The Short-Term Potential for Renewable Energy and Demand Reduction to provide Base-Load Power in New South Wales

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Contents

Executive Summary

This report was originally written as a submission to the 2007 Owen inquiry into the need for and means to supply base-load electricity for New South Wales. However, the report was not completed in time to be submitted and so it is presented as a discussion paper. It considers the potential for renewable sources of electricity and some demand reduction measures to substitute for a hypothetical proposed new 1000 MW conventional coal-fired power stations over two time periods in New South Wales: 2008–2014 and 2015–2020.

The study refutes the base-load fallacy (explained below) and then estimates the potential for various renewable energy technologies, their costs, the impediments to their further development, and the policy options required to obtain the technical potential. It also points out briefly the value of combining efficient energy use and renewable energy, and comments on the need to reduce demand growth by additional measures to efficient energy use.

Renewable sources of electricity are not receiving proper consideration, partly because of the widely disseminated fallacy that renewable energy cannot supply base-load power, that is, power 24 hours per day, seven days per week. In reality bioelectricity, solar thermal electricity with thermal storage and geothermal power can all be operated as base-load.

In addition, it is shown in this report that large-scale wind power at geographically distributed sites can also substitute for some conventional base-load power stations. Depending upon the degree of penetration of wind power in the electricity grid, wind power may or may not require some additional partial back-up with peak-load generators (e.g. gas turbines or hydro) that are operated infrequently. When wind contributes up to 20% of grid energy generation, the costs of back-up are quite small.

The first time period considered in this report, 2008–2014, represents the approximate time over which a large coal-fired power station could be planned, built and commissioned. Over this period, the principal renewable energy sources available in NSW are wind power and several low-cost forms of bioelectricity. Once the decision is made, much wind and bioelectricity can be installed within 2–3 years.

During the first period about 1200 MW of wind power capacity could be installed at the best (Category 1) sites in the State, with an annual average power output of 360 MW, corresponding to annual electrical energy generation of about 3 TWh (3000 GWh). This estimate is based on actual proposals by wind farm developers. Average costs of electricity are likely to be initially in the range 8–9 c/kWh, based on the levelised annuity formula with 8% discount rate, and will decline with time and scale of installation. This relatively small penetration of wind power into the NSW grid could be considered to be equivalent to a reliable source with capacity of about 360 MW and would not require any additional back-up.

In addition, it is estimated that, in the first period, 1277 MW of bioelectricity capacity, with annual electricity sent out of about 8.7 TWh, could be built to combust landfill gas and agricultural and forestry residues. This estimate assumes drought conditions similar to those in 2006. In ‘normal’ rainfall years, an additional 2.6 TWh per year would be expected from wheat stubble. While landfill gas and co-combustion of biomass in coal-fired power stations are expected to be either competitive or almost so with conventional coal power, initial prices for electricity generated from agricultural and forestry residues are expected to be in the range 10–15 c/kWh. Bioelectricity can be operated as base-load.

Thus total potential annual electricity sent out to the grid from wind and biomass by 2014 is estimated be 11.7 TWh. For comparison, a 1000 MW black coal-fired power station with capacity factor 85% would generate about 7. 5 TWh (7500 GWh) per year and would send out to the grid 6.9 TWh/yr if it is water-cooled and somewhat less if it is air-cooled. Thus wind and bioelectricity together could send out by 2014 the same annual quantity of electricity as a new 1700 MW coal-fired power station.

In the second period, 2015–2020, there is of course less certainty about potential resources and corresponding prices. However, it is very likely that, following current trends, the global market for wind turbines will have grown substantially and hence their capital costs will have declined significantly. The expected result is that lower wind speed (Category 2) sites in the NSW high country could be utilised without any increase in costs, compared with those of the earlier Category 1 installations. Category 2 wind power sites could supply possibly 15 TWh per year, that is, five times the annual electricity generation from Category 1 sites. Such a large amount of wind power generated from geographically distributed sites would require a small amount of dedicated peak-load back-up capacity, either in the form of new gas turbines or a dedicated amount of hydro capacity. This back-up would only have to be used infrequently.

In addition, it is likely that, in the period 2015–2020, more efficient means of combusting solid biomass will be available (in particular, gasification followed by combustion of the gas) and it is possible that dedicated biomass crops with multiple economic benefits, such as oil mallee, will be widely available at prices competitive with the combustion of biomass residues.

Also in 2015–2020 it is possible that low-cost solar thermal electricity with thermal storage and some hot rock geothermal will be available as base-load. Table ES1 summarises the potential for renewable energy in NSW in 2014 and the additional potential in 2020.

Table ES1: Potential electricity sent out to the grid in NSW by renewable energy by 2014 and 2020

Technology	**Capacity in 2014** (MW)	**Electricity sent out in 2014** (TWh)	**Additional capacity in 2020** (MW)	**Additional electricity sent out in 2020** (TWh)
Wind	1200	3	8600	15.0
Biomass	1277	8.7	550	3.9
Solar thermal	small	small	1000	7.5
Solar PV	small	small	1000	1.4
Hot rock geothermal	small	small	500?	3.5?
Total base-load	**2477** (of which about 1637 is ‘firm’)	**11.7**	**12 150** (of which about 5270 is ‘firm’)	**30.0** (excluding PV)

Notes: These results are additional to those for 2006. It is assumed conservatively that the contributions from solar thermal electricity, solar PV and hot rock geothermal will be too small to be counted in the 2014 totals in Columns 2 and 3. Solar thermal electricity is assumed to have overnight thermal storage and gas back-up, giving it a capacity factor of 85%. Although solar PV, with capacity factor 16%, is not counted in the total base-load, its contributions are valuable as intermediate- and peak-load. The 2020 entries are much less certain than the 2014 entries, with the geothermal contribution being very uncertain.

None of the above renewable energy supply technologies can compete economically with conventional coal power in NSW, which does not as yet have the environmental and health costs of its use included in its price. However, in a greenhouse-constrained world, in a State where water is a scarce commodity, and under contracts where power station developers are not protected by government from financial risks, it is quite feasible that carbon and water pricing would make wind power and some forms of bioelectricity economically competitive with conventional coal power before 2014.

The policies recommended to facilitate the rapid growth of renewable and other cleaner sources of electricity are as follows:

General market pull

1 NSW Government to double NRET and introduce the requirement that this target must be supplied from renewable energy sources in NSW only.

2 Federal Government to increase MRET substantially. Both NRET and MRET to be retained until the carbon price (see Policy Option 6) has risen to above $40 per tonne of CO_2 and remained continuously above that level for at least 12 months.

3 Federal, State and Local Governments to increase their use of Green Power for their own operations in steps until they are using 100% Green Power.

4. NSW Government to impose a greenhouse intensity limit of 0.4 tonnes of CO_2 emission per MWh of electricity generation on all new base-load power stations.

5 NSW Government to pass legislation ensuring that it will not to cover the carbon risk of any new or refurbished power station, nor permit this risk to be imposed upon taxpayers or electricity consumers.

6 The Federal Government to implement an emissions trading scheme of the cap and trade type. To be effective the scheme should have the following properties:

- Broad scope: all electricity generation, major industries and transport should be covered initially and agriculture should be brought in as soon as practicable.
- The cap on emissions should be sufficiently tight to push up the carbon price to at least $40 per tonne CO_2 within three years of operation of the scheme.
- At least half the permits to be issued initially by auction. Within three years, all permits to be issued by auction.
- Permits to be temporary licences to emit, not permanent property rights.

7 NSW Government to provide transmission links for wind farm developers in a region, provided the developers participate in a coordinated bulk purchase of wind turbines at discount price. This could be funded by a levy on electricity prices.

8 NSW Government to increase charges for water use by all generators to a realistic market value that takes account of the increased prevalence and severity of droughts.

Wind power

9 NSW Government to fund, commission and publish a site-specific wind energy survey of NSW, designed to identify additional Category 1 sites that are not included in current proposals.

10 Federal and State Governments to implement grid management policies that allow the incorporation of 24-hour wind farm output forecasting data.

11 Federal and NSW Governments to extend economic incentives for small solar electric systems to small wind systems.

12 NSW Government to streamline the planning process for wind farms, incorporating a mandatory community consultation process, a minimum distances for large (0.5 MW or greater) wind turbines from residential buildings of 500 m and a fee to be paid by the developer to local government for community development (suggested to be $5,000 per installed megawatt for wind farms larger than 10 MW and zero otherwise).

Bioelectricity

13 NSW Government to provide transmission/distribution links for bioelectricity power station developers in a region, funded by a levy on electricity prices.

14 NSW and Federal Governments to fund and publish a detailed bioenergy survey of NSW, encompassing the potential for all uses of biomass. This project could be linked to the Bioenergy Atlas of Australia.

15 NSW and Federal Governments to fund research on the production, storage, gasification and combustion of various sources of biomass that are prevalent in NSW.

16 Federal Government to fund the development of a Bioenergy Roadmap for Australia, which considers the situation of individual States as well as the nation as a whole.

17 NSW and/or Federal Governments to introduce Biomass Establishment Grants for growing energy crops that would assist in limiting dryland salinity, erosion and other forms of land degradation. These grants and other contributions could be funded from a levy on supermarkets.

18 NSW or Federal Government, whichever is funding farmers for growing crops for bioenergy and land remediation, to set up an organisation to ensure that biomass production is ecologically sustainable.

Solar electricity

19 Federal and State Governments to allocate increased R, D & D funding specifically for solar thermal electricity.

20 NSW Government to implement feed-in tariffs for solar electricity.

21 To support R & D, Federal Government to allocate $3 million per year for the next 7 years to keep Australia in the forefront of world research on solar electricity from thin films, including crystalline silicon on glass (CSG) cells at UNSW and Sliver® cells at ANU. This amount should be additional to any funding from the Australian Research Council research grants.

22 To provide market pull, the Federal Government fund an expanded photovoltaic rebate for 100,000 homes of $8 per peak watt (maximum $8000 per household) over the 5 years from 1 July 2007. The proposed subsidy, amounting to a maximum of $800 million over 5 years or $160 million per year, is small by overseas standards and indeed by the proposed federal funding of coal with CCS in Australia.

23 NSW Government to disseminate widely smart meters, together with time-of-day electricity pricing, to assist residential solar PV electricity (and energy conservation), because it would take account of the high economic value of solar electricity during summer peak demand.

Demand reduction (other than energy efficiency)

In the long run, efficient energy use and renewable energy will not be sufficient for reducing greenhouse gas emissions. The following policies, additional to policies to encourage efficient energy use, are recommended to assist in cutting demand growth. All can contribute to the reduction in base-load electricity supply.

24 NSW Government to mandate that all air conditioners be installed on a dedicated circuit with a smart meter, time-of-day pricing and accredited Green Power with 100% wind or solar power.

25 NSW Government to ban off-peak electric hot water rates as the first step in phasing out electric resistance hot water heaters.

26 NSW Government to hold a public enquiry into the proposal to replace stamp duty on house sales with an alternative tax that is not environmentally damaging.

27 NSW Government work with the States and Federal Government to reform the National Electricity Market (NEM) to transform it into a market for energy services.

1. Introduction

The New South Wales Government is considering options for a new base-load power station. To this end it has established an inquiry by Professor Anthony Owen into the need for and means to supply base-load electricity for NSW[1]. This report, on the potential for renewable energy and demand reduction to contribute to base-load power supply in NSW, was originally prepared as a submission to the Owen inquiry, but was not completed in time to be submitted. Increasing public concern about greenhouse gas emissions from coal-fired power stations is the primary motivation for the present study.

A base-load power station is one that is in theory available 24 hours a day, seven days a week, and operates most of the time at full power. In practice, base-load power stations break down from time to time and, as a result, can be out of action for weeks at a time. In NSW all large (1000 MW or more) base-load power stations are coal-fired.

Coal-fired power stations are by far the most polluting of all power stations, both in terms of greenhouse gas emissions and local air pollution. Coal power is the biggest single contributor to greenhouse gas emissions, both in NSW and in Australia as a whole. There are additional concerns about coal power that are relevant to its comparison with cleaner alternatives. All existing NSW coal-fired power stations use substantial amounts of water for cooling. A large fraction of these power stations use fresh-water and two of these are at present drawing upon Sydney’s drinking water supply. There is growing community concern about the land-use impacts of coal-mines and coal-fired power stations. These concerns have both environmental and economic implications.

Furthermore, in the context where a carbon emissions trading scheme (ETS) is operating in the European Union, another is being planned by a group of US states, and both major Australian political parties are planning an ETS, there is also considerable financial risk in building a conventional coal-fired power station.

These impacts and risks of conventional coal power strengthen the case for renewable energy sources. But first renewable energy sources must be placed into the context of other clean energy options.

The cheapest alternatives to coal are the myriad of technologies and processes involved in efficient energy use (discussed elsewhere) and in reducing demand growth by other means (see Section 8). These are also the fastest means of reducing emissions. To further reduce the demand for base-load electricity, these can be supplemented by the widespread dissemination of solar hot water. Fuel switching from electricity to natural gas at the point of use, especially for heating and cooling, can further reduce the demand for electricity and greenhouse gas emissions. On the supply side, the cogeneration of heat and electricity at the points of use, using gas as a fuel, is a highly efficient system, which can also reduce the demand for grid-connected base-load electricity. However, natural gas could become scarce and expensive in the second half of the 21st century, if not before, while renewable sources of energy are everlasting, provided that they are converted into useful energy at an appropriate rate.

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[1] http://www.premiers.nsw.gov.au/WorkAndBusiness/DoingBusinessInNSW/OwenInquiryIntoElectricitySupplyInNSW.htm accessed 26/6/07.

In theory, assuming low public opposition, a new conventional coal-fired power station of 1000 megawatts (MW) electrical could be operational in NSW by 2014. Therefore, this report investigates the potential contributions of renewable energy for 2014. Since the issues of new base-load electricity and greenhouse gas emissions are unlikely to be resolved by 2014, the potential contribution of renewable energy by 2020 is also considered briefly.

Renewable energy sources are treated here in order of present generation cost, commencing with the lowest. Thus the order of treatment is wind energy, bioelectricity, solar thermal electricity, solar photovoltaic (PV) and hot rock geothermal (which is not yet generating power). The ranking is actually more complex than this because, for each individual renewable energy source, there is a range of costs and a corresponding range of potential contributions to energy generation and greenhouse gas reduction. For instance, the least-cost forms of bioelectricity are landfill gas and the co-combustion of biomass in coal-fired power stations. But, although the costs of these bioelectricity sources are generally lower than those of wind power, their potential contributions are much smaller than that of wind power. The next least-cost contribution to bioelectricity is from the combustion of existing agricultural and forestry wastes, a large potential contribution, but generally somewhat dearer than wind power. Bioelectricity from dedicated crops is likely to be more expensive than from residues, although the potential contribution is also large. In such cases, we consider the least-cost contributions as those that could feasibly be installed by 2014 and the (currently) more expensive forms to be installed in the period 2015–2020.

Apart from efficient energy use and other measures for reducing electricity demand, no existing clean electricity alternative can compete economically with conventional ‘dirty’ coal power. This is as expected, since the price of conventional coal power does not include its environmental and health costs. To provide a market in which no more conventional coal-fired power stations are built, carbon pricing and specific renewable energy subsidies are required.

In mid-2007, there is already a small NSW Mandatory Renewable Energy Target (NRET)[2] and the policy that, if the ALP gains government in the forthcoming election, the national Mandatory Renewable Energy Target (MRET)[3] will be increased. In addition, both the Federal Coalition Government and Opposition support the development an ETS that should be operational by 2012 under the Coalition or 2010 under Labor. Under these circumstances, it is no longer valid to object to renewable and other clean energy sources on the simplistic grounds that they are currently more expensive than conventional coal. On the timescales considered in this report, that may no longer be true. Even if carbon pricing and the mandatory renewable energy targets prove insufficient to bridge the price gap between conventional coal and some renewable energy sources by (say) 2014, the different levels of financial risk must also be taken into account. Furthermore, over the period 2007 to 2020, large reductions can be expected in the costs of several non-hydro renewable energy sources, as the result of ongoing improvements in technologies and expanding markets.

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[2] New South Wales Government (2006) *NSW Renewable Energy Target*. Explanatory paper. <http://www.deus.nsw.gov.au/Publications/NRET%20Explanatory%20Paper%20FINAL.pdf> accessed 26/6/07.

[3] <http://www.greenhouse.gov.au/markets/mret> accessed 26/6/07.

For each technology considered in this report, the potential contributions to electricity generation of various stages of that technology and the corresponding approximate cost estimates are given. Policy options are suggested to facilitate the dissemination of each technology. Some comments are also given on environmental impacts. This report assumes that large-scale electrical storage will still be expensive in 2014 and probably in 2020. Under such circumstances solar PV could not be operated as base-load, although it could play a valuable role as intermediate-load, while also making contributions to peak demand. The report also assumes that marine power from waves, tides and ocean currents will not be a significant contributor in Australia before 2020.

Before discussing individual technologies, the report examines the claim that renewable energy cannot provide base-load electricity.

2. Balancing Supply and Demand

2.1 Introduction to the base-load fallacy

Opponents of renewable energy from competing industries and from NIMBY (Not In My Backyard) groups are disseminating the fallacy that renewable energy cannot provide base-load power to substitute for coal-fired electricity. Unfortunately even some politicians and journalists are propagating this conventional 'wisdom', although it is incorrect. The refutation of the fallacy has the following key logical steps:

- With or without renewable energy, there is no such thing as a perfectly reliable power station or electricity generating system.
- Electricity grids are already designed to handle variability in both demand and supply. To do this, they have different types of power station (base-load, intermediate-load and peak-load), some of which are reserve power stations.
- Some renewable electricity sources (e.g. bioenergy, solar thermal electricity and geothermal) have identical variability to coal-fired power stations and so they are base-load by definition. They can be integrated into electricity grids without any additional back-up, as can efficient energy use.
- Other renewable electricity sources (e.g. wind, solar without storage, and run-of-river hydro) have different kinds of variability from coal-fired power stations and so have to be considered separately.
- Wind power provides a third source of variability to be integrated into a system that already has to balance a variable conventional supply against a variable demand.
- The variability of small amounts of wind power in a grid is indistinguishable from variations in demand. Therefore, existing peak-load plant and reserve plant can handle small amounts of wind power without back-up and with negligible extra cost.
- For large amounts of wind power connected to the grid from several geographically dispersed wind farms, total wind power generally varies smoothly and therefore cannot be described accurately as 'intermittent' in the sense of switching on and off abruptly. Thus, the variability of large-scale dispersed wind power is unlike that of a single wind turbine. Nevertheless, with sufficient penetration into the grid, it may require some additional back-up.
- As the penetration of wind power increases substantially, so do the additional costs of reserve plant and fuel used for balancing wind power variations. However, when wind power supplies up to 20% of electricity generation, these additional costs are still relatively small.
- Solar electricity without overnight storage can provide intermediate-load and a contribution to peak-load.

These steps are now discussed in more detail. First it is necessary to consider the different roles of base-load, intermediate-load and peak-load power stations in an electricity grid.

2.2 Base-, intermediate- and peak-load power stations

As mentioned above, a base-load power station is one that is in theory available 24 hours a day, seven days a week, and operates most of the time at full power. In practice, this is an ideal. Even base-load power stations break down from time to time and, as a result, can be out of action for weeks. In mainland Australia, base-load power stations are mostly coal-fired – a few are gas-fired. Overseas, some base-load power stations are nuclear.

Renewable energy can provide several different clean, safe, base-load technologies to substitute for coal[4]:

- bioenergy, based on the combustion of crops and crop residues, or their gasification followed by combustion of the gas;
- solar thermal electricity, with low-cost overnight heat storage in water or rocks or a thermochemical store;
- hot rock geothermal power, which is currently being developed mainly in South Australia and Queensland, also has some potential in NSW;
- large-scale, distributed wind power, with a small amount of occasional back-up from peak-load plant.

It is obvious that the first three of these types of renewable power station are indeed base-load. Each of them is discussed in more detail in Sections 4, 5 and 7 respectively. Efficient energy use, the natural companion of renewable energy, can also substitute directly for base-load coal.

However, the inclusion of large-scale wind power in the above list may be a surprise to some people, because wind power is often described as an ‘intermittent’ source. The popular definition of ‘intermittent source’ is one that switches on and off frequently. It is shown below that large-scale wind power, from geographically distributed wind farms, cannot be described accurately as ‘intermittent’ in the popular sense, although it is intermittent in the technical sense that it cannot be despatched with 100% confidence. However, before a rigorous discussion of the variability of wind power can be undertaken, the concept of ‘optimal mix’ is introduced.

An electricity supply system cannot be built out of base-load power stations alone. These stations are inflexible to operate. They take all day to start up from cold and in general their output cannot be ramped (changed up or down) quickly enough to handle the peaks and other variations in demand. Brown coal and nuclear power stations cannot be ramped at all – in this sense they are very inflexible. Base-load power stations, especially coal-fired and nuclear, are generally cheap to operate, but their capital costs are high. To pay back their high capital costs, base-load power stations must be operated as continuously as possible at or near full power. Late at night, when demand is naturally at its lowest, demand is artificially boosted, for example, by means of low off-peak rates for electric hot water. This keeps more base-load generators operating near full power and unnecessarily increases CO_2 emissions.

To complement base-load and handle the peaks, a faster, cheaper, more flexible type of power station is used. Peak-load power stations are designed to be run for short periods of time each day to supply the peaks in demand and to handle unpredictable fluctuations in demand on timescales ranging from a few minutes to an hour or so. They can be started rapidly from cold and their output can be ramped rapidly. Some peak-load stations are gas turbines, similar to jumbo jet engines, fuelled by gas or (rarely) by oil. They have low capital costs but high operating costs (mostly fuel costs).

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[4] Diesendorf, M (2007) *Greenhouse Solutions with Sustainable Energy*, UNSW Press, Sydney.

Hydro-electricity with dams is an important source of peak-load power in NSW. Because the amount of water available is limited to that stored in the dam, the ‘fuel’ of a hydro power station is a scarce and therefore a valuable resource that is best used when its value is highest, that is, during the peaks. The capital cost of hydro is high, unless a hydro-electric power station is added to an existing dam.

A third type of power station, intermediate-load, runs during the daytime, filling the gap in supply between base- and peak-load power (see Figure 1). Its output is more readily ramped than base-load, but less than peak-load. Its operating cost lies between those of base- and peak-load. Some intermediate load is supplied by gas-fired power stations, some by older, smaller, black coal-fired stations and some by hydro-electricity with large, full storages. Table 1 summarises the main properties of the three types of power station, all of which are used in NSW.

Table 1: Properties of different types of power station

Type	Fuels	Capital cost (annualised)	Operating cost (mostly fuel)	Ability to ramp	Capacity factor
Base	Coal, nuclear, gas	High	Low	Low	High
Intermediate	Coal, gas	Medium	Medium	Medium	Medium
Peak	Gas turbine	Low	High	High	Low
Peak	Hydro[a]	High, if a dam has to be built, medium otherwise	Medium-high (virtual price)	High	Low usually. (Medium if storage is huge & full)

Note a. When hydro has a large, full storage, it can play the role of intermediate-load or even base-load, as in Tasmania. NEMMCO classifies Snowy hydro as intermediate-load, but at the time of writing (June 2007) storages are very low and hydro would realistically have to be classified as peak-load.

Capacity factor (given in the right-hand column of Table 1) is the average power output divided by the rated power, expressed as a percentage. A hypothetical ideal base-load power station would have a capacity factor of 100%. In practice a large coal-fired power station has a lifetime average capacity factor in the range 60–90%. In NSW in 2006, the annual average base-load capacity factor was 60%[5]. The deviation from 100% is the result of a combination of planned maintenance (which is undertaken during seasons of low demand) and unexpected breakdowns (known as ‘forced outages’). Other factors, such as drought, can also reduce operation time and hence capacity factor of water-cooled fossil-fuelled power stations and hydro. For base-load power stations, capacity factor is a measure of performance.

Because of their high fuel costs/values, peak-load power stations are operated as little possible. In other words, they have low capacity factors, typically less than 10%. Intermediate-load power stations generally have intermediate values of capacity factor. Clearly, for intermediate- and peak-load power stations, capacity factor is *not* primarily a measure of performance, but rather is an indication of their respective roles in the supply mix. Also contrary to popular belief, capacity factor is *not* a measure of the efficiency of energy conversion of any type of power station.

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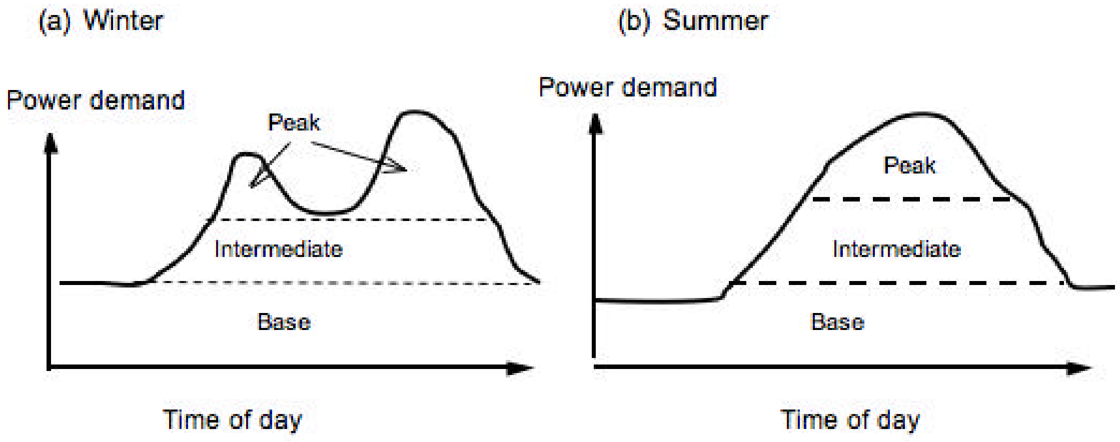
[5] NEMMCO (2007) *Potential Drought Impact on Electricity Supplies in the NEM – Final Report.* Version 1.0. National Electricity Market Management Company, Sydney, Figure 1.

If an electricity generating system depends upon too much peak-load plant, it will become very expensive to operate, because of high fuel costs, but if it depends upon too much base-load plant, the annualised capital costs will be very expensive. For a particular pattern of demand there is a mix of base-load, intermediate-load and peak-load plant that gives the minimum annual cost. This is known as the *optimal mix* of generating plant.

Figure 1 sketches how a mix of base-load, intermediate-load and peak-load generation combines to meet the daily variations in demand in Summer and Winter in a hypothetical electricity grid.

Figure 1: Typical power demand (load) by time of day in (a) winter and (b) summer

In Winter the two peaks occur at breakfast and dinner time. In Summer the single broad peak occurs in mid-afternoon, with air conditioning a large contributor.



2.3 Reliability of generating systems

A more detailed approach, that can be applied to the integration of wind power into electricity grids, is now outlined.

Even an optimal mix of fossil-fuelled power stations is not 100% reliable. To achieve this would require an infinite amount of back-up and hence an infinite cost. In practice, a generating system has a limited amount of back-up and a specified reliability. This can be measured in terms of e.g. (a) the average number of hours per year that supply fails to meet demand or (b) by the frequency and duration of failures to meet demand.

Thus the reliability of an electricity generating system is a property of the whole supply-demand system, not of individual generators. The system depends on random variables, that is, variables that are specified by probability distributions. Even in a generating system comprising entirely fossil fuelled power stations, the demand for electricity (called the load) and availability of generators to generate are separate random variables. In other words, uncertainty is inherent in balancing supply and demand. The addition of wind or solar power simply adds another random variable. The mathematical formulation of the optimal mix problem is sketched in Appendix A. The results for the integration of wind power into electricity grids are given in the next subsection.

2.4 *Wind power replacing base-load coal*

In this section it is assumed that the lifetime average capacity factor of a new base-load coal-fired power in NSW would be 80%. This is generous, because at present typical capacity factors are (65 ± 5)% [6]. It is further assumed that the capacity factor of the wind farms required to replace coal power in NSW is 30%. Then, to replace the electricity generated by a 1000 megawatt (MW) coal-fired power station, with annual average power output of 800 MW, a group of wind farms with capacity (rated power) of 800/0.3 MW = 2666 MW is required. The higher wind capacity allows for the variations in wind power and is taken into account in the economics of wind power.

Although this substitution involves a large number of wind turbines (for example, 1333 turbines, each rated at 2 MW), the area of land actually occupied by the wind turbines and access roads is only 5–20 square km, depending upon wind speed. Farming continues between the wind turbines. For comparison, the coal-fired power station and its open-cut coal-mine could occupy over 50 square km.

Although a single wind turbine is indeed intermittent in the popular sense, that is, it switches on and off frequently in low fluctuating winds, this is not generally true of the total output from a system of several wind farms, separated by several hundred kilometres and experiencing different wind regimes. The total output of such a system generally varies smoothly and only rarely experiences a situation where there is no wind at any site.

The most detailed study of this has been published recently for the United Kingdom, where hourly wind speed data spanning 30 years from 66 sites was analysed[7]. The study found that the correlation coefficient of wind power fell from 0.6 at 200 km to 0.25 at 600 km separation (a perfect correlation would have coefficient equal to 1.0.) There were no hours in the data set where wind speed was below the cut-in wind speed of a modern wind turbine throughout the UK, and low wind speed events affecting more than 90% of the UK had an average recurrent rate of only one hour per year. Nowadays wind power generation can be predicted with increasing accuracy from hour to hour and from day to day.

In South Australia five wind farms with rated power totalling 388 MW are installed in a concentrated area and tend to be lined up in one direction. Under some weather conditions there are sudden peaks and troughs in the total wind power output[8]. These effects are more pronounced than for a set of wind farms that is geographically dispersed more widely in two dimensions. To the best of this author's knowledge, there are no studies of the effect of geographic dispersion in NSW.

A system of multiple, geographically dispersed, wind farms can be made as reliable as a conventional base-load power station by adding a small amount of peak-load plant (either gas turbines or hydro) that is only operated when required.

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[6] The annual reports of the generator corporations reveal that almost all existing coal-fired power stations in NSW had capacity factors less than 70% in financial year 2005-06 and several of these were less than 65%. Mount Piper's performance is not disclosed.

[7] Sinden G (2007) Characteristics of the UK wind resource: long-term patterns and relationship to electricity demand. *Energy Policy* 35: 112–27.

[8] Cutler N et al. (2007) High-risk scenarios for wind power forecasting in Australia. EWEC07 conference, <http://www.ceem.unsw.edu.au> accessed 26/6/07.

Computer simulations and modelling show that the integration of wind power into an electricity grid changes the optimal mix of conventional base-load and peak-load power stations. The method is to include wind power as a negative load in Equations *(1)* and *(2)* of Appendix A. Empirical data are used for the probability distribution of wind power.

The particular calculation cited here has been carried out under the simplifying assumption that all the wind power is concentrated at a single site[9]. Even under this worst-case assumption, the result is that wind power replaces base-load with the same annual average power output. However, to maintain the reliability of the generating system at the same level as before the substitution, some additional peak-load plant may be needed. This back-up does not have to have the same capacity as the group of wind farms. In the worst-case example, when all the wind power is concentrated at a single site, the required back-up is about half the wind capacity[10]. More recent studies consider geographically dispersed wind farms and find that the required back-up capacity is much smaller, typically one-fifth to one-third of the wind capacity, depending upon the spatial correlations in wind speed[11].

The misconception that a wind power capacity of (say) 1000 MW requires a back-up of 1000 MW of conventional power plant arises from the failure to consider the probabilistic nature of wind power, load and conventional power plant. Part of the time wind power will be at its maximum when there would otherwise be a loss-of-load event. Some loss-of-load events do not occur during periods of maximum demand (e.g. they occur when one or more conventional generators are experiencing forced outages). Some loss-of-load events will occur even when wind power is operating at full capacity. By taking into account all the probabilities, the references cited above find that the amount of back-up capacity is general much smaller than the wind power capacity. Furthermore, the amount of required back-up capacity declines as the geographic dispersion of wind farms increases[12].

Because the back-up is peak-load plant, it does *not* have to be run continuously while the wind is blowing. Instead the gas turbines or hydro can be switched on and off quickly when required. If a gas turbine is used, its low capital cost and low fuel use make it a form of reliability insurance with a small premium. If hydro is used as the peak-load back-up for wind, it does not require a large storage. Hence its capital and operating costs are small too.

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[9] Martin B and Diesendorf M (1982) Optimal thermal mix in electricity grids containing wind power, *Electrical Power & Energy Systems* 4: 155–161.

[10] Martin and Diesendorf 1982, op. cit.

[11] Grubb, MJ (1988a) The potential for wind energy in Britain, *Energy Policy* 16: 594-607;
Grubb, MJ (1988b) The economic value of wind energy at high power system penetrations: an analysis of models, sensitivities and assumptions, *Wind Engineering* 12: 1–26;
Carbon Trust and DTI (2004) *Renewable Networks Impact Study: Annex 1 – Capacity Mapping and Market Scenarios for 2010 and 2020.* www.carbontrust.co.uk/Publications/publicationdetail.htm?productid=CT-2004-03;
Dale, L, Milborrow, D, Slark, R & Strbac, G (2004) Total cost estimates for large-scale wind scenarios in UK, *Energy Policy* 32: 1949–956;
ILEX (2002) *Quantifying the System Costs of Additional Renewables*. ILEX/UMIST, <www.dti.gov.uk/energy/developep/080scar_report_v2_0.pdf>;
UKERC (2006) *The Costs and Impacts of Intermittency*, UK Energy Research Centre, <www.ukerc.ac.uk/content/view/258/852>.

[12] Haslett J (1981) The effect of dispersal on the capacity value of wind power. *Wind Engineering* 5: 1–5.

If a national electricity grid is connected by transmission line to another country (for example, as Western Denmark is connected to Norway), it does not need to install any back-up for wind, because it purchases supplementary power from its neighbours when required and sells excess wind energy to its neighbours. In practice it makes little difference whether a generating system installs its own back-up for wind or purchases it from neighbours.

2.4 Special case of low penetration of wind power into the grid

Another approach to the reliability of wind power is to calculate its *capacity credit* or *capacity value* (which should not be confused with capacity factor). Incidentally, the concept of capacity credit can be applied to any power station that is unreliable to some degree (in other words, to all real power stations). The capacity credit of wind power in megawatts (MW) can be defined to be the capacity in MW of hypothetical 100% reliable power plant that the wind power is equivalent to. This definition of capacity credit is known as the *equivalent firm capacity* of wind power.

Another definition of capacity credit is the amount by which the load (demand) on the grid can be increased while adding wind power to the grid, without decreasing the reliability of the generating system as measured by Loss of Load Probability. This definition of capacity credit is known as the *Effective Load Carrying Capability*.

Mathematical definitions are given in Appendix A. Numerical evaluation of capacity credit, based on empirical or theoretical probability distributions for each of load, availability of conventional power plant and wind power, shows that the two definitions give almost identical results. The principal results[13] are that the capacity credit of wind power depends sensitively upon the penetration of wind power into the grid (that is, the average wind power divided by the average load on the grid), the unit sizes of conventional generators in the grid and the cut-in wind speed of the wind turbines. Any study that obtains the result that capacity credit of wind is generally independent of penetration is fallacious. This can be demonstrated mathematically[14].

In the limit of small penetration of wind power into the grid (that is, average wind power divided by average load is much less than one), the capacity credit of wind power simply reduces to the average wind power[15]. This is even true when all the wind power is concentrated at a single site. This limiting case is the most likely penetration for the 2014 scenario. Looking ahead to Section 3, 1200 MW of wind power with capacity factor 30% gives an average wind power output of 360 MW. This is about 4% of the average annual

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[13] Kahn E (1978) Reliability of wind power for dispersed sites: a preliminary assessment. Lawrence Berkeley Laboratories, Energy and Environment Division, LBL-0889;

EPRI (1979) Requirements assessment of wind power plants in electric utility systems. Electric Power Research Institute, Summary report ER-978-SY, Volume 1.

Deshmukh RG (1979) A probabilistic study of wind electric conversion systems from the point of view of reliability and capacity credit. PhD thesis, Oklahoma State University;

Martin B and Diesendorf M (1980) The capacity credit of wind power: a numerical model. *Proc. Third Int. Symp. on Wind Energy Systems*, Lyngby, Denmark, paper L3. BHRA Fluid Engineering, Cranfield UK, pp. 555–564;

Haslett J and Diesendorf M (1981) The capacity credit of wind power: a theoretical analysis. *Solar Energy* 26: 391–401.

[14] Haslett and Diesendorf (1981) op. cit.

[15] See references in footnote 13 (above).

generation of the NSW grid of 8.5 GW (74 TWh/year) and is a much smaller percentage of the generation of the National Electricity Market (NEM). Therefore, the capacity credit of 1200 MW of wind power capacity in NSW is to a good approximation equal to 360 MW. For such a small amount of wind power (approximately half the capacity of a single coal-fired turbogenerator in NSW) it is unnecessary to reoptimise the mix of base-, intermediate- and peak-load plant. Furthermore, it is unlikely that this small amount of wind power in the NSW grid would require any additional peak-load back-up.

In the future, with thousands of megawatts of wind power installed in *each* of NSW, Victoria and South Australia and strengthened transmission links between all three states, it is likely that some peak-load back-up would be required.

2.5 Conclusion: the base-load fallacy

Combinations of efficient energy use and renewable sources of electricity can replace electricity generating systems based on fossil fuels and nuclear power. With renewable sources, base-load electricity can be provided to the grid by bioenergy, hot rock geothermal, solar thermal electricity with thermal storage in water, rock or thermochemical systems, and wind power with a little back-up from gas turbines or dedicated hydro. The renewable energy supply mix can be just as reliable as the greenhouse-intensive fossil-fuelled system that it replaces.

3. Wind Power

3.1 Background

Averaged over the past 20 years or so, wind power has been the fastest growing electricity generation technology in the world. At the end of 2006, total installed global capacity was 74,000 MW, with the largest capacities in Germany, Spain, the United States, India and Denmark, in that order[16]. Denmark has the largest percentage of electricity generation from the wind, 20%. At appropriately windy sites, wind power it is the least-cost of the 'new' renewable energy sources. In parts of the USA it is already economically competitive with nuclear power and gas power.[17]

Contrary to misinformation being disseminated by vested interests and others, wind power is one of the most environmentally sound of all electricity generation technologies. Bird kills are rare at all but three of the many thousands of wind farms scattered around the world, noise levels are generally very low at a range of 400 m and land actually used (as opposed to land spanned) is generally less than that of an equivalent coal-fired power station and associated coal-mine.[18]

The notion that large-scale wind power has no value in substituting for base-load coal is refuted in Section 2. Like all power generation technologies, wind power is a partially reliable source, but it has different statistical properties from coal power. With the assistance of a little additional peak-load plant that is infrequently operated, 1333 wind turbines rated at 2 MW could replace a 1000 MW coal-fired power station, both in terms of electricity generation and reliability.

3.2 Wind power potential

At a coarse scale, an atlas of favourable regions for wind farms in NSW has been published by the former Sustainable Energy Development Authority of NSW[19]. The main area of high potential in NSW is the Southern Tablelands, with additional potential in previously cleared farming land in highlands extending up to the Northern Tablelands. In coastal areas of NSW wind power is limited by the prevalence of settlements, forest and national parks. Nevertheless, there are a few potential locations for small wind farms there.

Wind power is highly site specific, because the power in the wind varies as the cube of the wind speed. This means that a site with double the wind speed of a comparison site will produce $2^3 = 8$ times the wind power. Numerous wind power surveys have been conducted at specific sites in NSW, but unfortunately almost all the results are commercial-in-confidence. However, an indication of the high-wind sites can be obtained from the public list of wind farms proposed by developers for NSW in the past (that is, when the subsidy from MRET was about 4 c/kWh) and at present. These are listed in Table 2, which gives a

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[16] World Wind Energy Association <http://www.wwindea.org/home/index.php?option=com_content&task=view&id=167&Itemid=4>

[17] Diesendorf (2007) chapter 6.

[18] Diesendorf (2007) chapter 6.

[19] <http://www.deus.nsw.gov.au/energy/Renewable%20Energy/Wind.asp#P68_5191> accessed 19/6/2007.

total capacity of about 1200 MW. The corresponding annual electricity generation is about 3 TWh.

Table 2: Wind farms proposed by developers for NSW

Project and Location	Owner/Developer	Total Size (MW)	Status at June 2007[a]
Black Springs	Wind Corporation	40	Feasibility
Cooma	Pacific Hydro	100	Feasibility
Crookwell II	TME Australia	92	Planning Approved
Southern Highlands	ANZ Infrastructure Services	30	Project Suspended
Lord Howe Island	NA	0.3	Feasibility
Spring Hill	ACTEW AGL	10	Feasibility
Murrurundi	GHG & GREP	35	Feasibility
Rock Flat Creek	Pacific Hydro	100	Feasibility
Woodlawn/Tarago	Collex/ Acciona Energy/ ActewAGL/ ANZ Inf.Services	50	Project Suspended
Molonglo	Acciona Energy	120	Feasibility
Snowy Plains (nr Berridale)	EPURON Pty Ltd	30	Planning Approved
Taralga	RES	105	Planning Approved
Gunning	Delta Energy	62	Planning Approved
Ben Lomond Guyra	Allco Wind Energy Management	106	Seeking Approval
Liverpool Range	Macquarie Generation	6.6	Seeking Approval
Paling Yards	TME Australia	90	Feasibility
Conroys Gap Yass	EPURON Pty Ltd	30	Seeking Approval
Cullerin Range	EPURON Pty Ltd	30	Planning Approved
Evandale Goulburn	EPURON Pty Ltd	30	Feasibility
Capital Bungendore	Renewable Power Ventures	126	Seeking Approval
	Total	1193	

Source: Australian Wind Energy Association <http://www.auswind.org/auswea/index.html> accessed 17/6/2007.
Note a: from Feasibility to Planning Approved to Under Tender to Under Construction

In siting a wind farm, other factors than wind speed, such as the locations of existing transmission and distribution lines and access roads, are also taken into consideration. With possible government policies on the provision of basic infrastructure (discussed below), additional medium-to-high-wind sites would become available. From this author's qualitative observations made while leading a wind energy research team in CSIRO, the proposals listed in Table 2 do not exhaust all the potential medium-to-high wind sites in NSW.

Therefore, in the short term, that is to 2014, it is assumed in this report that 1200 MW of wind power could be installed in NSW with annual electricity generation of about 3 TWh (3000 GWh). These are considered to be Category 1 wind farms for NSW. These sites are mostly in high country (altitude above 500 m), located on ridges and hills that are exposed to a long sweep of prevailing winds.

There is a much larger potential for Category 2 sites, also mostly in high country, but with less exposure and hence lower wind speeds. A combination of more efficient technologies, lower unit costs and economic instruments will allow these sites to be developed post-2014.

To determine the exact magnitude and locations of Category 2 sites requires a publicly available wind energy survey and appropriate policies by Federal and NSW Governments. However, expert opinion by a professional wind power prospector suggests there is about 20 times the amount of land available in Australia at lower but still utilisable wind speeds[20]. Because of the cubic law, this does not mean that there is 20 times the wind power available, since typical capacity factors will be lower at Category 2 sites, assuming the same wind turbines are installed. Nevertheless, it would not be unreasonable to assume that there is at least five times the wind energy available at Category 2 sites compared with Category 1. This is 15 TWh generated annually from wind turbines with capacity about 8600 MW. Category 2 sites could be developed between 2014 and 2020 as the price of wind turbines declines.

Adding the potential contributions from Categories 1 and 2 gives a total annual wind energy output of about 18 TWh by 2020. This is roughly equivalent to the electricity sent out from three 1000 MW coal-fired power stations. The greenhouse gas savings have to be calculated on the energy generated by the coal stations, which is about 7% more than the energy sent out[21]. Assuming 0.9 tonnes CO_2/MWh generated, the annual CO_2 savings by wind power in 2020 would be

$$18 \times 1.07 \times 0.9 \text{ Mt} = 17 \text{ Mt}.$$

This would be reduced slightly by emissions generated by peak-load gas turbines used as back-up. To calculate the exact reduction would require detailed operation and generation planning models with reoptimised mix of base-, intermediate- and peak-load generators, a major study that lies beyond the brief of the present study.

3.3 Wind power economics

This report uses a levelised annuity method[22] to compare the economics of different electric power technologies. In 2005, the capital cost of large wind farms installed near the grid in Australia was about $1800/kW. (All dollar amounts are in AUD, unless otherwise indicated.) In 2006, a jump in demand for wind turbines in the USA pushed up the price in Australia to about $2200. Currently, with the high Australian dollar, the price is about $2000/kW and declining. As manufacturing capacity catches up with demand, the price is expected to drop back to $1800/kW by 2008 and then to decline over a period of five years or so to below $1500/kW.

In this report a real discount rate of 8% is used for renewable energy. Assuming an installed capital cost of $1800/kW, maintenance cost of 1.2 c/kWh, lifetime of 20 years and capacity factor of 30% gives a cost of energy for a typical NSW Category 1 wind farm of 8.2 c/kWh. It should be emphasized that a large order for several wind farms from a single wind turbine manufacturer would substantially decrease the price of wind turbines[23] and hence the cost of energy.

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[20] Gareth Johnston (2003) WindLab Systems Pty Ltd, personal communication.

[21] The difference is the energy used to operate the power station. An air-cooled power station would use significantly more than 7% internally.

[22] Diesendorf (2007) Appendix B.

[23] Junginger M et al. (2005) Global experience curves for wind farms. *Energy Policy* 33: 13350.

A rough check on the economics can be made by considering that almost all of the 1200 MW of Category 1 wind farms were proposed when the value of Renewable Energy Certificates (RECs) was about 4 c/kWh and the spot price of wholesale electricity in NEM was about 4.0 c/kWh. Then the levelised cost of wind power at these very good sites would be about 8.0 c/kWh. At present, taking into account the financial risk of carbon pricing (which could increase the discount rate by 2–3 percentage points), increased prices of construction materials (which have already been taken into account for wind turbines) and the need to pay a realistic price for cooling water, the cost of electricity from a new coal-fired power station could be significantly more expensive than 4.0 c/kWh. Building an air-cooled power station would reduce the demand for water but would not necessarily improve the economics, since air-cooled power stations have higher capital cost and internal energy consumption.

On the basis of these estimates, Category 1 wind farms commenced in 2008 and completed in 2009 would be economically competitive with conventional coal, *provided* wind received a subsidy of about 4 c/kWh. This could come either from an expanded MRET or NRET, an emissions trading scheme with CO_2 priced at about $40/tonne, realistic pricing of cooling water for thermal power stations, or (most likely) a combination thereof. This subsidy could be seen as compensation for the existing environmental and health subsidies to conventional coal power.

By 2015 the installed cost of wind farms could be around $1200/kW, with operation and maintenance costs under 1 c/kWh, reducing the levelised cost of electricity from Category 2 wind farms with capacity factors of 20% to under 8 c/kWh. Thus, as the global scale of wind power increases, the price of wind turbines continues to decrease and carbon prices increase, several thousand megawatts of Category 2 wind farms could be installed rapidly in the period 2015–2020. Wind power can clearly make a substantial substitution for new and retiring coal-fired power stations.

3.4 Impediments to wind power

The main non-economic impediments are:

- lack of detailed, site-specific, publicly available, wind speed data for NSW;
- anti-wind power fallacies that are being disseminated by vested interests and some NIMBY (Not-In-My-Backyard) groups;
- lack of certainty that conventional coal-fired power stations will no longer be built;
- lack of transmission or distribution lines in some regions of otherwise high resource potential.

3.5 Recommended policy options for disseminating wind power

It is recommended that all of the following policy options be implemented. The first eight policies will benefit all renewable energy sources to some extent, however the lower cost technologies – wind, hydro and some forms of bioelectricity – will benefit most. Solar electricity is still too expensive to benefit significantly from Policies 1–8. The policies are in italics and brief explanatory comments are given in ordinary text.

1 *NSW Government to double NRET and introduce the requirement that this target must be supplied from renewable energy sources in NSW only.*

The present target gives an additional renewable electricity of 1317 GWh/year in 2010 and 7250 GWh/year by 2020, which may be sourced from anywhere in the National Electricity Market[24]. A doubled target could be met by wind power alone in NSW. However, in practice, it would probably be met by a combination of wind, bioelectricity and hydro. These technologies would create several times more jobs per unit of electricity generated than coal power.[25]

2 *Federal Government to increase MRET substantially. Both NRET and MRET to be retained until the carbon price (see Policy Option 6) has risen to above $40 per tonne of* CO_2 *and remained continuously above that level for at least 12 months.*

Sufficient renewable energy to meet the Federal Government's tiny MRET for 2010 was already installed by 2006. As a result, the price of Renewable Energy Certificates dropped dramatically from its typical 2006 value of about $40/tonne of CO_2. To build up the wind industry and parts of the bioelectricity industry, this level of subsidy must be restored until the carbon price from emissions trading can take over. It is expected that initially the carbon price from emissions trading would be set at too low a level to assist renewable energy sources.

3 *Federal, State and Local Governments to increase their use of Green Power for their own operations in steps until they are using 100% Green Power.*

Green Power is independent of MRET and NRET. It provides a useful supplementary scheme for offsetting emissions by individuals, households and organisations. Governments should use Green Power to set an example for the rest of the population and provide an incentive for increased energy efficiency in its own operations.

4. *NSW Government to impose a greenhouse intensity limit of 0.4 tonnes of* CO_2 *emission per MWh of electricity generation on all new base-load power stations.*

This limit would stop the development of new coal-fired power stations without CCS and single-cycle base-load gas-fired power stations without CCS. A new conventional 1000 MW coal-fired power station would emit 6–7 Mt of CO_2 per year for about 40 years, a total of 240–280 Mt or about half of Australia's annual CO_2-equivalent emissions. Building and commissioning such a power station would inevitably undermine programs for efficient energy use and renewable energy.

5 *NSW Government to pass legislation ensuring that it will not to cover the carbon risk of any new or refurbished power station, nor permit this risk to be imposed upon taxpayers or electricity consumers.*

Any proponent of a new coal-fired power station should be exposed to the full market risk that a carbon price may be applied. At $40/tonne CO_2, the additional cost of operating a 1000 MW coal-fired power station would be about $240–$280 million per year or $9.6–$11 billion over 40 years. A developer of such a power station should not be protected from this cost by the government, the taxpayer, or electricity consumers.

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[24] New South Wales Government (2006) *NSW Renewable Energy Target*. Explanatory paper.

[25] Diesendorf (2007) p. 306.

The proposed legislation would deter developers of conventional coal-fired power stations.

6 *Either the Federal Government or a group of State Governments to implement an emissions trading scheme of the cap and trade type. To be effective the scheme should have the following properties:*

- *Broad scope: all electricity generation, major industries and transport should be covered initially and agriculture should be brought in as soon as practicable.*
- *The cap on emissions should be sufficiently tight to push up the carbon price to at least $40 per tonne CO_2 within three years.*
- *At least half the permits to be issued initially by auction. Within several years, all permits to be issued by auction.*
- *Permits to be temporary licences to emit, not permanent property rights.*

With these requirements, the scheme would work, allowing cleaner energy technologies to gradually replace dirty coal.

7 *NSW Government to provide transmission links for wind farm developers in a region, provided the developers participate in a coordinated bulk purchase of wind turbines at discount price. This could be funded by a levy on electricity prices.*

New transmission lines are essential infrastructure for distributed energy sources such as wind and bioelectricity. It is far less expensive for society to plan and coordinate such infrastructure for groups of distributed sources than for each developer of each distributed source to provide a separate transmission link. This proposed policy combines this advantage with the price advantage of bulk purchase.

8 *NSW Government to increase charges for water use by all generators to a realistic market value that takes account of the increased prevalence and severity of droughts.*

In a situation of limited water and constrained CO_2 emissions, the market should be shaped to reward the most sustainable sources of energy. Wind and solar power use negligible water.

9 *NSW Government to fund and publish a site-specific wind energy survey of NSW, designed to identify additional Category 1 sites that are not included in current proposals*.

Follows from discussion above.

10 *Grid management policies that allow the incorporation of 24-hour wind farm output forecasting data. This will require input from both Federal and NSW Governments.*

This allows for the fact that different energy sources have different variability characteristics and the principle that all readily available data should be utilised to optimise grid operation.

11 *Federal and NSW Governments to extend economic incentives for small solar electric systems to small wind systems.*

This removes an anomaly in existing incentives. It allows small wind to compete with solar PV at appropriate sites.

12 *NSW Government to streamline the planning process for wind farms, incorporating a mandatory community consultation process, minimum distances for large wind turbines from residential buildings (suggested to be 500 m) and a fee to be paid by the developer to local government for community development (suggested to be $5,000 per installed megawatt for wind farms larger than 10 MW and zero otherwise).*

This would manage several sources of conflict over the siting of wind farms. In particular, some communities are split because those farms where wind turbines are installed receive generous rent, while neighbours may receive nothing.

4. Bioelectricity

4.1 Background

Bioenergy is energy generated from biomass (organic matter), that is, material derived recently from plants and animals. Thus bioenergy is obtained from recently stored solar energy. Feedstocks include forestry and agricultural wastes and residues, food wastes, woody weeds, animal manures, sewage, dedicated energy crops and the organic fraction of municipal solid wastes. When the useful bioenergy obtained from biomass is in the form of electricity only, this report calls it 'bioelectricity'. The general term 'bioenergy' is used when, for example, the cogeneration of heat and electricity is discussed.

When biomass is converted into bioenergy, it emits the carbon dioxide (CO_2) that it originally absorbed from the atmosphere when it existed in the form of growing plants. Therefore, in theory, the use of biomass for energy production could be neutral in terms of net CO_2 emissions, provided an equivalent amount of biomass regrows. If CO_2-neutral bioenergy is used to substitute for fossil fuels, it substitutes for the CO_2 emissions that would have been emitted in the combustion of those fossil fuels. In practice, fossil fuels may be used to assist growing and harvesting the plants (fuelling tractors and making fertiliser), in transporting the harvested biomass and in converting it into useful energy forms. When these fossil fuel inputs are included in the energy balance, they offset at least part of the CO_2 benefit of using biomass. However, with thoughtful design of the system, including the use of bioenergy for processing and transporting the biomass, there can be substantial greenhouse benefits.

4.2 Bioelectricity potential

There are many pathways for converting biomass feedstocks into useful energy[26]. This report focuses on electricity generation from biomass.

Of all the potential processes, the combustion of solid biomass is best understood, straightforward, commercially available, readily integrated with existing infrastructure and low in cost, provided the fuel does not have to be transported long distances or stored under cover. As the size or capacity of the power station increases, its capital cost in dollars per installed kilowatt decreases, while its cost per tonne of fuel increases, because fuel has to be transported from further afield. The optimal size of a biomass power station varies with geographic region, quantity of available local biomass and the cost of transportation of its biomass fuel; however, it is generally much smaller than the economic optimal size of a coal-fired power station. In NSW bioelectricity power stations that combust crop and forestry residues are likely to have capacities in the range 5–30 MW electrical.

The main processes for converting biomass into electricity, in order of increasing cost, are listed in Table 3. To assist in ranking them, only qualitative estimates of their potential and cost are given. The economics of these various processes will be discussed in more detail below. Here it is simply stated that some projects from the first three processes are likely to

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[26] Stucley, CR, Schuck, SM, Sims, REH, Larsen, PL, Turvey, ND & Marino BE (2004) *Biomass Energy Production in Australia: Status, costs and opportunities for major technologies*, A report for the Joint Venture Agroforestry Program, RIRDC Publication No. 04/031, Rural Industries Research & Development Corporation, Canberra.

be economically competitive with conventional coal now, while others will be when only a carbon price is applied. The respective potential contributions from the first three processes are small. In the long run, waste minimisation and recycling policies should eliminate the organic component of municipal solid wastes and hence landfill gas.

Table 3: Processes for generating electricity from biomass, in order of increasing cost

Process	Feedstock	Potential contribution	Current cost of electricity
Category 1: 2008–2014			
Co-combustion in existing coal-fired power stations	Solid biomass	Always small	Comparable with conventional coal
Combustion of landfill gas	Landfill gas	Always small	Comparable with conventional coal
Combustion of biogas	Wet organic wastes	Always small	Comparable with conventional coal
Combustion of residues in small dedicated power stations	Agricultural and forestry residues	Medium to 2014; large 2015–20	More than double conventional coal
Category 2: Mainly 2015–2020			
Gasification and then combustion of gas in small dedicated power stations	Agricultural and forestry residues	Small to 2014; large 2015–20	N/A at present. Post-2014 possibly double conventional coal
Combustion of energy crops, either directly or via gasification	Agriculture and forestry	Medium to 2014; large 2015–20	More than triple conventional coal

Source: the author.
Note: By 'conventional coal', this report means 'coal power without a carbon price'.

The main biomass contributions to electricity generation in the period 2008–2014 can be obtained from the combustion of existing agricultural and forestry residues, even if forestry residues are limited to those from plantations. These are classified as Category 1 bioenergy in this report (as indicated in Table 3). With small technological improvements, it should be possible by 2015, if not before, to gasify these organic residues and then combust the gas in small, dedicated power stations, a more efficient process than combusting the solid biomass. This, together with the combustion of energy crops (either directly or after gasification) is classified as Category 2 bioenergy in this report. It is expected to make its main contribution after 2015.

Table 4 is a summary of the 2003 and estimated future generating capacity from biomass in NSW, as published in the *NSW Bioenergy Handbook*[27].

Table 4: Potential generation capacity for NSW bioenergy from currently available biomass resources

Feedstock	Generation capacity in 2003 (MW)	Estimated potential capacity (MW)
Wet organic wastes (to biogas)	23	40
Landfill gas from municipal, industrial and commercial wastes	29	100
Plantation forestry residues (thinnings and sawmill wastes)	4	105
Sawmill wastes (from native forest sawlog production)	16	42
Agricultural residues (bagasse only)	175	740
Energy crops	0	550
Total	**90**	**1577**

Source: NSW Bioenergy Handbook, Table 3

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[27] Rutovitz J and Passey R (2004) *NSW Bioenergy Handbook*. Department of Energy, Utilities and Sustainability, Sydney.

As the authors of the *NSW Bioenergy Handbook* acknowledge, this is a very conservative estimate of future potential. In particular, it gives a very low estimate for the potential contribution from wheat straw, which is a significant biomass resource, even during drought conditions, as discussed below.

Although this paper does not include energy crops in Category 1 bioenergy, it is possible that one approach could contribute significantly before 2014. This is oil mallee, a eucalyptus tree that grows quickly, does not require irrigation and can be coppiced every 2–4 years, depending upon location. It is an energy crop with multiple economic and environmental benefits[28]. A demonstration integrated wood processing plant at Narrogin in Western Australia has produced three saleable products – renewable electricity, activated carbon and eucalyptus oil – from mallee eucalypts grown on farms in the wheat belt of Western Australia. In addition, there are environmental benefits of the perennial oil mallee tree:

- decreased waterlogging and therefore increased cropping yields;
- reduction of dryland salinity;
- shelter for stock, and therefore increased lambing rates;
- reduced erosion by wind and water;
- increased biodiversity and aesthetic value.

Even before energy crops are developed, the *Bioenergy Handbook* estimates that there is potential for about 1000 MW of bioelectricity. In the view of the author of the present 2007 report, almost all of this capacity could be obtained from sources that could be developed before 2014. The first five items, totalling 287 MW, are from Category 1 sources that are likely to be cost-competitive with conventional coal in the presence of either realisticv water pricing or a small carbon price ($20/tonne CO_2). There is no technological barrier for the 287 MW to be generated by small, efficient power stations in rural areas, and operated with capacity factors of at least 80%. Thus, annual energy generation of 2 TWh/yr could be obtained at relatively low cost. Including the bagasse residues gives another 740 MW and 5.2 TWh/yr. In total, these sources of bioelectricity could replace a 1000 MW coal-fired power station. In addition, some of the sources (e.g. bagasse and some landfill gas) are suitable for cogeneration, giving emission-free industrial heat as a bonus. This study has not attempted to identify the fraction of bioelectricity sources that is close to existing transmission lines.

In the drought of 2006, Australia's wheat production dropped from 25 million tonnes (Mt) to 10 Mt[29]. In NSW wheat production fell from 6.3 Mt in 2005 to 2.1 Mt in 2006[30]. Adapting the national calculation of Diesendorf (2007)[31] with the assumptions that 2.4 green tonnes per hectare of wheat stubble with energy content 10 GJ/green tonne can be collected, leaving 1 green tonne per hectare on the ground, and that it is converted to electricity by combustion at 35% thermal efficiency, yields additional potential electricity generation of 1.4 TWh/yr. This is the result for a severe drought year. For 2007 and other 'normal' years, assuming that 'normal' years will return, the potential is 4 TWh/yr.

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[28] See <www.oilmallee.com.au>.

[29] ABARE <http://www.abare.gov.au> accessed 20/6/2007.

[30] NSW Department of Primary Industry (2006) *NSW Grains Report*. <http://www.dpi.nsw.gov.au/aboutus/resources/periodicals/newsletters/grains-report-nsw> accessed 20/6/2007.

[31] Diesendorf (2007) pp. 139–40.

Table 5 shows the author's estimate of the capacity and annual electrical energy that could be obtained from various biomass sources by 2014. In some cases (eg. bagasse) cogeneration plants would be used to provide industrial heat as well as electricity. Energy crops have been excluded from the 2014 mix.

Table 5: Potential generation capacity and energy generation for NSW bioenergy by 2014 from currently available biomass resources

Feedstock	Estimated potential capacity in 2014 (MW)	Estimated annual electricity generation in 2014 (GWh/year)
Wet organic wastes (to biogas)	40	283
Landfill gas from municipal, industrial and commercial wastes	100	707
Plantation forestry residues (thinnings and sawmill wastes)	105	743
Sawmill wastes (from native forest sawlog production)	42	297
Agricultural residues (bagasse only)	740	5235
Agricultural residues (wheat stubble), drought conditions	200	1414
Total	**1277**	**8679**

Source: the author, building upon Table 4.

Notes: Since the bioelectricity power stations would be operated as base-load, their capacity factors are assumed to be the same as new coal, 85%, for each feedstock. For biomass it is assumed conservatively that electricity sent out is 95% of electricity generated, with the difference used to run the power station.

For the period 2015–2020, it is likely that energy crops will be available. Indeed, some energy crops, such as oil mallee, could be making a significant contribution by 2014. The *NSW Bioenergy Atlas* assumes that the initial plantings would be in locations subject to dryland salinity and in the NSW wheat belt. This leads to feedstock sufficient for 550 MW of power station capacity, with annual electricity sent out 3.9 TWh. It is assumed here, that given appropriate government policies, all of this could be installed by 2020. Additional energy crops could be grown in NSW, however they would compete either with forestry or food production. Displacing some forestry may be beneficial in both economic and environmental terms.

4.3 Environmental impacts

The impact on soil of the production of bioenergy is the subject of some scientific and popular debate. For biomass residues combusted in small local power stations, the ash and hence the nutrients can be returned to the fields, back-loaded on the vehicles that collect the biomass feedstock.

Removal of biomass from the field entails the removal of carbon. Soil carbon losses are most likely where soil carbon is initially high, such as where improved pasture is converted to biomass production. Bioenergy systems are likely to enhance soil carbon where these replace conventional cropping, as intensively cropped soils are generally depleted in soil carbon. Measures that enhance soil carbon include maintenance of productivity through application of fertilisers, inclusion of legumes, and retention of nutrient-rich foliage on-site. Published experimental data and modelling results indicate that total soil carbon loss in bioenergy systems is generally small. Although there may be some decline in soil carbon associated with biomass production, this is negligible in comparison with the contribution of bioenergy systems towards greenhouse mitigation through avoided fossil fuel emissions.[32]

4.4 Bioelectricity economics

The cost of bioenergy depends sensitively upon several factors:

- whether residues from existing food and fibre crops or dedicated crops are used as feedstock;
- the type and location of the biomass – rainfall is a very important locational factor for crops that cannot extract groundwater;
- the distance it has to be transported for processing;
- the technologies used for processing and the size of the processing plant or power station;
- the kinds of bioenergy and co-products; and
- the location of the users of the bioenergy in relation to the processing plant.

In Australia, there is insufficient experience with most forms of bioenergy conversion to set down confident cost estimates. At best, several case studies can be developed. Table 6 reproduces the results of some desktop case studies by Stucley et al.[33]

Table 6: Estimated costs of bioelectricity from the combustion of crop residues

Component	5 MW gasification with waste heat boiler & steam turbine	30 MW boiler & steam turbine
Unit capital cost ($M/MW)	2.5	1.6
Operation & maintenance cost ($M/yr)	0.8	2.85
Fuel delivered to site @ $30/green tonne ($M/yr)	2.74	11.26
Price of electricity sold (c/kWh)	14.4	10.7

Assumptions: Interest rate 10%; capacity factor 91%; internal rate of return 15%.
Source: Stucley et al. (2004)

While the estimated electricity prices are high, they may be partially offset by locating some bioelectricity power stations near country towns and regional centres and thus avoiding transmission charges. The rest of the price gap compared with the low price of coal-fired electricity could be closed by means of a combination of carbon pricing, a Mandatory Renewable Energy Target (MRET or NRET), the value of coproducts and a value conferred by government for other environmental benefits (e.g. combating dryland salinity by means of deep-rooted biomass crops).

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[32] Cowie AL, Smith P and Johnson S (2006) Does soil carbon loss in biomass production systems negate the greenhouse benefits of bioenergy? *Mitigation and Adaptation Strategies for Global Change* 11: 979–1002.

[33] Stucley, CR, Schuck, SM, Sims, REH, Larsen, PL, Turvey, ND & Marino BE (2004) *Biomass Energy Production in Australia: Status, costs and opportunities for major technologies*, A report for the Joint Venture Agroforestry Program, RIRDC Publication No. 04/031, Rural Industries Research & Development Corporation, Canberra, Chapter 10.

4.5 Impediments to bioelectricity

The main impediments are:

- The high price of bioelectricity from crop residues and the even higher price from energy crops. This could be offset by the multiple economic and environmental benefits.
- Limited sources of finance for the construction of new, efficient, small power stations in rural areas.
- For crop residues, such as from sugar cane and wheat in various biogeographic regions, incomplete knowledge about year-round biomass availability and the potential to store biomass at low-cost.
- Lack of transmission or distribution lines in some regions of otherwise high resource potential.
- Uncertainty about the impact of climate change on feedstock.

4.6 Recommended policy options for disseminating bioelectricity

The first six recommendations for disseminating wind power also apply to bioelectricity. In addition it is recommended that:

13 *NSW Government to provide transmission/distribution links for bioelectricity power station developers in a region, funded by a levy on electricity prices.*

14 *NSW and Federal Governments to fund and publish a detailed bioenergy survey of NSW, encompassing the potential for all uses of biomass. This project could be linked to the Bioenergy Atlas of Australia.*

15 *NSW and Federal Governments to fund research on the production, storage, gasification and combustion of various sources of biomass that are prevalent in NSW.*

16 *Federal Government to fund the development of a Bioenergy Roadmap for Australia, which considers the situation of individual States as well as the nation as a whole.*

17 *NSW and/or Federal Governments to introduce Biomass Establishment Grants for growing energy crops that would assist in limiting dryland salinity, erosion and other forms of land degradation. These grants and other contributions could be funded from a levy on supermarkets.*

18 *NSW or Federal Government, whichever is funding farmers for growing crops for bioenergy and land remediation, to set up organisations to ensure that biomass production is ecologically sustainable.*

These recommended policies for bioelectricity follow from the preceding discussion.

5. Solar Thermal Electricity

The least-cost solar thermal technologies are those that produce low-temperature heat for use in the form of low-temperature heat rather than electricity. These technologies – solar hot water, solar space heating and solar industrial heat at temperatures below 300ºC – can contribute to the reduction of electricity demand and hence can help substitute for coal-fired power stations and heating by natural gas. However they are outside the ambit of this report.

Solar thermal electricity (STE), sometimes called Concentrated Solar Thermal Power, uses various forms of concentrators to focus sunlight to produce steam, which turns a turbine and thus generates electricity. STE has low environmental impacts and huge potential in Australia in general and in NSW in particular.

Twenty years ago STE began a commercial demonstration with the construction of a 354 MW power station in southern California that is still operating today. After a long period of quiescence, STE has recently undergone a revival in the USA and Europe, driven by solar feed-in laws and renewable energy portfolio standards. Demonstration plants of various types are being built and, as a result, costs and cost estimates for the near future are declining. These improvements are expected to result from a combination of technological improvements and scale-up of plant size and volume of production. Unfortunately one of Australia's leading researchers and developers of STE, Dr David Mills, has recently moved his company, Solar Heat and Power, from Sydney to California, where there are greater opportunities.

Although large-scale storage of electricity is very expensive, large-scale storage of heat is not necessarily so. Solar heat can be stored at low cost as heat in water, rocks or thermochemical systems, such as the ANU solar-ammonia system[34]. Therefore, STE with thermal storage can supply base-load and can be just as reliable as coal.

In NSW the best sites for concentrated solar power in the form of STE are west of the Great Dividing Range (where sunlight is mostly direct rather than diffuse) and close to the extremities of transmission lines or near gas pipelines. Here STE has increased economic value from its ability to strengthen local power supplies. Either thermal storage or natural gas back-up (or both) can be used to ensure that STE provides reliable base-load power. While it may be premature to envisage a significant contribution before 2014, a case could be made for at least one grid-connected demonstration plant to gain experience in the technology. This would help pave the way for a possible installed capacity of 2000 MW by 2020. Mass production prices of STE with ammonia storage are expected to be around 15–16 c/kWh[35] and this could be achieved internationally before 2014. On the basis of existing cost curves, prices under 10 c/kWh may be possible by 2020.

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[34] <http://solar.anu.edu.au> accessed 26/6/07.

[35] Lovegrove, K et al. (2004) Developing ammonia based thermochemical energy storage for dish power plants, *Solar Energy* 76: 331–37.

Policies that would benefit STE are:

19. *Federal and State Governments to allocate R, D & D funding specifically for solar thermal electricity.*

20 *NSW Government to implement feed-in tariffs for solar electricity.*
Useful to assist solar power stations, but not rooftop PV (see next section).

6. Solar Photovoltaic Electricity

Because it is still very expensive to store electricity on a large scale, grid-connected solar electricity is not stored. If and when advanced batteries, such as the flow batteries based on vanadium or zinc-bromine, become less expensive, PV electricity would become base-load. This could happen in the period 2015–2020. Meanwhile, even without storage, solar PV can substitute for much coal and gas combusted in intermediate-load power stations. In general, the largest quantity of electricity consumed in the course of 24 hours is used in daytime. Therefore, intermediate- and peak-load supply have important roles in balancing supply and demand. Once the high cost of PV modules is brought down, the potential in NSW is huge.

Although it is still expensive, residential and commercial solar electricity has the economic advantage over solar power stations that it competes with the *retail* price of electricity, which is typically 12–20 c/kWh in NSW (excluding off-peak rates), depending upon retailer and customer category. On the other hand, grid-connected solar power stations may have to compete with *wholesale* electricity priced at typically 4–5 c/kWh.

By orienting the solar collectors to the north-west instead of to the usual north (in the Southern Hemisphere), the peak in solar generation overlaps to a large degree with the broad daily peak in Summer demand. Thus, statistically speaking, even solar electricity without storage has a degree of reliability during the daytime and can contribute to peak-load.

New technological developments in solar electricity, coupled with expanding overseas markets, will gradually bring down prices. Some of the most promising are the thin film technologies, such as the Sliver® cells developed at the Australian National University, which may be manufactured by 2010 on a pilot scale by Origin Energy at Adelaide, and the crystalline silicon on glass (CGS) cells developed at UNSW and now being manufactured in Germany.

The main impediments to rapid growth in these technologies in Australia are insufficient R & D funding and insufficient 'market pull' support within Australia. To overcome these impediments, the following policies are recommended:

21. *To support R & D, an allocation by the Federal Government of $3 million per year for the next 7 years would keep Australia in the forefront of world research on thin films, both for CSG cells at UNSW*[36] *and Sliver® cells at ANU*[37]*. This amount should be additional to any funding from the Australian Research Council research grants.*

22. *To provide market pull, the Federal Government fund an expanded photovoltaic rebate for 100,000 homes of $8 per peak watt (maximum $8000 per household) over the 5 years from 1 July 2007. The proposed subsidy, amounting to a maximum of $800 million over 5 years or $160 million per year, is small by overseas standards and indeed by the proposed federal funding of coal with* CO_2 *capture and underground storage (CCS) in Australia.*

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[36] <http://www.pv.unsw.edu.au> accessed 26/6/2007.

[37] Blakers A et al. (2006) Sliver cells – a complete photovoltaic solution. Fourth World PV Conference, Hawaii, May

23. *NSW Government to disseminate widely smart meters, together with time-of-day electricity pricing, to assist residential solar PV electricity (and energy conservation), because it would take account of the high economic value of solar electricity during summer peak demand.*

Contrary to the notion held by part of the Australian environmental movement, feed-in tariffs would be unlikely to assist significantly in the dissemination of residential PV in Australia. The success of feed-in tariffs in Germany was the result of the extraordinarily high tariffs granted to solar PV, initially about $1/kWh. This in turn was achieved because the Greens were in coalition government at the time and they were in a position to implement the strong public support for solar energy. At $1/kWh in Germany (or $0.5/kWh in sunny Australia), it makes economic sense for householders to install more PV modules than are needed for their own residential use and sell electricity back to the grid. But, if there is a low feed-in tariff (as would be likely if adopted in Australia), every PV module that a householder installs would increase their economic loss and so there would be no incentive to feed-in. Under these conditions a rebate on the capital cost is a more effective incentive for residential PV.

7. Hot Rock Geothermal Power

Unlike New Zealand, Australia does not have the traditional form of geothermal power, which utilises steam emitted through vents in volcanic regions of the ground to generate electricity. However, Australia has a very large potential for hot rock geothermal power, manifest in huge volumes of hot granite located 3–5 km below ground level, mainly in the Great Artesian Basin. Although the largest potential is in the north-east of South Australia and south-west Queensland, there appears to be some potential in NSW and other States. Geodynamics Ltd has done preliminary drilling near Muswellbrook in the Hunter Valley. Although initial results are promising, deep drill wells are still required to determine the magnitude of the resource[38].

The resource can be tapped by drilling a pair of wells into the hot rock, fracturing the rock between them at the bottom of the drill wells, pumping water down one well, collecting superheated water or steam as it rises up the other, and using it to generate electricity. In theory, the water flows through a closed cycle and hence water demand would be very low after the initial amount. Strictly speaking, hot rock geothermal is not renewable, since the rate of heat extraction is much greater than the rate of replenishment from surrounding rocks. After a number of years, the temperature at a particular site drops and a new pair of holes must be drilled elsewhere.

This technology is still being developed and is not expected to generate electricity for several years. However, compared with coal with CCS, the technology is relatively simple, relying on existing techniques for drilling and fracturing that have been established by the petroleum industry. Therefore it is likely that power capacity of about 3000 MW could be brought on-line in Australia in the period 2015–2020. With the main potential in South Australia and Queensland, NSW's share of this initial development could be about 500 MW, but this figure is mainly guesswork[39].

This technology has actually received the largest amount of Federal Government R, D & D funding of all renewable energy technologies (at least $11.5 million to date). It is now mainly supported by venture capital and shareholders.

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[38] <http://www.geodynamics.com.au> accessed 28/6/2007.

[39] ibid.

8. Slowing Growth in Demand

Efficient energy use is a vital component of slowing growth in electricity demand in general and the demand for base-load supply in particular. But efficient energy use is not the only component. The following important drivers of unnecessary, unproductive growth in demand could also be addressed. Only a brief summary is offered here.

- Subsidies for off-peak electric hot water.
- Subsidies for the use of air conditioners.
- Subsidies for electricity used by aluminium smelters.
- Population growth.
- Declining household size.
- Government revenue based on quantity of electricity sold.
- The culture of consumption.

Recommendations 24–27 address some of these demand reduction issues.

8.1 Subsidies for off-peak electric hot water

Since base-load power stations have high capital cost and low fuel costs, they must be operated as much as possible at rated power, to pay off their capital costs. This economic requirement is reinforced by a physical one: the power output of conventional base-load power plant cannot be varied quickly enough to follow the daily variations in demand, including the drop in demand between midnight and dawn. Once fired up, base-load power stations must preferably be operated at rated power.

Until now the usual ‘solution’ to this problem has been to artificially boost the low late-night demand by offering low off-peak electricity rates. Since base-load power stations in eastern Australia are coal-fired and electrical heating is a very inefficient way of providing hot water, the low off-peak rates result in substantially increased greenhouse gas emissions.

An alternative solution is to remove the off-peak rate, allow the late-night demand to adjust to a lower level, reduce the amount of base-load plant in the system to the lower level, increase the amount of gas-fired intermediate-load plant and foster the use of solar hot water (gas-boosted wherever possible). It should be emphasized that this solution does not necessarily contradict the use of time-of-day pricing for daytime peaks, but simply recommends the removal of special low rates for hot water.

Removal of the subsidy should be the first step in phasing out electric resistance hot water heaters.

8.2 Subsidies for the use of air conditioners

When someone purchases and uses an air conditioner, all electricity users in the State have to pay for the costs of the additional infrastructure required: power stations and power lines. Rough estimates suggest that, for a single-phase 5 kW residential air conditioner, the real costs could be of the order of $1,500 p.a. based on a 10-year simple payback, that is, a total of $15,000. However, at present the customer may be paying only $60 p.a.[40].

One way of dealing with the subsidy could be to require air conditioners to be purchased with a ‘smart’ meter that measures electricity consumption by time of day and allows the use of the air conditioner to be controlled by both the customer and the energy retailer. Air conditioners must be on a separate circuit from all other residential electricity. The meter should provide instant feedback to the household, and should have a feature that allows the householder to program load shedding if the electricity price goes above a specified level. The energy retailer too would have the power to shed air conditioning load. The retailer would be required by law to charge for electricity consumed according to cost by time of day. Furthermore, a surcharge, that is independent of time-of-day, would be added to the price of each kilowatt-hour of electricity used by the air conditioner. The surcharge would provide accredited Green Power from either 100% wind or solar power.

Time-of-day pricing with Green Power surcharge would:
- discourage unnecessary use of air conditioners that have been purchased;
- encourage some prospective purchasers to install energy efficiency measures, such as shading of windows and insulation, instead of air conditioners;
- encourage the use of evaporative coolers and fans, which use much less electricity than air conditioners; and
- assist solar electricity systems, that tend to generate most during the hottest times of day, to compete with conventional peak-load electricity generation.

8.3 Subsidies for electricity used by aluminium smelters

Aluminium smelting uses 13% of Australia’s electricity. Overseas most aluminium smelting is powered by hydro-electricity, which generally has much lower greenhouse gas emissions than coal, the power source for aluminium smelting in mainland Australia. There are indications that electricity and infrastructure for aluminium smelting are heavily cross-subsidised by the other Australian electricity consumers. Unfortunately the details of the subsidies are only publicly available for Victoria, where they amount to approximately $200 million per year[41]. Statements by State Government Ministers at various times indicate that large subsidies are paid to smelters in NSW, although the precise amounts are not publicly available.

Removing the subsidies, when the contracts for aluminium smelting come up for renewal, could significantly reduce base-load demand in NSW. Furthermore, it is likely that the majority of the smelters that relocate to overseas destinations would use hydro-electricity and hence would have reduced greenhouse gas emissions.

8.4 Population growth

With Australia having the highest per capita greenhouse gas emissions in the world, population growth is a significant driver of emissions growth from stationary energy use in the residential sector. Every new birth and every new immigrant is a potential high emitter.

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[40] BCSE. 2003, Addressing peak demand, *EcoGeneration Magazine*, No. 20, 8-9

[41] Turton, Hal 2002, *The Aluminium Smelting Industry: Structure, Market power, subsidies and greenhouse gas emissions*, Australia Institute, Canberra, Discussion Paper 44.

Vested interests, such as the housing and property industries, claim that population growth is good for the economy, but this is debateable[42]. Although the housing/property industries may benefit, the vast majority of industries do not. Furthermore, population growth imposes higher infrastructure and pollution costs upon the community at large. Even if the requirements of a triple bottom line are ignored, economic performance of a nation or state is usually measured by GDP *per person*.

While the Federal Government is the main determinant of Australia's population policy, there is a potential role for individual States in influencing internal migration and whether or not the State capital is a major destination for immigration from overseas. Immigrants could be directed to the States with the lowest greenhouse gas emissions per capita, that is Tasmania and South Australia.

8.5 Declining household size

Declining household size (that is, the number of people per household) is a result of trends towards later marriage and an increasing divorce rate. Smaller households tend to use more energy per person. This is exacerbated by stamp duty on house sales, which discourages people who become single while living in large houses with high energy consumption from moving to smaller houses with lower energy consumption. Therefore, it is suggested that State Governments substitute a different type of tax, which does not have adverse environmental consequences, for stamp duty on house sales.

8.6 Government revenue based on quantity of electricity sold

The NSW Government owns the corporatised electricity utilities in NSW and receives revenue from the profit margin that these utilities make. The higher the sales of electricity, the higher is the government revenue. This inevitably creates a tension between the drive for increased government revenue and the need for energy efficiency and demand reduction.

A possible solution would be to restructure electricity/energy utilities to become energy service providers[43] and charge for energy services rather than energy supplied. Since energy services can contain a large component of efficient energy use, this restructuring would provide a framework for reducing growth in the demand for electricity. Restructuring would be difficult to achieve within the framework of the National Electricity Market (NEM), as it is currently structured. Ideally all the State Governments involved in the NEM and the Federal Government would cooperate to restructure the NEM.

8.7 The culture of consumption

As a major 'religion' in most countries, this culture demands faith that endless growth in consumption of products and services is good for individuals and societies and promotes happiness. This is too large a topic to address in the present report, where it is simply acknowledged that this is a major driver of *inter alia* electricity consumption and therefore merits further scrutiny in the context of reducing greenhouse gas emissions.

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[42] Cocks D (1996) *People Policy: Australia's Population Choices*. UNSW Press, Sydney.

[43] Diesendorf (2007), pp. 90–92.

Policy recommendations 24–27, which follow from this section on demand reduction, are listed in the executive summary.

9. Conclusion

Because of growing public concern about greenhouse gas emissions, there is growing public resolution that no new conventional coal-fired power stations be built in NSW.

By 2014 sufficient wind power and bioelectricity could be installed in the NSW to substitute for a new 1700 MW coal-fired power station, without any loss in reliability. The wholesale price of the renewable electricity would be roughly double that of conventional (i.e. dirty) coal power. However this substitution could be driven by carbon pricing at $40/tonne CO_2, assisted by more realistic water pricing and the requirement that developers of the coal station cover the financial risks of their project, without government assistance. Even a doubling of wholesale electricity price would only result in an increase in retail electricity prices of about one-sixth.

A rigorous program for efficient energy use could provide substantial economic savings to consumers of electricity, except possibly for energy-intensive industries. Thus, for most consumers, increases in the price electricity of a unit of electricity could be at least partially offset by reductions in the number of units purchased.

By 2020 it is expected that contributions from wind power and bioelectricity would continue to grow, solar electricity will provide both base-load and intermediate-load power, and hot rock geothermal may make an initial contribution. By 2020 and possibly by 2015 it should be clear whether coal with CO_2 capture and storage is technologically viable and whether it could become economically competitive with renewable sources of electricity post-2020.

It is emphasized that new policies, which are collated in the Executive Summary, are needed to facilitate the substitution of a much cleaner energy mix for conventional coal-fired power stations.

Appendix A
Mathematical formulation of optimal mix[44] and capacity credit[45]

Optimal mix

Consider an electricity generating system comprising N thermal power generation units with rated capacities c_i , where $i = 1, \dots, N$, with total rated capacity

$$C = \sum c_i$$

where the sum is over all values of i from 1 to N.

At a given time, the available capacity (i.e. that which is not undergoing planned or forced outage) of unit i is a random variable a_i and the total available capacity at a given time is

$$A = \sum a_i$$

The load or demand at a given time is the random variable L. One measure of the reliability of the generating system is the Loss of Load Probability (LOLP), denoted by p_0, which is the mean (average) value of the fraction of time that the load L is greater than the total available power A:

$$p_0 = Mean\ [Pr\ (A<L)] \qquad (1)$$

where Pr denotes ‘probability’. The value of p_0 is determined by the electricity utility’s choice of c_i, N and hence C. Ultimately the choice is political: how many hours per year of blackouts or brownouts can a government tolerate? It is impossible to build a generating system with $p_0 = 0$, because it would require an infinite amount of back-up and hence an infinite cost.

The economic optimal mix of thermal generating units, for a given value of p_0, is the configuration of base-load, intermediate-load and peak-load power stations that minimises the cost function

$$F = \sum c_i y_i + e_i z_i \qquad (2)$$

where the sum is again over all values of i. Here y_i is the annualised capital cost per megawatt of rated capacity c_i; e_i is the annual energy generated by unit i; and z_i is the total operation, maintenance and fuel cost per unit of energy generated.

The cost function Equation *(2)* has been evaluated numerically under the constraint given by Equation *(1)*[46]. The calculation is a non-trivial, since A and L are random variables (i.e. described by probability distributions which are obtained from empirical data). The results are obtained numerically. In special cases the probability distribution functions of A and L

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[44] Martin B and Diesendorf M (1982).

[45] Martin and Diesendorf (1980).

[46] Martin & Diesendorf (1982).

have been approximated by mathematical equations and the optimal mix has been evaluated analytically[47].

Wind power is included in this formulation as a negative load. Wind power too can be described by a probability distribution, which can be obtained from empirical data, or approximated by a mathematical function.

Capacity credit

Let's introduce into the electricity grid a hypothetical 'firm' capacity (that is, capacity with zero forced outage rate) C_f. Then LOLP is reduced from p_0 to p_f, where

$$p_f = Mean\ [Pr\ (A + C_f < L)]. \qquad (3)$$

Alternatively, if wind power with capacity (rated power) W_r (of which W will be available at a given time) is added to the original grid instead of C_f, then LOLP becomes p_w, where

$$p_w = Mean\ [Pr\ (A + W < L)]. \qquad (4)$$

As explained in the main text, there are three random variables to be considered: A, L and W.

The first measure of the capacity credit of wind power, the Equivalent Firm Capacity W_r , is then defined to be the value of C_f obtained by equating equations (3) and (4).

The second and better-known definition of capacity credit, the Effective Load-Carrying Capability (ELCC), is the value of a hypothetical firm load C_L (variance of $C_L = 0$) added to load L such that

$$p_0 = Mean\ [Pr\ (A + W < L + C_L\ )]. \qquad (5)$$

In other words, ELCC is the amount by which the load may be increased in the presence of wind power while the original LOLP of p_0 is maintained.

It should be noted that capacity credit may be calculated for a conventional power station as well as for wind power. In that case W will have a probability distribution function characteristic of the availability of the conventional power station instead of wind power.

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[47] Gates DJ (1985) On the optimal composition of electricity grids with unreliable units: solvable models. *Adv. App. Prob.* 17: 367–85.

Glossary

The terms defined here are given in italics where they first appear in the main text and in the definitions below.

Bagasse	The fibrous material left over after the sugar can is crushed and the raw sugar juice is extracted at a sugar mill.
Base-load	The minimum daily level of power. Also describes power stations that operate at rated power 24 hours per day, 7 days a week, wherever possible.
Bioelectricity	Electricity derived from biomass.
Bioenergy	Energy derived from biomass.
Biomass	Recent organic material, either plant or animal. Its stored solar energy may be converted into useful energy either by direct combustion or by first converting it into more useful forms by such processes as gasification, fermentation/distillation, anaerobic digestion, pyrolysis, etc.
Capacity credit	The average power value in megawatts of a power as a 100% reliable source of power. Is always less than the *rated power*.
Cap and trade	An emissions trading scheme that places place firm limits on total emissions in future years.
Capacity factor (of a power plant)	Average power output divided by *rated power*, usually expressed as a percentage.
Cogeneration	See *Combined heat and power*.
Combined cycle	A type of power station with two stages. Waste heat from the first stage, a gas turbine, is used to produce steam for the second stage, a boiler driving a steam turbine. Fuel can be gas, coal or biomass, however in practice is usually gas.
Discount rate	An interest rate used to discount income or expenditure in the future (see *net present value*) due to preference for consumption now rather than later. It is often expressed in 'real' terms, i.e. with the rate of inflation subtracted.
Distribution line	Power line for local distribution of electricity (e.g. in suburbs) at low voltages.
Economically efficient	Less expensive for the same outcome.
Effective Load Carrying Capability	One definition of *capacity credit* – see Section 2.4 and Appendix A.
Efficient energy use (sometimes shortened to 'energy efficiency')	Using less energy to provide the same amount of energy services: e.g. by insulating one's home, or using fluorescent light instead of incandescent, or replacing a fuel wasting car with a fuel efficient car.
Electricity 'sent out' from a power station	For a coal-fired power station, electricity sent out is about 93% of 'electricity generated'. the difference is used to run the power station.
Emissions trading scheme	Scheme in which tradable permits to emit pollutants are allocated or auctioned to emitters.
Energy efficiency	see *Efficient energy use.*
Equivalent firm capacity	One definition of *capacity credit* – see Section 2.4 and Appendix A.
Feed-in tariff	Long-term electricity tariff paid by a utility for electricity that it must purchase, that is fed back into the grid from a renewable energy source. The price is guaranteed by the government and paid for by electricity consumers, while the quantity of electricity sold is determined by the market.
Firm power	Power that is sufficiently reliable that it contributes to the avoidance of blackouts.

Green Power	A scheme in which electricity retailers provide customers with electricity from renewable sources for an additional price per unit of electricity.
Grid	A network of transmission lines joining a number of power stations to the main sites of electricity use.
Intermediate load	Power stations that supply the demand above base-load but below the sharp peaks in demand.
Optimal mix	The mix of base-, intermediate- and peak-load power stations connected to an electricity grid that gives the minimum total annual cost of generation.
Peak-load	Daily peaks in electricity demand. Also describes type of power station that is used specifically for supplying peaks in demand – usually gas turbines or hydro-electricity.
Photovoltaic cell	A material that directly produces electricity when exposed to sunlight.
Ramp (verb)	To change the output of a power station.
Rated power (of power station)	Maximum or peak power output recommended by manufacturers for normal operation.
Sent out	See *Electricity sent out*.
Smart meter	An electricity meter that displays electricity consumption in real time to the user and supplier. The 'smartest' meters may be controlled or programmed by both the consumer and supplier to switch circuits off and on when required.
Solar thermal electricity	Electricity generated by using the heat from focused sunlight to boil water to produce steam to turn a steam turbine.
Sustainable development	Best known definition is: 'to meet the needs of the present, without compromising the ability of future generations to meet their own needs'.
Synthesis gas	A mixture of carbon monoxide and hydrogen, produced by gasifying wood and other woody materials.
Thermal efficiency	In the process of energy conversion, useful energy output divided by energy input, usually expressed as a percentage.
Town centre	Centre of a *transit city*. Has population of about 100 000 residents and jobs within a radius of 3 km. (Sometimes called a Regional centre or Sub-centre.)
Tradable emission permits	Permit to emit a specified quantity of CO_2 or other pollutant. The permit has monetary value and may be traded in a market.
Transmission line	Power-line for carrying large quantities of electricity over long distances at high voltage.
Watt	Basic unit of power in SI units, the rate of change of energy generation or energy use over time. 1 watt = 1 joule/sec.

Acronyms and abbreviations

ABARE	Australian Bureau of Agricultural and Resource Economics
BASIX	Building Sustainability Index
CO_2	carbon dioxide
CCS	CO_2 capture and (underground) storage
MRET	Mandatory Renewable Energy Target
NEM	National Electricity Market
NEMMCO	National Electricity Market Management Company
NGO	non-government organization

NRET	NSW mandatory Renewable Energy Target
NSW	New South Wales
PV	photovoltaic
REC	renewable energy certificate
STE	solar thermal electric