Extracts from Stanwell Discussion Paper
"Trends in Generating Technologies"
Morrison, Doan and Gleeson 2006

1. Future Generation Technology Mix Drivers

1.1. Rising Demand for Electricity

There have been a number of studies completed, all of which show a steady growth in the demand for electrical services. The recent study by Simshauser and Doan[1] suggests that there is the potential for the demand to effectively double by 2030. It is particularly note worthy that the short term demand is getting more weather driven, leading to a volatile and peakier market. This demand growth and characteristics will continue to support all generation market segments, especially fast acting plant.

1.2. Primary Energy Source Availability - Australia

1.2.1. **Coal**

Australia contains significant reserves of both black and brown coals. Black coal reserves are indicated in the Tables below although the supply and economics are regional.

Identified In Situ Resources of Black Coal, Australia, 2004
(Million tonnes)

State	Underground	Open Cut	Total
New South Wales	21 030	13 580	34 610
Queensland	15 510	15 910	31 420
South Australia	2 450	3 100	5 550
Western Australia	890	1 230	2 120
Tasmania	500	20	520
Total	**40 380**	**33 840**	**74 220**

Source:Geoscience Australia - as published in 'Australian Black Coal Statistics 2004', Coal Services Pty Ltd.

1.2.2. **Nuclear**

Australia has a substantial part (about 30 percent) of the world's low-cost uranium resources, with Kazakhstan 17 percent, and Canada 12 percent. Australia however has no uranium processing industry or waste disposal facilities. The development of the necessary infrastructure to support an onshore nuclear industry will result in additional cost to nuclear power generation unless economies of scale can be achieved.

[1] Simshauser & Doan, Discussion Paper 80, July 2005.

Known Recoverable Resources* of Uranium

	tonnes U	percentage of world
Australia	1,074,000	30%
Kazakhstan	622,000	17%
Canada	439,000	12%
South Africa	298,000	8%
Namibia	213,000	6%
Brazil	143,000	4%
Russian Fed.	158,000	4%
USA	102,000	3%
Uzbekistan	93,000	3%
World total	3,537,000	

** Reasonably Assured Resources plus Inferred Resources, to US$ 80/kg U, 1/1/03, from OECD NEA & IAEA,* Uranium 2003: Resources, Production and Demand*, updated 2005 by Geoscience Aust.*

1.2.3. **Water**

The real value of water as a constrained resource is rising. In many areas of Australia the availability of water will play a major role in the design of generating units not only to mitigate the impact of future cost increases, but also as a response to very limited supply. The current water planning process in Queensland has identified that there are very few catchments that are not overcommitted at this point in time. This situation is likely to be exacerbated as a result of increasing population growth and the potential rainfall reductions as a consequence of climate change. Technologies developed and/or selected for the Australian context will have to be low in water use or make use of recycled water from other industrial or domestic reticulated water schemes. Limitations on the discharges may force power station to consider “zero discharge” through evaporation, or treatment to permit further recycling (such as through irrigation).

1.2.4. **Renewables**

Australia’s renewable energy resources are enormous. Many renewable energy sources are intermittent, being dependent on the weather, such as wind and solar, or are cyclic in nature such as tidal. Hydro, biomass and geothermal are more predictable and storable and can be despatched upon demand. This presents the challenge of energy storage and/or managing a portfolio of energy sources.

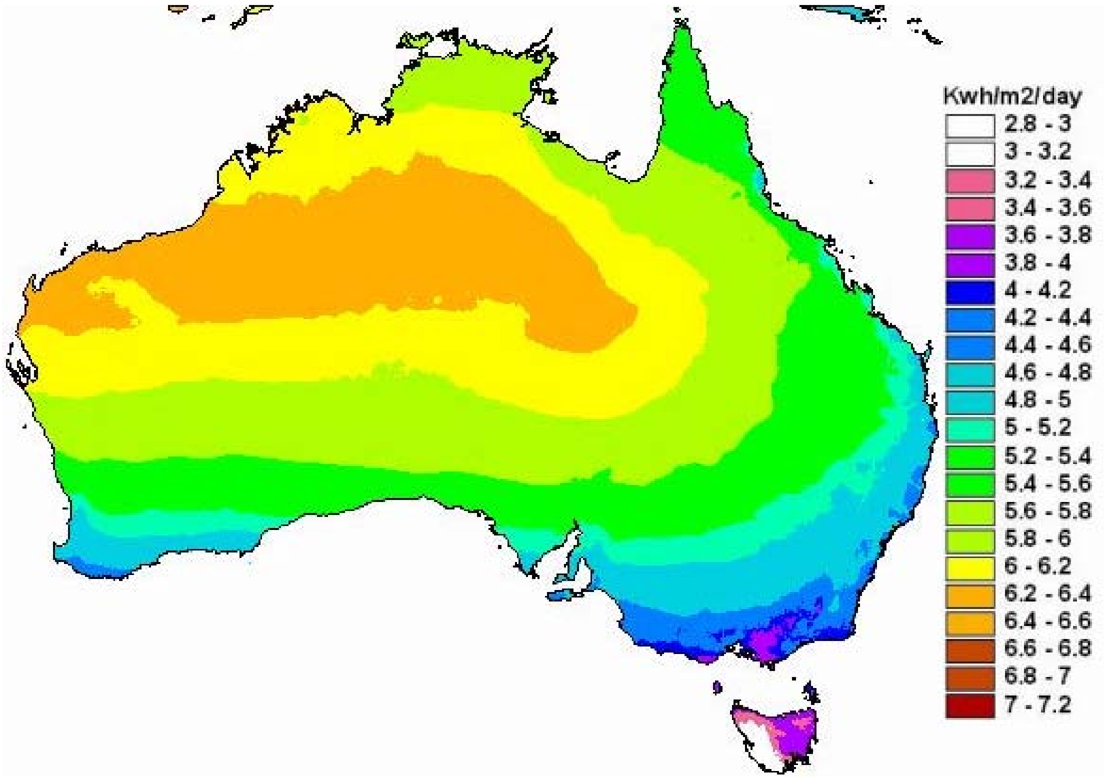
The main challenge facing renewable technology is cost effective utilisation, integration with networks, and the competing uses for the environments in which they are found.

- **Solar**

  Australia has some of the best solar resources in the world. Figure 1 below shows the distribution of solar resources across Australia. In one year, Queensland total land area receives ten times more solar energy than the total contained within the identified Queensland coal resource noted in Section 2.2.1 above.
  By way of comparison, and noting that only a small portion of the land area of Queensland would likely be available for harvest of solar energy, the area required to harvest and covert solar energy to produce the same annual output as Stanwell Power Station would be approximately 52 [2] square km.

  The challenges facing the large scale deployment of this technology are not only cost, but the availability of economically and environmentally suitable land.

[2] Based on the implementation of solar thermal technologies.



Improved global solar radiation map for Australia, mean annual solar radiation levels, kWh/m^2/day (constructed from data supplied in *ANUCLIM*). Source: Mills 2001

- **Wind**

Australia has wind resources comparable to that of Europe and the USA. Resources are mostly concentrated on southern coastal areas, especially the west coast of Tasmania. Queensland also has some significant resources in far north Queensland

In Australia, wind speeds of at least 7 m/s are currently required for a commercially viable wind farm supported by an MRET subsidy. Mills (2001) used wind resource data and GIS mapping techniques, to estimate the usable wind resources in Australia for sites with greater than 7 m/s within 50 km of the high voltage grid and avoiding high population densities and certain land uses. Mills concluded current technology could theoretically supply several times Australia's total electricity demand. Intermittency, grid issues, land use competition and other technical and non technical barriers are likely to limit the technology to well below its theoretical capability.

Europe has over 40,000 MW of capacity installed. Europe with its highly integrated electricity network can accommodate a higher level of intermittent generation than the Australian system. Wind sites are becoming scarce in some areas of Europe and focus has now turned offshore, where resources are even greater.

- **Geothermal**

Australia has limited traditional *volcanic* based geothermal resources, but is now recognised as having some of the best Hot Dry Rock (HDR) resources in the world, centred on the Cooper Basin of South Australia. These are areas where very hot granite rocks exist within several kilometres of the earth's surface. Australia is at the forefront of developing technology to tap these resources. Exploration licenses have been issued for 30000 square km in SA. As with many of the renewable energy sources obtaining sufficient confidence in the resource modelling to enable commercial investment is a major challenge. The location of the known HDR resources provides also challenges in getting the electricity to market.

- **Hydro**

Australia is a relatively dry continent with most available large scale hydro resources already developed or limited for further development due to environmental and social impacts. Some small scale opportunities, typically on existing dams and water infrastructure remain; however, development is dependent on economics.

- **Wave**

Australia has significant wave resources, particularly along the southern coast. These resources tend to be aligned with coastal wind resources. The wave resource is not well mapped, but is likely of similar magnitude to wind resources. Technologies for using wave resources are not well developed, but significant activity is underway around the world. Issues facing the technology include environmental and aesthetic impacts of the installations as well as costs.

- **Biomass**

Biomass is stored solar energy and takes the form of trees, crops, vegetation and animal wastes. While Australia has significant biomass resources, use as fuel for electricity production is limited by economics, as there is usually much higher value uses for the biomass e.g. food, wood, chemicals. Biomass is successfully used for power generation where it is a waste or as a by product of other uses e.g. Landfill gas, sewage gas, sugar bagasse, forestry residues. In these cases the significant cost of harvesting and transport is already covered. Biomass fuel supplies are subject to market and climate variability. Across Australia there are also significant forestry, grain and cotton crop residues that could be utilised given favourable economics.

- **Tidal**

Australia has large tidal resources but mostly located in areas remote from population centres e.g. NW Australia.

1.3. Environmental Constraints – Trends

While most of the generators in Australia compete in the National Electricity Market (NEM), the environmental emissions regulatory regime governing their operation is largely state based and therefore not equally applied to all players. The impact of this inequality takes two forms

- The licence limits may differ depending on the jurisdiction - impacting on the required capital investment and operating costs required to meet the licence limit.
- The licence fees also vary enormously

In Queensland the emission limits applied as part of the licence have tended to be derived based on their impact on human health or proven environmental harm. Ground level concentrations of emissions to air are a good example of this. Trends overseas, where population densities and pollutant concentrations are higher, now involve “regional caps” on various pollutants resulting in extremely low licence emission levels. The other trend being seen is the requirement for “best available” technology requirements in the permitting of new power stations.

1.3.1. Emissions to Air

- **Particulates**

  The primary focus here is coal based fly ash that escapes the electrostatic precipitator or the filter baghouse. Currently the limits are expressed as “weight of dust” in milligrams per volume of flue gas, regardless of the size of the carried particle. Focus is now shifting to regulate the emissions of the smaller particles given that particles less than 10 micron are respirable and have the potential to impact on human health. While on a world wide basis there are currently more electrostatic precipitators installed than baghouses the requirement to remove the finer particles has led to the implementation of filterbags as the technology of choice. As the focus shifts to even smaller particles (2.5 micron) wet scrubbers will be required to remove all the particulate matter. This additional equipment, when required, will further increase the capital and operating costs of the plant.

- **CO2**

  In Australia there have been a number of initiatives designed to encourage the electricity industry to lower greenhouse emissions. These include
  - The Greenhouse Challenge Programme (Federal)
  - The Generator Efficiency Standards (GES -Federal)
  - Mandatory Renewable Energy Target (MRET - Federal)
  - Queensland 13% Gas Scheme (GECs – Qld Govt.)
  - The NSW and ACT Benchmarks Scheme (NGACS – NSW Govt.)

  Some further schemes are proposed
  - Victorian version of MRET.
  - State based Emission Trading

  Of these schemes the first two are voluntary, and in the case of the generator efficiency standards, push the plant owner towards the best possible efficiency from the installed plant, making allowance for fuel type, age and technology. The next two schemes provide an incentive to invest in renewables and gas technologies respectively through the possibility of additional revenue. The NSW benchmark scheme is the only non technology specific scheme currently operating.

  Overseas we see the implementation of the European Carbon Trading Scheme where limits to CO2 emissions on a country basis were applied and individual plants have been “grandfathered” permits. New plant will likely have to purchase some or all of their permits.

- **SOx**

  As the contributor to human health impacts and acid rain, oxides of sulphur are a regulated pollutant. They occur as a result of sulphur present in the fuel (primarily coal). Limits in Australia are expressed as a concentration of SOx in the final flue gas or as a (derived) maximum limit on the sulphur content of the fuel (as at Stanwell Power Station). The limits are derived based on the impact on the local airshed and the impact of the other sources also contained within the airshed. As an example of this Tarong Power station was seen to be an influence on the Brisbane airshed, even though the station was some 220km from Brisbane. There is a growing trend for the regulatory authority (EPA) to ask for “best available technology”. Limits in Europe and the USA are much tighter than in Australia and can only be achieved for coal fired plant through the implementation of flue gas desulphurisation (FGD). At this point in time no Australian plant has been commissioned with FGD. The requirement for this level of pollutant control will significantly increase the capital and operating costs of the plant.

- **NOx**

  Oxides of Nitrogen are a contributor to photochemical smog and are also a regulated pollutant. Similar to SOx, licence limits in Australia are expressed as a concentration and will be subject to regional influences. NOx occurs as a result of two factors

    - The liberation of nitrogen present in the fuel (fuel NOx), and
    - as a result of the combustion process occurring in the presence of ambient nitrogen (air).

  The latter form of NOx can be controlled through influencing the temperature of combustion. This is achieved through what are termed “low NOx burners”. Trends in Australia and overseas see the allowable limits for NOx emissions reducing. Europe and the USA have limits that can <u>only be achieved</u> through the implementation of technology to remove the residual NOx from the flue gas. This technology is called selective catalytic reduction (SCR) and is expensive to install and operate.

- **Mercury**

  Mercury is a trace element found in coal and is liberated in various chemical forms during the combustion process. As a result of the higher levels of mercury in American coals and the higher density of coal based emitters the issue of mercury emissions has become a national focus in the USA. . The emergence of China as a large power generator and manufacturing economy has seen significant increases in mercury emissions from China over the past decade. Mercury travels in the atmosphere, therefore the emergence of new large sources of mercury emission is a concern for all countries.

  In the USA much of the mercury will be removed as a result of the particulate, SOx and NOx removal processes (if present). While not generating the same level of concern in Australia at this point in time, the regulator is certainly assessing the emissions of mercury using a calculated methodology based on the mercury contained within the coal. Assessments were made during the permitting of Tarong North and Kogan, although no limits were applied.

1.3.2. Emissions to Water

The trends in environmental regulation are designed to ensure that the site owner minimises the impact sustained on the environment by discharges to the local water catchment. The impacts are not only via pollutants but also via temperature impacts on the receiving water. Reductions in water use and discharge may occur through implementation of evaporation basins, or by installing dry cooling. Stations such as the proposed Kogan Creek are designed to use dry cooling albeit at a significant loss of station thermal efficiency and increased emissions of greenhouse gases comparative to similar plants using wet cooling.

- **Surface Overland Flow**

  Surface overland flows are usually stormwater related and may drain across contaminated areas (such as coal stockpiles/fuel storage areas). Treatment of these waters typically involves settlement ponds to reduce solid particles and encourage biological remediation followed by discharge or evaporation. Best practice technologies include reducing disturbed areas (for example by roofing or covering stockpiles, or restoring natural ground cover), instigating "first flush systems" which only treat the first fifteen or twenty minutes of runoff from an area before letting the rest of the stormwater flow to local discharge. These operate on the basis that only the initial stormwater is contaminated and the remainder requires no treatment. Other relevant issues include the size of the settlement ponds which are typically designed for a particular rainfall event or storm intensity.

- **Surface water discharge**

  Thermal power stations using wet cooling usually need to release large volume of spent cooling waters. Environmental licences will place conditions upon their release and may include limits on salt, metals (such as copper, chromium, and arsenic), temperature, organic compounds and disinfectants. Most inland power stations discharge water into streams where the water is abstracted and used by irrigators, for stock watering and occasionally for domestic purposes.

- **Groundwater discharges**

  Groundwater contamination can occur and is prevented through design of contaminated water storage areas (such as clay or plastic lining under ash containment areas, chemical effluent dams, evaporation ponds and similar structures. A system of monitoring bores is established to detect any leaching through the linings. Remediation of contaminated aquifers can be problematical.

  Direct groundwater injection of waters is not practised in power plants in Australia although other industries have proposed this as a means of disposal.

1.3.3. Emissions to Land

- **Coal Combustion Products**

  Coal combustion products come in two forms regardless of the generating technology – fly ash, and boiler ash or slag. While there are incentives for the producer to reduce the management costs through recycling, there are limited opportunities, and coal fired stations produce significant tonnages of both forms of coal combustion product. Fly ash is a regulated waste in Queensland and exemptions must be sought to recycle this product. Environmental concerns surround the potential leaching of trace elements contained within the ash into groundwater. There have been proposals under "polluter pays" licensing to charge for each tonne of ash produced. These have not been adopted to date.

- **Nuclear Waste**

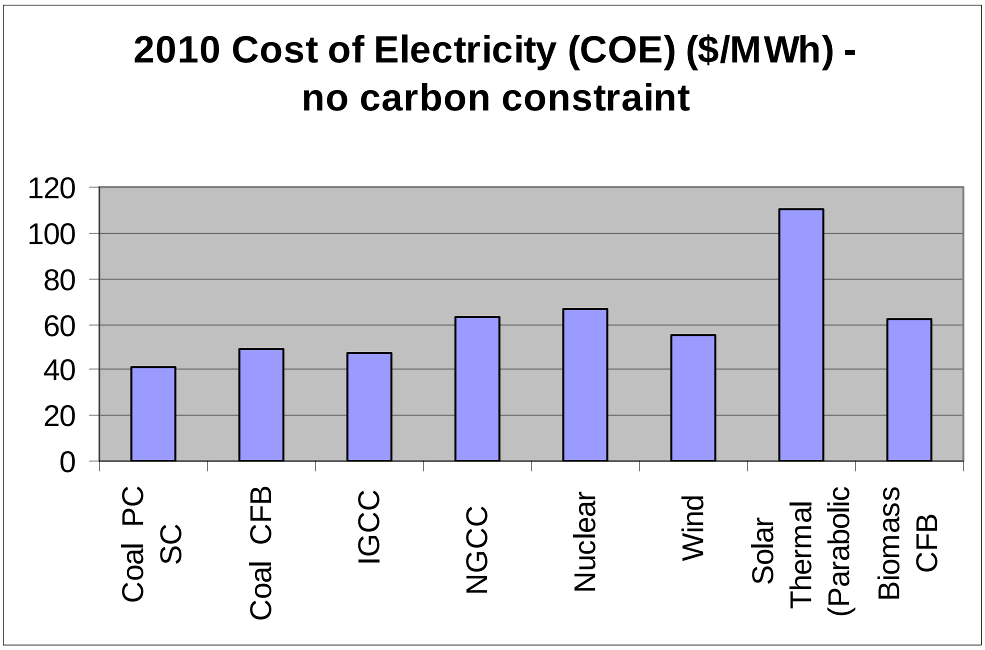
  At this point in time the Australian government has not had to deal with nuclear waste from power generation. It is assumed that a best practice approach will be adopted in response to the clear public concerns over the issue. Australia with low population density, and a seismically stable environment would appear to be well placed to implement secure nuclear waste disposal in deep geological storage.

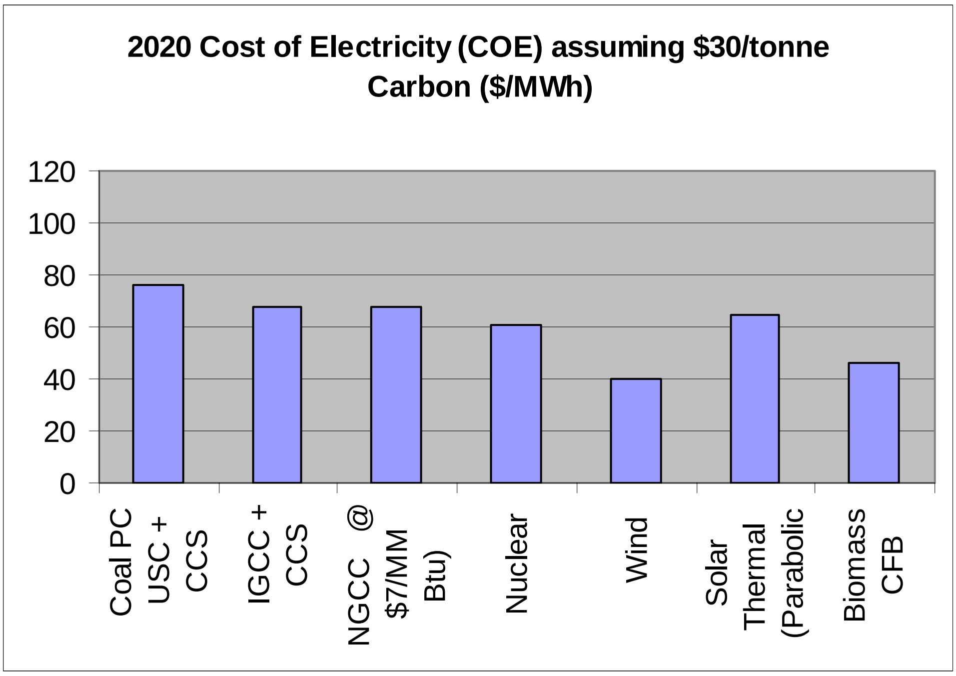
1.4. Economic Constraints and Opportunities

The following figures have been derived from a number of sources, and shows the Impact on the Cost of Generation in the American context of a carbon tax or trading scheme. These costs while in American dollars are useful ***as an indicator*** for what may be the case in Australia. Australian costs are expected to vary in absolute terms and the rankings may even change as a result of regional differences in technology implementation costs, and the movement in commodity prices.

However, the key points to note are:

- By 2020 there is a possibility that the IGCC with carbon capture, natural gas and nuclear technologies will all be at roughly the same price.
- If the value of carbon increases then the case for nuclear would become stronger.
- Recent work by Stanwell has confirmed that the Australian costs for any of the technologies will be higher than those stated, due to commodity price rises and the requirement to import all of the technology. Furthermore, it is assumed that there would be an additional premium on the cost of nuclear power in the Australian context due to the additional cost of establishing the fuel processing and waste disposal industries onshore.





1.4.1. **Market trends**

The NEM landscape has continued to change since the deregulation of the electricity market, with vertical integration as well as asset concentration and economies of scale being particularly strong influences. The drive for cost competitiveness, coupled with uncertainties in future GHG regulatory framework, have resulted in no new coal based capacity being committed since Kogan. Instead, efforts have been concentrated in increasing capacity of existing coal assets or building low emissions NGCC units and wind-farms.

The electricity distribution companies are attempting to improve financial returns of their essentially regulated asset base, by developing small generation facilities deep in their networks, thus optimising the network asset performance as well as minimising exposure to the de-regulated energy market.

1.4.2. **Transmission Issues**

The electricity production for the NEM is dominated by the major generating plants relying on the adequate transmission systems to reach customers. Much of the transmission infrastructure was built prior to the advent of the NEM by the respective state electricity commissions, which could optimise the planning of the transmission, generation and distribution infrastructure to meet the growth in demand. Since the start of the NEM, transmission investments have been regulated, while generation developments are not. The current network pricing regime does not provide incentives for generation to be embedded in the distribution network. While the pricing regime can be changed to reflect the benefits that embedded generation can provide, it is not foreseen that this will happen in the short term.

1.4.3. **Emissions Trading Schemes**

With the commencement of the European Union Emissions Trading Scheme (EU ETS) in January 2005, CO2 credit trading has become mainstream and trans-national. Prior to this, in response to the threat of climate change impacts from global warming, various national CO2 abatement schemes had been initiated. With the exception of a few European Countries (Germany, Denmark), these schemes have had a very small impact on overall CO2 emissions. Other national schemes are also being contemplated.[3] Work

[3] Doan, *Strategic values of the generation development from the Coke project, Discussion Paper 83*, Marketing and trading, March 2006.

is in progress to implement a Trading scheme for Kyoto signatories, due to commence in 2008.

In response to air quality issues and acid rain damage to cities and forests, NOx and SOx trading have been in existence for much longer. Major NOx and SOx trading schemes started in early 1990s in the US.
Given the wide consensus of the need to curb anthropogenic emissions of GHGs, emissions trading schemes will be the preferred mechanism to provide long term financial signals for CO2 abatement around the world. Clear policy directions for CO2 value is a necessary condition for the development of low emissions technologies, which are currently much more expensive than the conventional coal based generation.

In Australia, the abundance of low cost steaming coal has long underpinned our internationally competitive electricity cost. Consequently the cost gap between conventional generation technologies and low emissions technologies is commensurately larger than that existing in other countries. In the absence of a commitment to emissions trading from the Federal government, state governments are getting together to devise a state-based emissions trading scheme. This scheme is planned for 2008 start date, but it could be as late as 2010.

2. Technology Responses to Drivers

The uptake of new generation technologies in the Australian context is very dependent on the global effort in the development of these new technologies. The manufacturers of the major plant items tend to be the leaders in Research and Development of new products. Given the high capital intensity of the investments, and the "essential services" nature of the product, technological advances must be rigorously trialled before commercialisation to assist in managing the risk to the equipment supplier, the generator and the consumer.

The discussion below gives an overview of the directions that the technology is heading in given the drivers mentioned earlier. The discussion is limited to:-

- Fossil Fuel and related technologies
    - Coal
    - Gas
    - Hydrogen
    - CO2 Capture and Storage
- Nuclear
- Renewable Technologies
- Hybrid Technologies

2.1. Fossil Fuel Technology Response

2.1.1. **Gas**

- **Gas Turbines/CCGTs**

  <u>Central plants</u>
  Gas Turbines use an expensive fuel and in order to maximise the conversion of the fuel to electricity, are seeking to improve efficiency. This is achieved via a progression to higher firing temperatures and through increasing the scale of the plant as indicated in the table below.

  As in the coal fired boilers mentioned below the temperatures and pressures sought after in the steam cycle will increase in the quest for higher levels of efficiency.

Higher firing temperatures of gas turbines demands the development of more exotic metals and surface coatings to be used in the gas turbine high temperature zones. The challenges facing this evolution of the technology lies in preventing the rapid degradation of the materials subject to the extreme temperatures noted below.

The materials issue is further complicated when the machines burn different fuels – high Hydrogen syngas in the case of IGCC plants. The temperatures are higher and the issue of hydrogen embrittlement of the metals is a new risk for this technology and managing this is the subject of current research and development.

The development of low NOx technologies for the gas turbine to address the environmental concerns is well advanced. Gas Turbines regularly achieve NOx emissions 60-80% below those from existing coal fired plants in Australia.

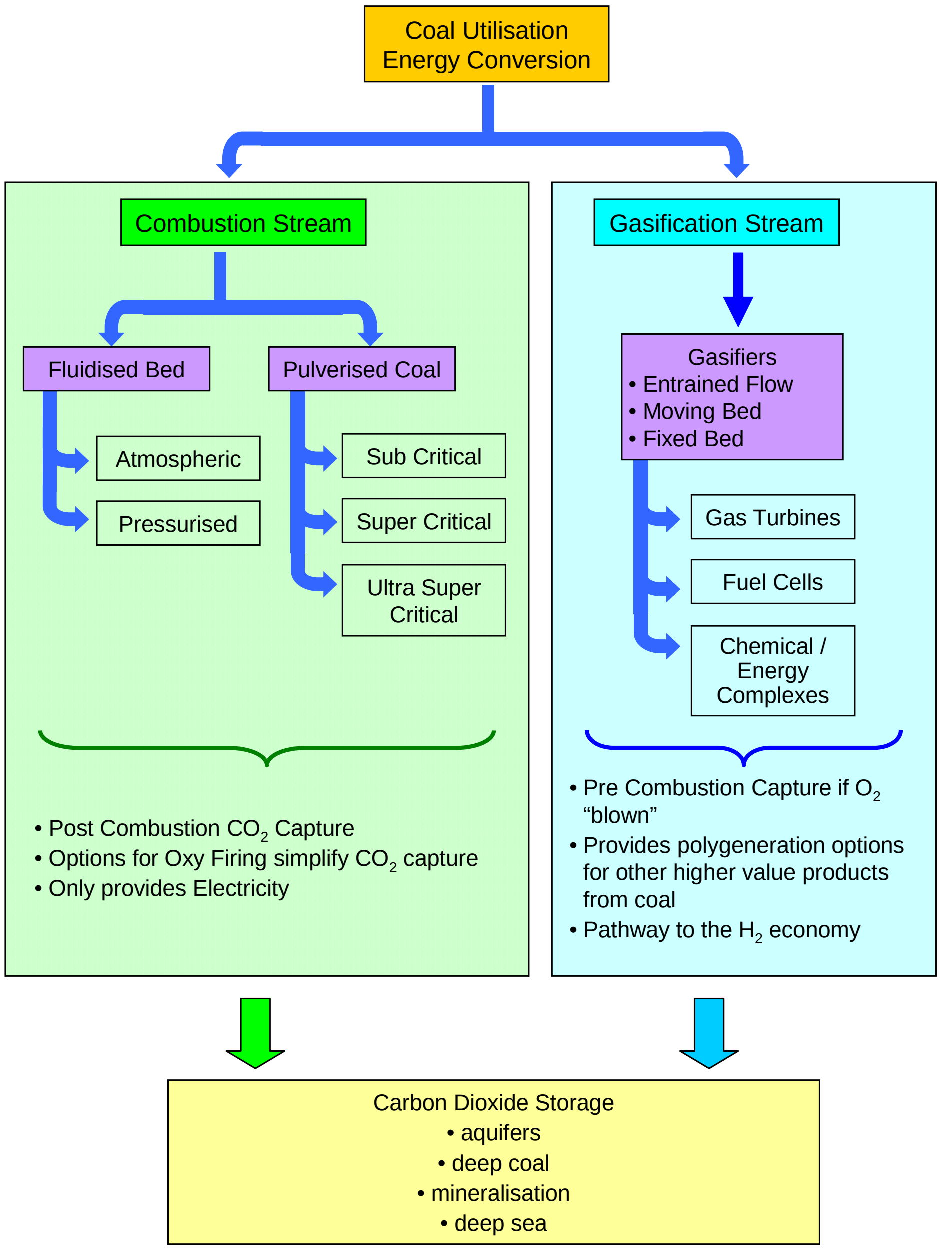
Table – Impact of Temperature and Scale on Gas Turbine Efficiency

Combined cycle plant designation	Net Power Plant Power(MW)	Net Plant heat rate LHV (kJ/kWh)	Thermal efficiency (%LHV)	Firing Temperature (C)
6B	64.3	7340	49.0	1004
6FA	107.4	6775	53.2	1327
9E	189.2	6935	52	1124
9EC	259.3	6660	54	1204
9FA	390.8	6350	56.7	1327
9H	480	6000	60	1426

Source: GE Combined Cycle Product Line and Performance GER-3567H

2.1.2. **Coal**

Coal fired plant falls into two streams as illustrated in the diagram below. The combustion stream is based around the traditional Pulverised Fuel boiler and the Fluidised Bed Boiler and has as its flagship the ultra supercritical technology, which can achieve thermal efficiencies of approximately 40%. In the search for increasing efficiency scale is important for the central station (>15MW) installations with the larger generating units able to achieve higher efficiencies.



- **Ultra supercritical Pulverised Fuel (USC)**

  Ultra supercritical has no strict definition, however a steam cycle above 22MPa in pressure and 580C in temperature is considered by most to be ultra supercritical. The push to operate coal fired plant at increasingly higher temperatures and pressures is based on the fact that greater efficiencies can be extracted from the thermodynamic cycle as temperatures and pressures increase. The main challenge facing this technology is the ability to manufacture materials that can operate reliably at these temperatures and pressures. Plans at the moment see the technology progressing to temperatures in excess of 700°C.

  There are in excess of 20 USC plants successfully in operation in Europe and Japan, although these are at the lower end of the ultra supercritical temperature range ~ 600°C. . The cost graphs give an indication of the cost per MWh for the ultra supercritical plants although these costs assume water cooled condensers. Dry cooling and ambient temperature will have a negative impact on both efficiency and costs.

  USC plants have a lower carbon intensity than the subcritical or supercritical plants. Most new coal fired plants in the US and Europe are built with flue gas desulphurisation (FGD) and selective catalytic reduction (SCR) for the control of SOx and NOx respectively and these installations are assumed in the costs above.

- **IGCC**

Coal gasification based generation has some inherent advantages over combustion based technologies in responding to the environmental drivers, because the fuel is converted to a gas, which has inherently lower emissions. Particulates and SOx are removed as part of the gasification and fuel cleanup process. IGCC also enables potentially lower cost CO2 capture, but to achieve this the hydrogen content of the syngas must be increased via the shift reaction. High hydrogen syngas presents new challenges for gas turbines due to high flame temperatures, and hydrogen embrittlement as discussed previously.

Despite this, the technology is expensive, and relies on the further evolution of gasifier technology, CCGT technology and the enabling technologies (gas separation, cleaning and processing) and a value on carbon for it to compete with other technologies in a carbon constrained world. Some work has been done which indicates that with a number of technology improvements the capital cost of an IGCC with carbon capture has the potential to fall by some 40-50% based on technology advances in major plant components (gasifier, CCGT, gas separation and processing). A large part of the effort involved in developing this technology is motivated by the ability to produce a range of other high value energy products from syngas and reduce dependence on oil imports in the case of the USA.

- **Oxy Firing**

  Oxy Firing can be applied to either the combustion or gasification streams. It involves the combustion occurring in the presence of pure oxygen rather than air. The advantages of this methodology are

  - Inherent control of NOx (the ambient nitrogen is removed from the combustion process)
  - Reduced volumes of gas through the boiler or gasifier – resulting in potential capital cost savings
  - Increased concentration of CO2 in the output gas (no diluting nitrogen) which improves the economics of carbon dioxide capture. In an oxyfired pulverised fuel plant the flue gas consists of almost pure CO2, thereby dispensing with the requirement for chemical separation of CO2 from the flue gas.
  - The base technology (gasification or combustion) remains essentially unaltered.

  The disadvantage at this point in time is that the economics of oxygen production is almost cost prohibitive. Development of low cost membrane technology for the separation of oxygen from air would greatly assist oxy-firing realise its potential and also improve the economics if IGCC.

- **Fluidised Bed Combustion**

Fluidised bed combustion is a method of burning coal in a bed of heated particles suspended in a gas flow. At sufficient flow rates, the bed acts as a fluid resulting in rapid mixing of the particles. Coal or other fuels are added to the bed and the continuous mixing encourages complete combustion and a lower temperature than that of PF combustion. As a result of the lower temperature NOx emissions are lower than PF boilers. Fluidised bed combustion is following the same pathway as the pulverised coal boilers in the quest for increasing efficiency, with stated intentions to take the technology to supercritical and ultra supercritical pressures and temperatures. This technology has not been adopted widely in Australia for mainstream power generation. The only large scale plant using fluidised bed technology in Australia is the 150MW Redbank Power Station near Singleton in NSW. This plant was completed in 2001.

2.1.3. Hydrogen

Hydrogen is an “energy carrier” rather than an energy source or technology, but has the advantage over electricity in that it can be more easily stored and has virtually no harmful emissions when used (only water). Hydrogen can be derived from coal or (more commonly) natural gas. It can then be used in a number of chemical or energy processes. The application of fuel cells in vehicles is seen as the way to address the emissions (CO2 and NOx) from the transport sector.

- **Fuel cells**

There are a number of different sorts of Fuel cells as indicated in the table below. While the technology is proven – the cost is currently high. They have no emissions other than water vapour. The efficiencies in the table below assume that electricity is the only product. If the available heat is used for other purposes then overall efficiencies of 80-90% can be achieved. Trials of fuel cells in motor vehicles have been proceeding for a number of years with considerable success (e.g. Perth bus fleet). The key challenge other than cost revolves around the safe storage and transport of the fuel.

Fuel Cell Types

Fuel Cell Type	**Operating Temperature**	**Efficiency**	**Fuel**
Polymer Electrolyte	80°C	40-45%	H_2
Direct Methanol	50-100 °C	30-40%	MeOH
Phosphoric Acid	160-220 °C	40-45%	H_2
Alkaline	120-250 °C	60%	H_2
Molten Carbonate	600-650 °C	50%	Syngas
Solid Oxide	700-1000 °C	50-55 °C	CH_4, Syngas

2.1.4. CO2 Capture and Storage

The progression of any of the fossil fuel technologies to low carbon emissions is dependent on the development of carbon capture and storage. While carbon capture has been in existence to service the food industry it has been deployed at small scale, for a high value product.

Long term CO_2 storage is a technology still in the early stages of development.

- **Capture Technologies**

Capture technologies to date have largely been based in the use of amines solvents, which can absorb CO_2 from a gas stream. These are expensive both from a purchase point of view and also in terms of the energy required to regenerate the solvent. As a result of their use a waste product is produced that has the potential to be injurious to human heath and needs careful management from an environmental perspective. Research and development seeks to address these issues and includes development of:-

- Enhanced solvents and adsorbents to lower regeneration energy and chemical losses
- Membranes for gas separation
- Improved cryogenics

- **Storage Methodologies**

  There are a number of potential storage areas for CO_2. These include saline aquifers, deep coal systems, and mineralisation. The key challenge for the adoption of these technologies is currently the lack of knowledge surrounding the available storage capacities and costs of using any of these systems and the ability to accurately assess the risks.. The response to these issues is still in the R&D phase, and involves

  - Technologies for Assessing Sites for CO2 Storage
  - Reservoir/Seal Characterisation and Stratigraphy (determination of the properties of the geological layers)
  - Short and Long-Term Reservoir Modelling
  - Monitoring and Verification
  - Risk Assessment Processes

2.2. Nuclear

Interest in Nuclear is rising as the requirement to limit carbon emissions becomes real and as value is placed carbon. New plants are now starting to be built after a 20 year hiatus during which existing plants had their capacity extended, but very few new plants were committed (other than in France and South Africa). New variants on the nuclear technologies – the Advanced Boiling Water Reactor and the Economic Simplified Boiling Water Reactor as well as newer reactor types such as the pebble bed reactor are appearing to address the cost and safety issues of the past. The key issue facing all of the countries currently with, or deploying a nuclear fleet of generators is the long term and safe storage of the resulting nuclear waste. Nuclear technology, more than most, will find it difficult to make large step changes, given the risks (both real and perceived) and the high capital intensity of the technology.

2.3. Energy Storage

Electricity is an instantaneous use commodity and cannot be stockpiled like other energy commodities such as coal or oil. Supply and demand must be balanced at all time to ensure the integrity of the entire power system. Given that electricity demand varies throughout the day, with low demand during the overnight period and high demand during the day, supplies must be available to meet the peak demand, which means that some of this capacity is underused during the low demand periods, leading to sub-optimal use of assets.

Energy storage technologies harvest energy when there is excess supply and store the energy in a form that can be released again later when needed or is more profitable to do so. An example is the Wivenhoe pumped storage scheme, where water is pumped to the upper storage dam during the low demand periods, and hence likely low spot prices, which will be released for electricity generation through the turbine connected to the same generator shaft during the high demand, and likely high prices, periods during the day. In other words, energy storage facilities allow time-shifting of the electricity supply curve for system benefits, be it security or stability of supply or generation system economics.

Energy storage schemes can have many roles in the electricity supply value chain:

- generation sector (where energy is typically stored for long durations of several hours up to several days and a high utilisation factor is required)
- the transmission and distribution sector (where it is stored for shorter durations, typically seconds to hours, to improve power system stability) and;
- the end user (where it is used to improve the customer's power quality and reliability).

In this discussion, we limit ourselves to the technologies with application to the generation sector.

A short to medium term application of the energy storage technologies is their ability to firm up the output from otherwise intermittent or renewable generation sources such as wind farms, thus allowing much higher level of penetration of these resources in the electricity grid.
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The key issues with energy storage technologies at present are

- the capital costs of the storage devices
- the small scale of some of the devices
- and the loss of efficiency that occurs when transforming energy into another form of energy and then converting it into electricity.

Energy storage technologies can be classified by the form in which energy is stored. Typically, for long duration storage technologies, these include:

- **Electro-chemical energy storage**

Electricity is transformed into chemical energy for storage, the simplest of which is the battery. Batteries can be charged and discharged as required to meet demand. Performance of potential technologies are included in the table below. Whilst some of the technologies have been commercially available, the more exotic and longer lasting ones are still under development testing.

Battery technology key performance characteristics.

Technology	**Capacity – MW**	**Life cycle (charging/discharging)**
lead acid	> 10 MWs	500 to 1500
nickel cadmium	10 MWs	2500
sodium sulphur	1 – 10 MWs	2500
sodium nickel chloride	10 – 100 kw	2500 +
lithium ion	~10 kw	1000 to 10000

- **Thermal energy storage**

Heat energy (which can be from cheap electricity or from other sources such as solar) is stored in materials at high temperature inside insulated areas and will be subsequently released for electricity generation via conventional steam generation facilities. Currently there are a number of research activities in material for storage, for example:

- Molten salt
- Concrete
- Phase change materials; and
- High purity graphite.

- **Potential energy storage**

Electricity is used during the charging cycle to increase the pressure (or potential) in the storage reservoir, which will then be used to drive the convention turbine/generator sets. Two common applications are water pumped storage schemes and Compressed Air Energy Storage (CAES) schemes. Spinning flywheels are another form of potential energy that has been used.

The pumped storage schemes are the most common application to date in the generation sector, with unit sizes up to 1000MW being possible. In Australia, Wivenhoe is the largest installation (2 x 250MW low head units). Global capacity for new pumped storages is believed to be rather limited as good sites have almost been exhausted. Tough environmental conditions add to the already high costs of construction and marginal geographic locations, make it very difficult for viable new investments in this area, particularly in deregulated electricity markets.

CAES is the other commercially available technology that can match the scale of pumped storage schemes. In CAES plant, electricity is used to drive the compressor of the GT to increase the pressure of the air storage reservoir, which can be man-made caverns, porous rock formations, used salt mines or depleted oil and gas reservoirs. The high pressure compressed air will then be fed to the same GT for combustion and electricity production when needed.

2.4. Renewable Technology Response

The key advantage of renewable energy is inherently low and in many cases close to zero carbon emissions. The key challenges are lowering cost and addressing intermittency. Many renewables are widely dispersed and lend themselves to distributed generation supported by "smart grids" that can quickly respond to changes in demand and generation output.

2.4.1. **Wind**

Wind technology is now mature, but incremental advances continue to be made. The general trend over the last 20 years has been to larger machines on taller towers combined with refinements in blade and electrical design. These improvements assist in the conversion of energy at sites that were considered inadequate for the earlier generations of wind turbine. Wind turbine sizes have increased from 150 kW to 5000 kW (prototype) over this period. Economies of scale, mass production and improvements in efficiency, construction methods and maintenance practises have significantly lowered the cost of generation. On the best wind sites, in favourable markets, wind competes directly with fossil fuels, without subsidy. Supportive government policies and financial incentives have allowed more widespread deployment of wind power and ensured continued development to keep costs falling. World wide Installed capacity is now more than 60,000 MW and has been growing at 15 % pa for the past 5 years. The world Wind Energy Association expects 120,000MW of wind power to be in operation by 2010.

The ultimate size of wind turbines is likely to be limited by the strength of materials, construction techniques and overall installation logistics. Machines of over 5MW are now in construction. With land based wind sites now becoming scarce in Europe, attention is focussing on offshore sites which present a new range of design and maintenance challenges.

As wind penetration continues, grid interconnection and stability issues emerge, due to wind's intermittency. Up to 10% penetration is generally manageable, and much higher levels are possible with active grid management and transmission system upgrades. This is highly dependent on the nature of the local electricity grid and is a hotly debated topic between transmission planners, network operators and wind project proponents. In Denmark wind already provides 25 % of installed capacity and 14% of total electricity generated, with much higher levels of generation in some regions. In Germany, where wind is less evenly distributed, wind provides 15% of installed MW capacity with plans to triple this by 2015 and to supply 14% of total electricity generated.

Australia is a long way from reaching 10% penetration on average (currently less than 2%), and may not do so as a result of transmission issues such as have already emerged in SA where a large number of wind farms have been constructed, with many more approved.

2.4.2. **Solar Photovoltaics**

Photovoltaics (PV) are a mature and proven technology, but the current cost is still high. Despite this and driven by the significant potential for the technology in the longer term, the PV market has been growing at more than 30% pa for the last eight years, albeit from a very small base. There is now over 1100 MW of PV installed worldwide. This has been primarily driven by highly supportive government policies and financial incentives in Japan, Germany and California.

PV is well suited to distributed generation and building integration as it is modular and can be implemented in almost any size increment.

PV is still very expensive by Australian standards at a price upwards of AUD $400/MWh. However, in Japan, where domestic electricity prices are high and interest rates low, PV is now economic on new houses, without subsidy.

There is great potential for further cost reduction in the longer term. The current installed costs are around AUD$6-8/watt for a cell around 12% efficiency. Over 90% of the current PV market is based on first generation *"crystalline silicon"* solar cells. While costs will continue to fall as production ramps up, reductions for first generation cells will be limited by the inefficient use of high cost silicon and a complex manufacturing process.

Focus is now on commercial delivery of second generation *"thin film"* cells, which have lower efficiency (6 to 10%), but much lower material use and simplified manufacturing processes. Some thin film cells are currently on the market, but they still have high potential for cost reduction through improved and higher volume manufacturing processes. Target costs are in the $0.5 to $1 /W range, which would make PV competitive with coal fired power generation in Australia.

Third Generation cells that combine high efficiency with minimal resource use and are suitable for low cost manufacturing processes, akin to printing, are now under development in the laboratory. The cost target is less than $0.5/W.

2.4.3. **Solar Thermal Electricity**

Solar Thermal Electricity Plants concentrate the suns energy with mirrors to generate very high temperatures, which is ultimately used to generate steam that can be used in conventional steam turbine generators. The technology is also known as concentrating solar power (CSP)[4]. The basic technology is well proven and 354 MW of solar thermal has been operating in the US since 1991. No commercial plants have been built since then, however, several demonstration plants have, and supporting technology development has continued. There has been a significant increase in activity in recent years with several new demonstration/commercial plants now committed and expected to be completed in the next few years, driven primarily by government initiatives. The US DOE has a target of 1000 MW to be installed in the US by 2010[5]. The CSP Global Marketing Initiative (GMI[6]) has set a target of 5000 MW to be installed globally by 2015, by which time they predict CSP will be competitive with fossil fuel technologies. An assessment of parabolic trough and power tower technologies for the US Government's , National Renewable Energy Laboratory (NREL) by Sargent and Lundy, predicted cost

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[4] CSP also includes concentrating PV and Stirling engine technologies that don't use a thermal or steam cycle. They are linked however because they all concentrate the suns rays using similar collector technologies.

[5] http://www.nrel.gov/csp/1000mw_initiative.html

[6] The Concentration Solar Power Global Market Initiative is an international public-private partnership with the aim of fostering the development of CSP by providing information, policy frameworks and a collaboration network. It is registered as UNEP Market Facilitation WSSD Type –II Public Private Partnership. The primary drivers are the European Solar Thermal Power Industries Association, IEA Solar PACES, and the US Solar Energy Industries Association Refer with support from various governments, UNEP and GEF. See http://www.solarpaces.org/GMI.HTM

would fall from around US $120/MWh with current technology to around US $60/MWh by 2020, given global installation of 2800 MW of plant.

A key focus of development is the addition of thermal storage that can extend the overall "capacity factor" providing better capital utilisation. A non storage plant that tracks the sun will achieve around 25% capacity factor. Addition of thermal storage using molten salts, hot water or oil can economically extend the capacity factor to 60% and provide reasonable control over generation output. Energy can be stored from the day for use in the late afternoon and evening peak. Molten salt and other thermal storage systems have been demonstrated, but further development is required to prove reliability and integration issues.

Australia has long been a world leader in the development of solar thermal technologies although most recent activity is occurring overseas, where incentives are greater. The exception is Australian company Solar Heat & Power who are currently developing a very promising collector technology known as the Compact Fresnel Linear Reflector (CFLR). A feedwater pre heating demonstration project at Liddel Power Station in NSW is currently entering into Phase 2 with the proponents claiming the cost of power will be less than $80/ MWh, competitive with other MRET sources.   They claim a stand alone version of the technology, with underground cavern hot water storage, could be competitive with coal fired power in the US by 2010[7]

Another area of active development is in solar assisted hybrid NGCC and pulverised coal plants, which are further discussed below.

2.4.4. **Geothermal (Hot Dry Rocks)**

Traditional geothermal captures the heat from steam issuing from areas of volcanic activity with heat exchangers and then uses traditional steam turbine technology to generate power.

Australia's geothermal resource is in the form of hot dry rock. The challenge is to extract the heat from the rock several kilometres underground. This entails creating an underground heat exchanger by carefully horizontally fracturing the rock between two drilled wells to create a flow path for water. By circulating water through the hot rock the heat is brought to the surface.

Geodynamics is currently a world leader in the development of this technology, with a demonstration project underway in the Cooper Basin.

This technology is at the very early stages of its development. Key issues to be resolved include

- The ability to successfully access the hot rocks – the current demonstration has struggled with many equipment failures
- Lowering the risk associated with the creation of an effective heat exchanger (through fracturing of the rock) and minimising water loss in operation.

2.4.5. **Wave**

Wave power generation is in its infant stage where wind power was in the 1970's. Some 18 consortiums are currently pursuing a range of different design solutions. The most promising option appears to be the surging device called "Pelamis" of 750 KW, destined to form the first commercial wave farm of some 23 MW in Portugal. An oscillating water column device of 500 kW capacity is currently being tested in Port Kembla, Australia. Floating buoy type wave energy converters are being pursued by several developers.

[7] From Mills 2004, for a 240 MWe CLFR plant with storage to achieve up to 68% capacity factor.   These cost projections are considerably lower than NREL 2003

2.4.6. **Tidal**

Tidal power generation is a special field of hydro power generation which can be categorised into tidal storage and tidal current. There is a small number of working tidal storage plants around the world. A large installation of 60 MW was proposed for Doctor's Creek, an ideal tidal plant location near Derby in WA. The challenge of the tidal current technology is to harness vast, relatively slow moving tidal currents. There are two small companies in Australia actively progressing the development of tidal current devices.

2.5. Technology Hybrids

2.5.1. **Integrated Gasification Fuel Cell (IGFC)**

IGFC is a potential future development utilising coal to produce hydrogen which is then utilised in fuel cells. There is some attraction to this concept given the extremely high efficiencies capable from a fuel cell (80-90%) in comparison to those capable from even proposed gas turbine technologies (60%). The key challenges are scale, both for the fuel cell and for the syngas cleaning and hydrogen separation technologies. As with other fossil fuel based technologies, the success of this technology in a carbon constrained world is based on successful carbon capture and storage.

2.5.2. **Solar Thermal / PF Boiler Integration**

The CO2 emission intensity of conventional coal fired power stations can be lowered by using solar thermal to heat feedwater and offset coal use. The solar fraction that can be easily added is limited to around 20%, but this is still significant amount of energy and provides the lowest cost use of direct solar energy. A similar concept can be used to integrate solar thermal with CCGTs. Steam integration & plant control are the major issues that require demonstration. Retrofit to existing power stations will likely be limited by availability of suitable land with adequate solar resources around the power station. The Liddel Power Station Project, already mentioned, could be the first successful commercial retrofit. There maybe potential for a similar project at SPS.

2.5.3. **CCGT/ PF Boiler Integration**

There are a number of plants world wide where the waste heat from a gas turbine installation is used to supplement the feedwater heating in a normal pulverised fuel boiler. The principle is very similar to that in 2.5.2 above. The attraction of this integration is the synergy between the two installations has the potential to deliver better capital efficiency for the integrated plant than two independent installations. These installations have not been proposed to manage CO2 emissions to date, but certainly provide an ability to generate electricity at a carbon Intensity between that of a CCGT and traditional coal using well known and low risk technologies. Hybrid gas/coal installations could provide a coal burning bridging technology for deployment prior to the widespread commercial competitiveness of IGCC with CCS technology.

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