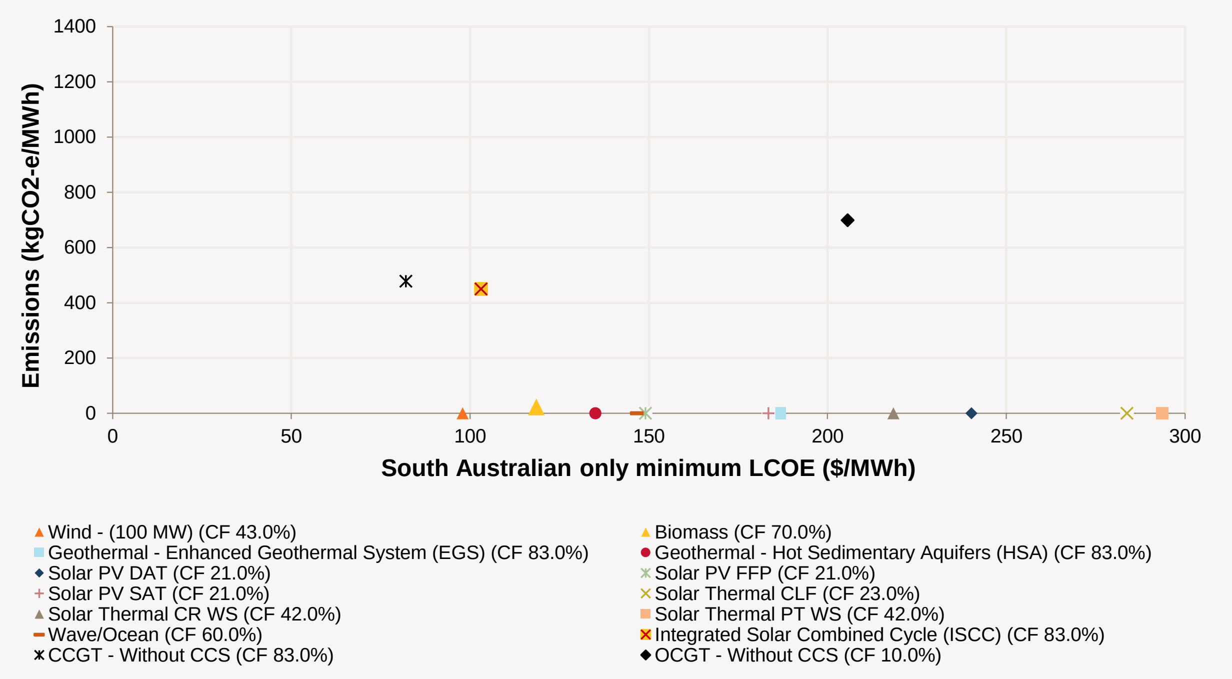
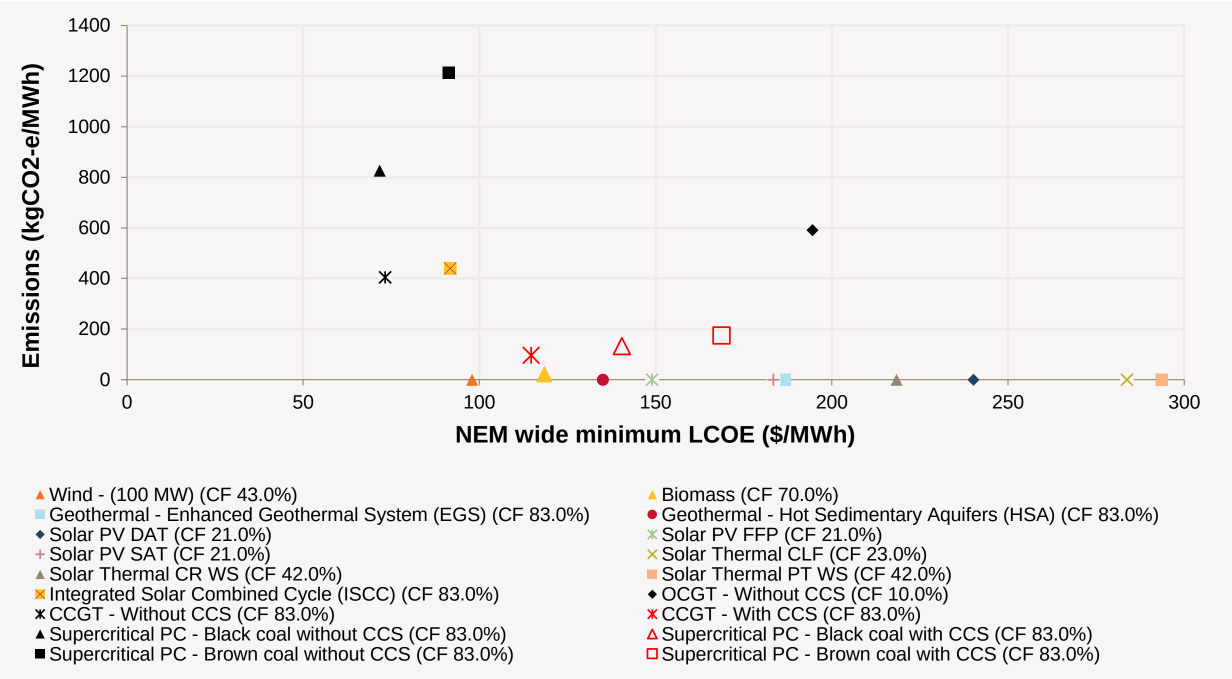


Figure 17 NEM emissions at minimum LCOE



APPENDIX A. METHODOLOGY

Levelised cost of electricity (LCOE)

Levelised cost of electricity (LCOE) is often cited as a convenient summary measure of the overall competiveness of different generating technologies. It represents the per-kilowatt-hour sent out 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, auxiliary load and an assumed utilisation rate for each plant type.

It does not, however, take into consideration revenue from operating different generating technologies, and the subsequent profit potential against which actual investment decisions are made. Regional capacity could result in a plant with lower cost not being scheduled as its availability coincides with other generation with lower costs.

Incentives that reward or penalise particular technologies can also impact investment decisions. Carbon pricing, included in the 2014 report, but excluded in the 2015 report, is a classic example.

Also of note is that LCOE calculations presented in this section apply only to the utility-scale use of technologies investigated, and are not directly applicable for residential rooftop PV where most of the growth in solar PV has occurred.

Assumptions

LCOE and emission calculations are based on the following assumptions:

- All technology is built “overnight” at the start of the 2014–15 financial year with a discount rate of 10% applied across technologies.
- Outlook period of 30 years, with costs not explicitly provided for the later years of the 30-year calculation period sourced unchanged from the last available year’s value. Capacity factors for various technologies ranged from 0% through to a maximum set by resources availability or plant available (set to 83% assuming downtime for maintenance and unplanned outages).
- Calculation at indicated capacity factor (for renewables, capacity factor will vary by location; values used represent the maximum likely values for South Australia).
- Capital costs, fixed operating and maintenance costs, variable operating and maintenance costs, fugitive emissions, combustion emissions, emissions captured, sequestration costs, fuel cost, auxiliary load and thermal efficiency sourced from the Fuel and Technology Cost Report prepared for AEMO by ACIL Allen.[159]

[159] ACIL ALLEN. June 2014 *Fuel and Technology Cost Report.* Available: http://www.aemo.com.au/Electricity/Planning/Related-Information/Planning-Assumptions. Viewed 1 Dec 2014.

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.[160]

Where:

- Net plant output = 1 MW (does not affect result)
- In terms of the equation for Mt, 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 Mt is calculated from the "non-captured combustion emissions plus all fugitive emissions", whereas the "sequestration costs" component of Mt is calculated from the captured combustion emissions.
- For supercritical pulverised coal–black coal oxy-combustion carbon capture and storage (CCS) technology, the input data suggests 0 kgCO_2-e/GJ for the combustion emissions factor. However, although 100% of emissions are assumed to be captured so no emissions are sent out from the plant, there is a sequestration (transport and storage) cost of that CO_2 produced (and the carbon price is paid on any fugitive emissions). To properly enable calculation of the sequestration cost, AEMO assumed a figure of 92.3 kgCO_2-e/GJ for the combustion emissions factor, based on comparing data provided in Table 3.1.1 and Table 3.1.2 in the 2012 Australian Energy Technology Assessment.
- For consistency with the intended operation of integrated solar combined cycle (ISCC) technology, AEMO used a figure of 47.32 kgCO_2-e/GJ for the combustion emissions factor, based on data provided in Section 5.9 of the WorleyParsons' Cost of Construction New Generation Technology report.[161] The fuel costs were assumed to be consistent with new combined cycle gas turbine (CCGT) plant.
- Input data selections are made from the planning scenario "MC05" in the Additional Modelling Data source.
- For the LCOE versus capacity factor plots, no data is plotted beyond the maximum typical capacity factor for that technology (see below). This presents a fairer comparison between technologies.

[160] BREE. *Australian energy technology assessments.* Available: http://www.bree.gov.au/publications/australian-energy-technology-assessments. Viewed: 23 Dec 2014.

[161] WorleyParsons, commissioned by AEMO. *Cost of Construction, New Generation Technology, 101010-00676 – Report.* 10 July 2012. Available: http://www.aemo.com.au/Electricity/Planning/Related-Information/~/media/Files/Other/planning/WorleyParsons_Cost_of_Construction_New_Generation_Technology_2012%20pdf.ashx. Viewed: 23 Dec 2014.

Emissions and carbon pricing

Emissions values calculated in this report are as kilograms of equivalent CO_2 produced per megawatt hour 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 BREE's 2012 Australian Energy Technology Assessment[162], with the exception of wind energy where a value of 43% was chosen based on actual data for South Australian wind farms in 2012–13.[163]
- 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, i.e., across the entire NEM or across South Australia.
- Emission costs are influenced by the price for carbon, which given repeal of the carbon pricing legislation in July 2014, has changed from last year. Carbon pricing in the 2015 report is set to zero until 2020–21, thereafter reverting to the forecast provided by Frontier Economics.[164]

[162] BREE. *Australian energy technology assessments.* Available: http://www.bree.gov.au/publications/australian-energy-technology-assessments. Viewed: 23 Dec 2014.
[163] AEMO. *2014 South Australian Wind Study Report.* Available: http://www.aemo.com.au/Electricity/Planning/South-Australian-Advisory-Functions/South-Australian-Wind-Study-Report. Viewed: 15 Dec 2014.
[164] Frontier Economics. June 2014. *Economic Outlook*. Available: http://www.aemo.com.au/Electricity/Planning/Forecasting/National-Electricity-Forecasting-Report/NEFR-Supplementary-Information. Viewed: 27 Nov 2014.

Table 16 LCOE cost assumptions

Technology	2014								2015							
	Auxiliary Load (%)	Capital costs ($/MW)	Fuel Costs ($/GJ) [165]	VOM ($/MWh sent out)	FOM costs ($/MW/yr)	Combustion Emission Factor (kg CO2e/GJ)	Emissions captured (%)	Thermal efficiency[166]	Auxiliary Load (%)	Capital costs ($/MW)	Fuel Costs ($/GJ) [167]	VOM ($/MWh sent out)	FOM costs ($/MW/yr)	Combustion Emission Factor (kg CO2e/GJ)	Emissions captured (%)	Thermal efficiency[168]
Renewable																
Wind (100 MW)	1%	2,671	-	12.49	41,647	-	-	100%	1%	2,550	-	15.00	45,000	-	-	100%
Biomass	0%	5,174	-	8.33	13,015	-	-	30%	8%	5,200	-	8.00	125,000	-	-	28%
Solar PV (FFP)	0%	3,518	-	0.00	39,321	-	-	100%	1%	2,350	-	-	25,000	-	-	100%
Solar PV (SAT)									1%	2,900	-	-	30,000	-	-	100%
Solar PV (DAT)									1%	3,800	-	-	39,000	-	-	100%
Solar thermal (CR with storage)	10%	5,356	-	15.62	62,470	-	-	100%	10%	6,700	-	5.70	72,000	-	-	100%
Solar thermal (CLF)	8%	9,132	-	20.82	67,676	-	-	100%	8%	4,500	-	15.20	64,000	-	-	100%
Solar thermal (PT with storage)	10%	8,481	-	15.62	62,470	-	-	100%	10%	9,100	-	11.40	73,000	-	-	100%
Wave									0.5%	5,900	-	20.00	40,000	-	-	100%
Geothermal – HAS	10%	7,462	-	0.00	208,233	-	-	100%								
Geothermal – EGS	10%	11,255	-	0.00	176,998	-	-	100%								
Storage																
Pumped hydro storage									1%	3,200	-	5.00	5,000	-	-	100%
Grid battery									0.5%	4,500	-	6.00	30,000	-	-	100%
Non-renewable																
Open cycle gas turbine (OCGT)	1%	746	4.17	10.41	4,165	50.07	-	35%	1%	725	5.90	10.00	4,000	57	-	35%
Combined cycle gas turbine (CCGT)	3%	1,153	3.33	4.16	10,412	50.60	-	50%	3%	1,092	3.90	7.00	10,000	57	-	51%
Combined cycle gas turbine (CCGT with CCS)	10%	3,034	3.33	9.37	17,700	47.92	85%	44%	10%	2,940	3.90	12.00	17,000	57	85%	44%
Integrated solar combined cycle gas turbine (ISCC)	5%	2,277	1.84	10.41	15,617	38.87	-	51%	5%	2,150	4.50	10.00	15,000	57		54%
Supercritical brown coal (SCPC)									9.6%	4,386	0.39	5.00	65,500	97	-	29%
Supercritical brown coal (SCPC with CCS)	24%	8,327	-	15.62	95,266	91.00	90%	21%	24.3%	8,277	0.39	11.00	96,500	97	90%	21%
Supercritical black coal (SCPC)									7.1%	2,880	1.55	4.00	50,500	91	-	42%
Supercritical black coal (SCPC with CCS)	23%	5,827	1.84	12.49	76,213	88.61	90%	32%	18.5%	5,388	1.55	9.00	73,200	91	90%	31%
Supercritical black coal (SCPC with oxy combustion CCS)	26%	6,195	1.84	14.58	64,552	-	100%	33%								
Integrated Gasification and Combined Cycle black coal (IGCC – with CCS)	32%	7,943	1.84	8.33	102,763	101.95	90%	29%								

[165] Fuel costs may vary by location. Representative value indicated either South Australian value or lowest in NEM. Refer to the 2014 ACIL Allen Fuel and Technology report for exact values.
[166] Sent out HHV (Higher Heating Value).
[167] Fuel costs may vary by location. Representative value indicated either South Australian value or lowest in NEM. Refer to the 2014 ACIL Allen Fuel and Technology report for exact values.
[168] Sent out HHV (Higher Heating Value).

MEASURES AND ABBREVIATIONS

Units of measure

Abbreviation	Unit of Measure
$/MWh	Australian dollar per megawatt hour
GJ	gigajoule
GWh	gigawatt hour
$kgCO_2$-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)
kW	kilowatt
MJ/kg	megajoule per kilogram
MPa	megapascal
MW	megawatt
MWh	megawatt hour
PJ	petajoule
TJ/a	terajoule per annum
TJ/d	terajoule per day

Abbreviations

Abbreviation	Expanded Name
ABARE	Australian Bureau of Agricultural and Resource Economics
AEMO	Australian Energy Market Operator
AETA	Australian Energy Technology Assessment
ARENA	Australian Renewable Energy Agency
ASEFS	Australian Solar Energy Forecasting System
AWEFS	Australian Wind Energy Forecasting System
BREE	Bureau of Resources and Energy Economics
CCGT	Combined cycle gas turbine
CO_2	Carbon dioxide
CSG	Coal seam gas
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DMITRE	South Australian Department for Manufacturing, Innovation, Trade, Resources and Energy
GBB	Gas Bulletin Board
GPG	Gas-powered generation
GSOO	Gas Statement of Opportunities
HHV	Higher heating value
IEA	International Energy Agency
IEA-ETSAP	International Energy Agency - Energy Technology Systems Analysis Program
IGCC	Integrated gasification and combined cycle
IRENA	International Renewable Energy Agency
LCOE	Levelised cost of electricity
LI	Large industrial
LNG	Liquefied natural gas
LRET	Large-scale Renewable Energy Target

Abbreviation	Expanded Name
MAPS	Moomba to Adelaide Pipeline System
MM	Mass market
MMLI	Mass market and large industrial
MSP	Moomba to Sydney Pipeline
NEFR	National Electricity Forecasting Report
NEM	National Electricity Market
NTNDP	National Transmission Network Development Plan
OCGT	Open cycle gas turbine
PC	Pulverised coal
PV	photovoltaic
QLD	Queensland
RET	Renewable Energy Target
SA	South Australia
SAAF	South Australian Advisory Functions
SEA Gas	South East Australia Gas Pipeline
SRES	Small-scale Renewable Energy Scheme
STE	Solar Thermal Energy
SWQP	South West Queensland Pipeline
UK	United Kingdom
USA	United States of America
VIC	Victoria
WA	Western Australia

GLOSSARY

Term	Meaning
1C contingent resources	Low estimate of contingent resources.
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.
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).
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.
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 (GBB)	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.
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'.
Linepack	The pressurised volume of gas stored in a pipeline system.
Liquefied natural gas (LNG)	Natural gas that has been converted into liquid form for ease of storage or transport.
LNG	Liquefied natural gas
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.
MMLI	Mass market and large industrial
National Electricity Market (NEM)	The wholesale market for electricity supply in Queensland, New South Wales (including the Australian Capital Territory), Victoria, South Australia, and Tasmania.
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 Large-scale Renewable Energy Target (LRET) is being implemented via Large-scale Generation Certificates (LGC), and targets 41,000 GWh of renewable energy by 2020.

Term	Meaning
Play	A project associated with a prospective trend of potential prospects, but which requires more data acquisition and/or evaluation in order to define specific leads or prospects. A project maturity subclass that reflects the actions required to move a project toward commercial production.[a]
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.
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.

[a] Society of Petroleum Engineers. *Guidelines for Application of the Petroleum Resources Management System*.
Available: http://www.spe.org/industry/docs/PRMS_Guidelines_Nov2011.pdf. Viewed: 19 Dec 2013.

List of Company Names

Company	Full Company Name
Alinta Energy	Alinta Energy
Altona Energy	Altona Energy
Armour Energy	Armour Energy Limited
Beach Energy	Beach Energy Limited
Carnegie Wave Energy	Carnegie Wave Energy Limited
Chevron Australia	Chevron Australia
Clean Energy Council	Clean Energy Council Limited
Core Energy Group	Core Energy Group Pty Ltd
CQ Partners	CQ Partners Pty Ltd
CSEnergy	CSEnergy Limited
DualGas	Dual Gas Proprietary Pty Ltd
Ecar Energy	Ecar Energy Ltd
ElectraNet	ElectraNet Pty Ltd
Geodynamics	Geodynamics Limited
HRL	HRL Limited
Mineral Carbonation International	Mineral Carbonation International Pty Ltd

Company	Full Company Name
Oceanlinx	Oceanlinx Limited
Origin Energy	Origin Energy
Petratherm	Petratherm Ltd
Raya Group	Raya Group Limited
SA Water	SA Water
Santos	Santos Ltd
Torrens Energy	Torrens Energy Limited
Wave Rider Energy	Wave Rider Energy Pty Ltd
WorleyParsons	WorleyParsons Ltd