Confidential

Review of EPRI cost data

Review of EPRI new entrant generation cost data for use within Energy White paper modelling

Prepared for AEMO/DRET

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ACIL Tasman

Economics Policy Strategy

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1 Introduction and background

ACIL Tasman has been engaged by the Australian Energy Market Operator (AEMO) to conduct a review for both AEMO and the Federal Department of Resources, Energy and Tourism (DRET), of generation cost data provided within the report[1] "*Assessment of Electricity Generation Technologies in Australia*" authored by the Electric Power Research Institute (EPRI). The cost data provided within this report is intended for use in modelling work for AEMO's National Transmission Development Plan (NTDP) and the Commonwealth Government's Energy White Paper.

ACIL Tasman has conducted a high level review of both the EPRI study methodology and results. The study's cost estimates have been compared with recent experience in the NEM and also with ACIL Tasman's own internal assessments. The purpose of ACIL Tasman's review is to gauge the suitability of the cost estimates for use within NTDP and Energy White Paper modelling exercises. AEMO and DRET, in consultation with the Stakeholder Reference Group have adopted values with reference to both EPRI and ACIL Tasman estimates.

Generation technology cost estimates are always subject to uncertainty. They are typically an area where industry participants and observers often have radically different views. As large-scale generation installations in Australia are relatively few and far between, it is also difficult to establish an accurate cost base from actual projects. In addition, generation projects inevitably have a number of unique characteristics in terms of their scale, configuration and site specific elements. This often makes like-for-like comparisons difficult.

This implies that there is significant uncertainty in relation to generation cost estimates – particularly for long-term modelling projects. While there is no one 'right' answer, it is typically necessary to develop a central point cost estimate for each technology for modelling purposes. Given this uncertainty, it is also valuable to stress-test results using a range of cost input assumptions. Importantly, as the demand for electrical energy is highly inelastic, it is not the absolute cost level which is of critical importance, but rather, the relative costs between different technologies.

This report presents the results of ACIL Tasman's review of the EPRI material. ACIL Tasman has also held discussions with EPRI representatives regarding a number of specific technology estimates and has provided EPRI

[1] EPRI, *Assessment of Electricity Generation Technologies in Australia*, Draft Report prepared for the Department of Resources, Energy and Tourism, February 2010.

with actual Australian project cost data (where available) in situations where differences in views arose. In some circumstances EPRI have reviewed a number of elements of its work and this has resulted in changes to some of its estimated cost values. Similarly, for some technologies, ACIL Tasman has revised its own work in light of the EPRI cost and performance data and as a consequence of discussion with the Stakeholder Reference Group. However, given the uncertainty noted above, there are a few areas where differences remain and we have provided our recommended central estimate in each case. While central estimates do differ in some cases, the EPRI, ACIL Tasman and Stakeholder Reference Group estimates all fall within the confidence interval of +/-30 percent established by the EPRI work.

This report is structured as follows:

- Chapter 2 provides an overview of the methodology used by EPRI in deriving its cost estimates
- Chapter 3 examines EPRI's cost estimates for each technology and compares them with recent ACIL Tasman's analysis
- Chapter 4 provides some concluding remarks regarding the appropriateness of the cost data for use within the Energy White Paper and NTDP modelling exercises.

2 Overview of EPRI approach

The methodology employed by EPRI in estimating the various cost and performance characteristics was essentially to establish a baseline for each technology based on current US Gulf Coast values in US dollars and then convert these to Australian conditions using adjustment factors for material costs, labour productivity, crew rates and exchange rate.

EPRI has undertaken the technology cost assessment through a detailed 'bottom-up' approach for new projects. By comparison, ACIL Tasman has established and maintains a database through observed and imputed values collected by ACIL Tasman from historical projects in Australia and Asian electricity markets.

2.1 Technical design considerations

The technical design basis for technology estimates are summarised as follows:

- all fossil fuel technologies are assumed to run at 85% capacity factor except peaking plant where 10% is assumed. Specific capacity factors apply to renewable technologies
- common plant sizing have been used in estimating costs (see Table 1)
- the location chosen is a generic greenfield site in Australia at an elevation of 111 meters, with ambient temperature of 25°C and 60% relative humidity
- The sites for the brown and black coal technologies are assumed to be mine mouth. Coal supply is assumed to be based on characteristics of Hunter Valley black coal and Latrobe Valley brown coal. The plant sites are assumed to be mine mouth with conveyors delivering coal from the mine to the site with storage sized for 5 days generation.
- No SO_2 or NOx reduction systems are included due to the very low sulphur content of Australian coal
- For all technologies, dry cooling systems are assumed to be necessary
- The generating unit boundary includes the area in which all unit components are located including all major parts of the unit, such as boiler and turbine generator, and all support facilities needed to operate the plant
- The cost boundary also includes the connection equipment, but not the switchyard and associated transmission line
- All technologies that include CO_2 capture and storage have a capture rate of 85-90%. The recovered CO_2 contains no more than 100 ppmv total sulphur and is compressed to 16 Mpa before exiting the plant boundary
- CO_2 compression equipment and energy penalties are included for plants with CCS, but the CO_2 pipeline and storage area for sequestration are not included in cost and performance estimates.

2.2 Cost estimates

The basis upon which costs are estimated is summarised as follows:

- Total Plant Cost (TPC) "Capital Cost," and Operation and Maintenance (O&M) cost estimates carry an accuracy of +/-30%
- All capital and O&M costs are presented as "Overnight Costs" expressed in June 2009 dollars
- Exchange rate of 1USD = 1.23486AUD (approximately US$0.80/A$)
- The capital cost estimate includes all anticipated costs for equipment and materials, installation labour, professional services (Engineering and Construction Management), and contingency
- The following items are excluded from the capital costs:
  - Escalation to period-of-performance
  - All taxes, with the exception of payroll taxes
  - Site specific considerations – including but not limited to seismic zone, accessibility, local regulatory requirements, excessive rock, piles, lay down space, etc.
  - CO_2 injection wells, pipelines to deliver the CO_2 from the generation plant fence to the storage facility and all administration supervision and control costs for the facility
  - Additional premiums associated with an EPC contracting approach
  - Import Duties.
  - Owner's costs – including, but not limited to land acquisition and right-of-way, permits and licensing, royalty allowances, economic development, project development costs, allowance for funds-used-during construction, legal fees, Owner's engineering, pre-production costs, initial inventories, furnishings, Owner's contingency, etc.
- The EPRI study allowed 7.5% on top of TPC to account for project specific costs such as site and technology selection studies, rights of way, road modifications and upgrades and permitting etc.
- The production costs or operating costs and related maintenance expenses (O&M) pertain to those charges associated with operating and maintaining the power plants over their expected life. These costs include:
  - Operating labour
  - Maintenance – material and labour
  - Administrative and support labour
  - Consumables
  - Waste Disposal
  - Co-Product or By-Products credit (that is, a negative cost for any by-products sold).

2.3 ACIL Tasman comments on methodology

Overall the design and basis for cost estimates are sound and align closely with other estimates produced for the Australian market. One notable variation was the exclusion of grid connection costs in EPRI's original capital cost estimates. While these costs are only a relatively small component for large generation developments, they can be significant for smaller, lower capital cost plants such as OCGT and CCGT plant. The convention in other estimates produced for the Australian market is for capital costs relating to connection assets, including switchyard and grid connection to be included within the capital cost total.

EPRI included an additional 7.5% expenditure allowance for project specific costs, including switchyard costs in its estimates. EPRI specifically excluded other grid connection costs including those relating to transmission infrastructure. This is because grid connection can vary significantly on a project-by-project basis. These alternative methodologies may have contributed to differences between EPRI and ACIL Tasman in relation to gas technology capital costs. Apart from this, there is a close alignment of EPRI and ACIL Tasman overnight capital costs definitions.

Another issue which was identified early in the review was the different basis upon which capital costs were quoted. EPRI quote capital costs as A$/kW sent-out, whereas the convention in Australia is to quote capital costs as A$/kW installed. For technologies with low auxiliary use, the two figures are very close. However, for plant with large auxiliaries, such as CCS plant, the difference can be much larger. Within this report, ACIL Tasman has converted EPRI's figures to A$/kW installed for purposes of comparison.

In relation to the overall methodology, ACIL Tasman notes the difficulty in translating US projects and prices into an Australian context. In our review we have identified a number of differences in estimates of overall capital costs when compared with actual costs of known Australian projects, the majority of which are probably a result of different component manufacture and supply conditions in Australia and the US. This may have been a factor which contributed to cost differences between EPRI and ACIL Tasman in relation to wind, solar PV and gas-fired technologies.

We also note the coal specifications used for black and brown coal which was based on Hunter Valley Latrobe Valley coal respectively. While this basis appears to be acceptable, it should be noted that other Australian coal deposits (such as Leigh Creek in South Australia and Collie Basin in Western Australia) will have different characteristics to the two reference coals used.

2.4 Technologies examined

Table 1 lists the technologies that EPRI provided cost and performance data within its study.[2] The technologies include the predominant non-renewable and renewable technologies that could potentially be deployed in Australia over the period to 2030.

Table 1 **Technologies examined by EPRI study**

Technology Type	Size, MWe (sent out basis)
Non-Renewable	
Integrated Gasification Combined Cycle (IGCC)	
Black coal	700-800 MW
Black coal, with CCS (85-90%)	600-700 MW
Pulverized Coal (PC)	
Brown coal, no NOx/SO2 controls	750 MW
Brown coal, with CCS (90%) & NOx/SO2 controls as reqd	750 MW
Black coal, no NOx/SO2 controls	750 MW
Black coal, with CCS (90%) & NOx/SO2 controls as reqd	750 MW
Oxy-combustion with black coal	750 MW
Combustion Turbine Combined Cycle (CTCC)	
Without CCS	600-800 MW
With CCS	600-800 MW
Simple Cycle Combustion Turbine (CT)	
Heavy Duty	160-190 MW
Nuclear	
Generation III/III+ (with seawater cooling)	1100-1600 MW
Renewable	
Solar Thermal	
Parabolic trough w/6 hours storage (also w/o storage)	200-300 MWe
Central receiver w/6 hours storage (also w/o storage)	200-300 MWe
Solar Photovoltaic (PV)	
Utility scale centralized PV, fixed flat plate PV	1x5 MWe, 10x5 MWe
Utility scale centralized PV, single axis tracking PV	1x5 MWe, 10x5 MWe
Utility scale centralized PV, two axis tracking	1x5 MWe, 10x5 MWe
On-shore wind	
On-shore wind (class 3, 4, 5, & 6)	25x2 MW, 100x2 MW, 250x2 MW
Geothermal	
Enhanced Geothermal System (EGS)	50 MW
Hot Sedimentary Aquifers (HSA)	50 MW

Data source: EPRI

[2] While a number of other technologies were discussed no cost or performance data was provided.

3 Comparison with ACIL Tasman's view

For each of the cost and generator performance characteristics, ACIL Tasman has compared the EPRI estimates with its own internal view. In some cases ACIL Tasman's estimates have been previously incorporated in public reports such as work completed recently for the IRPC.[3] These values are provided along with the value actually adopted by AEMO/DRET and the Stakeholder Reference Group for the modelling task.

For the purposes of this report, ACIL Tasman has only considered the capital costs, operating costs and generator characteristics (thermal efficiency, auxiliary use etc). We have not reviewed EPRI's calculation of the Levelised Cost of Electricity (LCOE). This is because the subsequent stages of this project will require market modelling which will implicitly calculate its own LCOE values and will not utilise values calculated by EPRI.

The following sections examine each of the key cost and performance figures for non-renewable and renewable technologies.

3.1 Capital costs

3.1.1 Non-renewable technologies

Figure 1 compares EPRI and published estimates from ACIL Tasman for technology capital costs, expressed in A$/kW installed. ACIL Tasman has not previously published estimates for CCGT with CCS or Oxy-combustion black coal and hence, no comparative estimate is provided.

Figure 2 shows an alternative view of the capital cost comparisons and also includes the 'high' and 'low' ranges on the EPRI figures. In all cases the ACIL Tasman estimates falls within the EPRI range of uncertainty however there are some key differences:

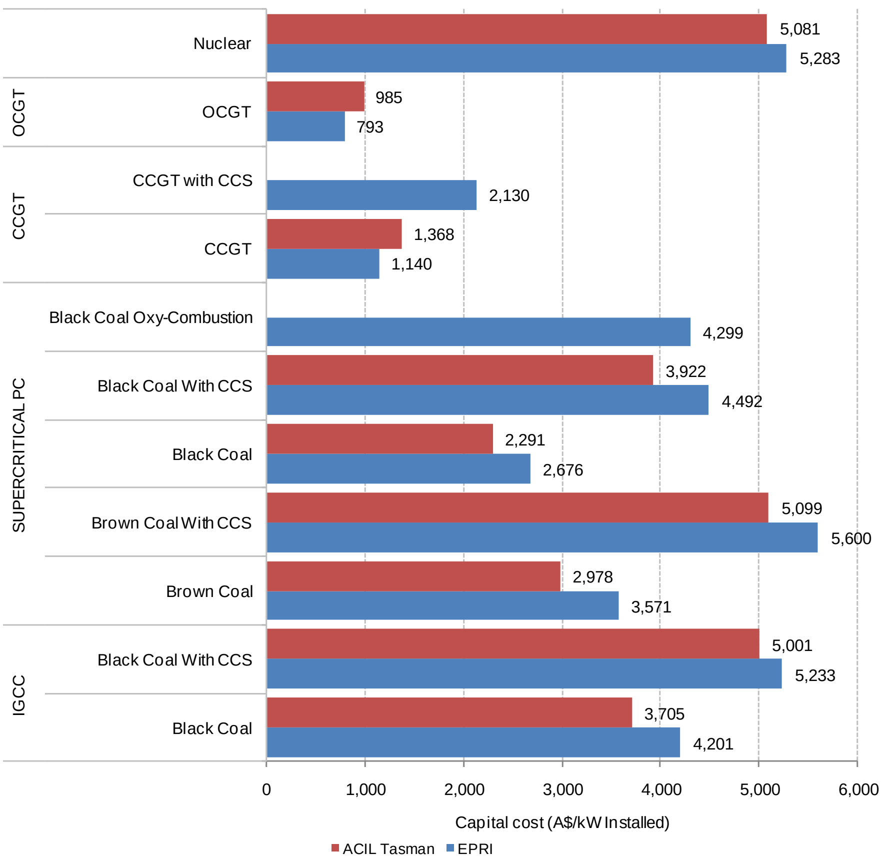
- For CCGT and OCGT gas-based technologies ACIL Tasman estimates lie in the extreme upper end of the EPRI estimates. We have been unable to determine the exact reason for this difference but believe this may relate to inherent differences within the 50Hz and 60Hz markets for turbines. ACIL Tasman has access to recent project costs in Australia and has also discussed costs with proponents who have recently constructed these units, reaffirming ACIL views. ACIL Tasman believes the EPRI figures are somewhat low relative to Australian market conditions, albeit still within the +/- 30% accuracy range.

[3] ACIL Tasman, *Fuel resource, new entry and generation costs in the NEM*, April 2009

- Upon review of supercritical brown coal costs, ACIL Tasman has concluded that the EPRI estimates are reasonable and that the original ACIL Tasman estimates (published for the IRPC) were too low relative to black coal plant of the same type. While there have been no brown coal developments for around 15 years in Australia, a premium of around 30% can be expected over the comparable black coal plant. ACIL Tasman recommends that the EPRI brown coal figures be adopted.

ACIL Tasman recommends the EPRI estimates for other non-renewable technologies be adopted as given.

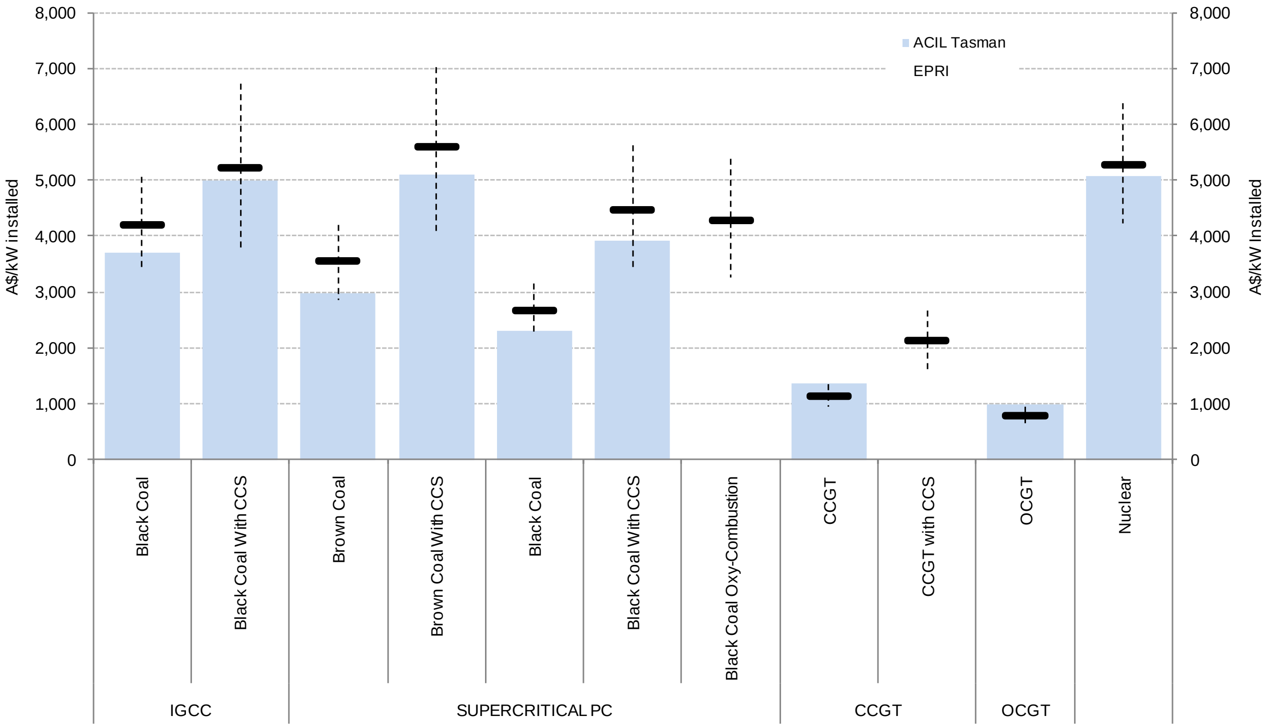
Figure 1 **Comparison of non-renewable technology capital costs**



Note: Figures presented for a 2015 installation. Costs presented in $/kW of installed capacity.

Data source: ACIL Tasman, EPRI

Figure 2 **Comparison of non-renewable capital costs with EPRI ranges (A$/kW installed)**



Note: Black horizontal line represents EPRI's central capital cost estimate. Dotted line shows high and low estimate range. ACIL Tasman has not published capital cost estimates for all technologies evaluated by EPRI. Figures presented for 2015 installation in real 2009 dollars.

Data source: ACIL Tasman, EPRI

Table 2 summarises the proposed changes for capital costs. Changes are proposed for gas-based technologies (CCGT and OCGT) and by implication, CCGT technology that employs CCS.

Table 2 **Summary of proposed changes to EPRI supplied 2015 non-renewable capital costs (A$/kW installed)**

Type	Technology	Midpoint EPRI estimate	ACIL Tasman estimate	Point value adopted for modelling	Difference from EPRI estimate
IGCC	Black Coal	4,201	3,705	4,201	0
	Black Coal With CCS	5,233	5,001	5,233	0
SUPERCRITICAL PC	Brown Coal	3,571	2,978	3,571	0
	Brown Coal With CCS	5,600	5,099	5,600	0
	Black Coal	2,676	2,291	2,676	0
	Black Coal With CCS	4,492	3,922	4,492	0
	Black Coal Oxy-Combustion	4,299	n/a	4,299	0
CCGT	CCGT	1,140	1,368	1,368	228
	CCGT with CCS	2,130	n/a	2,359	228
OCGT	OCGT	793	985	985	192
Nuclear	Nuclear	5,283	5,081	5,283	0

Note: Values shaded grey indicate a proposed change from the estimate provided by EPRI. Figures provided for 2015 installation in real 2009 dollars.

Data source: ACIL Tasman

The estimated capital costs for non-renewable technologies for development in 2030 are shown in Table 3. EPRI has not provided estimates for 2030 installation of technologies which do not employ CCS aside from OCGT and nuclear. In these instances, ACIL Tasman has proposed a point value for use in the modelling based on other EPRI capital cost reductions. The 2030 figures will be used to trend capital costs annually in the intervening years.

Table 3 **Summary of proposed changes to EPRI supplied 2030 non-renewable capital costs (A$/kW installed)**

Type	Technology	Midpoint EPRI estimate	ACIL Tasman estimate	Point value adopted for modelling	Difference from EPRI estimate
IGCC	Black Coal	n/a	2,484	3,232	n/a
	Black Coal With CCS	3,202	3,229	3,726	523
SUPERCRITICAL PC	Brown Coal	n/a	2,856	3,214	n/a
	Brown Coal With CCS	4,638	3,997	4,638	0
	Black Coal	n/a	2,197	2,408	n/a
	Black Coal With CCS	3,677	3,075	3,677	0
	Black Coal Oxy-Combustion	3,422	n/a	3,422	0
CCGT	CCGT	n/a	1,170	1,170	n/a
	CCGT with CCS	1,757	n/a	1,757	0
OCGT	OCGT	872	835	872	0
Nuclear	Nuclear	4,486	4,091	4,486	0

Note: Figures provided for 2030 installation in real 2009 dollars.

Data source: ACIL Tasman

Table 4 summarises the real reduction in capital costs from 2015 to 2030.

Table 4 **Real capital cost reduction for non-renewable technologies from 2015 to 2030**

Type	Technology	Midpoint 2015 capital cost ($/kW)	Midpoint 2030 capital cost ($/kW)	Real reduction (%)
IGCC	Black Coal	4,201	3,232	23%
	Black Coal With CCS	5,233	3,726	29%
SUPERCRITICAL PC	Brown Coal	3,571	3,214	10%
	Brown Coal With CCS	5,600	4,638	17%
	Black Coal	2,676	2,408	10%
	Black Coal With CCS	4,492	3,677	18%
	Black Coal Oxy-Combustion	4,299	3,422	20%
CCGT	CCGT	1,368	1,170	15%
	CCGT with CCS	2,359	1,757	26%
OCGT	OCGT	985	872	11%
Nuclear	Nuclear	5,283	4,486	15%

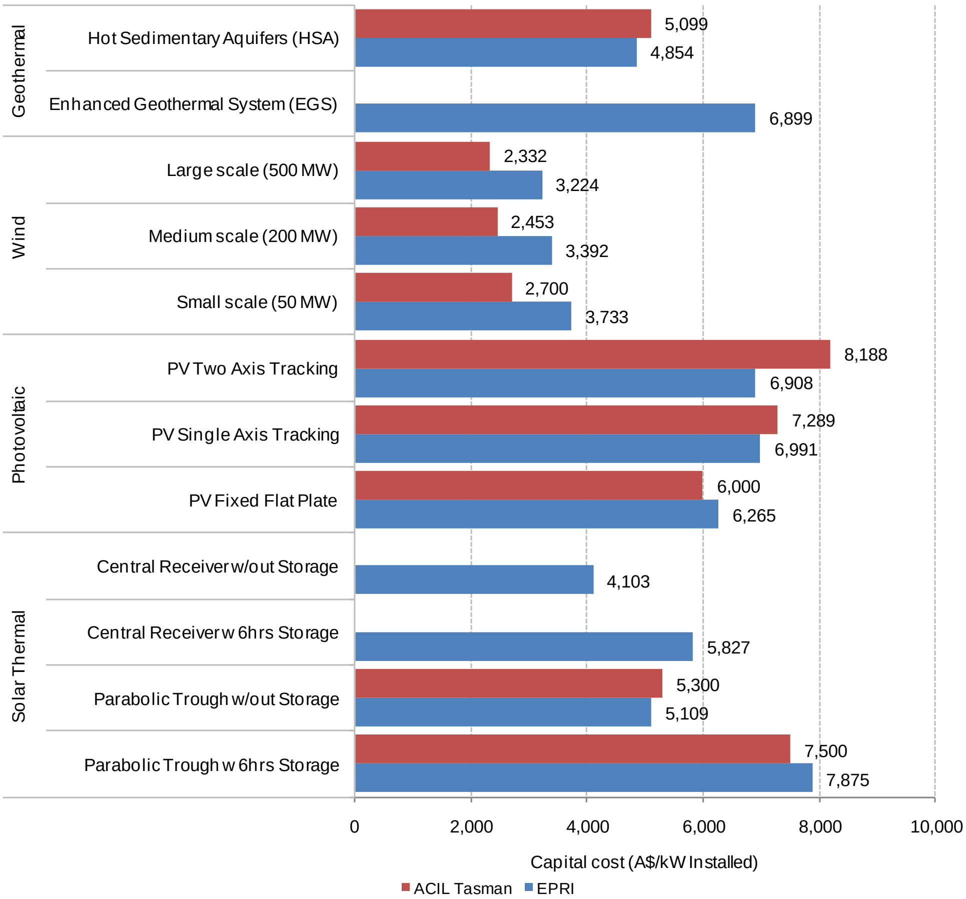
Note: Capital costs are interpolated for intervening years

Data source: ACIL Tasman

3.1.2 Renewable technologies

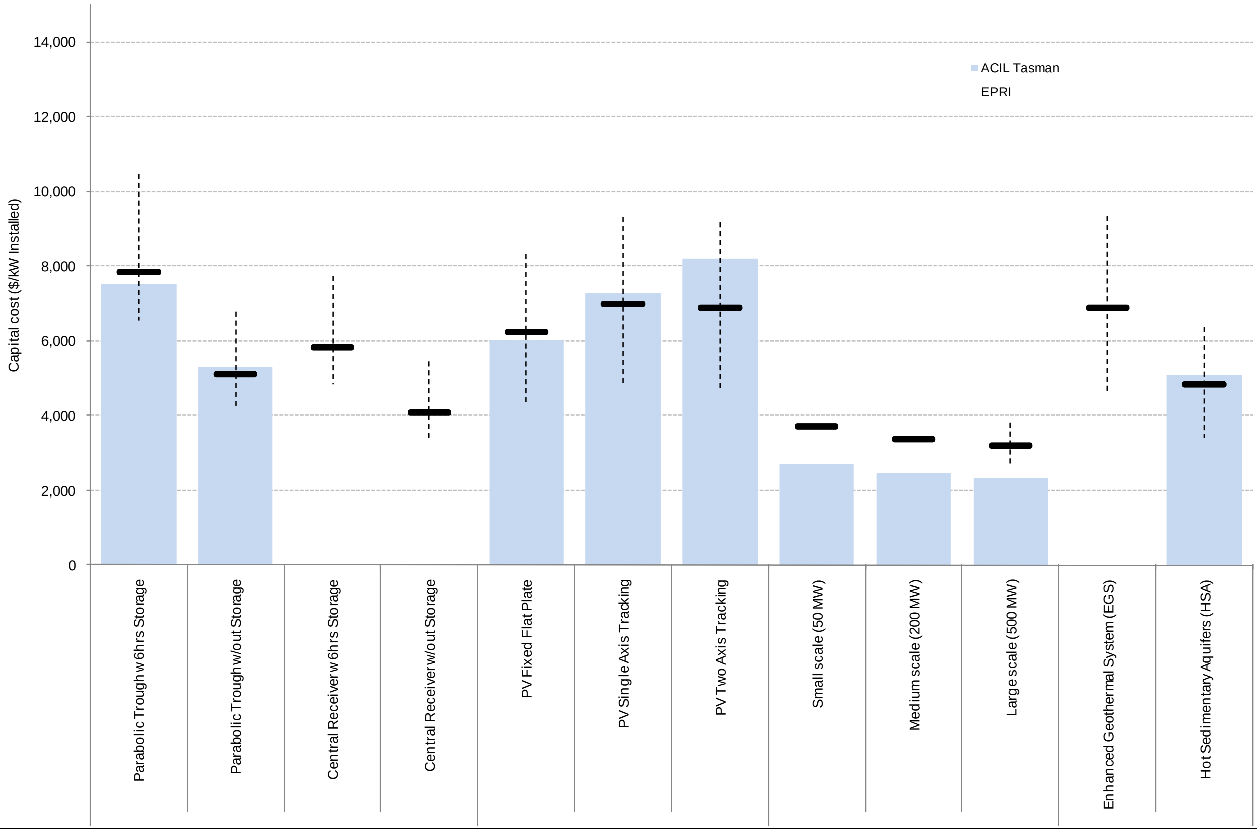
A comparison of renewable technology capital costs between EPRI and ACIL Tasman estimates as shown in Figure 3 and Figure 4.

Figure 3 Comparison of renewable technology capital costs



Note: Figures presented for 2015 installation in real 2009 dollars.
Data source: ACIL Tasman, EPRI

Figure 4 **Comparison of renewable capital costs with EPRI ranges (A$/kW installed)**



Note: Black horizontal line represents EPRI's central capital cost estimate. Dotted line shows high and low estimate range. ACIL Tasman has not published capital cost estimates for all technologies evaluated by EPRI. Figures presented for 2015 installation in real 2009 dollars.

Data source: ACIL Tasman, EPRI

The ACIL Tasman and EPRI values are reasonably close for all technologies with the exception of wind.

For wind turbines EPRI appear to have based its cost estimates upon high-end 'intelligent' turbines which include a number of power system features not commonly installed in Australia. These turbines include models from GE, Enercon and REPower. In Australia, wind turbines installed to-date have generally been lower cost Vestas or Suzlon machines (as detailed in Table 5) that generally do not incorporate these more sophisticated features.

Table 5 **Turbine type and total project costs for wind farm installations in Australia**

Project	Region	Commissioned	Capacity (MW)	Turbine type	Capex (A$/kW installed)
Toora	VIC	2002	21	Vestas V66	1,810
Starfish Hill	SA	2003	34.5	Vestas NM64C	1,884
Challicum Hills	VIC	2003	52.5	NEG Micon NM64	1,448
Woolnorth	TAS	2004	64.75	Vestas	1,510
Canunda	SA	2005	46	Vestas V80	2,011
Wattle Point	SA	2005	90.8	Vestas V82	1,982
Mt Millar	SA	2006	70	Enercon E70	1,971
Yambuk (Portland Stage 1)	VIC	2007	30	NEG Micon NM82	1,667
Lake Bonney Stage 2	SA	2008	159.5	Vestas V90	2,508
Snowtown Stage I (Barunga)	SA	2008	98.7	Suzlon S88	2,268
Cullerin Range	NSW	2009	30	REPower	3,167
Hallett Stage 2 (Hallett Hill)	SA	2009	71.4	Suzlon	2,325
Waubra	VIC	2009	192	NEG Micon NM82	2,344
Clements Gap	SA	2010	56.7	Suzlon	2,381
Hallett Stage 4 (North Brown Hill)	SA	2011	132.3	Suzlon S88v3	2,577
Waterloo	SA	2011	117	Vestas V90	2,308
Oaklands Hill	VIC	2011	63	Suzlon S88 ?	3,175

Note: Table does not contain a complete list of Australian wind farms

Data source: ACIL Tasman analysis

In the future as wind penetration increases, the technical licensing requirements for wind turbines may be tightened including greater levels of voltage control and system support. There is evidence that this is already occurring in South Australia with the new draft technical licensing requirements for wind[4] requiring the National Electricity Rules automatic access standard (the upper end of the technical range) for fault ride through and also more stringent reactive power capabilities such as fast-acting, continuously variable, voltage control systems. This may require the installation of more advanced wind turbines (such as the GE, Enercon and REPower models), and/or installation of STATCOM (Static Var Compensation) at the substation level. Installation of STATCOM would be in the order of A$5-A$10 million per 100 MW wind farm.

While these requirements are likely to increase wind farm development costs slightly, they are unlikely to significantly increase costs faced by developers.

These additional requirements will only apply to wind installations in South Australia in the near-term, however, other NEM regions may also increase the technical requirements as wind penetration increases. For other regions such as Victoria and New South Wales which are significantly larger than South

[4] See http://archive.escosa.sa.gov.au/webdata/resources/files/090616-WindGenerationLic-DraftDecision.pdf

Australia, significant additional wind capacity could be installed before wind penetration became a significant issue.

Based on actual wind project costs to-date and discussions with wind proponents within Australia, ACIL Tasman recommended the use of a lower capital cost figure than EPRI's estimate. Even with the transition to meet increases licensing requirements ACIL Tasman does not expect installed wind turbine costs to reach levels suggested by EPRI.

The figures adopted by the AEMO and DRET in consultation with the Stakeholder Reference Group for wind lie roughly in the middle between the EPRI and ACIL Tasman estimates.

ACIL Tasman has some recent experience with parabolic trough proponents in Australia in response to the Government's Solar Flagship program. Costs estimates are reasonably close to EPRI's figures and it is recommended these are adopted.

ACIL Tasman does not have any detailed cost data on solar thermal central receiver technology but has significant doubts whether this offers lower capital costs relative to parabolic trough designs. However, in the absence of other data, ACIL Tasman recommends the EPRI estimate should be adopted.

AEMO/DRET have adopted a lower capital cost than both EPRI and ACIL Tasman for solar photovoltaic based on feedback from the Stakeholder Reference Group.

Table 6 summarises the EPRI and ACIL Tasman capital cost estimates and the figures recommended for use by the Stakeholder Reference Group.

Table 6 **Summary of changes to EPRI supplied 2015 renewable capital costs (A$/kW installed)**

Type	Technology	Midpoint EPRI estimate	ACIL Tasman estimate	Point value adopted for modelling	Difference from EPRI estimate
Solar Thermal	Parabolic Trough w 6hrs Storage	7,875	7,500	7,875	0
	Parabolic Trough w/out Storage	5,109	5,300	5,109	0
	Central Receiver w 6hrs Storage	5,827	n/a	5,827	0
	Central Receiver w/out Storage	4,103	n/a	4,103	0
Photovoltaic	PV Fixed Flat Plate	6,265	6,000	4,650	-1,615
	PV Single Axis Tracking	6,991	7,289	5,100	-1,891
	PV Two Axis Tracking	6,908	8,188	5,650	-1,258
Wind	Small scale (50 MW)	3,733	2,700	3,178	-555
	Medium scale (200 MW)	3,392	2,453	2,886	-506
	Large scale (500 MW)	3,224	2,332	2,744	-480
Geothermal	Enhanced Geothermal System (EGS)	6,899	n/a	6,899	0
	Hot Sedimentary Aquifers (HSA)	4,854	5,099	4,854	0

Note: Values shaded grey indicate a proposed change from the estimate provided by EPRI. Figures provided for 2015 installation in real 2009 dollars.
Data source: ACIL Tasman

EPRI have also provided capital cost estimates for renewable developments in 2030 as detailed in Table 7. ACIL Tasman has accepted each of these values as given. AEMO/DRET have adopted lower 2030 figures based on revisions adopted for 2015 installations.

Table 7 **Summary of changes to EPRI supplied 2030 renewable capital costs (A$/kW installed)**

Type	Technology	Midpoint EPRI estimate	ACIL Tasman estimate	Point value adopted for modelling	Difference from EPRI estimate
Solar Thermal	Parabolic Trough w 6hrs Storage	5,513	n/a	5,513	0
	Parabolic Trough w/out Storage	3,321	n/a	3,321	0
	Central Receiver w 6hrs Storage	3,788	n/a	3,788	0
	Central Receiver w/out Storage	2,462	n/a	2,462	0
Photovoltaic	PV Fixed Flat Plate	4,072	n/a	3,255	-817
	PV Single Axis Tracking	4,544	n/a	3,570	-974
	PV Two Axis Tracking	4,490	n/a	3,955	-535
Wind	Small scale (50 MW)	3,360	n/a	2,543	-817
	Medium scale (200 MW)	3,052	n/a	2,308	-744
	Large scale (500 MW)	2,902	n/a	2,195	-707
Geothermal	Enhanced Geothermal System (EGS)	6,507	n/a	6,507	0
	Hot Sedimentary Aquifers (HSA)	4,527	n/a	4,527	0

Note: Values shaded grey indicate a proposed change from the estimate provided by EPRI. Figures provided for 2030 installation in real 2009 dollars.
Data source: ACIL Tasman

Table 8 details the implied real capital cost reduction from 2015 to 2030 for renewable technologies. The EPRI figures show large cost reductions for solar technologies. Cost reduction for geothermal technologies is lower given geothermal inputs – primarily above ground technology and drilling capital costs – being well established and have been assumed to offer little scope for large cost reductions. ACIL Tasman notes that the EPRI report considers that there is likely to be scope for resource specific capital cost improvements in geothermal technology over time.

Table 8 **Real capital cost reduction for renewable technologies from 2015 to 2030**

Type	Technology	2015 capital cost ($/kW)	2030 capital cost ($/kW)	Real reduction (%)
Solar Thermal	Parabolic Trough w 6hrs Storage	7,875	5,513	30%
	Parabolic Trough w/out Storage	5,109	3,321	35%
	Central Receiver w 6hrs Storage	5,827	3,788	35%
	Central Receiver w/out Storage	4,103	2,462	40%
Photovoltaic	PV Fixed Flat Plate	4,650	3,255	30%
	PV Single Axis Tracking	5,100	3,570	30%
	PV Two Axis Tracking	5,650	3,955	30%
Wind	Small scale (50 MW)	3,178	2,543	20%
	Medium scale (200 MW)	2,886	2,308	20%
	Large scale (500 MW)	2,744	2,195	20%
Geothermal	Enhanced Geothermal System (EGS)	6,899	6,507	6%
	Hot Sedimentary Aquifers (HSA)	4,854	4,527	7%

Note: Capital costs are interpolated for intervening years

Data source: ACIL Tasman

3.2 Operating and maintenance costs

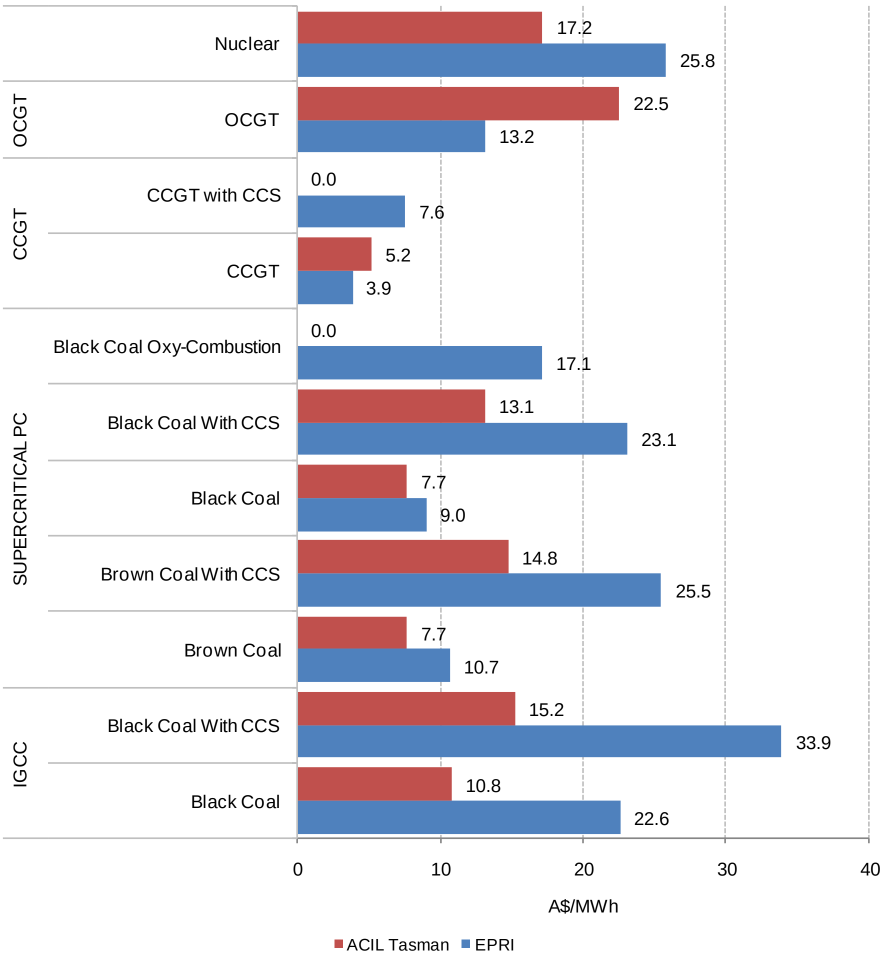
Operating and maintenance (O&M) costs comprise both fixed and variable components. Variable O&M (or VOM), is required for the estimation of SRMC, while Fixed O&M (FOM) costs are required for new entrant costs and decisions relating to retirements of incumbent plant.

FOM represents costs which are fixed and do not vary with station output, such as major periodic maintenance, wages, insurances and overheads. VOM are costs which are directly related to plant output and generally include consumables such as water and chemicals, material handling (for example ash disposal) and may also include an allowance for start-up costs and maintenance where this is based on runtime.

3.2.1 Non-renewable technologies

Given differences in definitions used by EPRI and ACIL Tasman to allocate O&M into fixed and variable components, it is more useful to compare overall O&M costs (fixed plus variable components based on assumed capacity factors). These comparisons are made in Figure 5.

Figure 5 **Comparison of total operation and maintenance costs**



Note: Based on assumed capacity factor of 85% for all technologies except OCGT where 10% is used.
Data source: ACIL Tasman, EPRI

Table 9 summaries the total O&M costs. AEMO/DRET adopted the EPRI numbers having regard to the views of the Stakeholder Reference Group. ACIL Tasman note that EPRI's O&M figures are generally higher across the board, however the large differences are generally for emerging technologies for which there is little (if any) actual Australian data to refer to.

Both fixed and variable O&M costs elements are held constant in real terms over the modelling horizon.

Table 9 **Summary of total O&M costs (A$/MWh)**

Type	Technology	EPRI estimate	ACIL Tasman estimate	Point value adopted for modelling	Difference from EPRI estimate
IGCC	Black Coal	23	11	23	0
	Black Coal With CCS	34	15	34	0
SUPERCRITICAL PC	Brown Coal	11	8	11	0
	Brown Coal With CCS	25	15	25	0
	Black Coal	9	8	9	0
	Black Coal With CCS	23	13	23	0
	Black Coal Oxy-Combustion	17	n/a	17	0
CCGT	CCGT	4	5	4	0
	CCGT with CCS	8	n/a	8	0
OCGT	OCGT	13	23	13	0
Nuclear	Nuclear	26	17	26	0

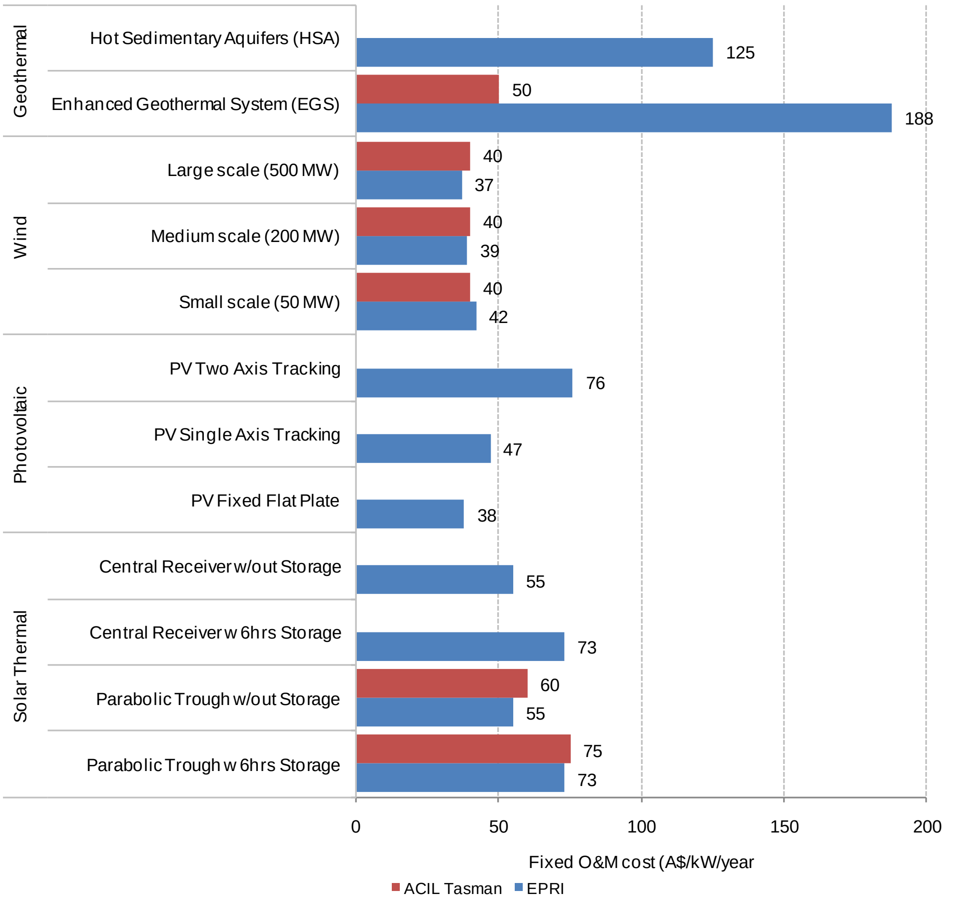
Note: Figures provided in real 2009 dollars. Based on assumed capacity factors of 10% for OCGT and 85% for all other technologies.
Data source: ACIL Tasman

3.2.2 Renewable technologies

Figure 6 compares FOM costs for renewable technologies. For those technologies for which ACIL Tasman has historically undertaken estimates, there is good alignment with the EPRI figures. The only exception is in relation to geothermal technologies where there is significant uncertainty given that we do not have any operational plants at this stage.

EPRI and ACIL Tasman FOM estimates as well as values adopted by the Stakeholder Reference Group are detailed in Table 10. The Stakeholder Reference Group made relatively minor adjustments to EPRI values based on changes to capital cost estimates for these technologies.

Figure 6 **Comparison of renewable fixed operation and maintenance costs**



Note: Figures presented for 2015 installation in real 2009 dollars.
Data source: ACIL Tasman, EPRI

Table 10 **Summary of changes to EPRI supplied renewable FOM costs 2015 (A$/kW/year)**

Type	Technology	EPRI estimate	ACIL Tasman estimate	Point value adopted for modelling	Difference from EPRI estimate
Solar Thermal	Parabolic Trough w 6hrs Storage	73	75	73	0
	Parabolic Trough w/out Storage	55	60	55	0
	Central Receiver w 6hrs Storage	73	n/a	73	0
	Central Receiver w/out Storage	55	n/a	55	0
Photovoltaic	PV Fixed Flat Plate	44	n/a	38	-6
	PV Single Axis Tracking	57	n/a	47	-10
	PV Two Axis Tracking	62	n/a	76	14
Wind	Small scale (50 MW)	50	40	42	-8
	Medium scale (200 MW)	45	40	39	-6
	Large scale (500 MW)	42	40	37	-5
Geothermal (midpoint)	Enhanced Geothermal System (EGS)	188	50	188	0
	Hot Sedimentary Aquifers (HSA)	125	n/a	125	0

Note: Figures provided for 2015 installation in real 2009 dollars.
Data source: ACIL Tasman

Renewable technologies generally do not incur variable O&M costs. EPRI assumes these values to be zero for all technologies examined. ACIL Tasman agrees with this assumption and zero VOM costs have been adopted by AEMO/DRET.

3.3 Thermal efficiency

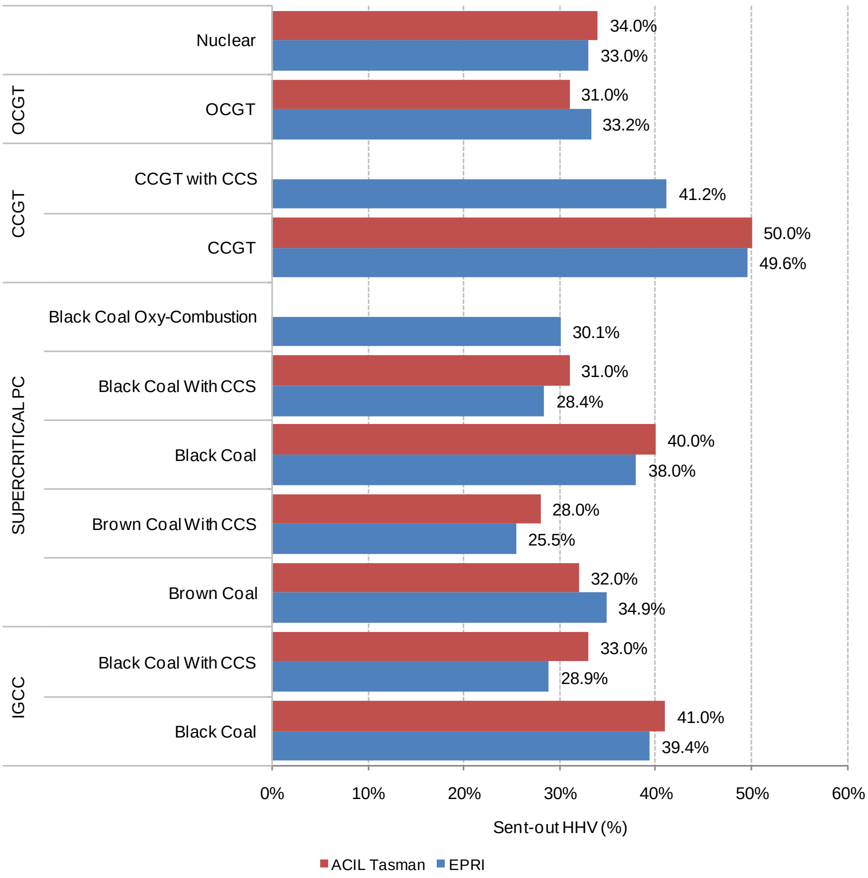
Figure 7 shows a comparison of EPRI and ACIL Tasman thermal efficiency assumptions across the non-renewable technologies examined. In general the estimates are closely aligned with no major divergence in views. For technologies where ACIL Tasman does not have a published estimate available, the EPRI estimate appears reasonable.

The estimated sent-out thermal efficiency figures are also detailed in Table 11.

EPRI has not provided thermal efficiency estimates for technologies that do not employ CCS for 2030. In these instances ACIL Tasman has supplied an estimate for these technologies which is broadly in-line with EPRI anticipated efficiency improvements as detailed in Table 12.

AEMO/DRET have adopted the EPRI thermal efficiency figures for all technologies for 2015 and 2030.

Figure 7 **Comparison of thermal efficiency estimates (sent-out % HHV)**



Note: Values presented for 2015 installation

Data source: ACIL Tasman, EPRI

Table 11 **Summary of proposed changes to EPRI supplied non-renewable thermal efficiency 2015**

Type	Technology	EPRI estimate	ACIL Tasman estimate	Point value adopted for modelling	Difference from EPRI estimate
IGCC	Black Coal	39.4%	41.0%	39.4%	0.0%
	Black Coal With CCS	28.9%	33.0%	28.9%	0.0%
SUPERCRITICAL PC	Brown Coal	34.9%	32.0%	34.9%	0.0%
	Brown Coal With CCS	25.5%	28.0%	25.5%	0.0%
	Black Coal	38.0%	40.0%	38.0%	0.0%
	Black Coal With CCS	28.4%	31.0%	28.4%	0.0%
	Black Coal Oxy-Combustion	30.1%	n/a	30.1%	0.0%
CCGT	CCGT	49.6%	50.0%	49.6%	0.0%
	CCGT with CCS	41.2%	n/a	41.2%	0.0%
OCGT	OCGT	33.2%	31.0%	33.2%	0.0%
Nuclear	Nuclear	33.0%	34.0%	33.0%	0.0%

Note: Figures provided for 2015 installation in sent-out HHV terms.

Data source: ACIL Tasman

Table 12 **Summary of proposed changes to EPRI supplied non-renewable thermal efficiency 2030**

Type	Technology	EPRI estimate	ACIL Tasman estimate	Point value adopted for modelling	Difference from EPRI estimate
IGCC	Black Coal	n/a	45.0%	45.0%	n/a
	Black Coal With CCS	35.6%	40.0%	35.6%	0.0%
SUPERCRITICAL PC	Brown Coal	n/a	47.1%	47.1%	n/a
	Brown Coal With CCS	37.7%	35.0%	37.7%	0.0%
	Black Coal	n/a	48.0%	48.0%	n/a
	Black Coal With CCS	38.5%	39.0%	38.5%	0.0%
	Black Coal Oxy-Combustion	38.7%	n/a	38.7%	0.0%
CCGT	CCGT	n/a	57.6%	57.6%	n/a
	CCGT with CCS	49.3%	n/a	49.3%	0.0%
OCGT	OCGT	40.0%	36.0%	40.0%	0.0%
Nuclear	Nuclear	33.0%	34.0%	33.0%	0.0%

Note: Figures provided for 2030 installation in sent-out HHV terms.
Data source: ACIL Tasman

Table 13 details the improvement in thermal efficiency over the period 2015 to 2030. Overall these values are consistent with ACIL Tasman assumptions, and relativities between technologies appear reasonable.

Table 13 **Improvement in thermal efficiency for non-renewable technologies from 2015 to 2030**

Type	Technology	2015 thermal efficiency (HHV)	2030 thermal efficiency (HHV)	Efficiency improvement (percentage points)
IGCC	Black Coal	39.4%	45.0%	5.6%
	Black Coal With CCS	28.9%	35.6%	6.7%
SUPERCRITICAL PC	Brown Coal	34.9%	47.1%	12.2%
	Brown Coal With CCS	25.5%	37.7%	12.2%
	Black Coal	38.0%	48.0%	10.0%
	Black Coal With CCS	28.4%	38.5%	10.0%
	Black Coal Oxy-Combustion	30.1%	38.7%	8.6%
CCGT	CCGT	49.6%	57.6%	8.1%
	CCGT with CCS	41.2%	49.3%	8.1%
OCGT	OCGT	33.2%	40.0%	6.8%
Nuclear	Nuclear	33.0%	33.0%	0.0%

Note: Thermal efficiency values are interpolated for intervening years
Data source: ACIL Tasman, EPRI

Thermal efficiency figures are not relevant for renewable technologies.

3.4 Auxiliary load

Auxiliary load is an electricity load used within a power station as part of the electricity generation process (also called a parasitic load). The usual way of expressing the station auxiliaries is in percentage form and when applied to the gross capacity of the station provides a measure of the net capacity or sent-out capacity of the station.

3.4.1 Non-renewable technologies

Figure 8 compares ACIL Tasman and EPRI estimates for auxiliary use across the non-renewable technologies. In general there is good alignment between the datasets, with the exception of CCS equipped ICGG plant.

In relation to CCS equipped IGCC, the EPRI estimate for auxiliary usage appears high. While stripping CO_2 from the syngas stream results in a reduction in thermal efficiency its does not (to the best of ACIL Tasman's knowledge) result in a significant increase in auxiliary use. The water-gas shift reactor is an exothermic reaction (i.e. it gives off heat) and will require more syngas to be produced as the energy contained within the syngas has been reduced. As mentioned by EPRI within its report, some of this heat can be utilised within the plant to generate high pressure steam which will offset to some extent this loss in efficiency.

As far as ACIL Tasman is aware, the only major additional internal electrical load from the addition of CO_2 stripping to IGCC plants is in relation to CO_2 compression prior to pipeline transport. Other generation cost studies indicate that an increase to IGCC auxiliary use of around 9.5% is required to capture 90% of CO_2 emissions (IGCC auxiliaries without capture being around 16%, and with capture being around 25.4%).[5]

For this reason, ACIL Tasman has suggested an amendment the auxiliary estimate for CCS equipped IGCC black coal plant as detailed in Table 14. These adjustments have taken into account in the values adopted by AEMO/DRET while all other EPRI estimates for auxiliaries have been adopted as given.

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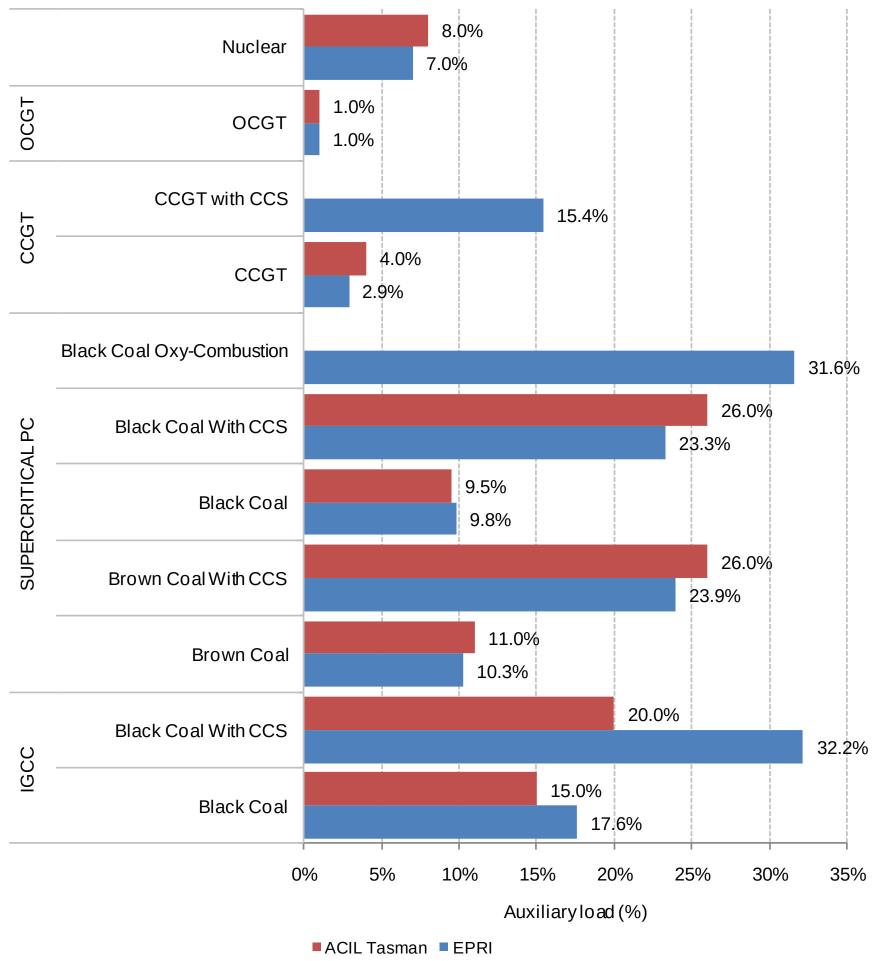
[5] US Department of Energy/NETL, *Cost and Performance Baseline for Fossil Energy Plants*, August 2007

Figure 8 **Comparison of station auxiliary use**



Note: Values presented for 2015 installation.

Data source: ACIL Tasman, EPRI

Table 14 **Summary of proposed changes to EPRI supplied non-renewable auxiliary usage**

Type	Technology	EPRI estimate	ACIL Tasman estimate	Point value adopted for modelling	Difference from EPRI estimate
IGCC	Black Coal	17.6%	15.0%	17.6%	0.0%
	Black Coal With CCS	32.2%	20.0%	23.5%	-8.7%
SUPERCRITICAL PC	Brown Coal	10.3%	11.0%	10.3%	0.0%
	Brown Coal With CCS	23.9%	26.0%	23.9%	0.0%
	Black Coal	9.8%	9.5%	9.8%	0.0%
	Black Coal With CCS	23.3%	26.0%	23.3%	0.0%
	Black Coal Oxy-Combustion	31.6%	n/a	31.6%	0.0%
CCGT	CCGT	2.9%	4.0%	2.9%	0.0%
	CCGT with CCS	15.4%	n/a	15.4%	0.0%
OCGT	OCGT	1.0%	1.0%	1.0%	0.0%
Nuclear	Nuclear	7.0%	8.0%	7.0%	0.0%

Note: Values shaded grey indicate a proposed change from the estimate provided by EPRI. Figures provided for 2015 installation.
Data source: ACIL Tasman

EPRI has not appeared to alter auxiliary usage for plants commissioned in 2030. While there may be some improvements in electricity consumption by each technology, holding this value constant appears reasonable.

3.4.2 Renewable technologies

EPRI has not provided any auxiliary estimates for renewable plants within their report or dataset. Correspondence with EPRI on this matter resulted in the provision of estimates as detailed in Table 15. The Stakeholder Reference Group adopted these values.

Table 15 **Summary of proposed changes to EPRI supplied renewable auxiliary usage**

Type	Technology	EPRI estimate	ACIL Tasman estimate	Point value adopted for modelling	Difference from EPRI estimate
Solar Thermal	Parabolic Trough w 6hrs Storage	10%	10%	10%	0
	Parabolic Trough w/out Storage	10%	10%	10%	0
	Central Receiver w 6hrs Storage	10%	10%	10%	0
	Central Receiver w/out Storage	10%	10%	10%	0
Photovoltaic	PV Fixed Flat Plate	0%	0%	0%	0
	PV Single Axis Tracking	0%	0%	0%	0
	PV Two Axis Tracking	0%	0%	0%	0
Wind	Small scale (50 MW)	0%	0%	0%	0
	Medium scale (200 MW)	0%	0%	0%	0
	Large scale (500 MW)	0%	0%	0%	0
Geothermal	Enhanced Geothermal System (EGS)	15%	15%	15%	0
	Hot Sedimentary Aquifers (HSA)	15%	15%	15%	0

Note: Values shaded grey indicate a proposed change from the estimate provided by EPRI. Figures provided for 2015 installation.
Data source: ACIL Tasman

3.5 Emission intensity

Estimates of emission intensity are derived from emission factors and thermal efficiencies. There are two types of emission factors:

- combustion emissions factors (typically expressed in kg CO_2-e/GJ of fuel) relate to the emissions from the combustion of fuel at the power station site.
- fugitive emission factors which relate to emissions from the production and transport of fuel to the station (also expressed in kg CO_2-e/GJ of fuel).

These emission factors are estimated based on the fuel type and are completely independent of the power station.

Together these two elements add to give the total emission factor, which when applied to the thermal efficiency (and also carbon capture rate for CCS equipped plants), gives the emission intensity of a plant which is typically expressed as tonnes CO_2 per MWh.

ACIL Tasman takes its emission factor estimates from the 2008 National Greenhouse Accounts NGA Factors workbook.[6]

Figure 9 provides a comparison of EPRI and ACIL Tasman emission intensity figures for non-renewable technologies. In general, ACIL Tasman's figures are slightly higher than EPRI's as a result of the inclusion of fugitive emissions with the ACIL Tasman numbers. Capture rates for CCS equipped plant are broadly similar between the two estimates.

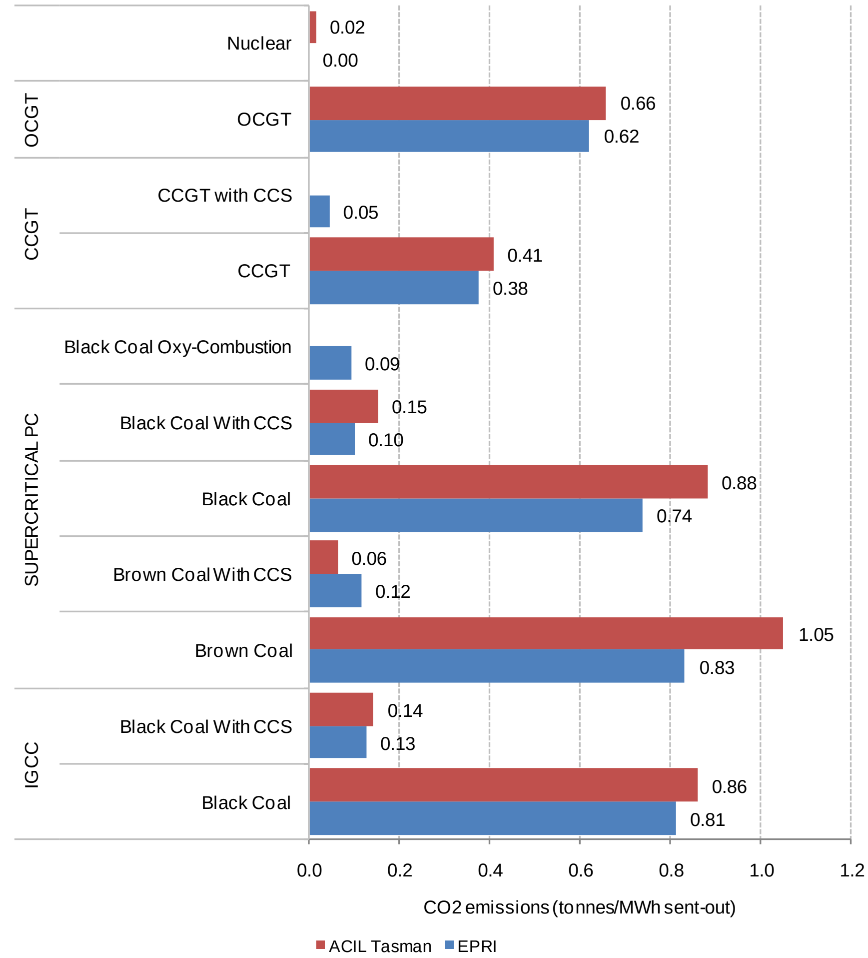
As emission intensity is a derived figure rather than a direct input, these comparisons are made for information only. Any changes to these figures would be effected via changes to thermal efficiency or emission factors.

It is assumed that the capture rate for CCS equipped plant remains constant over the modelling period. The capture rates for CCS equipped plant are:

- IGCC Black coal with CCS: 88.5%
- Supercritical PC Brown coal with CCS: 90.0%
- Supercritical PC Black coal with CCS: 90.0%
- Supercritical PC Black coal oxy-combustion with CCS: 90.0%
- CCGT with CCS: 90.0%.

[6] Department of Climate Change, *National Greenhouse Accounts (NGA) Factors*, January 2008

Figure 9 **Comparison of emission intensity estimates**



Note: Values presented for 2015 installation in tonnes CO_2/MWh sent-out.
Data source: ACIL Tasman

4 Conclusions/recommendations

ACIL Tasman has reviewed the EPRI generation cost data provided within the report "*Assessment of Electricity Generation Technologies in Australia*". The purpose of ACIL Tasman's review is to gauge the suitability of the cost estimates for use within NTDP and Energy White Paper modelling exercises.

The EPRI estimates align well with ACIL Tasman's internal view, other generation cost studies and values used in previous public modelling exercises undertaken in Australia.

The central points of the EPRI cost and performance estimate ranges have largely been adopted for the modelling. While still within the confidence interval of the report, there were instances where ACIL Tasman suggested a different value be used as an input to the modelling. These suggested changes include:

- Capital cost estimates for gas-based OCGT and CCGT technologies where we proposed the use of higher figures based on recent local installations and local market intelligence.[7]
- Lower capital cost estimates for wind based on recent experience and local market intelligence.
- Lower auxiliary load for IGCC plant which employ CCS based on other generation cost studies.
- Non-renewable operating and maintenance costs where we have suggested the use of ACIL Tasman figures for these elements based on experience with existing plants and other international generation cost studies.

ACIL Tasman notes that the Stakeholder Reference Group considered the information provided by both ACIL Tasman and EPRI in forming a view on the appropriate single point modelling input data.

Overall, ACIL Tasman is of the view that the cost and performance data set out in the EPRI report for each technology is within the range expected for 2015 and 2030, given Australian project experience.

EPRI provided cost and performance data for technologies for installation in 2015 and 2030. However, EPRI were not commissioned to provide cost and performance data for non-CCS fossil fuel plant in 2030 as it had been assumed that generation plant with CCS would be a requirement in this period. ACIL Tasman provided performance data for non-CCS fossil fuel plant in 2030

[7] It must be noted however that for gas-based technologies fuel cost assumptions are generally a larger proportion of overall costs than capital.

based on year 2015 estimates and taking into consideration estimated cost reductions and efficiency improvements for CCS equipped plants.

Generation technology cost estimates are always subject to uncertainty. They are typically an area where industry participants and observers often have radically different views. As large-scale generation installations in Australia are relatively few and far between, it is also difficult to establish an accurate cost base from actual projects. In addition, generation projects inevitably have a number of unique characteristics in terms of their scale, configuration and site specific elements. This often makes like-for-like comparisons difficult.

This implies that there is significant uncertainty in relation to generation cost estimates – particularly for long-term modelling projects. While there is no one 'right' answer, it is typically necessary to develop a central cost estimate for each technology for modelling purposes. Given this uncertainty, it is also valuable to stress-test results using a range of cost input assumptions. Importantly, it is not the absolute cost level which is of critical importance, but rather, the relative costs between different technologies.

ACIL Tasman is of the view that the values adopted by AEMO / DRET and the Stakeholder Reference Group are suitable for use within NTDP and Energy White Paper modelling exercises.