Projected energy prices in selected world regions

The estimation of energy prices
for existing and new technologies
in a number of regions around

Prepared for the Department of the Treasury

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ACIL Tasman
Economics Policy Strategy

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1 Introduction

This report has been prepared by ACIL Tasman and PB Power for the Commonwealth Treasury (the Treasury) and is the first draft of a report intended to provide the costs of electricity generation in each of 8 zones of the world, including Australia. The generation cost data is to be used by the Treasury in its modelling work on the development of a national emissions trading scheme. .

This report sets out the methodology, data sources and results of the work.

1.1 An overview of the information to be provided

The project is intended to provide electricity generation costs over the period to 2050 for use in General Equilibrium modelling of an emissions trading scheme. The more precise specification of project outputs is set out in Box 1.

Box 1 Summary of outputs from the project

LRMC of generation technologies	A discounted cash flow calculation using a weighted average cost of capital (WACC) as a discount rate and calculating a cost per unit of output (in A$/MWh) required over project life to realize a zero net present value, presented in the following breakdown: • Fuel • Fixed O & M • Variable O & M • Capital cost • Tax • Carbon certificates
Currency	Costs quoted in 2008 Australian dollars
Years	2010, 2020, 2030, 2040, 2050, including an estimate of the change in the real cost of these generation technologies over these years based upon the effects of a learning curve and technological advances.
Regions	Australia, United States, European Union, Japan, Russian Federation, China, India and Brazil
Technologies	Coal (super and ultra super critical), integrated gasification combined cycle (IGCC), natural gas open and combined cycle, nuclear, hydroelectricity, solar thermal, solar photovoltaic, wind, biomass, geothermal (including hot dry rocks in Australia), carbon capture and storage (for both coal and gas fired generation)

2 A definition of Long Run Marginal Cost (LRMC)

The long run marginal cost of a generator is the cost of producing each unit of electricity over the life of the power station. The cost depends on:

- the short run marginal cost (SRMC, discussed below)
- capital cost, including connection and other infrastructure
- fixed operating and maintenance costs
- tax costs
- discount factor (WACC)
- capacity factor over the assumed life of the power station
- the assumed life of the power station

2.1 Variable costs

2.1.1 Fuel costs

For this project, a power station's short run marginal cost is defined as the typical cost of increasing output by one unit (i.e. 1 MWh) when the power station is operating in the region of its typical level of output. This will be mainly the cost of additional fuel but also includes any additional costs in operation and maintenance (eg water, chemicals, ash disposal, bringing forward of maintenance, etc). Capital and periodic maintenance costs are not included.

Specific projects may vary from the average in having more expensive or cheaper fuel supply and transport arrangements. The costs provided are intended to be typical of those experienced by new entrants in each of the regions under study.

2.1.2 Variable operation and maintenance

The additional operational and maintenance costs for an increment of electrical output depend on a number of factors, including the size of the increment in generation, the way in which wear and tear on the generation units is accrued between scheduled maintenance (hours running or a specific number of start-stop cycles) and whether operation is as a base load or peaking facility. Variable O&M is a relatively small portion of overall SRMC.

For coal, variable O&M includes additional consumables such as water, chemicals and energy used in auxiliaries and additional running costs such as ash handling.

For gas, in addition to consumables and additional operating costs, an allowance is included for major maintenance. The reason for including an allowance for major maintenance in the variable O&M for gas turbines is because this maintenance is not periodic, as it is for coal plant, but determined by hours of use and the number of starts. Furthermore, it is the additional starts that mean that an OCGT peaking plant has even higher variable O&M per MWh than either a CCGT base or intermediate load plant.

Variable O&M costs usually represent a small portion of a generator's SRMC.

The variable O&M value is usually expressed in sent-out terms to account for internal usage by the station (see below) rather than in 'as generated' terms.

2.1.3 Station auxiliaries

In general terms, an auxiliary load is an electricity load used within a power station as part of the electricity generation process – that is, it is an electricity load used in the making of electricity (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.

Station auxiliaries also impact the sent-out or net thermal efficiency of the station, and therefore the station's SRMC.

2.1.4 Thermal efficiency

The thermal efficiency of a plant (or similarly the heat rate) is used in the calculation of the plant's SRMC in that it measures the energy from the fuel required to generate a unit of electricity. Thermal efficiency depends on numerous factors such as load factor, type of plant (e.g. CCGT, sub critical coal, super-critical coal, etc.), type of cooling, ambient temperature, type and quality of fuel, etc. Thermal efficiency is usually a trade-off with capital costs.

2.1.5 CO_2-e emission factors

Emission factors are included in the calculation of SRMC in order to take in to account the cost of emissions associated with the generation of an additional unit of energy. These factors are usually allocated by the regulatory agency in each region but in this study ACIL Tasman has assumed or estimated an emissions factor for each technology based on the factor currently ascribed in Australia.

Emission factors for calculating direct emissions are expressed in the form of a quantity of a carbon dioxide equivalent (tonnes of CO_2-e) per MWh generated.

2.2 Fixed costs

2.2.1 Capital costs

Capital costs for a new power station include engineering, procurement and construction (EPC), planning and approval, professional services, land acquisition, infrastructure costs (incl. water), spares and workshop etc as well as costs associated with connection to the electricity network, fuel connection, handling and storage, etc. Capital costs have been changed into Australian dollars per kW.

2.2.2 Fixed O&M costs

Fixed O&M costs include maintenance, operating, and overhead costs that are generally not dependent on the hour-by-hour level of generation from the power station.

2.2.3 Capacity factor

The capacity factor is the expected output from the station (in GWh) divided by the product of plant capacity and 8760 (the number of hours in a year). A capacity factor assumption is required if the LRMC is to be expressed in $/MWh.

3 Sources of data

In this project data has been gathered from a variety of sources, including;

- PB Power's international data base of generator costs and performance drawing on internal data and published information
- ACIL Tasman's own database on NEM generators, covering heat rates, auxiliary use, fuel costs and variable operation and maintenance costs
- International reports identified from research and work undertaken by both firms
- recent market intelligence on fuel costs,
- analysis of future likely future movements in construction and fuel costs and in generator efficiency
- consideration of efficiency and performance improvements possible over the forecasting period,

The ACIL Tasman and PB Power generator databases are kept up to date by clients and others providing comment on costs and performance characteristics and these have been used as a base upon which to build projections of energy prices and generator performance over the next forty years. In the course of carrying out projects clients frequently provide data that is classified commercially confidential. The generator information provided for such projects has necessarily been kept separate from the databases used for this exercise.

In preparing the cost estimates ACIL Tasman has used the best available data as input to the calculation of LRMC. Where possible this has been cross checked with other reports where available to confirm the reasonableness of the assumptions.

In respect of generator costs the following reports provided the foundations upon which the estimates of the components of LRMC were constructed:

- Fuel resource, new entry and generator costs in the NEM prepared by ACIL Tasman for NEMMCO in 2007 (ACIL Tasman, 2007)
- The cost of generating electricity prepared by PB Power for the Royal Academy of Engineering, in 2004 (PB Power, 2004)
- Emerging supply side energy technologies for the NZ Ministry of Economic Development – PB Power (PB Power, 2006)
- Fossil fuel fired power generation published by the International Energy Agency in 2007 (International Energy Agency, 2007)
- Cost of fossil fuel generating plant prepared by East Harbour Management Services for the New Zealand Ministry of Economic Development in May 2002 (East Harbour Management Services Ltd, 2002)
- Wind Energy Integration in New Zealand prepared by Energy Link and MWH NZ for the Ministry of Economic Development in 2005 (Energy Link and MHW NZ, 2005)
- The WACC Users Guide prepared by UBS Investment Bank in 2005 (UBS Investment Bank, 2005)
- Cost and quality of fuels issued by the US Energy Information Agency (Energy Information Agency, 2008)
- Cost and performance of Fossil Energy Power Plants published by the US Department of Energy (Department of Energy, 2007)
- Systems assessment of Future Electricity Generation Options for Australia, Cooperative Research Centre for Coal in Sustainable Development – the Cottrell Report (CRC for Coal in Sustainable Development, 2003)
- The potential for renewable energy resources prepared by ACIL Tasman for the Department of Industry, Tourism and Resources in 2006 (ACIL Tasman, 2006)
- Uranium processing and nuclear energy, Department of Prime Minister and Cabinet released in 2007 (Department of Prime Minister and Cabinet, 2007)

The key sources of data are outlined in the following sections and referred to in Chapter 4.

3.1 Fuel costs

Fuel costs for Australia have been based on analysis included in ACIL Tasman's report for NEMMCO (ACIL Tasman, 2007). This report analysed price trends for coal and natural gas based and delivered costs based on ACIL Taman's analysis and gas market modelling.

Transportation costs can vary depending on capacity factors and infrastructure capability. These have been taken into account at a broad level.

International fuel costs were based on PB Power's base case projections of steaming coal and LNG prices. Adjustments were made for transport costs to arrive at average delivered prices in each region.

3.2 Operating and maintenance costs

There is very little international data on operating and maintenance costs in the public domain. As the IEA noted in its recent report on coal generation costs, commercial confidentiality precludes full disclosure (International Energy Agency, 2007). Some information is available in reports discussed above but it is not complete.

Estimates of operating and maintenance costs in OECD countries were based on ACIL Tasman's report for NEMMCO for Australia. Estimates for non-OECD countries were adjusted for lower labour costs using the PB Power and ACIL Tasman breakdown of representative operating cost structures.

3.3 Generator characteristics

3.3.1 Auxiliaries

Estimates of auxiliaries were based on ACIL Tasman internal data which has been developed over years of modelling power stations. A full discussion of the background to and factors defining auxiliaries is contained in the ACIL Tasman NEMMCO report.

Auxiliaries are specific to a particular technology and not to a location. Therefore the same factors have been applied across all regions.

3.3.2 Efficiency

Estimates of efficiencies were based on ACIL Tasman's reports to NEMMCO and DITR (ACIL Tasman, 2006) augmented by information from reports cited above.

3.3.3 Capacity factor

Capacity factors for Australia are based on information available to ACIL Tasman as discussed in its report to NEMMCO.

Capacity factors for other regions have been adjusted to take into account overall estimates of the regional characteristics that are understood to apply in relation to the structure of their electricity markets. These estimates are at a high level given the scale of each region.

3.4 Capital Costs

The estimates of capital costs were based on estimates of costs in Australia as a starting point using the ACIL Tasman report prepared for NEMMCO (ACIL Tasman, 2007). Costs were broken down into three categories

- specialised equipment such as blades, turbines etc which may be imported in some countries)
- other equipment such as control systems control systems, electronics and monitoring systems which are more generally available
- commodities such as steel and concrete which will be sourced locally or from local suppliers.

Regional adjustment factors for each category were estimated from internal PB Power data drawing on exchange rate and local costs assumptions. The relative proportion of each category in total capital cost was also estimated drawing on assumptions on likely level of imported equipment in each case and local costs.

The regional estimates of capital cost were then derived from the Australian data adjusted by the regional adjustment factors. The results were then compared with other international reports including the PB Power Report prepared for the Society of Engineers (PB Power, 2004), the IEA report on generator costs (International Energy Agency, 2007) and the reports on generator costs and wind generation prepared for the Ministry of Economic Development in New Zealand (East Harbour Management Services Ltd, 2002)(Energy Link and MHW NZ, 2005).

3.5 Discount rate

Estimates of the WACC were made using established methodology drawing on a range of international and domestic estimates of financial parameters and ACIL Tasman assumptions on debt to equity. A basis source was the USB WACC users' guide. Risk free rates were sourced from the following:

- S&P Global ratings handbook
- The Economist

- Bloomberg
- Credit Delta
- US Federal Reserve Bank
- Asia Bonds Online
- European Central Bank
- Bank of China
- Reserve Bank of India

3.6 Tax

Corporation tax rates were sourced from the Indian Embassy in the US, Chinese Embassy in the US, The Economist, US IRS, Brazilian energy regulator – Eneel, Worldwide-Tax.org and KPMG report.

3.7 Emission factors

Estimates of emissions factors have been developed by ACIL Tasman over the past 8 years. These have been cross checked with the generic values published by the Australian Greenhouse Office's (AGO) (Australian Greenhouse Office, 2007).

3.8 Carbon pricing

For the purposes of modelling it was assumed that a uniform carbon charge would apply in all regions, increasing over time. While there is no consensus at the present time on climate change policies between the different regions it was considered reasonable to assume that over the longer term some convergence on policy would emerge.

The modelling therefore assumed that the same carbon charge applied in all regions, increasing from zero in 2008 to $60 per tonne CO_2-e by 2050.

4 Estimates of the components of LRMC

4.1 Fuel costs

Fuel costs were based on estimates made by ACIL Tasman and PB Power. They are summarised in the following tables for each region.

Table 1 **Fuel costs Australia (A$ 2008 prices)**

Technology	2008	2010	2020	2030	2040	2050
	$/GJ	$/GJ	$/GJ	$/GJ	$/GJ	$/GJ
Black coal (super critical)	1.50	1.50	1.50	1.50	1.50	1.50
Black coal (ultra super critical)	1.50	1.50	1.50	1.50	1.50	1.50
IGCC	1.50	1.50	1.50	1.50	1.50	1.50
CCGT	3.80	3.91	4.52	5.23	6.05	6.99
OCGT	7.50	7.72	8.93	10.32	11.94	13.81
Nuclear ($/MWh)	10.00	10.00	10.00	10.00	10.00	10.00
Hydropower	0.00	0.00	0.00	0.00	0.00	0.00
Solar thermal	0.00	0.00	0.00	0.00	0.00	0.00
Photovoltaic	0.00	0.00	0.00	0.00	0.00	0.00
Wind	0.00	0.00	0.00	0.00	0.00	0.00
Biomass	1.22	1.22	1.22	1.22	1.22	1.22
Geothermal	0.00	0.00	0.00	0.00	0.00	0.00
Coal USC plus CCS (95%)	1.50	1.50	1.50	1.50	1.50	1.50
Gas CCGT plus CCS (95%)	3.80	3.91	4.52	5.23	6.05	6.99

Data source: ACIL Tasman and PB Power

The cost of gas in OCGT power stations in Australia is assumed to be higher than for CCGT. This is because OCGT power stations in Australia generally contract gas on a firm basis which includes higher charges to ensure supply and reserve capacity in transmission pipelines. This is a feature of the Australian gas market that is not reflected in markets in the other regions. This difference is therefore not reflected in the OCGT and CCGT costs for the regions below.

Table 2 **Fuel costs USA (A$ 2008 prices)**

Technology	2008	2010	2020	2030	2040	2050
	$/GJ	$/GJ	$/GJ	$/GJ	$/GJ	$/GJ
Black coal (super critical)	2.30	2.30	2.30	2.30	2.30	2.30
Black coal (ultra super critical)	2.30	2.30	2.30	2.30	2.30	2.30
IGCC	2.30	2.30	2.30	2.30	2.30	2.30
CCGT	8.00	8.24	9.52	11.01	12.73	14.73
OCGT	8.00	8.24	9.52	11.01	12.73	14.73
Nuclear ($/MWh)	10.00	10.00	10.00	10.00	10.00	10.00
Hydropower	0.00	0.00	0.00	0.00	0.00	0.00
Solar thermal	0.00	0.00	0.00	0.00	0.00	0.00
Photovoltaic	0.00	0.00	0.00	0.00	0.00	0.00
Wind	0.00	0.00	0.00	0.00	0.00	0.00
Biomass	1.22	1.22	1.22	1.22	1.22	1.22
Geothermal	0.00	0.00	0.00	0.00	0.00	0.00
Coal USC plus CCS (95%)	2.30	2.30	2.30	2.30	2.30	2.30
Gas CCGT plus CCS (95%)	8.00	8.24	9.52	11.01	12.73	14.73

Data source: ACIL Tasman and PB Power

Table 3 **Fuel costs EU (A$ 2008 prices)**

Technology	2008	2010	2020	2030	2040	2050
	$/GJ	$/GJ	$/GJ	$/GJ	$/GJ	$/GJ
Black coal (super critical)	1.50	1.50	1.50	1.50	1.50	1.50
Black coal (ultra super critical)	1.50	1.50	1.50	1.50	1.50	1.50
IGCC	1.50	1.50	1.50	1.50	1.50	1.50
CCGT	6.00	6.18	7.14	8.26	9.55	11.04
OCGT	6.00	6.18	7.14	8.26	9.55	11.04
Nuclear ($/MWh)	10.00	10.00	10.00	10.00	10.00	10.00
Hydropower	0.00	0.00	0.00	0.00	0.00	0.00
Solar thermal	0.00	0.00	0.00	0.00	0.00	0.00
Photovoltaic	0.00	0.00	0.00	0.00	0.00	0.00
Wind	0.00	0.00	0.00	0.00	0.00	0.00
Biomass	1.22	1.22	1.22	1.22	1.22	1.22
Geothermal	0.00	0.00	0.00	0.00	0.00	0.00
Coal USC plus CCS (95%)	1.50	1.50	1.50	1.50	1.50	1.50
Gas CCGT plus CCS (95%)	6.00	6.18	7.14	8.26	9.55	11.04

Data source: ACIL Tasman and PB Power

Table 4 **Fuel costs Japan (A$ 2008 prices)**

Technology	2008	2010	2020	2030	2040	2050
	$/GJ	$/GJ	$/GJ	$/GJ	$/GJ	$/GJ
Black coal (super critical)	2.30	2.30	2.30	2.30	2.30	2.30
Black coal (ultra super critical)	2.30	2.30	2.30	2.30	2.30	2.30
IGCC	2.30	2.30	2.30	2.30	2.30	2.30
CCGT	8.50	8.75	10.12	11.70	13.53	15.65
OCGT	8.50	8.75	10.12	11.70	13.53	15.65
Nuclear ($/MWh)	10.00	10.00	10.00	10.00	10.00	10.00
Hydropower	0.00	0.00	0.00	0.00	0.00	0.00
Solar thermal	0.00	0.00	0.00	0.00	0.00	0.00
Photovoltaic	0.00	0.00	0.00	0.00	0.00	0.00
Wind	0.00	0.00	0.00	0.00	0.00	0.00
Biomass	1.22	1.22	1.22	1.22	1.22	1.22
Geothermal	0.00	0.00	0.00	0.00	0.00	0.00
Coal USC plus CCS (95%)	2.30	2.30	2.30	2.30	2.30	2.30
Gas CCGT plus CCS (95%)	8.50	8.75	10.12	11.70	13.53	15.65

Data source: ACIL Tasman and PB Power

Table 5 **Fuel costs RF (A$ 2008 prices)**

Technology	2008	2010	2020	2030	2040	2050
	$/GJ	$/GJ	$/GJ	$/GJ	$/GJ	$/GJ
Black coal (super critical)	1.50	1.50	1.50	1.50	1.50	1.50
Black coal (ultra super critical)	1.50	1.50	1.50	1.50	1.50	1.50
IGCC	1.50	1.50	1.50	1.50	1.50	1.50
CCGT	4.00	4.12	4.76	5.51	6.37	7.36
OCGT	4.00	4.12	4.76	5.51	6.37	7.36
Nuclear ($/MWh)	10.00	10.00	10.00	10.00	10.00	10.00
Hydropower	0.00	0.00	0.00	0.00	0.00	0.00
Solar thermal	0.00	0.00	0.00	0.00	0.00	0.00
Photovoltaic	0.00	0.00	0.00	0.00	0.00	0.00
Wind	0.00	0.00	0.00	0.00	0.00	0.00
Biomass	1.22	1.22	1.22	1.22	1.22	1.22
Geothermal	0.00	0.00	0.00	0.00	0.00	0.00
Coal USC plus CCS (95%)	1.50	1.50	1.50	1.50	1.50	1.50
Gas CCGT plus CCS (95%)	4.00	4.12	4.76	5.51	6.37	7.36

Data source: ACIL Tasman and PB Power

Table 6 **Fuel costs China (A$ 2008 prices)**

Technology	2008	2010	2020	2030	2040	2050
	$/GJ	$/GJ	$/GJ	$/GJ	$/GJ	$/GJ
Black coal (super critical)	1.50	1.50	1.50	1.50	1.50	1.50
Black coal (ultra super critical)	1.50	1.50	1.50	1.50	1.50	1.50
IGCC	1.50	1.50	1.50	1.50	1.50	1.50
CCGT	6.00	6.18	7.14	8.26	9.55	11.04
OCGT	6.00	6.18	7.14	8.26	9.55	11.04
Nuclear ($/MWh)	10.00	10.00	10.00	10.00	10.00	10.00
Hydropower	0.00	0.00	0.00	0.00	0.00	0.00
Solar thermal	0.00	0.00	0.00	0.00	0.00	0.00
Photovoltaic	0.00	0.00	0.00	0.00	0.00	0.00
Wind	0.00	0.00	0.00	0.00	0.00	0.00
Biomass	1.22	1.22	1.22	1.22	1.22	1.22
Geothermal	0.00	0.00	0.00	0.00	0.00	0.00
Coal USC plus CCS (95%)	1.50	1.50	1.50	1.50	1.50	1.50
Gas CCGT plus CCS (95%)	6.00	6.18	7.14	8.26	9.55	11.04

Data source: ACIL Tasman and PB Power

Table 7 **Fuel costs India (A$ 2008 prices)**

Technology	2008	2010	2020	2030	2040	2050
	$/GJ	$/GJ	$/GJ	$/GJ	$/GJ	$/GJ
Black coal (super critical)	1.50	1.50	1.50	1.50	1.50	1.50
Black coal (ultra super critical)	1.50	1.50	1.50	1.50	1.50	1.50
IGCC	1.50	1.50	1.50	1.50	1.50	1.50
CCGT	4.00	4.12	4.76	5.51	6.37	7.36
OCGT	4.00	4.12	4.76	5.51	6.37	7.36
Nuclear ($/MWh)	10.00	10.00	10.00	10.00	10.00	10.00
Hydropower	0.00	0.00	0.00	0.00	0.00	0.00
Solar thermal	0.00	0.00	0.00	0.00	0.00	0.00
Photovoltaic	0.00	0.00	0.00	0.00	0.00	0.00
Wind	0.00	0.00	0.00	0.00	0.00	0.00
Biomass	1.22	1.22	1.22	1.22	1.22	1.22
Geothermal	0.00	0.00	0.00	0.00	0.00	0.00
Coal USC plus CCS (95%)	1.50	1.50	1.50	1.50	1.50	1.50
Gas CCGT plus CCS (95%)	4.00	4.12	4.76	5.51	6.37	7.36

Data source: ACIL Tasman and PB Power

Table 8 **Fuel costs Brazil (A$ 2008 prices)**

Technology	2008	2010	2020	2030	2040	2050
	$/GJ	$/GJ	$/GJ	$/GJ	$/GJ	$/GJ
Black coal (super critical)	2.30	2.30	2.30	2.30	2.30	2.30
Black coal (ultra super critical)	2.30	2.30	2.30	2.30	2.30	2.30
IGCC	2.30	2.30	2.30	2.30	2.30	2.30
CCGT	6.00	6.18	7.14	8.26	9.55	11.04
OCGT	6.00	6.18	7.14	8.26	9.55	11.04
Nuclear ($/MWh)	10.00	10.00	10.00	10.00	10.00	10.00
Hydropower	0.00	0.00	0.00	0.00	0.00	0.00
Solar thermal	0.00	0.00	0.00	0.00	0.00	0.00
Photovoltaic	0.00	0.00	0.00	0.00	0.00	0.00
Wind	0.00	0.00	0.00	0.00	0.00	0.00
Biomass	1.22	1.22	1.22	1.22	1.22	1.22
Geothermal	0.00	0.00	0.00	0.00	0.00	0.00
Coal USC plus CCS (95%)	2.30	2.30	2.30	2.30	2.30	2.30
Gas CCGT plus CCS (95%)	6.00	6.18	7.14	8.26	9.55	11.04

Data source: ACIL Tasman and PB Power

4.2 Operating and maintenance costs

4.2.1 Variable

There is very little information in the public domain on variable costs. ACIL Tasman used internal reports to develop estimates for Australia which were applied in all regions. A distinction was made between operating costs for developed and developing countries. Australian levels of variable operating costs were used for developed economies. For developing economies 80 per cent of developed economies variable operating costs were adopted to reflect lower labour costs in developing countries.

The assumed variable costs for developed economies are summarised in Table 9.

Table 9 **Estimates of variable operating and maintenance costs for developed economies (A$ 2008 prices)**

Technology	2008	2010	2020	2030	2040	2050
	$/MWh	$/MWh	$/MWh	$/MWh	$/MWh	$/MWh
Black coal (super critical)	1.20	1.20	1.20	1.20	1.20	1.20
Black coal (ultra super critical)	1.20	1.20	1.20	1.20	1.20	1.20
IGCC	1.50	1.50	1.50	1.50	1.50	1.50
CCGT	4.85	4.85	4.85	4.85	4.85	4.85
OCGT	7.50	7.50	7.50	7.50	7.50	7.50
Nuclear	2.00	2.00	2.00	2.00	2.00	2.00
Hydropower	2.00	2.00	2.00	2.00	2.00	2.00
Solar thermal	1.50	1.50	1.50	1.50	1.50	1.50
Photovoltaic	1.50	1.50	1.50	1.50	1.50	1.50
Wind	1.60	1.60	1.60	1.60	1.60	1.60
Biomass	3.00	3.00	3.00	3.00	3.00	3.00
Geothermal	2.00	2.00	2.00	2.00	2.00	2.00
Coal USC plus CCS (95%)	1.20	1.20	1.20	1.20	1.20	1.20
Gas CCGT plus CCS (95%)	1.20	1.20	1.20	1.20	1.20	1.20

Data source: ACIL Tasman and PB Power

The assumed variable costs for developing economies are summarised in Table 10.

Table 10 **Estimates of variable operating and maintenance costs for developing economies (A$ 2008 prices)**

Technology	2008	2010	2020	2030	2040	2050
	$/MWh	$/MWh	$/MWh	$/MWh	$/MWh	$/MWh
Black coal (super critical)	$0.96	$0.96	$0.96	$0.96	$0.96	$0.96
Black coal (ultra super critical)	$0.96	$0.96	$0.96	$0.96	$0.96	$0.96
IGCC	$1.20	$1.20	$1.20	$1.20	$1.20	$1.20
CCGT	$3.88	$3.88	$3.88	$3.88	$3.88	$3.88
OCGT	$6.00	$6.00	$6.00	$6.00	$6.00	$6.00
Nuclear	$1.60	$1.60	$1.60	$1.60	$1.60	$1.60
Hydropower	$1.60	$1.60	$1.60	$1.60	$1.60	$1.60
Solar thermal	$1.20	$1.20	$1.20	$1.20	$1.20	$1.20
Photovoltaic	$1.20	$1.20	$1.20	$1.20	$1.20	$1.20
Wind	$1.28	$1.28	$1.28	$1.28	$1.28	$1.28
Biomass	$2.40	$2.40	$2.40	$2.40	$2.40	$2.40
Geothermal	$1.60	$1.60	$1.60	$1.60	$1.60	$1.60
Coal USC plus CCS (95%)	$0.96	$0.96	$0.96	$0.96	$0.96	$0.96
Gas CCGT plus CCS (95%)	$0.96	$0.96	$0.96	$0.96	$0.96	$0.96

Data source: ACIL Tasman and PB Power

4.2.2 Fixed

There is little global information on fixed costs available at the present time. ACIL Tasman has drawn on its reports for NEMMCO and the former Department of Industry Tourism and Resources to compile cost estimates for fixed costs(ACIL Tasman, 2007)(ACIL Tasman, 2006). A recent IEA report also provided some examples of fixed costs for coal generation; however this information is quite limited because of confidentiality concerns(International Energy Agency, 2007). A 2002 report for New Zealand also outlined some cost estimates (East Harbour Management Services Ltd, 2002). Some of these figures are summarised in Table 11.

These estimates suggest that Australian figures might be appropriate for developed economies and lower figures might be more appropriate for developing economies. For the modelling, the Australian fixed cost estimate was used for developed economies and 80 per cent of Australian fixed cost estimate was used for developing economies.

Table 11 **Available estimate of fixed costs (A$ 2008 prices)**

Fixed operating costs $/MW/year	Australia (ACIL Tasman)	OECD Asia (IEA Clean Coal centre)	IEA (IEA Clean Coal Centre)	Non OECD (Clean Coal Centre)	NZ (East Harbour 2002)
Black coal (super critical)	40,000	22,000	53,000	29,000	40,000
Black coal (ultra super critical)	40,000				
IGCC	40,000				54,000
CCGT	12,800				24,360
OCGT	7,500				10,400
Nuclear	130,000				
Hydropower	15,000				
Solar thermal	100,000				
Photovoltaic	20,000				
Wind	20,000				
Biomass	40,000				
Geothermal	40,000				
Coal USC plus CCS (95%)	60,000				
Gas CCGT plus CCS (95%)	32,800				

Data source: ACIL Tasman, IEA, East Harbour

ACIL Tasman's assumptions for developed economies are summarised in Table 12. The assumptions for developing economies are summarised in Table 13.

Table 12 **Estimates of fixed operating and maintenance costs for developed economies (A$ 2008 prices)**

Technology	2008	2010	2020	2030	2040	2050
	$/MWh	$/MWh	$/MWh	$/MWh	$/MWh	$/MWh
Black coal (super critical)	40,000	40,000	40,000	40,000	40,000	40,000
Black coal (ultra super critical)	40,000	40,000	40,000	40,000	40,000	40,000
IGCC	70,000	70,000	70,000	70,000	70,000	70,000
CCGT	12,800	12,800	12,800	12,800	12,800	12,800
OCGT	7,500	7,500	7,500	7,500	7,500	7,500
Nuclear	130,000	130,000	130,000	130,000	130,000	130,000
Hydropower	15,000	15,000	15,000	15,000	15,000	15,000
Solar thermal	100,000	100,000	100,000	100,000	100,000	100,000
Photovoltaic	20,000	20,000	20,000	20,000	20,000	20,000
Wind	20,000	20,000	20,000	20,000	20,000	20,000
Biomass	40,000	40,000	40,000	40,000	40,000	40,000
Geothermal	40,000	40,000	40,000	40,000	40,000	40,000
Coal USC plus CCS (95%)	60,000	60,000	60,000	60,000	60,000	60,000
Gas CCGT plus CCS (95%)	32,800	32,800	32,800	32,800	32,800	32,800

Data source: ACIL Tasman, IEA, East Harbour

Table 13 **Estimates of fixed operating and maintenance costs for developing economies (A$ 2008 prices)**

Technology	2008	2010	2020	2030	2040	2050
	$/MWh	$/MWh	$/MWh	$/MWh	$/MWh	$/MWh
Black coal (super critical)	$32,000	$32,000	$32,000	$32,000	$32,000	$32,000
Black coal (ultra super critical)	$32,000	$32,000	$32,000	$32,000	$32,000	$32,000
IGCC	$56,000	$56,000	$56,000	$56,000	$56,000	$56,000
CCGT	$10,240	$10,240	$10,240	$10,240	$10,240	$10,240
OCGT	$6,000	$6,000	$6,000	$6,000	$6,000	$6,000
Nuclear	$104,000	$104,000	$104,000	$104,000	$104,000	$104,000
Hydropower	$12,000	$12,000	$12,000	$12,000	$12,000	$12,000
Solar thermal	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000
Photovoltaic	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000
Wind	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000
Biomass	$32,000	$32,000	$32,000	$32,000	$32,000	$32,000
Geothermal	$32,000	$32,000	$32,000	$32,000	$32,000	$32,000
Coal USC plus CCS (95%)	$48,000	$48,000	$48,000	$48,000	$48,000	$48,000
Gas CCGT plus CCS (95%)	$26,240	$26,240	$26,240	$26,240	$26,240	$26,240

Data source: ACIL Tasman, IEA, East Harbour

4.3 Generator Characteristics

4.3.1 Auxiliaries

Table 14 shows the percentage of energy generated in each technology which is assumed to be used internally in the generation process. The difference between energy generated and energy sent out is auxiliary use. This energy is usually used to drive equipment such as conveyer belts, coal pulverisers and blowers, circulation pumps for cooling water and equipment for removing particulates and gases from exhaust fumes. In the future it could well include energy to run equipment that separates and compresses CO_2 before piping it for sequestration.

Table 14 **Energy used in auxiliaries**

Technology	2008	2010	2020	2030	2040	2050
Black coal (super critical)	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%
Black coal (ultra super critical)	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%
IGCC	11.0%	11.0%	11.0%	11.0%	11.0%	11.0%
CCGT	2.4%	2.4%	2.4%	2.4%	2.4%	2.4%
OCGT	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%
Nuclear	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%
Hydropower	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%
Solar thermal	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%
Photovoltaic	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%
Wind	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%
Biomass	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%
Geothermal	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%
Coal USC plus CCS (95%)	9.5%	9.5%	9.5%	9.5%	9.5%	9.5%
Gas CCGT plus CCS (95%)	4.5%	4.5%	4.5%	4.5%	4.5%	4.5%

Data source: ACIL Tasman assumptions

4.3.2 Efficiency

The efficiencies assumed are based on a review of the reports listed in this document and are assumed to be identical by region. Efficiencies are presented on a sent out basis, meaning that energy used by auxiliaries is assumed to be part of the energy consumed in generation and efficiency is lower by this amount.

We have allowed for some improvement in efficiency in all technologies except biomass to reflect improvements in combustion and operating performance consistent with expected developments in power generation technologies and increased competitiveness in electricity markets in all regions over the longer term.

Efficiency of electricity generation from biomass includes combustion of bagasse and dewatered wood and plant residues. The heat produced is fed into a steam turbine to produce electricity. This is a fully mature technology and it is considered that there is unlikely to be a major technical breakthrough in combustion techniques. There is a possibility of generation from pyrolysis of biomass which produces an oil that can be used as an energy source for generation. While there is some research underway in this technology, it is not considered that it will compete successfully with other alternative sources of energy in electricity generation. It has not been taken into account in this analysis.

Table 15 **Sent out efficiency (HHV)**

	2008	2010	2020	2030	2040	2050
Black coal (super critical)	42%	42%	43%	44%	44%	44%
Black coal (ultra super critical)	44%	45%	48%	51%	51%	51%
IGCC	40%	45%	49%	50%	50%	50%
CCGT	52%	53%	57%	60%	60%	60%
OCGT	31%	31%	34%	36%	36%	36%
Biomass	20%	20%	20%	20%	20%	20%
Coal USC plus CCS (95%)	36%	37%	40%	43%	43%	43%
Gas CCGT plus CCS (95%)	44%	44%	45%	46%	46%	46%

Note: Thermal efficiency is based on HHV

Data source: ACIL Tasman assumptions

Capacity factor

The capacity factors for all regions are summarised in Table 16. Capacity factors are assumed to change over time as certain technologies, such as gas-fired generation and coal and gas fired plants with carbon capture and sequestration, are relatively expensive in the early years of the projection but later become lower in cost relative to technologies that emit higher levels of CO_2.

Table 16 **Capacity factor**

Technology	2008	2010	2020	2030	2040	2050
Black coal (super critical)	90%	90%	87%	83%	75%	70%
Black coal (ultra super critical)	90%	90%	87%	83%	75%	70%
IGCC	90%	90%	87%	83%	75%	70%
CCGT	50%	50%	65%	80%	85%	85%
OCGT	2%	2%	2%	2%	2%	2%
Nuclear	90%	90%	90%	90%	90%	90%
Hydropower	35%	35%	35%	35%	35%	35%
Solar thermal	31%	35%	44%	44%	44%	44%
Photovoltaic	25%	25%	30%	30%	30%	30%
Wind	35%	35%	35%	35%	35%	35%
Biomass	75%	75%	75%	75%	75%	75%
Geothermal	85%	85%	85%	85%	85%	85%
Coal USC plus CCS (95%)	90%	90%	90%	90%	90%	90%
Gas CCGT plus CCS (95%)	50%	50%	65%	80%	85%	90%

Data source: ACIL Tasman assumptions

4.4 Capital costs

Project capital costs for a new power station include:

- engineering, procurement and construction (EPC)
- planning and approval
- professional services
- land acquisition
- infrastructure costs (incl. water)
- spares and workshop etc and
- connection to the electricity network,
- fuel connection, handling and storage and
- mining infrastructure and development for coal fired developments.

Capital costs are usually expressed in $/kW.

There has been an escalation in capital costs for all power generation technologies reflecting global growth in demand for generation capacity. It is not clear how long this trend will persist and in some cases there is some evidence that the rate of increase is now slowing. We have allowed for the recent cost increases in our modelling assumptions but have not included further escalation in capital costs.

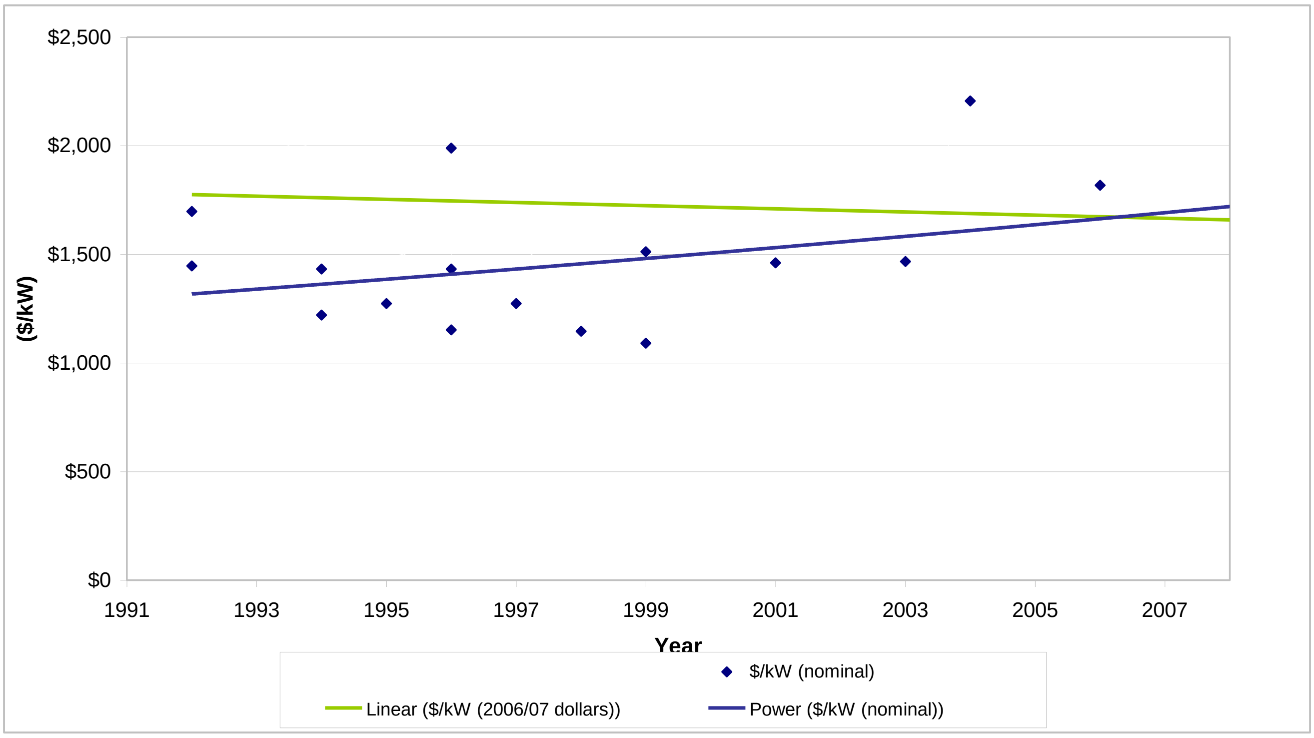
The analysis behind the assumptions used in the LRMC modelling is discussed in the following sections. Tables setting out the assumptions for each country over time are provided at the end of this section.

4.4.1 Coal

ACIL Tasman analysed the costs of coal technologies in its 2007 report to NEMMCO (ACIL Tasman, 2007) and has updated this with the analysis of recently constructed coal fired power stations in Australia, Europe, USA and Asia. The results are summarised in Figure 1. From this analysis ACIL Tasman concluded:

- Costs appear to have been declining slightly in real terms.
- There does not appear to be a relationship between project size and cost per kW.
- Increases in steel prices after 2004 have had an effect but the small number of observations makes it impossible to quantify.

Figure 1 **Historical project capital costs ($/kW) for a new build coal-fired power station by year of project**



Note: Estimates exclude mine development costs

Data source: ACIL Tasman analysis of data from http://www.power-technology.com/projects/#top and various generator company websites

This analysis indicated a median cost of a super critical PCC plant to be around $1, 900/kW for an Australian plant.

The ACIL Tasman NEMMCO report also reviews the emerging technologies of ultra supercritical PCC plants (USC) and integrated gasification combined cycle plants (IGCC) with and without carbon capture and storage.

- USC is incremental technology, which is undergoing extensive development and re-engineering in Japan, USA and Europe.
- IGCC is a relatively new technology for power generation, with most of the earlier applications of coal gasification being used for chemical production. IGCC is undergoing extensive RD&D for the production of both electricity and hydrogen. Inherent advantages of the technology are the relative ease of producing hydrogen and CO_2-e capture.

Capital costs are discussed in the Cottrell report (CRC for Coal in Sustainable Development, 2003) and also in the US Department of Energy Report (Department of Energy, 2007). The capital costs provided in the Cottrell report have been adjusted to take into account all-up project capital costs for a new entrant project but maintaining the relativity between the different technologies in terms of cost. The estimated project capital costs are shown in Table 17.

Table 17 **Estimates of project capital cost per kW in 2007/08 and escalation rate for new build power station by type**

Technology	$/kW	Escalation rate (% of CPI)
USC	1,800	80%
USC plus 95% CCS	3,900	80%

Note: Includes capital cost of CO_2 transmission and storage

Data source: ACIL Tasman analysis of Cottrell et al (2003) and IPCC (2005)

The estimates for ultra super critical dry cooled coal fired generation based on PB Power data and ACIL Tasman estimated data for 2008 are summarised in Table 18.

Table 18 **Estimate of capital cost for coal technologies in 2008 - $/kW**

Technology	Australia	USA	EU	Japan	RF	China	India	Brazil
Black coal (super critical)	1,900	1,583	1,820	1,750	1,616	1,235	1,504	1,813
Black coal (ultra super critical)	2,400	1,999	2,299	2,211	2,041	1,560	1,899	2,290
IGCC	2,100	1,749	2,012	1,934	1,786	1,365	1,662	2,004
Coal USC plus CCS	4,100	3,415	3,928	3,777	3,486	2,664	3,245	3,912

Note: Estimates for countries based on PB Power regional adjustment multipliers

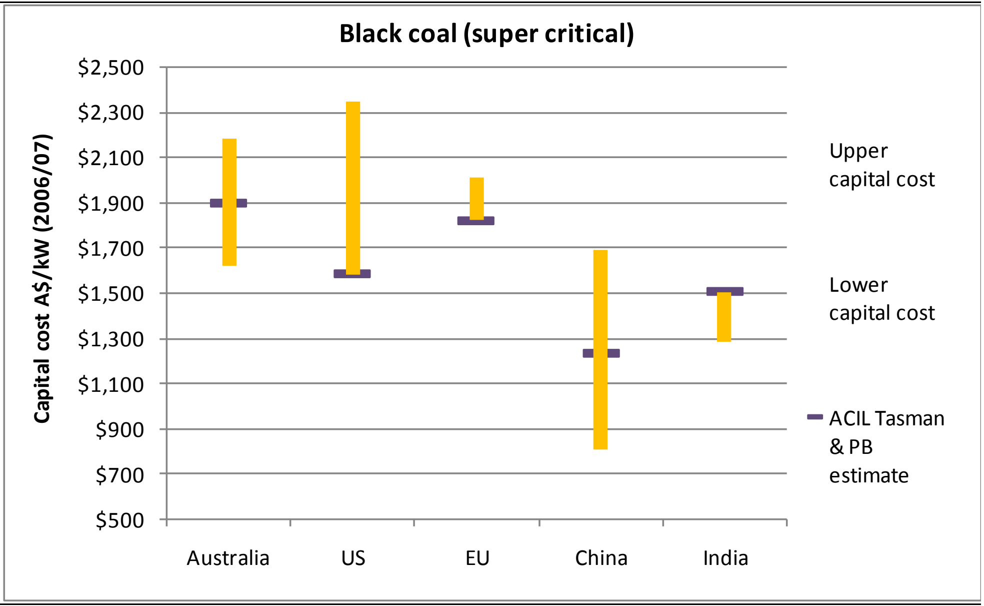
Data source: ACIL Tasman, PB Power and reference material referred to in this report

To check these figures a comparison was made with other data available from reports on capital costs around the world. The results are provided in the following charts. The results for super critical black coal and IGCC are summarised in Figure 2 and Figure 3 respectively.

The figures show that the estimates of costs for a super critical PCC plant used in the model fall within a reasonable range for the US and China and at the upper end for Australia and the lower end for the EU.

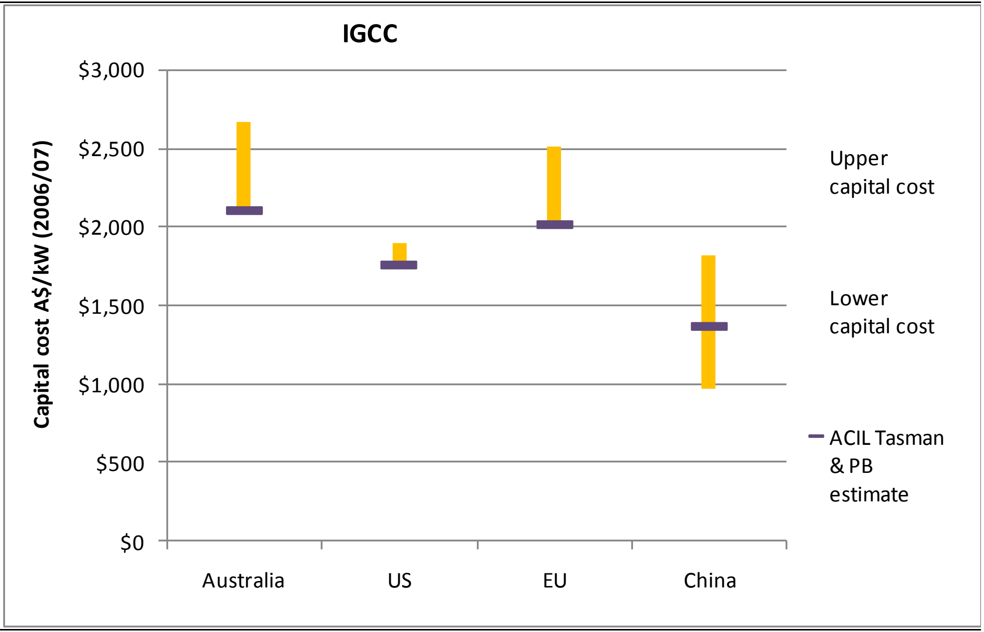
For the IGCC, the assumed costs fall within a reasonable range for the US and China and at the lower end for Australia and the EU.

Figure 2 **Comparison of assumptions with examples from reports for a super critical coal plant**



Data source: ACIL Tasman and reports referred to in text

Figure 3 **Comparison of capital costs for an IGCC plant**



Data source: ACIL Tasman and reports referred to in text

4.4.2 OCGT

In its report for NEMMCO, ACIL Tasman estimated the cost of a new entrant OCGT at around $720/kW. In its UK report, PB power estimated the cost to be £330/kW in 2006 which is equivalent to $A867/kW at the current rate of exchange.

Allowing for differences in sampling between the two analyses, the figure used for modelling purposes was $750/kW. The assumptions used for modelling for this report by region are based on this estimate and adjusted using the PB regional ratios. This results in a lower figure for the UK than quoted above. However, given the margin of accuracy it is considered appropriate to use these figures for consistency in the analysis.

Table 19 **Capital cost assumptions for OCGT in 2008 - $/kW**

Technology	Australia	USA	EU	Japan	RF	China	India	Brazil
OCGT	750	625	719	691	583	456	570	684

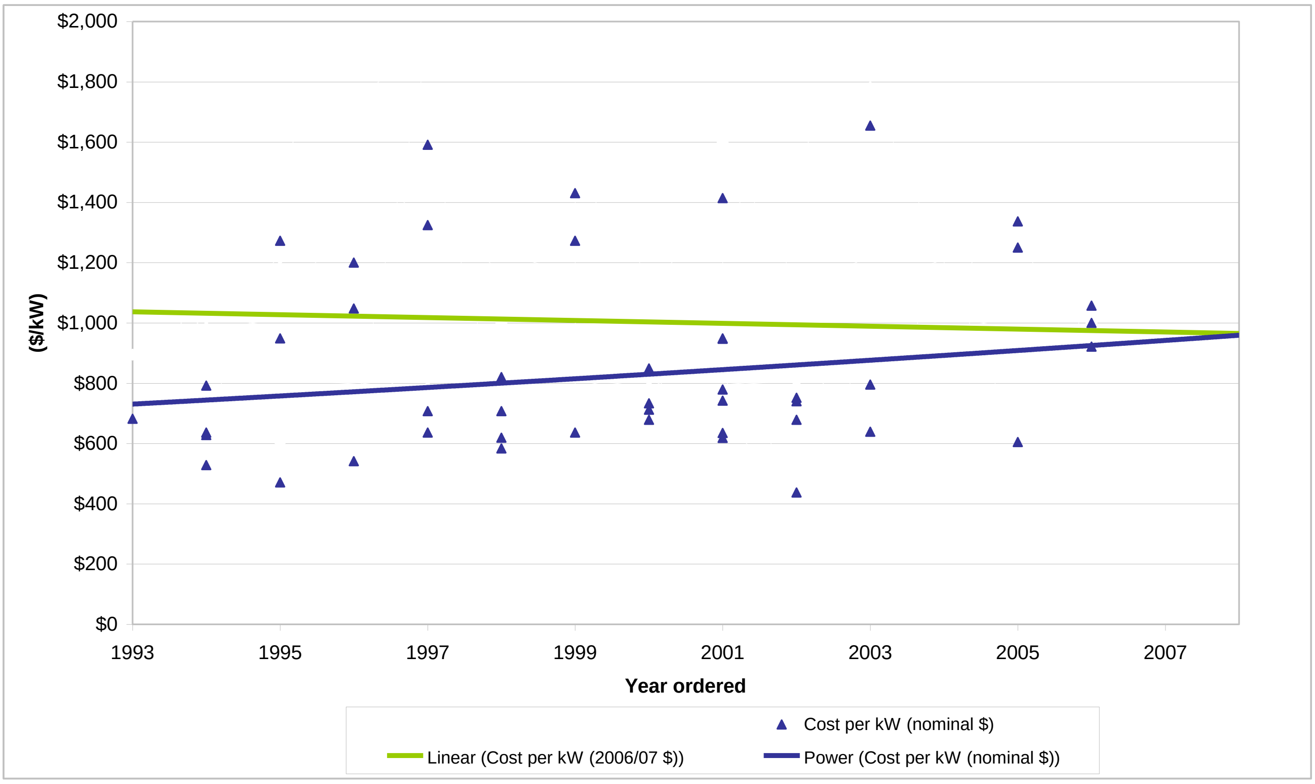
Data source: ACIL Tasman and PB Power

4.4.3 CCGT

Figure 4 plots the historical capital cost for CCGT projects between 1993 and 2006. There are 48 individual projects included in the graph, representing projects from Europe, USA and Asia. The costs have been plotted in two ways – in nominal terms (costs of the day) as well as in real terms (in 2006/07 dollars assuming an inflation rate of 2.5% per year). Based on these observations and analysis of the relationship between cost and size, ACIL Tasman drew the following conclusions:

- There are two broad groups of projects – those with a cost greater than $1,000/kW pre 2004 and those (the larger of the two groups) less than $1,000/kW pre 2004. The group with costs greater than $1,000/kW represents about 20% of the number of observations and is thought to consist of cases where project capital costs have blown out to a point. These outliers are not unexpected given that the opportunity for costs to overrun is greater than the opportunity for them to be less than expected.
- The regression lines shown in Figure 4 include the influence of the outlying cost observations. This suggests that location and other regional specific factors could lead to a wider range of cost outcomes.
- Costs have been declining slightly in real terms.
- There does not appear to be a relationship between project size and cost per kW.

Figure 4 **Historical project capital costs ($/kW) for a new build CCGT power station by year of project**



Data source: ACIL Tasman analysis of data from http://www.power-technology.com/projects/#top and various generator company websites

ACIL Tasman concluded that a reasonable assumption for capital costs in Australia in 2007 would be around $1000/kW. We have used $1050/kW to represent the price in Australian dollars in 2008. The price assumptions by region using the PB Power regional adjustment factors are summarised in Table 20.

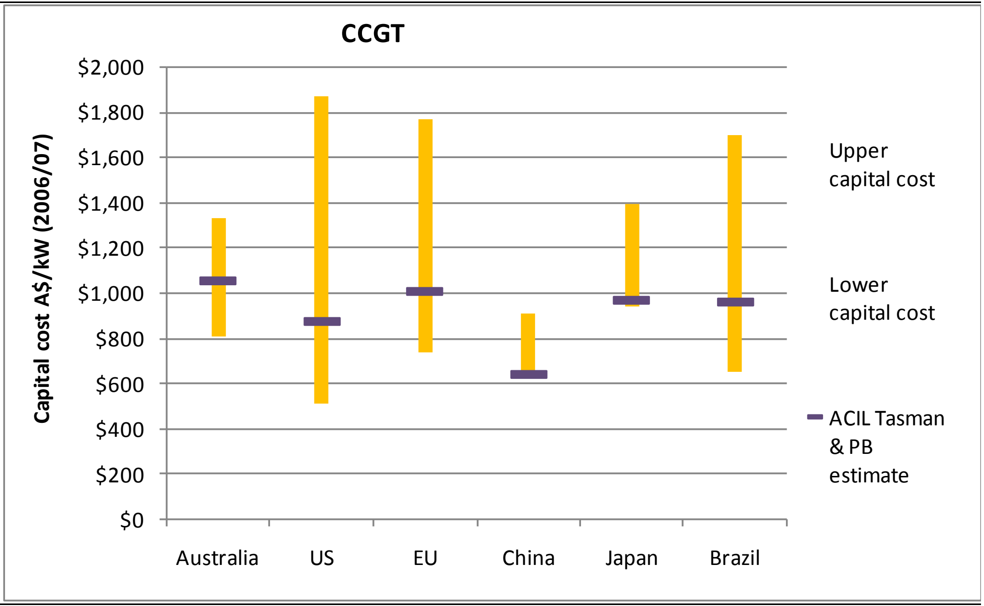
Table 20 **Capital cost assumptions for CCGT in 2008 - $/kW**

Technology	Australia	USA	EU	Japan	RF	China	India	Brazil
CCGT	1,050	875	1,006	967	816	639	798	958

Data source: ACIL Tasman and PB Power

A comparison of these numbers with examples drawn from the reports cited above is provided in Figure 5. The comparisons indicate that these assumed costs fall within a reasonable range of observed cases for Australia, the US, the EU, China and Japan. There is no data from the other regions for such comparisons.

Figure 5 **Comparison between assumed costs for CCGT with examples from other studies**



Data source: ACIL Tasman, PB Power and reports cited in this document

4.4.4 Nuclear

Estimates of the capital cost of nuclear power available to PB Power suggest a range of between $3,513/kW for a standard nuclear reactor to $4,218/kW for a pebble bed reactor. The latter are under development and not likely to be into commercial production until 2018 at the earliest.

In a report prepared by the Nuclear Energy Association in 2005 costs of around $US 2000/kW (around $ A3000/kW in 2008 dollars) were quoted although these did not include decommissioning costs (World Nuclear Association, 2005). The report also suggested that lower costs were possible in the future.

For this report it was assumed that capital costs in Australia would be of the order of $3,500/kW. Using the regional adjustment factors provided by PB Power capital cost assumptions per region were calculated and shown in Table 21.

Table 21 **Capital cost assumptions for nuclear in 2008 - $/kW**

Technology	Australia	USA	EU	Japan	RF	China	India	Brazil
Nuclear	3500	2915	3353	3216	3092	2332	2842	3419

Data source: ACIL Tasman and PB Power

4.4.5 Hydro-electricity

Hydro-electricity cost estimates by PB Power ranged between $1,720/kW and $2,500/kW. Whilst hydro-electricity machinery costs are relatively stable, civil costs can vary widely depending upon the site.

For the purposes of this study, a capital cost of $2,000/kW for Australia was assumed and the regional adjustment factors used to estimate costs in other regions.

Table 22 **Capital cost assumptions for hydro -electricity in 2008 - $/kW**

Technology	Australia	USA	EU	Japan	RF	China	India	Brazil
Hydropower	2,000	1,666	1,916	1,842	1,642	1,266	1,558	1,875

Data source: ACIL Tasman and PB Power

4.4.6 Solar Thermal

The most prospective technology among the solar thermal candidates is the solar trough. It has more capacity built than any other solar thermal technology (such as the solar tower or solar dish). It also has modular design and can be built up over time.

Trough technology mostly includes storage, which improves viability, and can include the use of auxiliary firing fuels, such as local sources of natural gas.

In 2003 the US Department of Energy revisited the Solar Energy Generating Station (SCEGS) technology and assessed what an identical 30MW solar electric generating system would cost then. The resulting cost of electric energy (in 2003$) was US$0.17/kWh for a solar only and US$0.14/ kWh for a hybrid plant.

Since then some technological advances have been achieved that will have an impact on the cost of a modern SEGS plant. For instance, a new parabolic trough receiver has been developed which has improved thermal and optical properties, increasing the thermal performance by 20%. Parasitic pressure losses through the hydraulic hose system, originally a size limiting factor, have been reduced by 50%. Other areas for reductions are:

- The overall plant size (the cost of the steam and generator unit does not increase proportionately with unit size and similarly with O&M costs).
- The introduction of a Thermal Energy Storage (TES) system.
- The optimisation of O&M activities.

We have included these improvements in the assumptions on the costs of solar thermal power in 2020. The financial new entry model assumes that capital costs fall by 20% in real terms but increase with the general inflation of capital goods. The efficiency of these plants is also assumed to improve and the inclusion of thermal storage improves capacity factor.

Solar thermal assumptions were derived from ACIL Tasman internal data and adjusted using the PB Power regional adjustment factors (Table 23). It has been assumed that solar thermal efficiency improvement of 0.5% per year will be achievable.

Table 23 **Capital cost assumptions for solar thermal in 2008 - $/kW**

Technology	Australia	USA	EU	Japan	RF	China	India	Brazil
Solar thermal	5,000	4,165	4,790	4,606	4,252	3,249	3,957	4,771

Data source: ACIL Tasman and PB Power

4.4.7 Solar photovoltaic

PV life cycle costs are dominated by the cost of cells and their conversion efficiency. Using pure silicon crystal wafers offers high efficiencies but will always be constrained by the high cost of pure silicon crystals. Ways are being developed to use the silicon wafers much more efficiently (Australian Sliver® technology is an example of a clever use of the silicon wafer) but it will still be limited by silicon costs.

Thin film technology has offered lower costs in the past but cost reductions are still limited by the need for vacuum deposition (of the thin films) and lower efficiencies (from amorphous film).

Thin film technology now offers a major breakthrough with materials such as a thin film of copper, indium, gallium and selenium (CIGS) technology or something similar. This technology avoids using pure silicon, crystals or vacuum deposition. It involves applying a thin film of CIGS compound using printing techniques and nano - technology to improve conductivity and therefore efficiency.

CIGS appears to be the best opportunity for significant advance and currently appears to have the best chance of providing a cost breakthrough and mass production in the next 20 years.

Balance of system components such as inverters will reduce in price as production increases and there is more competition. However, the technology is unlikely to change radically and costs will reduce but not fall by the same magnitude as PV modules.

Current PV cells have an estimated 20% learning rate (the cost reduction expected with every doubling in capacity) while balance of systems (BOS) components such as inverters will have much smaller cost reductions have an estimated 10% learning rate. BOS includes electrical installation, inverters, support structure and in the case of distributed PV, building integration.

An estimate of the capital cost of photovoltaic capital costs made by ACIL Tasman is provided in Table 25 (ACIL Tasman, 2006).

Table 24 **Estimates of photovoltaic capital costs**

	2006		2020	
	Conventional (silicon crystal)	Sliver	Sliver	Thin Film CIGS
Cell cost $/kW	3900	3100	840	500
Balance of systems $/kW	2500	2500	1600	1600
Efficiency (DC)	12.00%	14.00%	19.00%	15.00%
DC to AC derating factor	0.85	0.85	0.85	0.85

Data source: ACIL Tasman report *(ACIL Tasman, 2006)*

Solar photovoltaic assumptions were derived from ACIL Tasman internal data and adjusted using the PB Power regional adjustment factors. It was assumed that the technology achieved an efficiency improvement of 5% per year and costs decreased in real terms by 1.5% per year.

Table 25 **Capital cost for solar photovoltaic in 2008 - $/kW**

Technology	Australia	USA	EU	Japan	RF	China	India	Brazil
Photovoltaic	7,529	6,272	7,213	6,920	6,433	4,892	6,021	7,230

Data source: ACIL Tasman and PB Power

4.4.8 Wind

While wind power has been used for thousands of years, modern wind turbines are a relatively new technology. Apart from a few very small stand-alone systems of various designs early in the twentieth century, the late 1970s was the beginning of modern wind power utilisation.

Three forms of wind generation technology have been developed and demonstrated:

- The horizontal axis wind turbine.
- The vertical axis turbine, sometimes called the Darius wind generator.
- The diffuser wind generator.

In this study we have concentrated on the use of horizontal wind turbines as the form of the technology that has developed most rapidly and appears to be the most likely candidate for further development in the future. All of the advances in conversion efficiency, capital cost improvements, turbine design and sizing appear to be based on the horizontal axis turbine.

The cost of wind energy has fallen by approximately 50% in the last 15 years, primarily due to turbine design and efficiency. In the next 15 years, cost reductions are expected to be due to manufacturing improvements and economies of scale, reducing costs by about 10-15%.
In the short-term, the capital costs of wind turbines may increase as the cost of most capital items is increasing presently as the cost of steel and other construction materials has increased. The demand for wind turbines is also currently high supporting upward pressure on wind turbine prices.

The long run marginal cost was calculated assuming a capital cost of $2,400/kW in 2006, which reduces in real terms by 1% per year.

Wind energy capital costs were based on ACIL Tasman estimates and adjusted using the regional adjustment factors. The 2008 costs by region are provided in Table 26.

Table 26 **Capital cost assumptions for wind generation in 2008 - $/kW**

Technology	Australia	USA	EU	Japan	RF	China	India	Brazil
Wind	2,400	1,999	2,299	2,201	1,991	1,520	1,909	2,280

Data source: ACIL Tasman and PB Power

4.4.9 Biomass

Biomass energy in the form of ethanol or biodiesel may be used in thermal plants to replace diesel or fuel oil. Technology developments may reduce the costs of fuel slightly but the generation technology is fairly conventional and is not likely to be subject to significant cost reductions.

Capital costs were based on PB Power estimates and adjusted using the regional adjustment factors. No cost improvements in real terms were assumed.

Table 27 **Capital cost assumptions for biomass in 2008 - $/kW**

Technology	Australia	USA	EU	Japan	RF	China	India	Brazil
Biomass	2,200	1,833	2,108	2,026	1,806	1,393	1,714	2,062

Data source: ACIL Tasman and PB Power

4.4.10 Geothermal

There are two geothermal technologies – geothermal fluid and hot dry rock (HDR). The emerging geothermal energy resource is HDR. This technology aims to exploit the land areas under which the rock temperature exceeds 200°C at depths less than 5 km where the permeability of these formations is low.

The principle of HDR technology is to circulate a fluid between an injection well and a production well, along pathways formed by fractures in the hot rocks that act as deep heat exchangers. The fluid transfers heat to the surface where it can be converted to electricity. The deep heat exchanger is fabricated by hydraulic stimulation. This involves pumping high pressure water into the hot rock that opens stressed natural fractures and facilitates micro-slippage along them. Releasing the water pressure allows the fractures to close but the slippage that occurred results in a million-fold permanent increase in permeability along the fracture systems and a heat exchanger is created that can be used to extract energy.

The scope of the HDR technology has broadened as fluids have been frequently found from deep boreholes drilled in crystalline rocks. In fact, between fully hydrothermal reservoirs and totally impermeable hot rocks, there is a complete series of low to medium-permeability rocks which cannot be exploited for geothermal energy production without specific engineering enhancements. The technology of enhancing the permeability of these systems is called Enhanced Geothermal Systems (EGS).

PB Power provided cost estimates for geothermal generation based on HDR technology on a global basis. These are summarised in Table 28.

Table 28 **Capital cost estimates for geothermal**

	Cost	MW	Cost/kW	
	$US m		$US/kW	$A/kW
2000 metre well	59.6	20	2,980	3,973
4000 metre well	120	20	6,000	8,000

Data source: PB Power

For this report a capital cost estimate of $5,000/kW was taken for Australia. Estimates for the other regions were calculated using the PB Power regional adjustment factors. At this stage, neither India nor Brazil has developed geothermal power.

It has been assumed that geothermal costs will improve by around 0.5% in real terms as a result of improvements in generator systems and rock fracturing techniques.

Table 29 **Capital cost assumptions for geothermal in 2008 - $/kW**

Technology	Australia	USA	EU	Japan	RF	China	India	Brazil
Geothermal	5,000	4,165	4,790	4,606	3,814	3,000	3,770	4,520

Note: India and Brazil have not developed geothermal power

Data source: ACIL Tasman and PB Power

4.4.11 CCGT with CCS

The estimate of capital costs of gas CCGT with CCS was based on data provided in the Cottrell report (CRC for Coal in Sustainable Development, 2003). The assumed cost by region was calculated using the PB Power regional adjustment factors.

Table 30 **Capital cost assumptions for CCGT-CCS in 2008 - $/kW**

Technology	Australia	USA	EU	Japan	RF	China	India	Brazil
Gas CCGT plus CCS(95%)	2,850	2,374	2,730	2,625	2,423	1,852	2,255	2,719

Data source: ACIL Tasman and PB Power

It has been assumed that technology improvements will lead to a 0.5% improvement in capital costs in real terms.

4.5 Changes in costs over time

Most technologies will be subject to changes in costs over time as improvements in design, manufacturing and materials occur and as industry learning occurs. An estimate of learning rates was provided in the CRC report produced in 2003 (CRC for Coal in Sustainable Development, 2003).

ACIL Tasman has drawn on the discussion in this report to estimate relative cost changes over time for each technology. We have not varied these assumptions between regions. This may not be realistic as it might be expected that learning rates in countries such as India, China and Brazil would be different to those in say the USA or the EU. Assuming the same rate of change in costs is the same as assuming that technological innovations are passed on rapidly between developed and developing countries. In the energy industry this may be a reasonable assumption as industries such as generator manufacture are global and advances in efficiency have been made in all sales. Improvements in wind turbines also have been adopted in all countries regardless of whether they are considered developed or developing.

The assumed changes in inflation and capital costs made for this report are summarised in Table 31. An index that is higher than the CPI index indicates a real increase in prices while an index which is lower indicates a real reduction in prices.

Table 31 **Index of capital costs 2008 to 2050**

Inputs	Annual percent change	2008	2010	2020	2030	2040	2050
Consumer price index (CPI)	2.5%	1.000	1.051	1.345	1.722	2.204	2.821
Producer price index (PPI)	2.5%	1.000	1.051	1.345	1.722	2.204	2.821
Capital costs	2.5%	1.000	1.051	1.345	1.722	2.204	2.821
Electricity capital costs (turbines etc)	2.2%	1.000	1.044	1.298	1.614	2.006	2.494
Solar thermal efficiency improvement	0.5%	1.000	1.000	1.062	1.185	1.185	1.185
Photovoltaic capital cost change, avge % pa	1.0%	1.000	1.000	1.105	1.220	1.348	1.489
Photovoltaic efficiency improvement	5.0%	1.000	1.103	1.980	1.980	1.980	1.980
Wind capital cost increase	1.5%	1.000	1.030	1.196	1.388	1.610	1.869
Geothermal capital cost increase	2.0%	1.000	1.040	1.268	1.546	1.885	2.297
CCS capital cost increase	2.0%	1.000	1.040	1.268	1.546	1.885	2.297

Data source: ACIL Tasman

4.6 Capital cost assumptions by region and "Learning Curves"

During the 1960s the Boston Consulting Group popularised the learning curve. They further developed the theory and published a number of articles on the subject (BCG 1968 in IEA 2000). They also coined the term "experience curve", as distinct from "learning curve". The Progress Ratio (PR) became a well used ratio of final to initial costs associated with a doubling of cumulative output. The Learning Rate (LR) represents the proportional cost savings made for a doubling of cumulative output.

In the absence of a reliable method to make cost projections for new energy technologies, experience curves have been used extensively in the literature to provide indications of "potential" cost reduction as experience is gained. The approach is often used to estimate the "potential" learning investments required to reach a situation of break-even, the point where a new technology surpasses an incumbent technology in terms of cost-effectiveness.

The primary criticism of this method surrounds the use of a Single Factor Learning Curve that calculates price as a unique function of cumulative experience. This takes no account of R & D effort and results or other important factors specific to the technology.

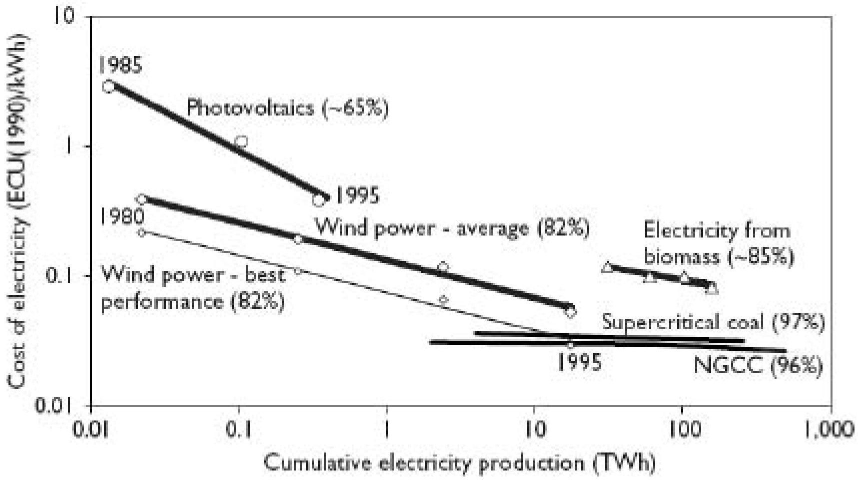
Learning curves are often estimated ex post from the cost reduction history of a successful technology, such as aeroplanes or motor vehicles. The resulting curves are often then used to show that, for almost any new technology, if production can be increased enough, and consumers encouraged to buy enough of it, then costs, and presumably prices, will come down by orders of magnitude.

The approach has been developed into a 2 Factor Learning Curve, usually incorporating cumulative production and cumulative R&D spending. This should be a better predictor of future outcomes but it is difficult to implement as the data required is usually difficult to acquire. Studies based on multi-factor learning curves use technical factors to explain changes in the dependant variable (usually price or cost) and have been shown to offer informative results, such as in the case of wind power (Coulomb, 2005). Nevertheless, despite their evident relevance in describing historical trends, when it comes to predicting future costs one faces a problem of compounding uncertainties. That is, not only should the relationship between independent and dependant variables be maintained but one must also be able to forecast future values for what are generally highly uncertain independent variables. A further perceived limitation is the absence of floor costs that have been shown to exist particularly for technologies that reach maturity.

The IEA publication 'Experience Curves for Energy Technology Policy' (IEA, 2000) presents a broad overview of the work covered up to the end of the 1990s and also presents the findings from the 1999 IEA workshop on this subject. Their recommendation was that experience effects should be "explicitly considered in exploring scenarios to reduce CO_2 emissions and calculating the cost of reaching emissions targets" (IEA, 2000).

Figure 6 (IEA 2000) presents learning rates for a number of electricity producing technologies where electricity costs are shown in ECU per kWh and are graphed against cumulative production in TWh. The figure shows the lines of best fit on a log-log scale with associated progress ratios included. For each technology the linear slope can be transferred into a Learning Rate. For example in this study, photovoltaics has a PR of 65% which means that if there was a doubling of cumulative photovoltaic electricity production then the price according to the learning curve theory should be reduced to 65% of the present value. Alternatively one could say that for every doubling of cumulative production, there is a cost reduction equal to the Learning Rate (LR) which is 1-PR, or 35%. In the case of wind power, this study projects a Learning Rate of 18%.

Figure 6 **Learning curves for selected generation technologies**



Source: IEA 2000

In Table 32 to Table 39 we have shown the capital cost of new and conventional generation technologies as real costs of capital per kW of installed capacity. These costs decrease relatively steeply for photovoltaic, solar thermal, wind and geothermal technologies and at a lesser rate for more established technologies, such as CCGT and USC coal generation. Photovoltaic capital costs are assumed to reduce most rapidly as the costs of production fall and improvements are made in the cell efficiency (thereby requiring fewer cells to do the same job).

Table 32 **Capital costs – Australia (A$ 2008 prices)**

Technology	2008	2010	2020	2030	2040	2050
	$/kW	$/kW	$/kW	$/kW	$/kW	$/kW
Black coal (super critical)	1900	1900	1900	1900	1900	1900
Black coal (ultra super critical)	2400	2400	2400	2400	2400	2400
IGCC	2100	2100	2100	2100	2100	2100
CCGT	1050	1044	1008	979	950	923
OCGT	650	646	628	609	592	575
Nuclear	3500	3500	3500	3500	3500	3500
Hydropower	2000	2000	2000	2000	2000	2000
Solar thermal	5000	5000	4757	4525	4525	4525
Photovoltaic	7529	6500	5609	4840	4177	3604
Wind	2400	2522	2134	1934	1754	1590
Biomass	2200	2200	2200	2200	2200	2200
Geothermal	5000	4951	4715	4490	4276	4072
Coal USC plus CCS (95%)	4100	4060	3866	3682	3506	3339
Gas CCGT plus CCS (95%)	2850	2822	2688	2559	2437	2321

Data source: ACIL Tasman and PB Power

Table 33 **Capital costs – USA (A$ 2008 prices)**

Technology	2008	2010	2020	2030	2040	2050
	$/kW	$/kW	$/kW	$/kW	$/kW	$/kW
Black coal (super critical)	1583	1583	1583	1583	1583	1583
Black coal (ultra super critical)	1999	1999	1999	1999	1999	1999
IGCC	1749	1749	1749	1749	1749	1749
CCGT	875	870	839	815	792	769
OCGT	625	621	603	586	569	552
Nuclear	2916	2916	2916	2916	2916	2916
Hydropower	1666	1666	1666	1666	1666	1666
Solar thermal	4165	4165	3962	3770	3770	3770
Photovoltaic	6272	5415	4673	4032	3479	3002
Wind	1999	2100	1777	1611	1461	1324
Biomass	1833	1833	1833	1833	1833	1833
Geothermal	4165	4124	3928	3740	3562	3392
Coal USC plus CCS (95%)	3415	3382	3221	3067	2921	2781
Gas CCGT plus CCS (95%)	2374	2351	2239	2132	2030	1933

Data source: ACIL Tasman and PB Power

Table 34 **Capital costs – EU (A$ 2008 prices)**

Technology	2008	2010	2020	2030	2040	2050
	$/kW	$/kW	$/kW	$/kW	$/kW	$/kW
Black coal (super critical)	1820	1820	1820	1820	1820	1820
Black coal (ultra super critical)	2299	2299	2299	2299	2299	2299
IGCC	2012	2012	2012	2012	2012	2012
CCGT	1006	1000	965	938	910	884
OCGT	719	714	694	674	654	635
Nuclear	3353	3353	3353	3353	3353	3353
Hydropower	1916	1916	1916	1916	1916	1916
Solar thermal	4790	4790	4557	4335	4335	4335
Photovoltaic	7213	6227	5374	4637	4001	3453
Wind	2299	2416	2044	1853	1680	1523
Biomass	2108	2108	2108	2108	2108	2108
Geothermal	4790	4743	4517	4301	4096	3901
Coal USC plus CCS (95%)	3928	3890	3704	3527	3359	3199
Gas CCGT plus CCS (95%)	2730	2704	2575	2452	2335	2223

Data source: *ACIL Tasman and PB Power*

Table 35 **Capital costs – Japan (A$ 2008 prices)**

Technology	2008	2010	2020	2030	2040	2050
	$/kW	$/kW	$/kW	$/kW	$/kW	$/kW
Black coal (super critical)	1750	1750	1750	1750	1750	1750
Black coal (ultra super critical)	2211	2211	2211	2211	2211	2211
IGCC	1934	1934	1934	1934	1934	1934
CCGT	967	962	928	901	875	850
OCGT	691	687	667	648	629	611
Nuclear	3217	3217	3217	3217	3217	3217
Hydropower	1842	1842	1842	1842	1842	1842
Solar thermal	4606	4606	4381	4168	4168	4168
Photovoltaic	6920	5974	5155	4449	3839	3313
Wind	2201	2312	1957	1774	1608	1458
Biomass	2026	2026	2026	2026	2026	2026
Geothermal	4606	4561	4343	4136	3938	3750
Coal USC plus CCS (95%)	3777	3740	3561	3391	3229	3075
Gas CCGT plus CCS (95%)	2625	2600	2476	2357	2245	2138

Data source: ACIL Tasman and PB Power

Table 36 **Capital costs – RF (A$ 2008 prices)**

Technology	2008	2010	2020	2030	2040	2050
	$/kW	$/kW	$/kW	$/kW	$/kW	$/kW
Black coal (super critical)	1616	1616	1616	1616	1616	1616
Black coal (ultra super critical)	2041	2041	2041	2041	2041	2041
IGCC	1786	1786	1786	1786	1786	1786
CCGT	816	811	783	761	739	717
OCGT	583	580	563	547	531	515
Nuclear	3093	3093	3093	3093	3093	3093
Hydropower	1642	1642	1642	1642	1642	1642
Solar thermal	4252	4252	4045	3848	3848	3848
Photovoltaic	6433	5554	4793	4136	3569	3080
Wind	1991	2091	1770	1604	1455	1319
Biomass	1806	1806	1806	1806	1806	1806
Geothermal	3814	3776	3596	3425	3261	3105
Coal USC plus CCS (95%)	3486	3452	3288	3131	2981	2839
Gas CCGT plus CCS (95%)	2423	2400	2285	2176	2072	1973

Data source: *ACIL Tasman and PB Power*

Table 37 **Capital costs – China (A$ 2008 prices)**

Technology	2008	2010	2020	2030	2040	2050
	$/kW	$/kW	$/kW	$/kW	$/kW	$/kW
Black coal (super critical)	1235	1235	1235	1235	1235	1235
Black coal (ultra super critical)	1560	1560	1560	1560	1560	1560
IGCC	1365	1365	1365	1365	1365	1365
CCGT	639	635	613	595	578	561
OCGT	456	454	440	428	415	403
Nuclear	2332	2332	2332	2332	2332	2332
Hydropower	1266	1266	1266	1266	1266	1266
Solar thermal	3249	3249	3091	2941	2941	2941
Photovoltaic	4892	4223	3644	3145	2714	2342
Wind	1520	1597	1351	1225	1110	1007
Biomass	1393	1393	1393	1393	1393	1393
Geothermal	3000	2971	2829	2694	2565	2443
Coal USC plus CCS (95%)	2664	2638	2512	2392	2278	2170
Gas CCGT plus CCS (95%)	1852	1834	1746	1663	1584	1508

Data source: ACIL Tasman and PB Power

Table 38 **Capital costs – India (A$ 2008 prices)**

Technology	2008	2010	2020	2030	2040	2050
	$/kW	$/kW	$/kW	$/kW	$/kW	$/kW
Black coal (super critical)	1504	1504	1504	1504	1504	1504
Black coal (ultra super critical)	1899	1899	1899	1899	1899	1899
IGCC	1662	1662	1662	1662	1662	1662
CCGT	798	793	766	744	722	702
OCGT	570	567	550	535	519	504
Nuclear	2843	2843	2843	2843	2843	2843
Hydropower	1558	1558	1558	1558	1558	1558
Solar thermal	3957	3957	3764	3581	3581	3581
Photovoltaic	6021	5198	4486	3871	3340	2882
Wind	1909	2006	1697	1539	1395	1265
Biomass	1714	1714	1714	1714	1714	1714
Geothermal	3770	3733	3555	3385	3223	3070
Coal USC plus CCS (95%)	3245	3213	3060	2914	2775	2642
Gas CCGT plus CCS (95%)	2255	2234	2127	2025	1929	1837

Data source: *ACIL Tasman and PB Power*

Table 39 **Capital costs – Brazil (A$ 2008 prices)**

Technology	2008	2010	2020	2030	2040	2050
	$/kW	$/kW	$/kW	$/kW	$/kW	$/kW
Black coal (super critical)	1813	1813	1813	1813	1813	1813
Black coal (ultra super critical)	2290	2290	2290	2290	2290	2290
IGCC	2004	2004	2004	2004	2004	2004
CCGT	958	952	919	893	867	842
OCGT	684	680	661	642	623	605
Nuclear	3420	3420	3420	3420	3420	3420
Hydropower	1875	1875	1875	1875	1875	1875
Solar thermal	4771	4771	4538	4318	4318	4318
Photovoltaic	7230	6242	5386	4648	4011	3461
Wind	2280	2395	2027	1837	1666	1510
Biomass	2062	2062	2062	2062	2062	2062
Geothermal	4520	4520	4520	4520	4520	4520
Coal USC plus CCS (95%)	3912	3874	3689	3513	3345	3186
Gas CCGT plus CCS (95%)	2719	2693	2564	2442	2325	2214

Data source: ACIL Tasman and PB Power

4.7 WACC

In deriving the WACC for each region, we have concentrated on systematic risk, sometimes called non-diversifiable risk.

Systematic risk can be reflected in the country's sovereign risk. Sovereign risk relates to the country's political and economic environment and includes currency fluctuations, changes in tax or local content laws, quotas and tariffs, and the sudden imposition of labor or environmental regulation.

Calculating foreign WACC in Australian dollars involves adding a sovereign risk premium to the domestic WACC (UBS Investment Bank, 2005).

Global financial services firm, UBS, estimates sovereign risk using foreign debt yields and insurance premiums that guarantee foreign investments against sovereign risk.

These estimates of sovereign risks are listed in Table 1 .They reflect sovereign risk relative to AAA credit countries like the US and Australia.

Estimated WACC for each region, expressed in Australian dollars, for an Australian post-tax real WACC of 6.58% is shown in the final row of Table 40.

Risk free rates and corporation tax rates for each region are also included. The risk free rates are measured by 10 year treasury bonds, or equivalent low risk financial instruments.

Table 40 **Global WACC (AUD)**

	Australia	United States	Japan	EU	China	India	Federation of Russia	Brazil
Risk free rate	5.70%	4.20%	1.56%	4.67%	4.43%	8.50%	10%	12.91%
Corporate tax rates	30%	35%	40.69%	24.2%	24%	33.99%	24%	34%
Sovereign Risk (%)	0	0	0	0.45	0.6	1.2	2.5	4.3
Post-tax (Officer) real WACC	6.58%	6.58%	6.58%	7.03%	7.18%	7.78%	9.08%	10.88%

Data source*:* S&P Global ratings handbook, The Economist, Bloomberg, and Credit Delta cited in the WACC Users Guide, March 2005, UBS Investment Banking, Risk free rates sourced from the US Federal Reserve Bank, Asia Bonds Online, European Central Bank, Bank of China, Reserve Bank of India, International Monetary Fund, and Bloomberg. Corporation tax rates are soured from the Australian Taxation Office (ATO), US Internal Revenue Service (IRS), KPMG International Corporate Tax Survey 2007, Brazilian Energy Regulator (Eneel), the Australia-Russia Business Council, the Embassy of China and the Embassy of India.

4.7.1 ACIL Tasman WACC

ACIL Tasman utilises the post-tax real (Officer) WACC within its new entrant model. The Officer formula incorporates all tax effects in the WACC calculation and is applied to simple post-tax cash flows. The Officer WACC is the most widely cited as the target post-tax WACC because this definition of WACC is commonly used for asset valuation and project evaluation.

The post-tax nominal Officer WACC as used by ACIL Tasman is expressed as:

$$WACC_{Officer\ (post-tax\ nominal)} = \frac{E}{V} \times R_e \left(\frac{(1-T)}{(1-T(1-G))} \right) + \frac{D}{V} \times R_d (1-T)$$

Where:

D = total market value of debt

E = total market value of equity

V = total enterprise value (value of debt plus equity)

R_e = the nominal post-tax cost of equity as estimated using CAPM

R_d = the nominal post-tax cost of debt

T = corporate tax rate

G = Gamma, which is the value of imputation tax credits as a proportion of the tax credits paid.

This is adjusted into real terms using the Fischer equation as follows:

$$WACC_{Officer\ (post-tax\ real)} = \left(\frac{(1 + WACC_{Officer\ (post-tax\ nominal)})}{(1+F)} \right) - 1$$

Where:

F = inflation rate

4.7.2 Tax

Domestic corporate tax rates for each region are in Table 41.

The tax rates quoted are the most recent rates sourced from the Australian Taxation Office (ATO), US Internal Revenue Service (IRS), KPMG International Corporate Tax Survey 2007, Brazilian Energy Regulator (Eneel), the Australia-Russia Business Council, the Embassy of China and the Embassy of India.

Table 41 **Corporate tax rates, by region**

	Australia	United States	Japan	EU	China	India	Federation of Russia	Brazil
Corporate tax rate	30%	35%	40.7%	24.2%	24%	33.99%	24%	34%

Data source: Australian Taxation Office (ATO), US Internal Revenue Service (IRS), KPMG International Corporate Tax Survey 2007, Brazilian Energy Regulator (Eneel), the Australia-Russia Business Council, the Embassy of China and the Embassy of India.

Note that some tax rates vary according to factors, for example, company income level or location. The tax rate quoted is for domestic companies in India with income of more than 1 million Rupees (INR 1 crore). The Japanese corporate tax rate includes inhabitants' tax and enterprise local tax. Corporation tax for domestic companies in China is 30%, but is usually reduced to 24% if the enterprise is located in specially designated zones (the Embassy of China quotes 24%).

4.8 Emission factors

Emissions in tonnes CO2-e per MWh for each region are calculated using emissions factors fro each fuel type, as shown in Table 42.

Table 42 **Emissions factors (tonnes CO_2-e per PJ), by fuel type**

Fuel type	Emissions factor (tCO2-e/PJ)
Black coal	0.09
Natural gas	0.0511
Biomass	0.0015
Renewables and other zero emission *	0
Black coal with CCS (95%)	0.09*0.05=0.0045
Natural gas with CCS (95%)	0.0511*0.05=0.002555

Note: * Renewables and zero emission include nuclear, hydropower, solar thermal, photovoltaic, wind and geothermal.

The emissions factors are converted to tonnes of CO_2-e per MWh using technology efficiencies given in Table 43.

Table 43 **Sent out efficiency (used in the emissions calculations)**

Technology	2008	2010	2020	2030	2040	2050
Black coal (super critical)	42%	42%	43%	44%	44%	44%
Black coal (ultra super critical)	44%	45%	48%	51%	51%	51%
IGCC	40%	45%	49%	50%	50%	50%
CCGT	52%	53%	57%	60%	60%	60%
OCGT	31%	31%	34%	36%	36%	36%
biomass	20%	20%	20%	20%	20%	20%
Coal USC plus CCS (95%)	36%	37%	40%	43%	43%	43%
Gas CCGT plus CCS(95%)	44%	44%	45%	46%	46%	46%

a

4.9 Carbon pricing

For each region, the following real carbon prices are assumed (Table 44).

Table 44 **Carbon prices (real A$ per tonne CO2-e)**

Year	Carbon price (real A$/tCO2-e)
2020	$20
2030	$30
2040	$40
2050	$50

a

4.10 Constraints and timing

There are no physical or technical constraints on the timing of introduction of traditional black and brown coal power stations, CCGT and OCGT technologies, hydro power, photovoltaic or wind energy technologies.

There is currently no geothermal electricity generation in Brazil or India although it is understood that there are geothermal resources in both countries. Geothermal should be constrained for five years in these countries .

Wind energy exhibits variability which can affect grid performance requiring additional reserve generator capacity for supply security, voltage and frequency management. For example a sudden fall in wind generation creates problems in managing frequency and voltage in AC transmission grids. In order to do this, reserve generation is required to be brought into production at short notice. Coal fired power stations require up to 8 hours to bring on line because of technical constraints associated with steam raising and turbines. Gas or hydro power can provide this backup as they can be brought into service with short notice. In most cases some spinning reserve is maintained with thermal generators operating but not generating so that they can be brought on line at short notice to maintain grid stability.

In Western Australia, the wind tends to blow at night when demand is low. This means that coal based power has to be scaled back overnight. However the coal fired generation capacity is still needed for the periods when wind generation is low or not available.

For these reasons it is considered appropriate to constrain wind to no more than 25 per cent of total generation capacity in each region for this modelling exercise.

IGCC is still in the demonstration stage and is not likely to be commercially or technically viable until after 2015. CCS technologies are not likely to be commercially viable until 2020 at the earliest.

New pebble bed nuclear technologies are expected to become available in 2015. These have the advantage of modular construction (200MWe) and safer operations. They have the potential to exhibit slightly lower operating costs but initially capital and operating costs are expected to be higher than existing nuclear technologies.

CCS technologies depend on the availability of suitable sites for sequestration of carbon dioxide and other greenhouse gases. The technologies for sequestration are still being evaluated with the first experiment in Australia commencing in April 2008 under the CRC for Greenhouse Gas Technologies.

CCS involves keeping CO_2 secured deep underground in an appropriate geological formation. The ideal characteristics of a storage site involve simple geology; a porous/permeable rock containing saline groundwater, overlaid by an impermeable seal at a depth below the surface of 800 m or more. Potential sites include:

- Depleted oil and gas reservoirs
- In enhanced oil recovery
- Deep unused saline water saturated reservoir rocks
- Deep un-mineable coal seams
- Other cavities in basalts, oil shales etc.

According to the CRC on Greenhouse Gas Technologies, all of the regions under study will have suitable sedimentary basins either onshore or offshore. The feasibility of developing economic storage sites will depend on their location in relation to sources of emissions as well as geological structure and characteristics. It is too early to rule out any region as not suitable for geosequestration. Some countries, such as Japan may find they have to look offshore for such sites. Japan however has a strong research program into CCS as does China and some South American countries (CRC on Greenhouse Gas Technologies, 2008).

ACIL Tasman considers that there is insufficient information available at the present time to make informed judgements about the limitations for CCS in any of the regions.

5 The new entrant model

The estimation of the generation costs of different electricity generation technologies in 8 different world regions is based on the estimation of the price required over the life of a generation project to pay all of its component costs, including fuel, operation and maintenance, tax, a return on capital, the payment of any emissions permit costs and the cost of any carbon capture and storage. These costs are brought together in ACIL Tasman's new entrant financial models for conventional technologies, including gas and coal-fired plants. Similar models for other technologies, such as wind, photovoltaics, solar thermal, nuclear and coal fired plants including carbon capture and storage have also been developed.

Using the new entrant models, a comparison of life cycle costs and operating performance can be made for each of the years and regions in the study. A number of the inputs to the financial models will vary from region to region. Factors which we have varied between regions include:

- Fuel prices
- Capital costs
- The weighted average cost of capital
- O & M costs
- Company tax
- Carbon pricing

Factors that remain constant between regions include conversion efficiency (heat rate), internal energy use and emissions factors. Capacity factors are an important determinant of the unit cost of a power station's output and these have been kept constant between regions in the case of base load generation technologies such as coal and nuclear. In the case of technologies such as wind, solar photovoltaic and solar thermal they have been allowed to vary to reflect local conditions.

One of the important elements of the project is the estimation of changes in costs over time. This involves the interaction of a number of factors including; technological learning curves, changes in the real price of commodities such as steal, underlying oil and energy price movements, economies of scale resulting from the wider uptake of new technologies and variations in the costs of capital.

6 Results

The results of the modelling of the long run marginal cost for the technologies specified and the years specified are summarised in Table 45 to Table 58. Note that these costs are in real terms.

Table 45 **Black coal super critical LRMC ($/MWh)**

	2008	2010	2020	2030	2040	2050
Australia	$45.99	$45.99	$61.87	$70.19	$81.25	$91.35
USA	$49.67	$49.67	$65.28	$73.29	$83.98	$93.81
EU	$45.09	$45.09	$60.93	$69.22	$80.17	$90.19
Japan	$54.05	$54.05	$69.80	$78.04	$89.24	$99.44
RF	$45.75	$45.75	$61.62	$69.95	$81.01	$91.11
China	$35.69	$35.69	$51.21	$59.04	$68.93	$78.17
India	$44.28	$44.28	$60.10	$68.36	$79.25	$89.22
Brazil	$65.87	$65.87	$82.04	$90.87	$103.46	$114.70

Table 46 **Black coal ultra super critical LRMC ($/MWh)**

	2008	2010	2020	2030	2040	2050
Australia	$54.00	$53.73	$67.88	$74.79	$85.84	$95.66
USA	$56.37	$55.95	$69.55	$75.91	$86.46	$95.93
EU	$52.89	$52.61	$66.72	$73.59	$84.50	$94.23
Japan	$62.21	$61.79	$75.60	$82.25	$93.48	$103.45
RF	$54.69	$54.42	$68.60	$75.57	$86.71	$96.62
China	$40.86	$40.58	$54.29	$60.56	$70.11	$78.83
India	$52.51	$52.23	$66.34	$73.19	$84.09	$93.81
Brazil	$79.87	$79.45	$93.87	$101.41	$114.72	$126.22

Table 47 **IGCC LRMC ($/MWh)**

	2008	2010	2020	2030	2040	2050
Australia	$56.85	$55.35	$69.03	$77.12	$88.44	$98.50
USA	$60.24	$57.94	$70.98	$78.75	$89.63	$99.37
EU	$55.83	$54.33	$67.99	$76.02	$87.22	$97.20
Japan	$65.56	$63.26	$76.48	$84.52	$96.01	$106.21
RF	$56.40	$54.90	$68.58	$76.65	$87.96	$98.01
China	$43.81	$42.31	$55.56	$63.01	$72.85	$81.83
India	$54.41	$52.91	$66.52	$74.49	$85.57	$95.45
Brazil	$80.54	$78.24	$91.98	$100.78	$114.04	$125.55

Table 48 **Gas fired CCGT LRMC ($/MWh)**

	2008	2010	2020	2030	2040	2050
Australia	$58.38	$58.50	$60.06	$61.42	$68.07	$76.44
USA	$84.53	$84.96	$89.48	$94.41	$106.63	$121.31
EU	$72.75	$73.03	$75.97	$79.09	$88.62	$100.29
Japan	$91.98	$92.43	$96.19	$100.86	$113.53	$128.90
RF	$56.81	$56.96	$59.12	$60.92	$67.92	$76.61
China	$62.77	$63.10	$68.33	$72.85	$82.82	$94.62
India	$56.77	$56.92	$59.09	$60.90	$67.90	$76.59
Brazil	$82.91	$83.13	$83.20	$84.58	$93.55	$105.04

Table 49 **Gas fired OCGT LRMC ($/MWh)**

	2008	2010	2020	2030	2040	2050
Australia	$522.64	$521.73	$528.05	$530.31	$541.19	$554.90
USA	$534.30	$533.45	$540.03	$542.69	$554.49	$569.29
EU	$549.25	$547.82	$551.57	$550.91	$557.36	$566.17
Japan	$613.51	$612.32	$617.22	$618.40	$629.29	$643.41
RF	$509.55	$507.80	$510.00	$507.25	$509.56	$513.54
China	$385.01	$384.48	$392.65	$396.28	$406.91	$419.77
India	$507.37	$505.63	$507.89	$505.20	$507.57	$511.61
Brazil	$764.80	$762.05	$759.32	$752.36	$752.70	$755.57

Table 50 **Nuclear LRMC ($/MWh)**

	2008	2010	2020	2030	2040	2050
Australia	$76.13	$76.13	$76.13	$76.13	$76.13	$76.13
USA	$70.49	$70.49	$70.49	$70.49	$70.49	$70.49
EU	$74.53	$74.53	$74.53	$74.53	$74.53	$74.53
Japan	$78.15	$78.15	$78.15	$78.15	$78.15	$78.15
RF	$76.15	$76.15	$76.15	$76.15	$76.15	$76.15
China	$57.16	$57.16	$57.16	$57.16	$57.16	$57.16
India	$72.84	$72.84	$72.84	$72.84	$72.84	$72.84
Brazil	$99.51	$99.51	$99.51	$99.51	$99.51	$99.51

Table 51 **Hydro-electricity LRMC ($/MWh)**

	2008	2010	2020	2030	2040	2050
Australia	$71.93	$71.93	$71.93	$71.93	$71.93	$71.93
USA	$64.09	$64.09	$64.09	$64.09	$64.09	$64.09
EU	$69.63	$69.63	$69.63	$69.63	$69.63	$69.63
Japan	$74.79	$74.79	$74.79	$74.79	$74.79	$74.79
RF	$70.29	$70.29	$70.29	$70.29	$70.29	$70.29
China	$47.33	$47.33	$47.33	$47.33	$47.33	$47.33
India	$68.24	$68.24	$68.24	$68.24	$68.24	$68.24
Brazil	$102.30	$102.30	$102.30	$102.30	$102.30	$102.30

Table 52 **Solar Thermal LRMC ($/MWh)**

	2008	2010	2020	2030	2040	2050
Australia	$224.37	$198.90	$152.17	$146.13	$146.13	$146.13
USA	$202.02	$179.10	$137.19	$131.88	$131.88	$131.88
EU	$217.82	$193.09	$147.78	$141.95	$141.95	$141.95
Japan	$232.53	$206.13	$157.64	$151.33	$151.33	$151.33
RF	$222.40	$197.12	$150.49	$144.26	$144.26	$144.26
China	$153.49	$136.09	$104.31	$100.32	$100.32	$100.32
India	$212.88	$188.69	$144.11	$138.19	$138.19	$138.19
Brazil	$312.04	$276.51	$210.57	$201.42	$201.42	$201.42

Table 53 **Photovoltaics LRMC ($/MWh)**

	2008	2010	2020	2030	2040	2050
Australia	$384.38	$333.33	$241.18	$209.39	$181.96	$158.29
USA	$339.83	$294.86	$213.52	$185.52	$161.36	$140.52
EU	$372.51	$323.08	$233.81	$203.03	$176.47	$153.56
Japan	$401.28	$347.92	$251.68	$218.45	$189.78	$165.03
RF	$405.77	$351.49	$253.95	$220.16	$190.99	$165.83
China	$256.32	$222.47	$161.17	$140.09	$121.91	$106.21
India	$384.43	$333.07	$240.70	$208.72	$181.13	$157.32
Brazil	$606.27	$524.59	$378.43	$327.57	$283.69	$245.82

Table 54 **Wind energy LRMC ($/MWh)**

	2008	2010	2020	2030	2040	2050
Australia	$93.31	$97.62	$83.87	$76.81	$70.41	$64.60
USA	$83.16	$86.96	$74.85	$68.63	$62.99	$57.88
EU	$90.61	$94.78	$81.47	$74.63	$68.43	$62.81
Japan	$96.96	$101.45	$87.11	$79.75	$73.07	$67.02
RF	$94.38	$98.82	$84.63	$77.35	$70.74	$64.75
China	$61.56	$64.34	$55.46	$50.90	$46.76	$43.01
India	$91.71	$96.02	$82.27	$75.20	$68.80	$62.99
Brazil	$141.21	$148.02	$126.27	$115.09	$104.96	$95.77

Table 55 **Biomass LRMC ($/MWh)**

	2008	2010	2020	2030	2040	2050
Australia	$70.34	$70.34	$70.88	$71.15	$71.42	$71.69
USA	$65.71	$65.71	$66.25	$66.52	$66.79	$67.06
EU	$69.10	$69.10	$69.64	$69.91	$70.18	$70.45
Japan	$72.18	$72.18	$72.72	$72.99	$73.26	$73.53
RF	$69.25	$69.25	$69.79	$70.06	$70.33	$70.60
China	$54.70	$54.70	$55.24	$55.51	$55.78	$56.05
India	$67.63	$67.63	$68.17	$68.44	$68.71	$68.98
Brazil	$90.18	$90.18	$90.72	$90.99	$91.26	$91.53

Table 56 **Geothermal LRMC ($/MWh)**

	2008	2010	2020	2030	2040	2050
Australia	$87.42	$86.65	$82.89	$79.32	$75.91	$72.67
USA	$77.94	$77.26	$73.95	$70.80	$67.80	$64.95
EU	$84.89	$84.14	$80.51	$77.05	$73.75	$70.61
Japan	$91.19	$90.38	$86.45	$82.71	$79.14	$75.74
RF	$81.77	$81.03	$77.47	$74.08	$70.85	$67.77
China	$55.02	$54.54	$52.24	$50.05	$47.97	$45.99
India	$81.72	$80.98	$77.42	$74.03	$70.80	$67.73
Brazil	$126.03	$126.03	$126.03	$126.03	$126.03	$126.03

Table 57 **Coal USC plus CCS (95%) LRMC ($/MWh)**

	2008	2010	2020	2030	2040	2050
Australia	$85.80	$84.80	$81.62	$78.25	$76.00	$73.88
USA	$86.50	$85.35	$81.94	$78.39	$76.46	$74.63
EU	$83.85	$82.87	$79.79	$76.50	$74.34	$72.30
Japan	$96.71	$95.46	$91.56	$87.56	$85.19	$82.95
RF	$87.42	$86.39	$83.04	$79.51	$77.11	$74.84
China	$63.26	$62.46	$60.26	$57.81	$56.45	$55.17
India	$83.60	$82.60	$79.44	$76.08	$73.84	$71.73
Brazil	$127.95	$126.38	$120.92	$115.41	$111.62	$108.03

Table 58 **Gas CCGT plus CCS (95%) LRMC ($/MWh)**

	2008	2010	2020	2030	2040	2050
Australia	$112.69	$112.90	$96.55	$88.51	$90.65	$94.37
USA	$138.39	$139.70	$130.27	$128.90	$138.62	$150.96
EU	$128.38	$129.14	$115.83	$110.92	$116.90	$125.02
Japan	$154.59	$155.90	$143.81	$141.08	$150.94	$163.64
RF	$116.72	$116.93	$100.06	$91.80	$94.09	$98.04
China	$104.43	$105.41	$98.32	$97.27	$104.60	$113.89
India	$112.19	$112.45	$96.77	$89.26	$91.81	$95.99
Brazil	$171.65	$171.97	$147.08	$135.00	$138.41	$144.30

These costs are broadly in line with costs available from other sources where available. Cost comparisons with estimates for China using the IEA World Energy Outlook for 2007 and for the UK using PB Power's 2004 report on electricity costs in the UK are provided in Appendix B. In general the ACIL Tasman estimates are consistent with these studies. Where differences occur it is thought that assumptions relating to capacity factor resulted in differences.

The above cost estimates are considered to correspond in general to other studies.

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B Selected comparisons

In the body of this report ACIL Tasman has provided comparisons of cost components with comparable studies. These showed that in general the assumptions of capital costs per kW and operating costs assumed in the modelling were within the band of other studies.

The resulting LRMC estimated from the modelling quoted in Chapter 6 are considered reasonable estimated for the purpose of modelling.

Where other studies of costs provided LRMC comparisons were made. Two specific studies provided the opportunity to compare per kWh costs for China and the UK.

The comparison with China was possible from estimates made by the IEA in its World Energy Outlook 2007 which included a specific section on China. The results are shown in Table 59.

Table 59 **Comparison with IEA estimated for China**

	ACIL	IEA low	IEA high
	$A/MWh	$A/MWh	$A/MWh
Nuclear	57.16	56.00	61.33
CCGT	62.77	62.67	104.00
Coal	35.69	36.00	57.33
Advanced coal	40.86	36.00	58.67
Wind	61.56	57.33	65.33
Large Hydro	47.33	53.33	76.00

Note: An exchange rate of $A0.75 per $US was assumed
Data source: IEA *(IEA, 2007)*

The ACIL Tasman estimates are within reasonable agreement with those of the IEA apart from large hydro. Given uncertainties relating to regulations, standards and the use of clean development mechanisms this is not considered material.

Comparison between ACIL Tasman estimates for the EU can be made with estimates made by PB Power in 2004 for the UK (PB Power, 2004). The results are shown in

Table 60 **ACIL Tasman and PB Power estimates for the EU and UK**

	ACIL (EU)	UK
	$A/MWh	$A/MWh
Coal PF	45.09	52.16
Coal ICGT	55.83	65.72
Gas OCGT	549.25	63.63
GAS CCGT	72.75	45.90
Nuclear	74.53	46.94
Wind	90.61	108.49

Note: Exchange rate of $A2.0865 = £UK1 assumed
Data source: *(PB Power, 2004)*

There is general correspondence apart from nuclear. The ACIL Tasman estimates for nuclear and gas in the EU are significantly higher than for the PB Power estimates for the UK. The differences are reflect different assumptions concerning capacity factor. The UK assumed that the gas and coal fired power was base load whereas ACIL Tasman assumed lower capacity factors. The differences comparisons and are not considered material for the purposes of modelling.