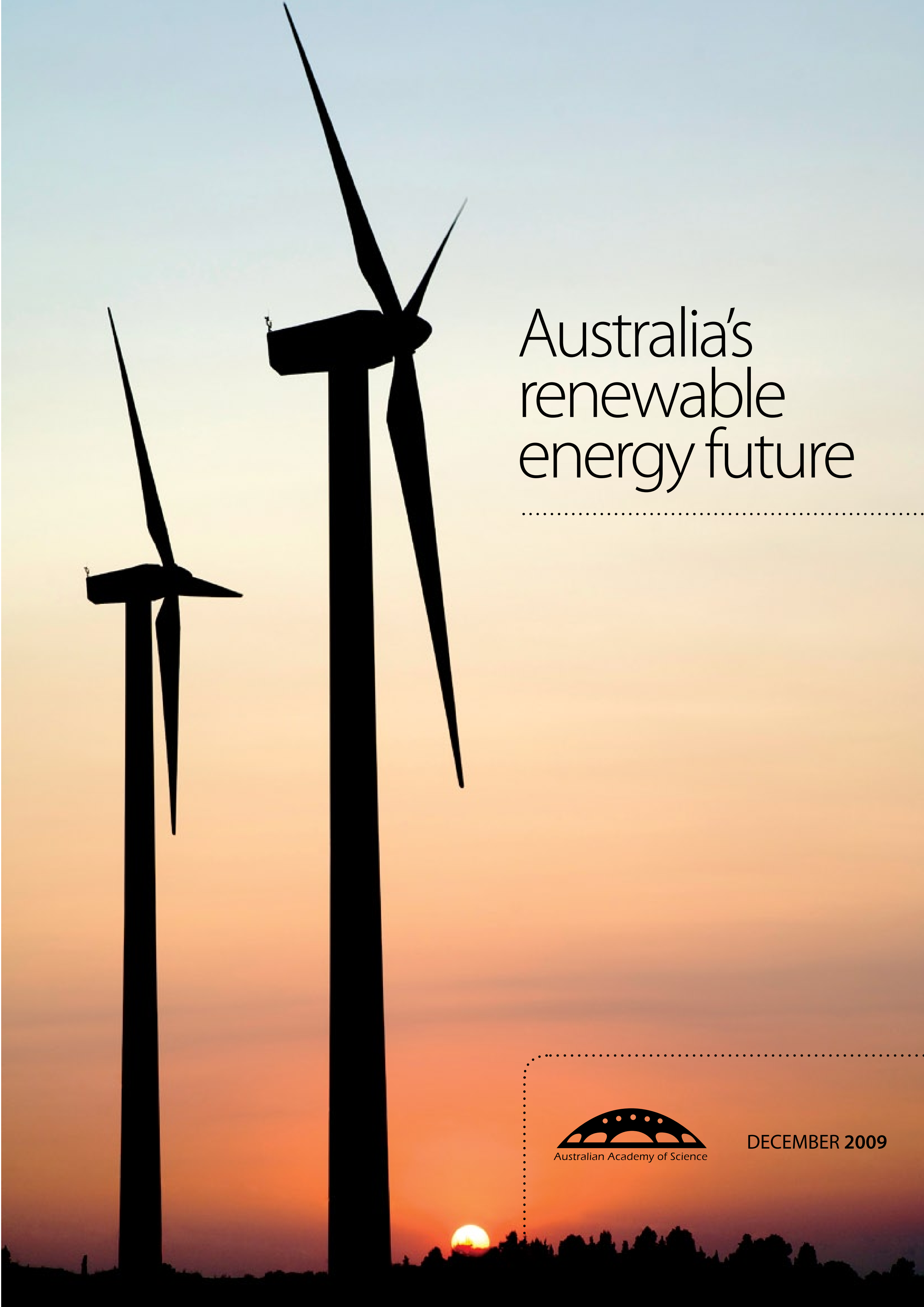

Australia's renewable energy future

Australian Academy of Science

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1. Introduction

Consistent with the Australian Academy of Science's endorsement of the findings of the Fourth Assessment Report (2007) of the Intergovernmental Panel on Climate Change (IPCC), Australia's Renewable Energy Future was chosen as the theme of the Academy's 2008–09 monthly public lecture series held at the Shine Dome, Canberra.

The Academy has long recognised the extensive evidence and theory that underpins anthropogenic climate change. The Academy recognises too that leading-edge science to understand climate change will continue to be debated: such is the nature of scientific progress. The Academy's ever-developing understanding leads it to agree with the August 2009 article in the international journal *Science* that states:

> Despite some uncertainties, today's scientific and political consensus is that the level of global emissions of greenhouse gases needs [to stabilise at] atmospheric concentrations somewhere between 450 and 500 parts per million to avoid serious, if not catastrophic, effects on life and property. Achieving this goal poses some formidable challenges.[1]

As a contribution to exploring these challenges for Australia, *Australia's Renewable Energy Future* presents a collation of the substance and conclusions of the 2008–09 lectures. It is our hope that this will inform a greater understanding of the state of renewable energy science and technology. The lecturers in the series presented expert opinion about the state and context of various technologies, in recognition of the need to deploy available, and soon to be available, renewable energy technology in response to climate change. Points 4.2 and 5.5 of the 2007 *IPCC Synthesis Report* represent this rationale:

> 4.2. A wide array of adaptation options is available, but more extensive adaptation than is currently occurring is required to reduce vulnerability to climate change. There are barriers, limits and costs, which are not fully understood.
> 5.5. There is high agreement and much evidence that all stabilisation levels assessed can be achieved by deployment of a portfolio of technologies that are either currently available or expected to be commercialised in coming decades, assuming appropriate and effective incentives are in place for their development, acquisition, deployment and diffusion and addressing related barriers.[2]

All assessed stabilisation scenario indicate that 60 to 80% of the reductions would need to come from energy supply and use, and industrial processes, with energy efficiency playing a key role in many scenarios.[3]

It is a remarkable fact that, in maintaining our standard of living, each Australian produces enough carbon dioxide (CO_2) to replace the column of atmosphere above one square metre of land every year. An average Australian house will, in a person's lifetime, produce enough CO_2 to entirely replace the atmosphere above it with this greenhouse gas.

The impact upon the climate caused by our current energy use cannot be sustained. The economic costs of current energy arrangements have been analysed in the *Garnaut Climate Change Review Final Report*.[4] There exists a large difference between the price paid by consumers in Australia for electrical energy, over 80% of which is produced from black and brown coal, and the true cost of this energy, when we factor in the environmental impacts. Such market distortions hinder the development and deployment of cleaner alternatives.

Likewise, in the area of transport, current practices in terms of supply and environmental impact are unsustainable in the longer term. At present, our transport needs are driven by the use of liquid hydrocarbons. This was at least domestically serviceable when Australia was self-sufficient in oil production, but this is no longer the case. A recent report has highlighted Australia's growing dependence on foreign oil, which doubled our petroleum trade deficit to $10.85 billion in 2007–08.[5] This deficit can only grow over time, as Australia's oil reserves continue to be depleted and production continues to fall.[6] The likely projection for production versus demand is shown in Figure 1. With an assumed price of oil at US$100 per barrel, by 2020 our petroleum trade deficit will have risen to over $40 billion per annum, comparable to the size of the recent economic stimulus package.

The adaptation of the electricity and power distribution grid to facilitate the low-carbon economy appears to be pivotal. The current model of a 'dumb' grid, centralised power generation, and high-loss transmission is unsustainable. To quote our sister academy, the Australian Academy for Technological Sciences and Engineering:

> Australia's energy security requires a major increase in base-load electric power generation capacity to meet the expected growth in demand. The electricity grid must be planned to meet the long-term demands imposed by a diversity of technologies supplying power, including base-load and intermittent renewables, remote locations for some power generation and the need for stability of the system under variable supply and demand situations. There is a need to introduce consideration of the 'national interest' when planning future expansion of the grid.[7]

Replacing the current energy generation regime with a model based upon renewable technologies will not be easy. Minister Martin Ferguson argues, 'the factors limiting the uptake of renewables remain technical, not political. We must have a rational science-based pathway to overcome those hurdles. Faith alone will not get us there.'[8]

This report aims to inform such a rational science-based pathway offering contributions to overcoming these technological problems. However, as the lecture series clearly demonstrated, there are many areas where the key science and technical problems have already been solved. Impeding the deployment of these technologies is a lack of both routes and financial support for innovation. To hasten the transition to the low-carbon economy, advantages of scale need to be achieved.

Several speakers in the lecture series acknowledged that further research by scientists, engineers, social scientists, economists and public policy researchers is required to expedite deployment of technologies and the cost-effective transition to the low-carbon economy. However, the series as a whole demonstrated beyond doubt that there is no complete science-based pathway to renewable energy that can be found within a single technology. Rather, we find that a holistic approach embracing complementary aspects of different technologies is to be preferred. Only such an approach can successfully address issues such as base-load power supply by renewables.

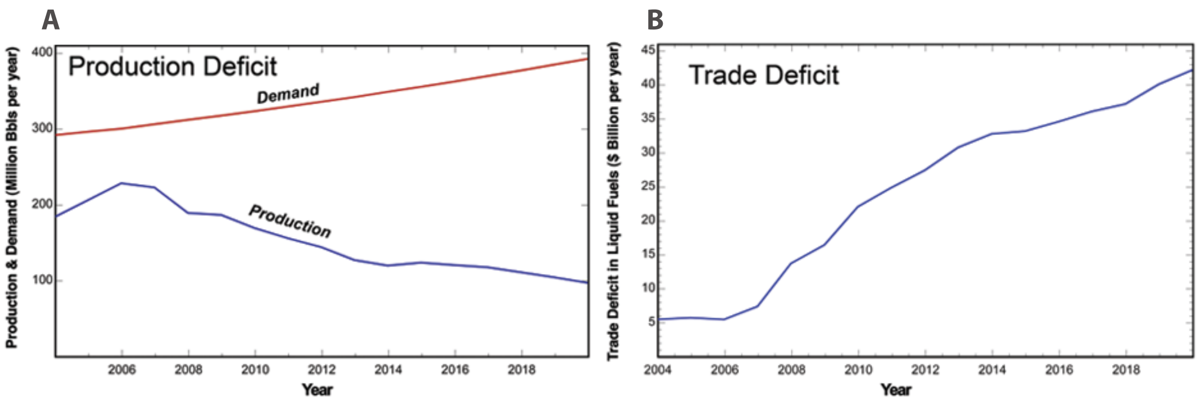

Figure 1

A. Australia's production and demand for crude oil and condensates (million barrels per year).
B. Australia's projected petroleum trade deficit. Based upon these statistics, it could be $20 billion by 2010 and rise to over $40 billion by 2020. Data source: Department of Industry, Tourism and Resources, *Oil and Gas Resources of Australia 2003*, www.ga.gov.au/image_cache/GA6111.pdf

A successful model for the low-carbon economy must also embrace efficient non-renewable forms of energy such as liquid natural gas (LNG). Natural gas provides notable advantages in electricity generation, heating and transport as it yields relatively less greenhouse gas emissions per energy output, and can make use of modern, efficient equipment.
Likewise, our approach to infrastructure development needs to be holistic and many-faceted. A report commissioned by WWF Australia states:

> … modelling finds that there are sufficient low emission energy resources, energy efficiency opportunities and emissions reduction opportunities in non-energy sectors to achieve reductions of 60 to 80%, and even emissions reductions of 90% or more if livestock emissions are reduced; and that there is sufficient time for the low emission technologies and services to grow at sustainable rates if development starts promptly. The model finds that a sequential approach to low emission industry development (lowest cost technology first, then the next lowest cost technology and so on) requires much higher growth rates for each industry than one that grows a number of technologies/industries concurrently.[9]

As Australia makes the transition to the low-carbon economy, some jobs in emission intensive industries will inevitably be phased out as alternative technologies and jobs appear to meet ongoing needs for energy, materials and services. The history of civilisation has many examples of occupations that have been revolutionised by new technologies which have served to raise living standards. Efforts should be taken to quantify the nature of the renewables revolution, especially in terms of workforce transitions and the need and perspective for retraining. However, to quote a CSIRO document:

> … achieving the transition to a low carbon sustainable economy will require a massive mobilisation of skills and training – both to equip new workers and to enable appropriate changes in practices by the three million workers already employed in these key sectors influencing our environmental footprint. Current approaches do not appear sufficient for meeting these challenges.[10]

We can become more energy efficient and at the same time grow our economy, as demonstrated by the example of Sweden. Since 1990, the economy of this country has grown by 50% while reducing its greenhouse emissions by 10%.[11] To achieve a similar outcome, Australia must build infrastructure to reduce our greenhouse gas footprint, cut our dependence on liquid fuels, and enable the transition to a low-carbon economy. The full gamut of low-carbon renewable energy generation techniques has been ably reviewed in the report *A Clean Energy Future for Australia*.[12]

This document builds upon the lecture series. It outlines the state of the technological alternatives, and provides a set of development options for consideration by policy-makers. The report is based upon, but is not strictly representative of, the inspiration and data provided by speakers at the Academy's series of monthly public lectures, *Australia's Renewable Energy Future,* held between 2 September 2008 and 4 August 2009. The original content of the talks, including transcripts and slides, is on the Academy's website.[13] The complete list of speakers was as follows:

Dr Anthony Budd
Geothermal Energy Project Leader, Onshore Energy and Minerals Division, Geoscience Australia
Geothermal energy in Australia: The who, what, where, when and how

Dr Tom Denniss
Executive Director and Chief Technology Officer, Oceanlinx
Wave energy: The industry now and in the future

Dr Tim Finnigan
Chief Executive Officer, BioPower Systems
Tidal energy: A viable form of renewable energy

Dr Karl Föger
Chief Technology Officer, Ceramic Fuel Cells Ltd
Fuel cells: A real option for base load electricity

Dr Barney Foran
Institute of Land Water and Society, Charles Sturt University, Albury
A low carbon economy based on renewable energy: The only way to go

Professor Martin Green
ARC Federation Fellow, Scientia Professor and Research Director of the Photovoltaic Centre of Excellence, University of New South Wales
Solar photovoltaics: Power source for the future?

Professor Keith Lovegrove
Solar Thermal Group Leader, Department of Engineering, Australian National University
Solar thermal concentrators: Capturing the sun for large scale power generation and energy export

Dr Steve Schuck
Manager, Bioenergy Australia
Bio-energy options for Australia

Professor David Wood
Priority Research Centre for Energy, University of Newcastle
Wind Energy: How it works and where is it going?

Dr John Wright
Advisor, Sustainable Energy Partnerships, CSIRO Energy Transformed Flagship
Australia's renewable energy future

1.2 Summary of development options

In this document the Academy of Science offers the following policy options developed from ideas presented during the *Australia's Renewable Energy Future* lecture series.

1. Consider increasing public education with clear guidelines for allowable noise levels and visual amenity to encourage the establishment of wind farms and other sources of renewable energy, such as solar thermal and biomass generation, on privately-owned land.
2. Consider a national system of feed-in tariff rates for all forms of renewable and sustainable energy in a policy setting that encourages community power schemes, small and medium businesses, and other organisations to install renewable generation. The ACT feed-in tariff legislation is an excellent template for this and the New South Wales 'gross' feed-in tariff scheme provides innovative guidance.
3. Consider setting an appropriate national digression rate on feed-in tariffs.
4. Consider a national system of feed-in tariff rates for combined heat and power (CHP) domestic generation.
5. Consider setting an appropriate digression rate feed-in tariff rates for CHP domestic generation.
6. Consider government incentives to construct industrial scale CHP plants for base-load management.
7. Consider setting national standards governing the level and type of sulphur compounds in commercially-supplied natural gas (compressed natural gas, liquefied natural gas, liquefied petroleum gas) or biofuels (biogas and bio-alcohols).
8. Consider giving priority support to geothermal energy and solar thermal energy such that they become major national energy sources.

9. Consider co-location of geothermal and solar thermal electrical energy generation stations.
10. Consider linking geothermal and solar thermal electrical energy generation with the national electricity grid through high voltage direct current (HVDC) transmission line technology.
11. Consider providing incentives or support to heavy industry located on the coasts to use wave and tidal energy.
12. Consider fast tracking the installation of smart meters in all Australian households, and phase in the introduction of time-of-use pricing, including dynamic peak pricing at times of high demand offset by lower prices at other times.
13. Consider integrating HVDC technology to transmit energy from the renewable energy production sites to cities and provide the HVDC system with efficient intercity links to allow for energy exchange as demand varies.
14. Consider providing incentives for the development of distributed power generation by fuel cells on both the domestic and small country town scales to stabilise base-load requirement and eliminate transmission losses.
15. Consider encouraging the development of a coast-to-coast integrated national natural gas distribution network.
16. Consider providing incentives for the greater adoption of liquefied natural gas to replace diesel and petrol.
17. Consider incentives to encourage the use of electrical or natural gas fuel cell electric hybrid vehicles, especially in cities.
18. Consider upgrading the interstate rail network to carry large loads, and link container ports or roll-on/roll-off facilities to encourage efficient distribution of goods.
19. Consider placing research and development priority on technological options for further reducing carbon and other emissions from shipping.
20. Consider measures to encourage and support the retrofit of all existing houses and apartments to at least a three star energy rating.
21. Consider a national seven star energy standard for all new houses by 2015.
22. Consider a national nine star energy rating for houses constructed after 2020.
23. Consider measures to encourage maximum standby power requirements on all domestic appliances and zero standby power usage where practical by 2015.
24. Consider a national scheme for feed-in tariff returns which encourages a high degree of domestic participation.
25. Consider dedicated Commonwealth and state government funding for Australian universities and research organisations to advance renewable energy research, from pure and applied research to development and commercialisation.

2. Alternative Energy Sources

It is often stated that the deployment of alternative energy resources will require a great deal of new research and development effort. This may have been accurate in the past, but is no longer correct, since we already have available a number of tried and tested technologies which can be deployed immediately. However, many of these technologies currently appear to be uneconomic when compared with coal-generated electricity, unless coal is fully costed for its CO_2 emissions, and unless the advantages of 100 years of public investment in coal-based infrastructure are recognised. These factors hinder the development of renewable technologies, and delay the transition to a low-carbon economy.

If the world introduces an emissions trading scheme (ETS), the basis for the current calculations will change. If, as seems likely, a carbon price is introduced at a level of $10 per tonne of CO_2, but rising rapidly in future years, the market will tilt in favour of greater use of renewables. Economic modelling by the CSIRO shows that renewable energy sources, other than growth in wind and bioenergy, will have little impact on Australia's energy mix before 2025. However, their introduction could be much hastened with only minor policy adjustments at federal government level.

Such policy adjustments would yield major economic dividends to Australia. What is currently lacking for many renewable technologies are economies of scale. A small stimulus, combined with the introduction of an ETS with strong targets, would allow many renewable energy technologies to compete head-to-head against coal-fired electricity generation within five years or so. In so doing, they will also provide significant employment and export opportunities.

However, the current climate of investment in Australia is not favourable to renewables. Without government intervention to 'tilt the marketplace', Australia will lose her competitive edge in developing renewable energy technologies and will become a passive importer of technologies developed overseas, instead of an innovator and major exporter in her own right.

What is the potential for alternative clean energy sources in the Australian context? Research commissioned by the Clean Energy Future Group and contained in the 2004 report *A Clean Energy Future for Australia* finds that Australia's greenhouse pollution can potentially halve by 2040 through a combination of energy efficiency and switching to currently available clean energy technologies.[14]

The following technologies are available 'off the shelf' and can be considered ready for exploitation.

Wind turbines

Though variable, wind turbines achieve a capacity factor (the ratio of average output power to the turbine's rated or maximum power) of up to 50% in Australian wind farms, and require less than 3 to 6 months to recoup the energy used in their manufacture. Currently, large wind turbines are cheaper than any other renewable energy source, and under the Mandatory Renewable Energy Target (MRET) they compete head-to-head with coal-fired electricity generation at current costs. As fossil fuels are anticipated to incorporate their environmental costs with the introduction of an emissions trading scheme, the competitive position of wind turbines should continue to strengthen. Subject to amenity and aesthetic considerations, there are significant opportunities for small- and medium-sized turbines to be installed in urban and semi-urban areas such as sporting fields, parks, shopping centre car parks and industrial areas.

Solar thermal

With appropriate energy storage, this technology offers potential load factors close to 100%, and is ideally suited for base-load power generation. It uses solar concentrators to focus sunlight for electricity generation. To put solar thermal generation systems into perspective, the Sun's energy falling on Australia in one day is equal to half the total annual energy required by the whole world. To power all of Australia's energy needs would require only 0.3% of the land surface to be devoted to solar power generation.

Solar photovoltaic

This technology provides a load factor of 15 to 20%. Solar photovoltaic cells are best for supplying peak demands in the middle of the day, but are less effective in managing the evening peak. Depending on feed-in tariffs, currently photovoltaics require between 4 and 10 years to recoup their investment and 2 to 3 years to recoup the energy used in their manufacture. Current costs are around $0.20 per kilowatt hour (kWh), but with the new technologies currently under development, generation costs are expected to reduce significantly. Solar photovoltaic systems are suited to domestic grid-connect power applications.

Biomass combustion

Potentially able to offer a high load factor, and a 2-year energy payback timescale, these provide a useful supplement to coal in centralised power stations. In semi-rural facilities, the process heat could be used for domestic applications.

Fuel cells

Fuel cells process gas to produce both electricity and heat. Both can be used in a domestic environment to give greater than 80% net efficiency, far exceeding conventional centralised power generation efficiencies, which in Australia are less than 30% for brown coal generators.

In the near term, we can expect the following technologies to come on-line for exploitation.

Geothermal

This relies on producing superheated steam in radioactively heated 'hot rock' granite deposits to generate electricity. This process works best when the substrate rock (approximately 5 kilometres deep) has been heated to over 250 degrees Celsius (°C). Fortunately, Australia has several such deposits, notably in the Cooper and Galilee Basins located close to the boundary of New South Wales, Queensland and the Northern Territory.[15] A cubic kilometer of hot granite at 250°C has the stored energy equivalent of 20 million barrels of oil. This technology is in development in Australia by several Australian companies at various levels of operation.

Wave energy

This technology has been well demonstrated overseas, and has shown to be viable in a number of different modes developed in Australia. Wave energy densities to the south of Australia are very high, with potential to offer very high load factors.

Tidal energy

The efficiency of tidal energy depends on the cube of the tidal current. In Australia, only a few locations provide suitable conditions, but this may be useful in niche areas such as supplying the energy needs of some remote settlements.

All of these technologies will be discussed in more detail. However, maps produced by government agencies show that most alternative power sources are generally concentrated at some distance from the main population systems.[16] Any systematic attempt to institute an alternative energy infrastructure in Australia must therefore address the structure of the national power grid.

2.1 Wind turbines

Tapping wind energy through wind turbines is the most cost-effective renewable energy technology, apart from hydro-electric generation. Wind farms are now a familiar aspect of the environment. Because the power output scales approximately as the cube of the wind speed, existing wind farms in Australia are concentrated along the windy southern littoral districts (see Figure 2).
The economies of scale have permitted wind power to reduce the cost of delivered power by more than 80% over the last 20 years. To quote the American Wind Energy Association:

> In the early 1980s, when the first utility-scale wind turbines were installed, wind-generated electricity cost as much as 30 US cents per kWh. Now, state-of-the-art wind power plants at excellent sites are generating electricity at less than 5 cents per kWh. Costs are continuing to decline as more and larger plants are built and advanced technology is introduced.[17]

Wind turbine technology is thus a growing energy source and with modest incentives currently in place in Australia, is able to compete with coal-fired generators, which also benefit from public subsidies.

Globally, wind power generation more than quadrupled between 1999 and 2005 (Figure 3). In the US the installed capacity in 2007 was 16 gigawatt (GW). With a reasonably stimulative legislative environment, the annual energy outlook for 2009 produced by the US Energy Information Administration estimates that this capacity will increase to between 35 and 50 GW by 2020.[18]

The limit to the power output of wind turbines is determined by their size. Current commercial turbines are rated at over 3 megawatt (MW) of power and use blades that are 60 metres or longer. The technological push is towards larger turbines and longer blades. Most current blades are a composite of fibreglass embedded in petroleum-derived resin. As blade size increases there is a major push for stronger and lighter reinforcement such as carbon fibres. Modern blades can weigh over 20 tonnes and there is increasing concern that the recycling and disposal of used blades may present environmental problems. There is significant research underway to investigate more benign materials. It appears, for example, that bamboo can provide a potentially valuable composite component.

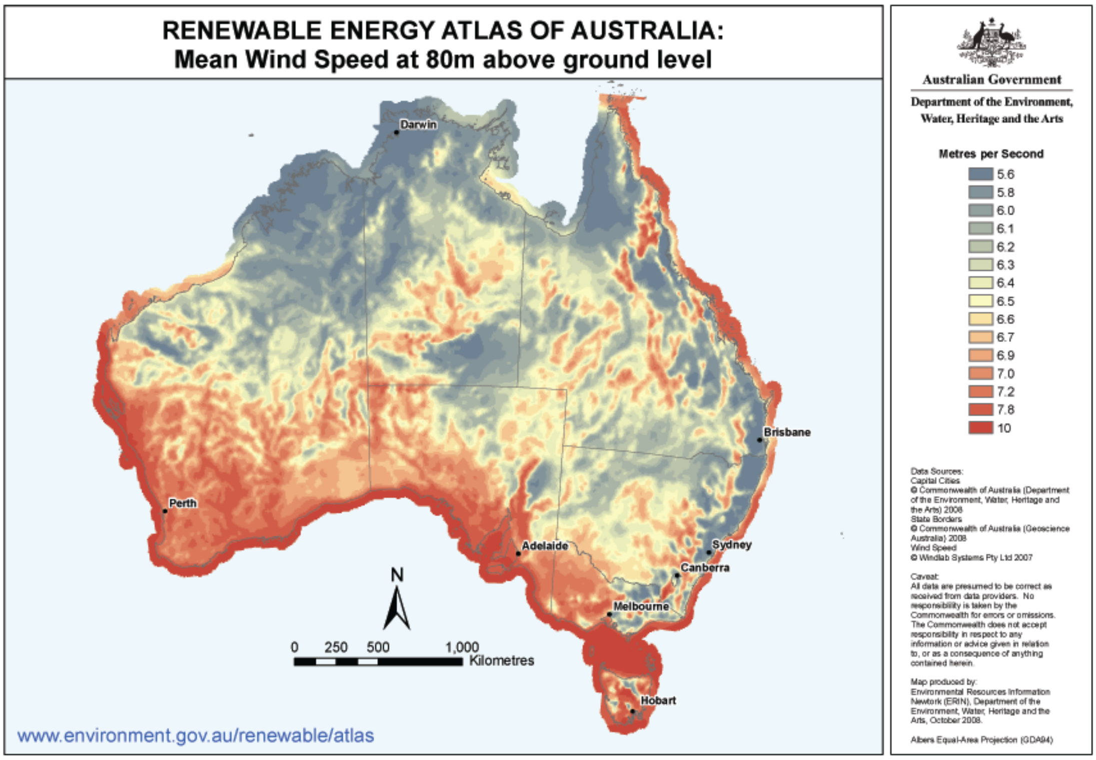

Figure 2: The potential for wind power generation in Australia

Image: Australian Government Department of the Environment, Water, Heritage and the Arts, *Renewable Energy Atlas* , October 2008, www.environment.gov.au/settlements/renewable/atlas/maps.html

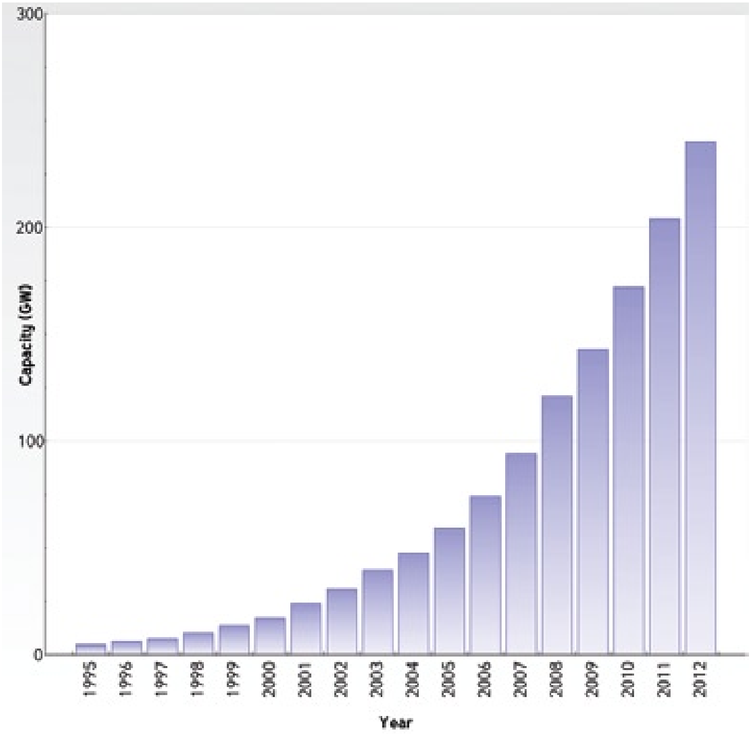

Figure 3: The growth of wind power electricity generation worldwide

Image: Wind Power, World Capacity, www.thewindpower.net/211-windfarms-production-world.php

In Australia, the wind turbine market is expected to benefit from Australia's new push for sustainable energy.[19] It is expected that wind energy will provide the largest share of Australia's targeted 20% renewable energy by 2020.

The major objections to the use of wind power in Australia are aesthetic, and a concern for the effect of wind farms on birdlife, although it is possible that based on experience elsewhere, the latter is somewhat over-rated. There can be, however, widespread noise and visual concerns with wind farm development, often expressed by residents and landowners objecting to proposed developments. These concerns, along with the limited availability of land in Europe, are driving the development of offshore wind farms, which in turn, makes larger turbines more economic. Australia has few options for offshore wind farms, and so it is important that increased public education and awareness of the role of wind farms and the need for renewable energy is undertaken.

Medium and small wind turbines have an important place in Australia's renewable energy future. Not only can they supply remote power for our sparsely populated country, but they can have similar roles as photovoltaic arrays in urban and semi-urban locations. At present, small turbines have an installed cost per unit of power output similar to that of photovoltaic arrays, but about three times higher than large wind farms. It is necessary to have feed-in tariffs that include wind energy to encourage the uptake of small turbines for individual houses, and medium turbines for community and business power schemes. The worldwide sale of small wind turbines has exploded over the last few years due to the establishment of attractive feed-in tariffs in Europe and the US.

Development option 1

Consider increasing public education with clear guidelines for allowable noise levels and visual amenity to encourage the establishment of wind farms and other sources of renewable energy, such as solar thermal and biomass generation, on privately owned land.

2.2 Solar thermal

In the US, over 450 MW of electricity is currently produced by this method. They provide a load factor of 35%, rising to 80% with storage, and require five months to recoup the energy used in their manufacture. Their cost is currently around US$0.25 per kWh, but could be reduced to half of this through the advantages of scale. An example of a US solar trough concentrator in Nevada is shown in Figure 4.

The early solar thermal plants tended to be parabolic trough concentrators which focused the solar energy on to water, air, oil or another heat exchange fluid. The heated fluid was used to power steam turbines to produce electricity.

Modern solar concentrators are able to overcome the issue of load factor by the use of energy storage before steam generation. These trough plants heat fluids to around 400°C which is used to heat a reservoir of molten salt. The stored energy allows this plant to run for 7.5 hours at essentially nominal power output without sunlight. An alternative medium for heat storage is a block of pure graphite, which has a very high heat capacity and also increases in heat capacity with temperature, making storage more efficient. This technology and the manufacturing process for the ultra-pure graphite have been developed in Australia, and are ready for large scale deployment.

At the Australian National University, the solar thermal research group has developed a Rankine cycle power conversion system based on the dissociation of ammonia by solar heat, coupled to an exothermic synthesis reactor. This method offers a high energy storage density, and stores the solar energy in chemical form before the power generation cycle, eliminating thermal losses in storage.[20]
The fundamental difficulty for the development solar technologies for base-load power supply is summarised in Figure 5. The places where power can be generated most efficiently are, in most cases, far from the major population centres. If solar power technology is used, Australia's future renewable energy generation plants will have to be located in the outback.

Figure 4: The solar thermal energy plant in Eldorado Valley, Nevada

This trough plant alone generates enough energy to power 60,000 homes. Overall, Australia has a high degree of expertise in the development of solar thermal technology. Solar concentrators have a major advantage over many other forms of renewable energy because the energy can be stored for long enough periods to overcome the base-load issue, which makes them attractive to consider for grid supply. Image: www.German-renewable-energy.com

From the viewpoint of infrastructure planning, it would be very useful to consider the co-location of any future solar thermal base-load plants with geothermal energy generation (such as in the Cooper Basin; see section 2.6). The power generated by both technologies could then be sent through HVDC power transmission lines to link into the national energy grid (section 3).

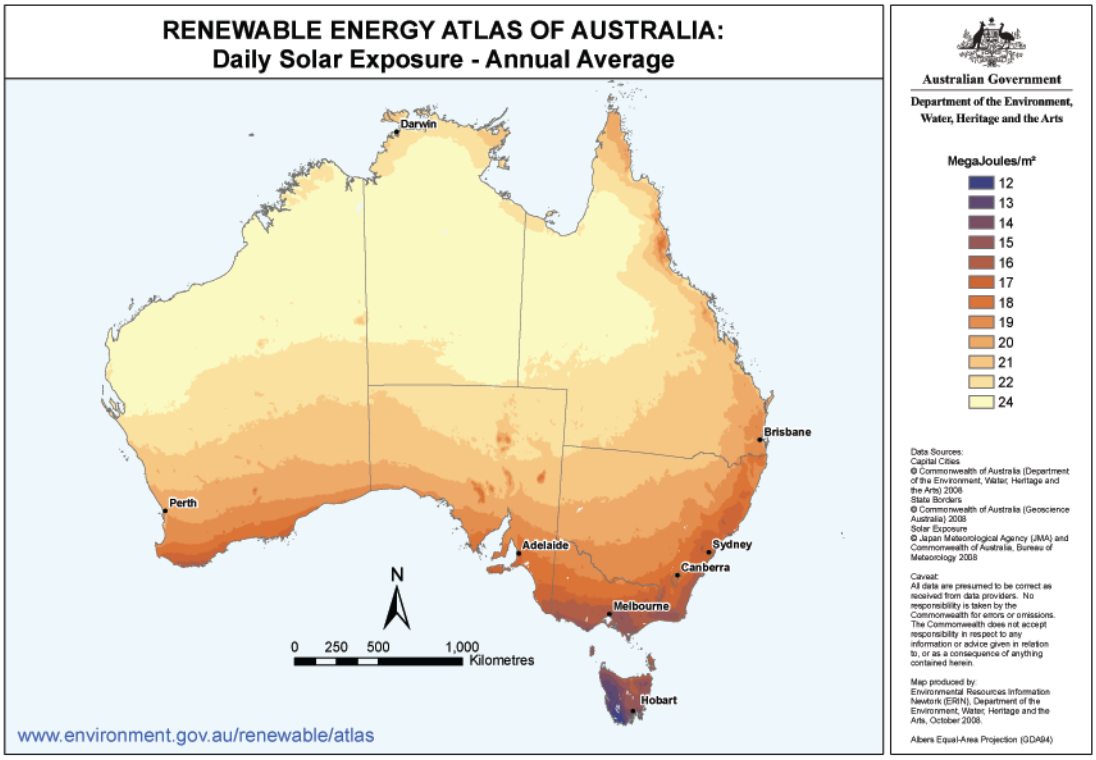

Figure 5: The potential for solar power generation in Australia

Image: Australian Government Department of the Environment, Water, Heritage and the Arts, *Renewable Energy Atlas* , October 2008, www.environment.gov.au/settlements/renewable/atlas/maps.html

2.3 Solar photovoltaic

Solar photovoltaics are ideally suited to domestic grid-connect power systems. Solar photovoltaic technology provides a load factor of 15 to 20%, and depending on feed-in tariffs, currently require between 4 and 10 years to recoup their investment, and 2 to 3 years to recoup the energy used in their manufacture. The current cost of modern large scale photovoltaic electricity generated is around US$0.20 per kWH, but with the new technologies currently under development generation costs are expected to continue to fall. Janet L Sawin has described the growth in photovoltaic cell production and installation as follows:

> Global production of photovoltaic or solar cells, which convert the sun's light directly to electricity, increased 51% in 2007, to produce 3.733 GW. According to early estimates, more than 2.935 GW of solar modules were installed that year, bringing cumulative global installations of photovoltaics since 1996 to more than 9.7 GW – enough to meet the annual electricity demand of more than 3 million homes in Europe. Over the past five years, annual global production of photovoltaic cells has increased nearly seven fold, and cumulative installations have grown more than five fold.[21]

With this continued stellar growth rate of over 25% per annum, the world solar photovoltaic energy capacity is expected to reach over 40 GW by 2012. Thanks to aggressive government policy initiatives, and the close engagement with academic and research institutes such as the various Fraunhofer institutes, the Forschungszentrum Jülich and the Hahn-Meitner Institut, Germany is now Europe's leading photovoltaic manufacturer. Germany has Europe's largest solar thermal market, and also the world's largest photovoltaics market, with 49% of global installations in 2007, and growing at over 28% per year. Nearly €176 million was invested in Germany for R&D for photovoltaics in 2007, with an expected increase to €224 million by 2010.[22]

Currently, when one takes into account the cost of the associated equipment needed to implement solar photovoltaic systems, the economics of these systems is not competitive without government subsidies for installation and feed-in tariffs. However, advances in the techniques of manufacture, particularly through thin-film or sliver cell technologies, are expected to bring the cost of these systems down below US$1 per installed watt, at which point these systems become independently financially viable.

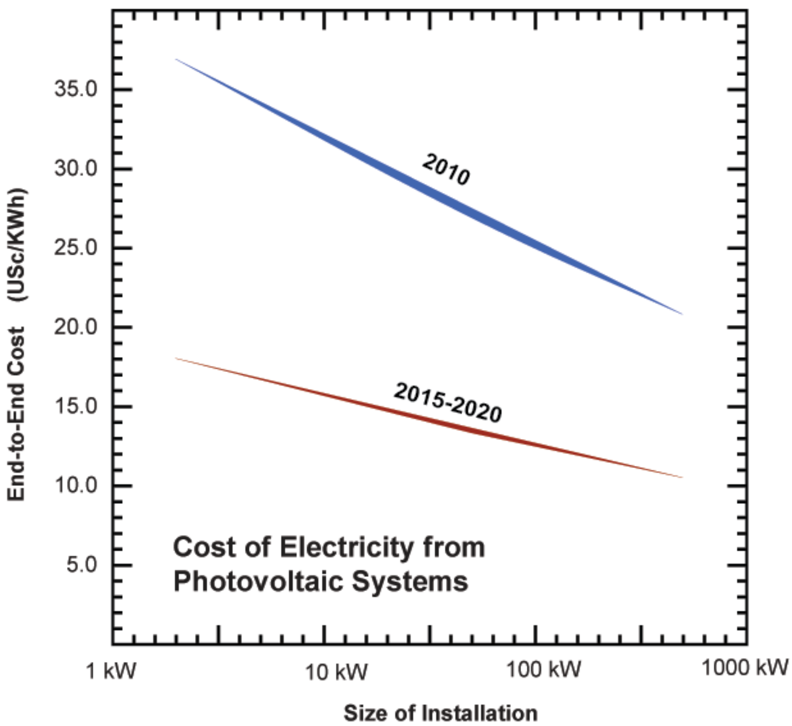

Figure 6

The whole of lifetime costs of energy production from photovoltaic systems as a function of size of the installed system. The cost includes the infrastructure (mounting systems, inverters, grid connection) as well as the basic costs of the panels. These costs are expected to fall by 50% by 2015–21. Data source: www.solarbuzz.com/solarindices.htm

The objective of the industry is to approach 'grid parity', the point at which the costs of generation by photovoltaic systems becomes equal to the cost of power generated by other means. In Europe, grid parity is expected for southern countries within five years, and for northern countries by about 2020. Figure 6 gives the (world averaged) expected life time costs of photovoltaic systems as a function of size of the installed system.

At first sight is may seem curious that a country as cloudy as Germany has become the world leader in photovoltaic systems. However, this is undoubtedly the case. To quote Janet L Sawin again:

> Europe, led by Germany, passed Japan to lead the world in photovoltaic manufacture, producing an estimated 1,063 MW of solar cells in 2007, up 56% over 2006. About 40,000 people are now employed in the photovoltaic industry in Germany alone, and the German company Q-Cells out-produced Japan's Sharp to become the number one manufacturer worldwide. Germany remains the world's top photovoltaic installer, accounting for almost half of the global market in 2007. Thanks to the country's feed-in tariff for renewable electricity, which requires utilities to pay customers a guaranteed rate for any renewable power they feed into the grid, Germans installed about 1,300 MW of new photovoltaic capacity, up from 850 MW in 2006, for a total exceeding 3,830 MW. As capacity has risen, photovoltaic installed system costs have been cut in half in Germany between 1997 and 2007. Photovoltaics now meet about 1% of Germany's electricity demand, a share that some analysts expect could reach 25% by 2050.[23]

The result of this growth has been a sharp increase in jobs in the sector. In 2004, Germany employed 25,100 in the photovoltaic sector. By 2006 this had risen to 40,200 and to 50,700 in 2007. New industries can create new job opportunities and new sources of economic growth.

The German success story is the result of enlightened government policy. The 'million homes initiative' to put photovoltaic systems on the roofs of one million German homes stimulated the industry through attractive feed-in tariffs. In 2008 the tariff was €0.47 per kWh. This creates powerful incentives for installation, and therefore stimulates industry to reap the advantages of scale and productive capacity. The key point of the German system is that it operates a 'digression' (or reduction) rate on the feed-in tariff, which progressively reduces the incentive to €0.27 per kWh in 2015 and €0.20 per kWh in 2020. Similar schemes operate for wind power, but with much lower feed-in tariffs, commensurate with the lower installation costs of this technology.

Despite our evident climatic advantages, Australia has no comparable scheme. Australia started late along the path of feed-in tariffs, and currently has an inconsistent and incomplete national system. States which have implemented feed-in tariffs operate under a variety of regimes, ranging from $0.60 per kWh in the ACT and New South Wales to as little as $0.20 per kWh in Tasmania. Western Australia has not introduced a scheme, despite this state having excellent natural conditions for solar electricity generation (Perth has 3,150 hours of sunshine per year, compared with just over 2,000 in Melbourne). This is an area where a national policy is urgently needed.

Development option 2
Consider a national system of feed-in tariff rates for all forms of renewable and sustainable energy in a policy setting that encourages community power schemes, small and medium businesses, and other organisations to install renewable generation. The ACT feed-in tariff legislation is an excellent template for this and the New South Wales 'gross' feed-in tariff scheme provides innovative guidance.

Development option 3
Consider setting an appropriate national digression rate on feed-in tariffs.

2.4 Biomass Energy

Bioenergy uses biomass directly to generate fuel or electricity. The potential of bioenergy for rural development, liquid fuel replacement and greenhouse gas reduction has generated a good deal of official interest in the field. A report by Stucley and colleagues summarises technological options and opportunities,[24] which will not be repeated here.

One of the major barriers to implementation of biomass energy in Australia has been the low cost of fossil fuels, specifically coal. Another barrier to implementation is the imperfect understanding of bioenergy among policy-makers and the general public. This results from the intrinsic complexity and variety of the bioenergy production techniques. The main conversion routes are described below.

Direct combustion

This technique accounts for about 90% of modern bioelectricity. It is very similar to coal-fired power stations: burning biomass to raise steam, which drives a turbine or steam engine, driving an alternator. Biomass can be added to the feed stock of conventional coal-fired stations without any modification, leading directly to a reduction in the greenhouse gas footprint of these stations.

Gasification

Gasification uses partial oxidation, in contrast to combustion which uses excess air. Gasification produces a combustible gas which is a mixture of carbon monoxide, hydrogen and methane – very similar to the town gas that used to be produced from coal – which can be reticulated for domestic use. Biomass gasification plants are in the early commercial stage of development. When used to produce electricity, there are considerable gains associated with scale. At 1 MWe (MW electrical) an updraft gasifier will provide about 10 to 20% efficiency, while a 10 MWe fluid bed gasifier is 25 to 35% efficient, and a 100 MWe entrained flow or pressurised circulating fluid bed gasifier works at 40 to 50% efficiency.

Pyrolysis

This fractionates the biomass into products of char, a combustible gas or liquid, and a solid component, and can be optimised for liquid production. About 75% of the dry weight of the biomass can be converted into this liquid form which has approximately 60% of the energy content of diesel on a volume for volume basis. Pyrolysis can also be used to generate bio-oil, used as a boiler fuel, extracted for transportation, fuels or refined for the chemicals it contains.

Biochemical

This uses microbes to convert biomass, usually in the form of wet slurries, into a gas rich in methane and CO_2. Australia disposes of most of its waste in landfills. Landfill gas consists of about half methane and half CO_2. This is generally run through spark ignition engines to produce electricity. In Australia we currently generate about 170 MW by this technique. Although burning methane produces CO_2 the net effect is much less harmful to the atmosphere, since methane is about 25 times more powerful as a greenhouse gas than CO_2.

Fermentation

This process directly produces ethanol, to be used as a transport fuel or a fuel additive. By adding vegetable oils the viscosity can be altered to ensure that it runs better in conventional engines (biodiesel).

Biomass integrated gasification combined cycle (BIGCC)

In this process, the biomass is first gasified, and then run through a combustion turbine to produce power. The heat that comes out of the exhaust of the gas turbine is recovered, and used to produce steam, which is then run through a steam turbine to provide additional energy. The first plant was set up over a decade ago in Sweden as a proof of concept commercial plant. It ran for several thousand hours in gasification mode and fully integrated mode.

There are concerns, particularly at the political level, about logging native forests. For that reason, in all of the mainland states of Australia where logging is permitted, the residues from logging activities cannot be used for bioenergy production; only post-processing residues may be used. Residues are often left in the forest, on occasions adding to the in-forest fuel loading. The economics of fuel procurement is an important issue. It is much less costly to dig a fossil fuel from the ground than to grow plants to produce biofuel or recover it from a waste stream. The energy density of biofuel feedstock is low, so it is less economic to transport than fossil fuels. Some of the projects are capital intensive and require up to 25 years to recover the capital on equipment.

In the case of liquid fuels, Australia has a fairly low target at the moment of 350 megalitres by 2010. There remains, however, a large unrealised potential for fuel supplementation. The *Australian Bioenergy Roadmap* for stationary energy indicates that bioenergy could be expanded four-fold by 2020.[25] Another study indicated that bioenergy could provide 29% of the electricity mix by 2040.[26]

2.5 Fuel Cells

Although not strictly a 'renewable' energy resource, the combined heat and power (CHP) technology, of which fuel cells are one type, represent an important part of Australia's energy future, given our very large resources of natural gas. This technology is suitable for use at both grid and domestic scales, and could save between 8 to 16 tonnes of per capita emissions of CO_2 equivalent per year. The use of renewable fuels in the future (eg biogas and ethanol) would also lead to a fully renewable base-load generator, making the most efficient use of these resources.

The advantages of fuel cell technology can be summarised as follows:

- very high efficiency of conversion to electrical power
- low CO_2 emissions and noise
- ideal for dispersed electrical generation
- excellent load-following capability
- suitable for co-generation (heat plus electricity).

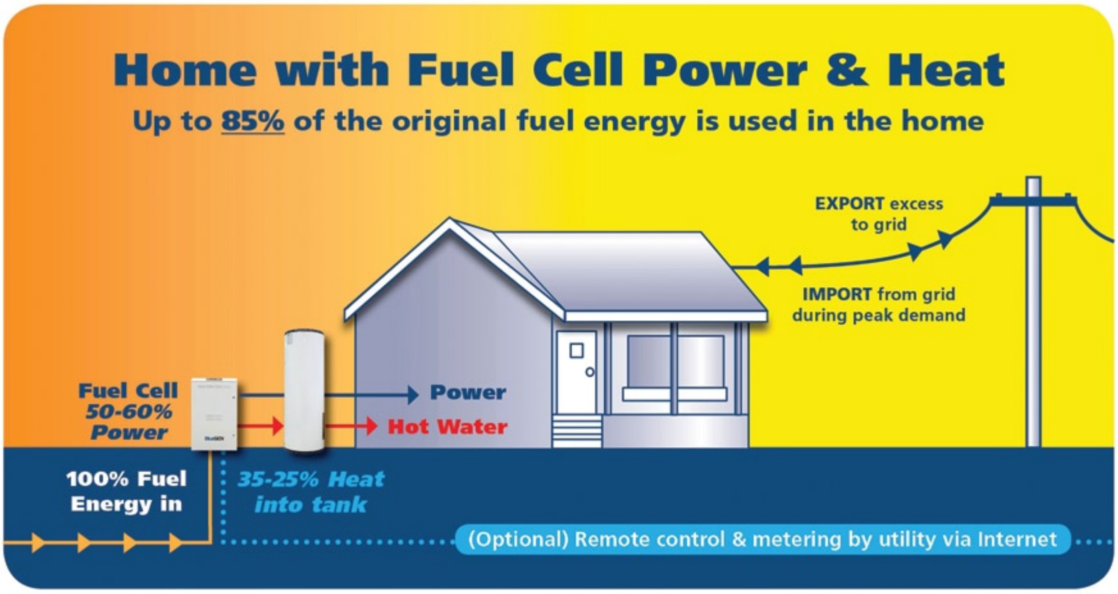

Figure 7

The use of fuel cell (CHP) generation at domestic level. Not only does this provide a highly efficient means of generating the base-load power requirements of the household, but can also provide the hot water and space heating requirements as well. Image: Courtesy of Ceramic Fuel Cells Limited.

A limitation of fuel cell systems is the need for pure fuel sources. Low temperature fuel cells such as polymer membrane fuel cells require pure hydrogen. High temperature ceramic fuel cell CHP systems are easily 'poisoned' by sulphur, whether present naturally in the feedstock or added as mercaptans to give natural gas a distinctive smell (for safety reasons).

Residential distributed generators (typically delivering less than 5 kW of electrical output) could provide base-load power at the residential level without transmission losses. With appropriate processing, suitable fuels would be natural gas, CNG, LNG, LPG and biofuels (biogas or ethanol). There are a number of other technologies competing in this market segment, including Stirling engines and Rankine cycle systems. However, in terms of efficiency, the most significant savings in greenhouse gas emissions are provided by highly efficient (greater than 50%) high temperature fuel cell technologies. A 'world record' electrical efficiency of 60% (and greater than 85% total efficiency with heat usage) has been proven in a 2 kW prototype system made by an Australian firm, shown in Figure 7.

Fuel cell technology has the potential to overcome the issue of limited load cycles associated with truly renewable energy resources such as wind and solar photovoltaic. Fuel cell grid systems provide a 'controllable' generator able to respond rapidly to changes in load, and would therefore make a substantial contribution to grid stability, comparable to installation of significant energy storage.

The fuel cell technology is available 'off the shelf', but requires stimulation of demand to achieve significant market penetration in Australia, as volume manufacturing and sales are required to achieve commercially attractive cost targets. The introduction of a national feed-in tariffs regime would significantly assist the market introduction of domestic photovoltaics.

Development option 4
Consider a national system of feed-in tariff rates for combined heat and power (CHP) domestic generation.

Development option 5
Consider setting an appropriate digression rate feed-in tariff rates for CHP domestic generation.

Development option 6
Consider government incentives to construct industrial scale CHP plants for base-load management.

Development option 7
Consider setting national standards governing the level and type of sulphur compounds in commercially-supplied natural gas (CNG, LNG, LPG), or biofuels (biogas and bio-alcohols).

2.6 Geothermal Energy

The potential for geothermal energy in Australia is truly enormous. Budd and colleagues have prepared the thermal map shown in Figure 8.[27] This estimates the energy contained in the upper 5 kilometres of Australia's crust at 1.9 x 10^{25} Joules, which is the equivalent of about 2.6 million years energy supply at 2004–05 consumption levels. Of course, not all of this energy will be accessible for extraction. Nonetheless, if a low estimate of 1% was taken geothermal sources could provide 26,000 years of energy supply. The Geothermal Energy Project of Geoscience Australia maintains a rich data base on geothermal energy

One key point should be noted. Whilst there is a pocket of high geothermal potential located near Melbourne, it is clear from the map of Australia in Figure 8 that the majority of our geothermal resource is a long distance from major population centres. Effective exploitation of geothermal energy will require the provision of an appropriate long distance power transmission network. This issue is discussed in more detail in section 3.

The feasibility of geothermal energy production is proven, and it is currently entering the commercial exploitation phase, with 32 companies aiming to deliver 'hot rock' power to the electricity grid. One company in Australia hopes to begin in 2012 with a 50 MW plant, has a target to produce more than 500 MW by 2016, and a long-term target of 10,000 MW output, the equivalent of 10 to 15 coal-fired power stations. The United Nations Environment Programme estimates that geothermal energy will provide about 7% of Australia's base-load power by 2030.[29]

In Australia geothermal energy receives support from the Australian Government's $500 million (US$436 million) Renewable Energy Fund to accelerate the roll-out of sustainable energy in the country, with a further $50 million already committed to helping geothermal developers meet the high up-front costs of exploration and drilling.

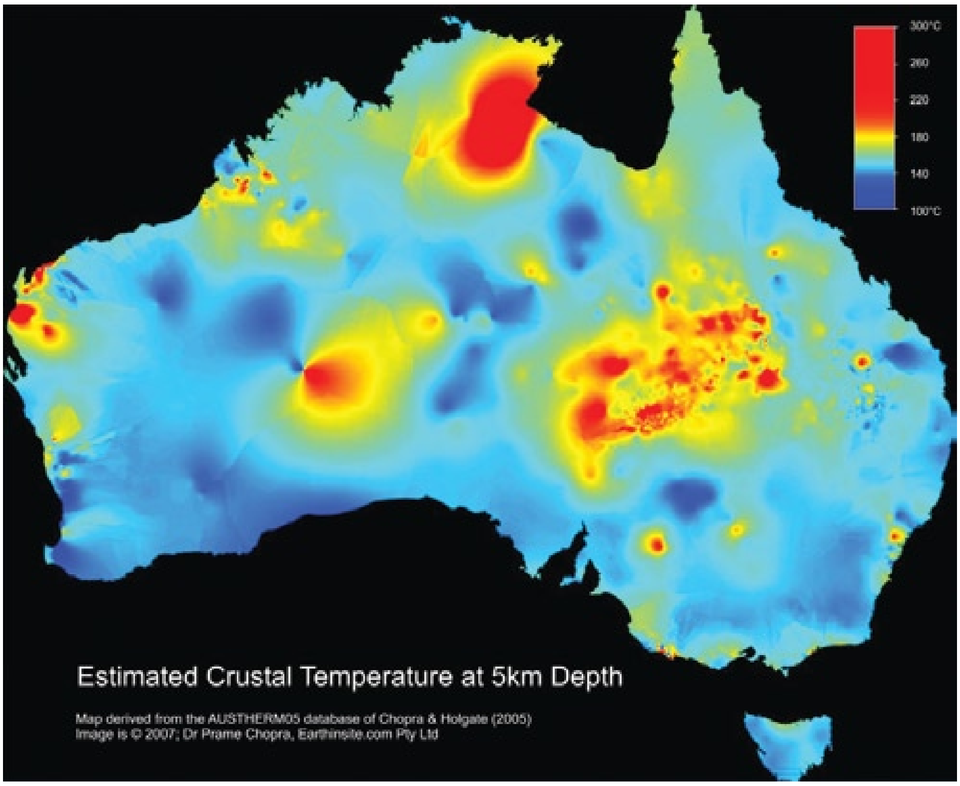

Figure 8

Modelled crustal energy content at 5 km depth, as presented by Budd, Holgate, Gerner, Ayling and Barnicoat at the *Australian Geothermal Conference 2009:* The temperature data contained in this image was derived from proprietary information owned by Earth Energy Pty Ltd, ABN 078 964 735, further developed by Geoscience Australia. Published with the permission of Earthinsite.com Pty Ltd and Geoscience Australia.

Development option 8
Consider giving priority support to geothermal energy and solar thermal energy such that they become major national energy sources.

Development option 9
Consider co-location of geothermal and solar thermal electrical energy generation stations.

Development option 10:
Consider linking geothermal and solar thermal electrical energy generation with the national electricity grid through HVDC transmission line technology.

2.7 Wave and Tidal Energy

Ocean energy, which primarily comes from wave and tide motion, is somewhat the 'sleeper' of all the renewable energies, even though it is globally available and occurs with a relatively high degree of predictability. Its potential is colossal – over 5,000 times the world's current use of electrical energy. Thus, even a miniscule fraction of this potential could add very meaningfully to the world's quest for a sustainable energy future.

Wave energy

There are many types of waves, perhaps the most familiar being the surface gravity waves, set up by wind blowing across the sea. Wave energy technologies concentrate on the deeper water swell, which has more energy than the waves crashing on the shore, which lose energy to the friction with the sea bed.

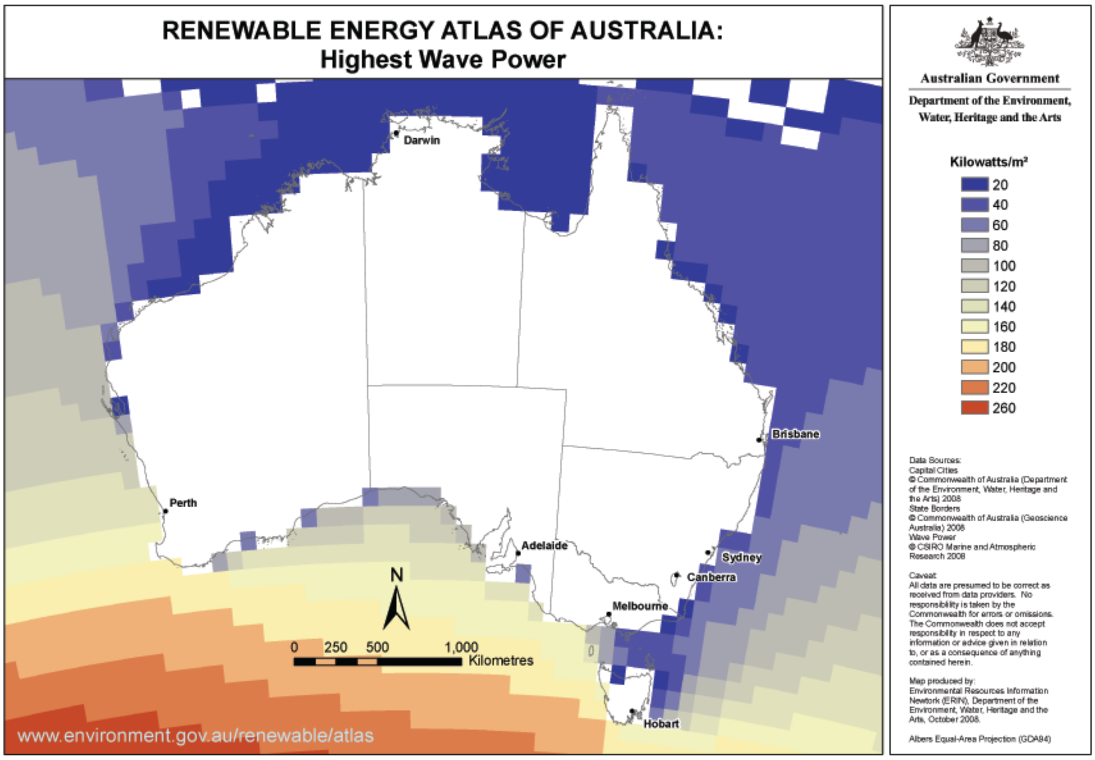

Figure 9: The potential for wave power generation in Australia

Image: Australian Government Department of the Environment, Water, Heritage and the Arts, *Renewable Energy Atlas* , October 2008, www.environment.gov.au/settlements/renewable/atlas/maps.html

Wave potential is usually measured in kW per metre of wave front, and a good wave climate has an annual average of 20 to 40 kW for every metre of wave front, though it varies enormously from 0 kW per metre in flat seas, to over 1000 kW per metre in major storms.

Although waves hit all coastlines, they tend to be bigger in the temperate zones between 30 and 70 degrees of latitude. This means that the Southern Ocean is an ideal place because at latitudes between 60 and 70 degrees there is nothing in the way of the waves as they generally propagate from west to east. Southern Australia, therefore, has some excellent wave climates, as shown in Figure 9.

The wave energy industry currently consists of about 50 companies worldwide, many employing different technologies; a situation which is very different to wind energy, where its technology converged very quickly. Some of the technologies are still at the R&D phase, with a handful nearing commercialisation. Examples include Pelamis – a Scottish based technology – and technologies by three Australian-based companies, including Oceanlinx with its main project at Port Kembla. Commissioned in June 2005, the Port Kembla facility is now being upgraded and is expected to be operating permanently from December 2009 and will be grid connected.

What does this mean for the future? Australia is well placed to be a large utiliser of wave energy, with up to 5% of our needs potentially coming from wave energy within 20 years and possibly up to 25% by 2060. Perhaps 10% of the world's electrical needs could be produced from waves within 50 years.

Tidal energy

Tides are the rising of the Earth's ocean surface caused by the gravitational forces of the Moon and the Sun acting on the oceans. The old technology of tapping into tidal energy was through tidal dams or barrages. However, this is no longer considered optimal from an ecological perspective.

A more suitable method now is with a simple wind turbine type device that is lowered into the tidal current. The technology is an application of biomimicry, innovation inspired by nature's designs. The advantages of this technology include:

- lightweight engineering designs
- smooth surfaces and slow-moving operation, for minimal impact on marine species
- limited seabed footprint with removable foundations
- efficient energy conversion
- reliable grid-ready power supply
- modular and scalable, enabling large plant capacity.

A number of pilot plants have been set up, such as those at Flinders Island and King Island in Bass Straight. It is envisioned that over the next several years these devices will be deployed in 'farms', and will have 40 to 50, and up to 100 MW capacity, and capable of feeding directly into the national grid.

Australia has abundant wave and tidal power resources and a variety of technologies have been well demonstrated in Australia and overseas. Wave energy densities in southern Australia are very high, with potential to offer very high load factors. Such potential could be readily harnessed by heavy industries (eg aluminium smelting) as manufacturing production can be managed to align with predictable peak generation periods. The challenge for commercialisation is to reduce the costs of large scale plants. The next generation of ocean energy technologies will offer significant potential to deliver high electricity loads to coastal regions.

Development option 11
Consider providing incentives or support to heavy industry located on the coasts to use wave and tidal energy.

3. The Grid: Bringing the Power to the People

The future power grid will look very different from the old model of centralised massive power stations coupled to a monolithic transmission and distribution network. Solar, wind, wave and fuel cell power generation facilities will range in size down to the domestic scale. Renewable energy sources with low load factors will require distributed storage. To quote the PriceWaterhouseCoopers 2007 survey of global utilities:

> Almost 40% of global utilities expect distributed generation and, especially, combined heat and power (CHP) technologies to have the greatest impact on generation and supply over the next ten years.[30]

According to the Energy Supply Association of Australia, the installed capacity of Australia's electricity generators comprises 44,900 MW in grid-connected capacity and a further 5,200 MW in embedded and non-grid capacity.[31] In a communiqué resulting from a three-day international workshop in Melbourne conducted by the Australian Academy for Technological Sciences and Engineering, the issues related to Australia's national grid were summarised as follows:

> Australia's energy security requires a major increase in base-load electric power generation capacity to meet the expected growth in demand – which growth will emerge independent of climate change and despite a much greater current focus on energy efficiency and conservation measures ... The electricity grid must be planned to meet the long-term demands imposed by a diversity of technologies supplying power, including base-load and intermittent renewables, remote locations for some power generation and the need for stability of the system under variable supply and demand situations. There is a need to introduce consideration of the 'national interest' when planning future expansion of the grid.[32]

The specific issues the current grid faces in New South Wales have been investigated in a report by Rutovitz and Duncan[33] for the Intelligent Grid (iGrid) cluster, a three-year national research collaboration between the CSIRO and five universities, funded under the CSIRO Energy Transformed Flagship. The iGrid research program aims to achieve major greenhouse gas emissions reductions by integrating 'distributed energy' technologies into a smarter electricity grid. Interestingly, this report finds that the shortfall in power generation expected on the basis of the Owen Inquiry[34] has already been largely filled due to renewable initiatives which were undertaken as part of the national Renewable Energy Targets (RET) for 20 to 25% renewable energy by 2020. With moderate additional energy efficiencies, any remaining shortfall can be filled without the need to construct additional coal-fired stations. The authors of the report claim that local energy options could save between $1.4 billion and $3.8 billion between now and 2020, and reduce emissions by 2020 by between 2.2 and 8.4 million tonnes of CO_2 per year.

This example shows how a simple government policy initiative can have far-reaching outcomes, transforming both conventional thinking and the way we do business in future. Policy initiatives such as the renewable energy target are essential to ensure Australia makes a smooth and rapid transition to the low-carbon economy.

Currently, there is no coast-to-coast interconnectivity of the grid. The so-called Australian Energy Market Operator only covers the eastern and southern market, and is separated from the local grids of Western Australia and Northern Territory. Northern Territory in the main operates with independent power producers and remote generators, with consequent high greenhouse gas emissions. This fragmentation of the national grid militates against the transport and distribution of renewable energy generation on a national basis.

3.1 The Smart Grid

The term 'grid' refers not only to the means of transmission and distribution of power, but also the need for a new 'smart grid'. Most renewable energy sources deliver load factors less than 50%. However, different sources are available at different times and in different locations. The grid needs to intelligently source the renewable energy in relation to the demand, and to provide storage of energy generated by renewable sources when they are not needed, to smooth out the load factor.

A smart grid would be far more responsive to changing power load requirements than today's dumb network. On the transmission side, sensors and digital relays (called synchrophasors) can deliver voltage and current readings every 0.02 seconds. This allows for more nimble control and response of power distribution, would help prevent power surges and blackouts, and would avoid wasteful use of fixed power generation capacity.

On the consumer side, the introduction of smart meters in households would provide direct savings, by eliminating the need to read meters. Faults would be identified and controlled locally, and consumers enabled to couple their power needs to power availability (such as charging electric cars only in periods of excess capacity in the grid). This last aspect has been demonstrated to reduce energy usage by about 7%, and as much as 15% in periods of peak demand.[35] Such savings lead to direct cost savings by eliminating both the need to over-engineer the grid to deal with exceptional loads and the need for additional investment in classical coal-powered generating stations. Overseas, smart metering, long used in industrial facilities, has finally broken into the domestic arena. California's investor-owned utilities are spending US$4.5 billion on deploying smart meters, while Enel, Italy's main power utility has, deployed more than 30 million smart meters since 2001. Enel spent €2.1 billion in installation, but now saves around €500 million each year as a result.[36,37]

Development option 12
Consider fast tracking the installation of smart meters in all Australian households, and phase in the introduction of time-of-use pricing including dynamic peak pricing at times of high demand offset by lower prices at other times.

3.2. Generation and Distribution

When alternative energy sources such as geothermal or solar are considered for Australia, the best regions for generation of energy are frequently not near the population centres. For example, the best areas for geothermal energy generation are around the Cooper Basin, near the intersection of the boundaries of New South Wales, Queensland and the Northern Territory. Effective use of solar energy is maximised in the interior and in the northern part of the continent. Australia's gas supplies (suitable for fuel cell power generation) are concentrated on our north-west continental shelf. However, the gas pipeline infrastructure which is currently being installed by such companies as DUET and other energy infrastructure trusts will provide a cheap and efficient national distribution system for this resource. This is not true for Australia's electricity distribution system. Australia includes many fringe grid areas where delivery of electricity is costly and inefficient, and grid stability may be an issue.

However, the existing system of alternating current (AC) power lines is high loss, and may not be the most efficient for long-distance power transmission. Any new power transmission system could be based upon high-voltage direct-current (HVDC) power transmission. Studies by the Oak Ridge National Laboratory in the US suggest that long-distance HVDC lines lose far less energy than AC lines over an equivalent span.[38] The US experience shows HVDC lines are also cheaper to build and require less land than the equivalent AC lines. HVDC lines could form a 'backbone' for long-distance power transmission in the same way as the proposed rail system (section 4.2) would provide a backbone for long-distance goods transmission. The lines would terminate at a number of converter stations where power would be

switched to AC for transmission to consumers using the existing power grid.
For distributed power generation, highly efficient fuel cell generators can provide low emission base-load power from all types of natural gas (LNG, CNG or LPG). These provide significant carbon savings. The 2 kW system of Ceramic Fuel Cells Limited, with greater than 55% electrical efficiency at the customer site, and with consequent elimination of transmission losses, could save between 8 and 16 tonnes CO_2 per year. If incorporated into a smart grid, these generators can also fulfill a similar function to grid storage installations to stabilise the grid. The use of renewable fuels in the future, such as biogas or ethanol, would lead to a fully renewable base-load generator, making the most efficient use of these resources.

There is potentially a major advantage in linking the west Australian grid to the south-eastern Australian grid, allowing peak demand to be better met by renewable sources. Since the local solar time in Western Australia is roughly two hours behind the eastern states, the solar electrical energy developed in Western Australia could be effectively used to flatten the evening peak load on conventional power generation in the east. This could only be accomplished if low-loss transmission is in place.

Development option 13
Consider integrating high-voltage direct-current (HVDC) technology to transmit energy from the renewable energy production sites to cities and provide the HVDC system with efficient intercity links to allow for energy exchange as demand varies.

Development option 14
Consider providing incentives for the development of distributed power generation by fuel cells on both the domestic and small country town scales to stabilise base-load requirement and eliminate transmission losses.

Development option 15
Consider encouraging the development of a coast-to-coast integrated national natural gas distribution network.

4. Transport Systems

4.1. Passenger vehicles

Australia consumed 30 billion litres of fuel for transportation in the 12 months prior to 31 October 2007 (62.8% petrol and 31.2% diesel). This is roughly the equivalent of 250 million barrels, or about 80% of Australia's total liquid fuel consumption. Of this total, petrol-consuming passenger vehicles accounted for nearly half of the total.[39] Addressing the issue of energy efficiency in road transport will reduce our petroleum trade deficit.

Governments can play a role by supporting research, development and demonstration activities to bring forward lower carbon vehicles. The recent government investment in the Toyota electric hybrid car construction facility in Australia is an example of such support, although such vehicles still rely on petrol. Biofuels may offer a useful fuel supplement. The fuel which is now being used by the high performance V8 Supercars is E85, a blend of 85% ethanol and 15% unleaded petrol. Currently, the level of ethanol in commercially available fuel is much lower. However, E10 (10% ethanol) fuel is now sold at over 800 retail outlets across Australia. There clearly exists the potential to increase this to E20 with little modification of engine technology. However, the source of the ethanol needs to be carefully considered, since some biofuels offer only scant savings in CO_2 emission.

With the development of improved battery technologies, plug-in (grid-charging) hybrids have been suggested as providing a useful urban alternative. However, the impact on CO_2 emissions from this technology is not favourable while our electricity is sourced from coal rather than from clean alternatives. Using electrical power sourced from the grid compares badly with the efficiency of modern diesel or hybrid cars. Consider three electric cars for which detailed data on battery size and range are published:

- BMW Mini – 35 kWh battery with 240 kilometre (km) range in city cycle giving 6.86 km per kWh
- Mitsubishi iMiEV – 16 kWh battery with 120 km range in city cycle giving 7.5 km per kWh
- Chevy Colt – 16 kWh battery with 64 km range in city cycle giving 4 km per kWh.

These figures should be compared with a petrol engine hybrid such as the Toyota Prius, which uses 3.8 litres per 100 km giving energy usage of 3.0 km per kWh. At first sight these numbers look good for electric vehicles. However, we should remember that the current electrical power generation efficiency is less than 30%. Allowing for a charging efficiency of 80% and 5% for other losses, the BMW Mini has an effective (whole of cycle) performance of 1.6 km per kWh, and the Chevy Colt only 0.9 km per kWh. In terms of their effective CO_2 emissions, the electric cars in this example lie in the range 62 to 110 gram per km, compared with 85 gram per km for the Toyota Prius.

Significant additional electricity infrastructure will be needed when a significant number of electric cars are on the road. For an average daily driving distance of 40 km (14,000 km per year) an electric car would require 2.85 MWh per year. A national fleet of one million cars would require at least 2.85 terawatt hours (TWh) of electricity.

This energy infrastructure issue can be offset. Charging the electrical car fleet at night (using smart meters and the smart grid) would allow the current electrical generation system to run continuously at full efficiency and allow a displacement of perhaps 50% of petrol usage and associated emissions, with little additional emissions. These can be reduced by the use of renewables. Given that it would require less than 20% of national electricity to run the car fleet, household efficiency savings could in principle supply this. These measures would reduce our petroleum dependence.

Biodiesel and bio-alcohols are not practical alternative fuels for road transport. They only have the potential to provide liquid fuel replacement at 10% or thereabouts. The full carbon accountancy shows that the net saving on CO_2 emissions for liquid biofuels is at best small, and in some cases negative. This would be the case for Australia where our dry climate means that only relatively low grade cellulose-rich feedstock would be available for biofuel production. These fuels would also require a large area of farmland for their production, and have the potential to distort food production.

For Australia, there is the also the option to use LNG in place of diesel. The extensive deposits of natural gas on the north-west shelf will last well beyond the depletion of our oil reserves.[40] There is likely to be a big future for a greater use of LNG for heavy duty transport in Australia.

Fuel cell technology currently has a number of unresolved problems before it can be used widely for motor transport. The most likely fuel cell type in cars will be proton exchange membrane fuel cells. These operate at around 90°C and would be ideal for vehicles if they can be produced cheaply and are robust, neither of which has yet been achieved. They also need to operate with hydrogen rather than natural gas. The only way this could be done is to use an on-board gas reformer which is very expensive, has a weight penalty and would probably have safety issues. Ceramic fuel cells can run with natural gas, but they operate at temperatures in excess of 600°C and therefore may be unsuitable for vehicular application.

Development option 16
Consider providing incentives for the greater adoption of LNG to replace diesel and petrol.

Development option 17
Consider incentives to encourage the use of electrical or natural gas fuel cell electric hybrid vehicles, especially in cities.

4.2 Rail

If we compare energy requirements, then rail is by far the most efficient land-based form of transport, barring bicycles.[41] The fundamental problem in Australia is the legacy of a sparse and inadequate rail network, with each state adopting a different gauge of track. Compared to countries such as France and Japan there has been relatively little recent investment in rail infrastructure. As a consequence, most of Australia's commerce is carried inefficiently (from an energy use point of view) by road.

A study by Federici, Ulgiate and Basosi[42] shows that the most important factors in determining the acceptability of a transportation system are not only the specific fuel consumption and the energy and material costs of vehicles, but also the energy and material costs for infrastructure construction, as well as intensity of use (with special focus on load factor of vehicles). These latter factors militate against the use of high speed trains. The needs of passengers pose stringent requirements on the performance (and subsequent cost) of a high speed rail system since, to be competitive, the passengers have to be transported between the major urban centres at speeds of 200 to 250 km per hour. Load factors are low, leading to very high energy consumption per passenger km, or per tonne km in the case of freight carried by such a system.

An alternative model would be to upgrade Australia's current 9,400 km interstate rail network as a heavy duty national rail grid backbone for long distance goods transport. This network is already based on a common gauge of track. The upgrades would be undertaken to make it capable of carrying much larger loads and at higher speeds than present.

Such a network would be linked to all major cities, ports, farming and mining centres. A key innovation would be the development of a number of 'container ports' with roll-on/roll-off facilities distributed at strategic points to allow efficient local distribution of goods by road.

Trains and rail infrastructure are long lived assets. The technology needs to be right from the outset, or have sufficient flexibility to adapt to technological developments. For Australia, it would seem logical to combine a new electric grid infrastructure, as proposed above, with the backbone rail grid, and to make the trains electric powered rather than diesel powered, using electricity sourced from alternative energy.

Development option 18
Consider upgrading the interstate rail network to carry large loads, and link container ports or roll-on/roll-off facilities to encourage efficient distribution of goods.

4.3 Shipping

Shipping is also a very fuel efficient method of moving bulk freight. It is easily the lowest carbon emitting method currently available for long distance movement of freight on a per tonne basis. Fuel makes up a relatively high proportion of international shipping costs and marine diesel engines are already efficient. Internationally, there has thus far been only a limited policy or commercial focus on technological options for reducing the carbon footprint of shipping. However, while highly efficient, shipping is a not an insignificant source of carbon emissions, as it is estimated to account for 1.8 to 3.5% of global carbon emissions.[43]

A problem of pollutants produced by shipping is caused by the general use of poor quality bunker oil, coupled with inadequate engine maintenance. Bunker C fuel is rich in heavy carbon compounds, sulphur and other irritants. Under proper conditions it can be burned completely, but the poorer the combustion efficiency, the greater the amount of pollutant discharged to the atmosphere. Also, with incomplete combustion leading to the build-up of deposits in the combustion chamber, hot spots can develop and become foci for production of oxides of nitrogen. In many cases simple fuel additives can mitigate these problems.

Development option 19
Consider placing research and development priority to technological options for further reducing carbon and other emissions from shipping.

5. Domestic Energy Reductions

There are currently 8 million households in Australia, and according to the Australian Bureau of Statistics the number will grow to 10.8 million by 2026.[44,45] In 2001 the International Energy Association reported that each Australian used 10.3 MWh of electricity, of which domestic use accounts for roughly 22%. This corresponds to energy consumption per household of roughly 15 kWh per household per day, and total emissions of over 45 million tons of CO_2 equivalent per annum. Most of this energy is used for space heating, water heating, domestic electronics and lighting. Wood and other forms of space heating account for additional CO_2 emissions.[46] Any reductions that can be made in household energy use and energy savings are desirable because such reductions save between $40 and $100 per tonne of CO_2.[47]

Practical near-term infrastructure initiatives that will help achieve a reduction in household energy usage include household insulation, standby power and domestic electrical power generation.

5.1. Household Insulation

Given that there are about 8 million households in Australia and housing stock replacement rates are only 1.9% per year, it will take nearly 50 years before there is a ‘modern’ stock of buildings with high insulation standards.

Most of our old building stock has an effective zero star energy efficiency rating. For example, the Australian Bureau of Statistics has found that about 40% of Australian homes currently have no ceiling insulation.[48] Increasing this to three stars through the provision of ceiling and wall insulation, and by the provision of double glazing, could cut domestic energy consumption by the energy equivalent of 16,000 kWh per household per year. Studies commissioned by the Insulation Council of Australia and New Zealand show that retrofitting insulation into currently uninsulated Australian homes would deliver immediate and lasting benefits, including:

- savings to householders of $2.9 billion on household energy bills over the period 2008–20 (or savings per retrofitted household of between $89 and $336 per year)
- abatement of 2.4 million tonnes of greenhouse gases per annum
- savings of $250 million on new energy infrastructure
- reduction in electricity prices through delayed infrastructure spending
- increase in GDP of $894 million over the period 2008–30. [49]

The current Australian Government policy is to provide $500 rebates to landlords to install insulation. However, the cost of ceiling and wall insulation is around $2,000 per household, and a single double glazed window costs about $1500. The cost to bring a zero star energy rated house up to a three star energy rating is of the order of $10,000.

Development option 20
Consider measures to encourage and support the retrofit of all existing houses and apartments to at least a three star energy rating.

For new buildings most state regulations currently call for five star energy ratings. Government regulations require that new residences have a six star or equivalent rating by 2010. However, if we are to meet the *Garnaut Report* standards for CO_2 emission reductions,[50] further encouragements would be desirable. While total costs for upgrading house energy efficiencies may seem high, they are more than offset by savings in lifetime energy costs.

The total space heating or cooling requirements for housing in Australia in megajoules (MJ) of energy for every square metre (MJ per metre^2) is published.[51] The star ratings are set for each climate zone taking into account the extremes of the local weather conditions, and have been developed to allow comparisons of building within and between climate zones. Typically, household heating or cooling energy consumption could be reduced by 44% by an improvement from a five to a seven star energy rating. This implies the construction of houses of a solar passive design, with double glazing throughout, and with excellent ceiling, wall and slab edge insulation. Typically, the additional insulation required would add $10,000 to the cost of a new house, and double glazing would add a further $20,000. Such costs could be recouped many times over during the lifetime of the house.

Development Option 21:
Consider a national seven star energy standard for all new houses by 2015.

Development Option 21:
Consider a national nine star energy rating for houses constructed after 2020.

5.2. Standby Power Reduction

Standby functions (eg remote control activation of a television set) and off-mode losses (occurring when a product cannot be switched off completely even when it provides no service or function) are a common feature of electrical and electronic household and office equipment (eg consumer electronics, information and communication technology equipment, personal care products). A study conducted by the Australian Greenhouse Office concluded that up to 80% of the electricity used by video cassette recorders was consumed in standby mode. In Europe, it is estimated that electricity consumption in standby/off-mode will be about 50 TWh per year in 2020, an amount comparable to the total electricity consumption of a country such as Greece or Portugal.[52]

Recent field studies show that in Australia standby power accounts for 11.6% of total domestic power consumption, an amount that doubles every five years.[53] A study in the US has shown that reducing energy wastage in electronics and lighting provides savings to the economy equivalent to a 'negative carbon tax' of US$110 per tonne of CO_2.[54]

Development option 23
Consider measures to set maximum standby power requirements on all domestic appliances and to aim for zero standby power usage where practical by 2015.

5.3. Domestic Power Generation

In Germany, the famous 'million homes' initiative put a generous national incentive regime into place to encourage the take-up of domestic grid connected photovoltaic schemes. This gave householders an initial feed-in tariff which helped to defray the installation costs of these systems. The scheme effectively acted as a direct stimulus to industry, so that today Germany is the world leader in photovoltaics and several other forms of renewable technologies.

Australia started late along the path of feed-in tariffs, and currently has an inconsistent and incomplete national system. Those states that have implemented feed-in tariffs operate under a variety of regimes, ranging from $0.60 per KWh in the ACT to as little as $0.20 per kWh in Tasmania. Neither New South Wales nor Western Australia has introduced such a scheme, despite these states having excellent natural conditions for solar electricity generation: Perth has 3,150 hours of sunshine per year, compared with just over 2,000 in Melbourne. Apart from solar power, domestic fuel cell technology could also supply energy to the grid.

The advantage of grid-connected systems is that they can help supply daytime peak demand on the grid, when industrial applications draw most heavily on the supply network and domestic use is relatively low (Figure 10). This would assist in flattening power demand which, in conjunction with a smart grid, could ensure a more stable electricity supply.

Development option 24
Consider a national scheme for feed-in tariff returns which encourages a high degree of domestic participation.

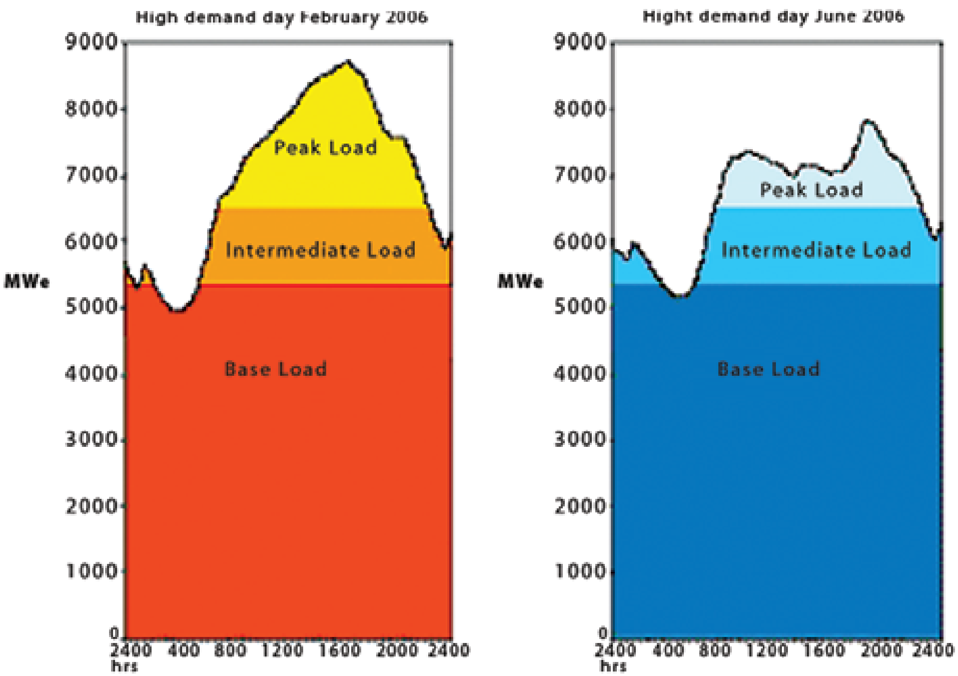

Figure 10: Load curve for Victorian electricity grid

Load curve of the Victorian electricity system in two peak days in 2006, showing the relative contributions of base, intermediate and peak-load plant duty. Here, the peaks reflect domestic demand related to a normal working day, with air conditioner demand evident on the hot summer day. Image courtesy of the Australian Energy Market Operator.

6. Building the Renewable Energy Future

The development of Australia's renewable energy future is currently being assisted by a number of government initiatives. These include:

- amendments to the renewable energy target which mandate 20% of electricity is to be supplied by renewable energy by 2020;
- environmental provisions of the Economic Stimulus Package (specifically the Energy Efficient Homes Package to improve insulation and install solar hot water systems in existing houses);
- interest-free Green Loans;
- Solar Flagships Program;
- Renewable Energy Development Fund; and
- Renewable Remote Power Generation Program.

Additional state government initiatives include rebates for the installation of solar panels, and the provision of feed-in tariffs to assist the growth of renewable energies and energy savings.

In the longer term, the introduction of an emissions trading scheme, combined with the mandatory renewable energy targets, could make by far the greatest impact on patterns of Australian energy use. This should result in alternative energy sources becoming progressively more economically attractive. With growth come the advantages of scale, which will ensure that they become cost competitive with conventional sources of energy.

The CSIRO Energy Transformed Flagship in conjunction with industry and other partners has recently completed very detailed economic modelling to determine how these policies could drive the introduction of renewables in Australia.[55,56] We have taken one figure from the first of these to show how the share of renewable electricity generation could increase up to 2050 (Figure 11).

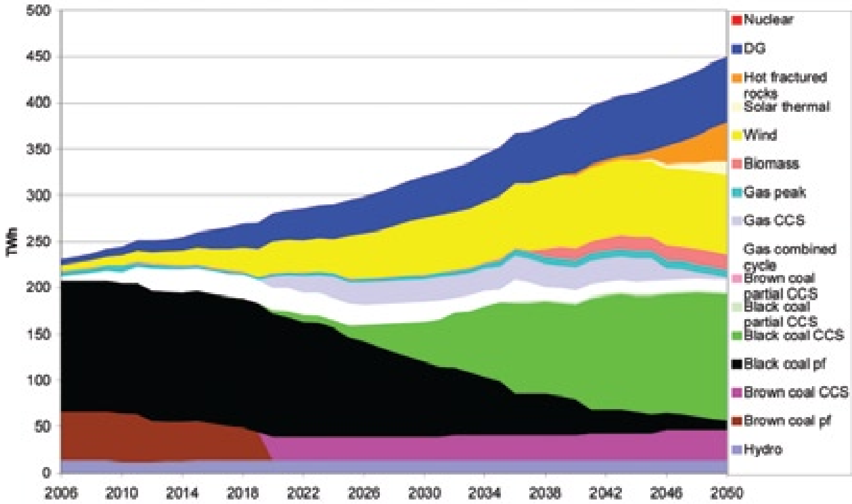

Figure 11

Electricity generation by technology: high oil price and 2000–60 emission target. Under the category of distributed generation (DG) are included both non-renewables such as internal combustion diesels or gas CHP as well as renewable sources such as biomass CHP, solar photovoltaic or wind. Image: from *Modelling the future of transport fuels in Australia* by Graham P, Reedman L and Poldy F, 2008, www.csiro.au/files/files/plm3.pdf

This modelling is based on an Australian energy sector model co-developed by CSIRO and the Australian Bureau of Agricultural and Resource Economics in 2006. It aims to mirror real world investment decisions by simultaneously assuming:

- the requirement to earn a reasonable return on investment over the life of a plant or vehicle;
- the actions of one investor or user affect the financial viability of all other investors or users simultaneously and dynamically;
- consumers react rationally to price signals;
- consumption of energy resources by one user affect the price and availability of that resource for other users, and the overall cost of energy and transport services; and
- energy and transport market policies and regulations are included.

As such, it gives the 'best prediction' based upon economic and policy factors that can currently be attained.

In this scenario of economic cost minimisation, the rate of introduction of renewables may seem slow. The balance between current technologies will change only slowly over time, unless the cost of carbon under an emissions trading scheme drives above the price threshold for the introduction of the new technologies. In particular, two of the best technologies for addressing Australia's base-load power requirements, solar thermal and geothermal (also called hot fractured rocks in Figure 11), do not appear in any significant proportion of the energy mix until about 2040.

Limitations of the CSIRO modelling are that it does not take account of technological advances, the introduction of disruptive technologies, the stimulus of export markets in lowering production costs, other commutative innovations, changes in consumer behaviors, the developing state of climate change science as a driver, or future effects of state and federal policy. For example, if policy mandated the construction of a HVDC infrastructure, the barriers against the early introduction of geothermal and solar thermal technologies (primarily that they are produced in geographically remote areas) would disappear rapidly. Likewise, the introduction of a national system of feed-in tariffs would stimulate domestic photovoltaic energy production, leading to efficiencies of scale. In the area of transport, a rapid transition from conventional fuels would avoid a large and increasing balance of payments and national security issues. The effect of policy changes upon Australia's economic productivity, export opportunities balance of payments, national security and employment opportunities remains to be properly modelled.

Australia's renewable energy future poses important national choices. We can adopt the reactive path of minimisation of known economic costs, leading to the slow uptake of renewables mapped above. Or we can be proactive in stimulating research and installation of renewables, a path that will lead to a more rapid uptake. The second option has the potential to put Australia at the leading edge of renewable energy technology, an objective of particular importance to the Australian Academy of Science. It may also have the potential for sustainable job creation and stimulation of export business opportunities. Government policies are crucial in determining both the rapidity of evolution and the future potential net economic value of our energy future, and we hope that this document provides a useful starting point to stimulate the policy debate.

Development option 25
Consider dedicated Commonwealth and state government funding for Australian universities and research organisations to advance renewable energy research, from pure and applied research to development and commercialisation.

7. List of Abbreviations

ABARE	Australian Bureau of Agricultural and Resource Economics
AC	alternating current
AEMO	Australian Energy Market Operator
ATSE	Australian Academy for Technological Sciences and Engineering
BIGCC	biomass integrated gasification combined cycle
CHP	combined heat and power
DC	direct current
DG	distributed generation
ETS	emissions trading scheme
GHG	greenhouse gas
HVDC	high voltage direct current
iGrid	intelligent grid
IPCC	Intergovernmental Panel on Climate Change
ISF	Institute for Sustainable Futures
KWh	kilowatt hours
LNG	liquid natural gas
LPG	liquefied petroleum gas
MRET	mandatory renewable energy target
MWh	megawatt hours
NG	natural gas
PV	photovoltaic
RET	renewable energy targets

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