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The Dead Fish Option for Australia's future electricity generation technologies: Nuclear Power

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1. Introduction

The discussion of the use of nuclear power in Australia has been ongoing since the late 1960s, the first large-scale reactor was supposed to be built near the Royal Australian Naval College on the coast of southern New South Wales. When the author was a Naval Officer under training at the college he remembers the early morning winter runs to the site! The site was not developed as a nuclear power station due to increasing concerns at that time about the operating safety of these plants and how the waste would be disposed of safely given that radioactive levels last for millennia. Although in a recent study (Macintosh, 2007) the site was amongst many suggested if nuclear power would be adopted in Australia, this is a politically contentious issue at this time in Australia even with concerns about climate change damage.

There has been a range of recent material on the issue of uranium and nuclear power in Australia (see Gittus, 2006; Commonwealth of Australia, 2006; Owen, 2006; Falk, Green and Mudd, 2006; Macintosh, 2007; Skoufa and Tamaschke, 2008). In addition there have been several studies on the merits of implementing an emissions trading scheme in Australia, which is known as the Carbon Pollution Reduction Scheme (CPRS). In, April 2010, the legislation was postponed until 2013 due to the Australian Federal government's concerns about its lack of support in the Senate (ABC, 2010). One of the background studies considered in the Australian government's formulation of the CPRS was the 2008 *Garnaut Climate Change Review*. The Garnaut (2008) study centred on what needed to be done by Australia in the face of growing concerns about the potential for future climate change damage. Another recent study in Australia also considered the effects of the hidden costs of power generation in Australia (Biegler, 2009) and was based on the European Union's ExternE project. Climate change issues and power generation technologies remain important issues in Australia. This book chapter attempts to take these previous works and other studies from abroad, into account to state that the use of nuclear power is not a dead-fish option for Australia.

This book chapter will cover the following. First, a review of the literature (academic and industry) will look at the major material published from not only an Australian perspective but also of American and other global sources. Second, this chapter will discuss the merits of using the various power generation technologies available for use in Australia, included in this will be discussion about centralised generation and distributed generation systems. Third and finally, the chapter will make a recommendation that nuclear power is in general a viable power generation technology in Australia.

2. Review of Ideas and Key Points

A perusal of recent literature (IEA, 2003; MIT, 2003; Gittus, 2006; Commonwealth of Australia, 2006; Kruger, 2006; Rothwell and Graber, 2010) suggests there are four realistic ways over the next few decades of reducing greenhouse gas emissions from electricity generation:

1. Increased efficiency in electricity generation and its use;
2. Expand the use of renewable sources such as wind, solar, biomass, and geothermal;
3. Capture carbon dioxide emissions from fossil fuelled plants (especially coal) and permanently sequester the carbon dioxide; and
4. Increase the use of nuclear power.

It is felt that Australia is well on the way to implementing the first three options shown above. If we consider option (4), Australia has major uranium deposits, which includes 38 percent of the world's low-cost uranium deposits according to a Commonwealth of Australia (2006) study on uranium mining and nuclear power. Presently Australia is almost exclusively involved in the mining and milling part of the uranium fuel cycle (Commonwealth of Australia, 2006). Australia also has experience with three small nuclear reactors and this is covered later in the book chapter. Australian society seems to be increasingly Climate Change proactive (e.g., see Commonwealth of Australia, 2006). If nuclear power becomes viable in the eyes of the general public and can supply part of the base-load section of electricity generation it would thereby displace some increasingly uncompetitive, and highly polluting, coal-fired and older gas-fired plants from the supply curve. At present coal-fired and gas-fired technologies are able to hold the base-load section of electricity generation due to their overwhelming cost competitiveness compared to nuclear plants. This is mainly due to the fact that externalities such as greenhouse gas emissions have not as yet been internalised into the cost structure for fossil fuel plants.

Australia is a nation that is fossil fuel rich, possessing large amounts of relatively cheap and easily accessible reserves of coal, gas and uranium that could be utilised for power generation purposes. Coal has been the primary fuel for power generation in Australia due to its abundance, low cost and government support (Kellow, 1996; Naughten, 2003; Thomis, 1987). It has taken several decades post World War 2 to build and then operate the large scale fossil fuel dominated electricity system infrastructure in Australia. Thus, to modify the system to accommodate climate change policy, in the form of an emission trading scheme or other instrument/s, will also need time for the existing infrastructure to adjust. Amongst many, one key issue/question is how current and potential new electricity generation firms will adjust? That is, with the experience and know-how they have can they change their dominant power generation technology mindset? Australia is quite large in area and its population is concentrated in coastal areas in mainly the eastern/south-eastern part of the continent. The electricity supply industry in Australia operates the longest interconnected system on the planet, a distance of some 5000 kilometres (AEMO, 2009). These long distances place a strain on the high-voltage transmission network since the locations of large power stations may be hundred of kilometres from large load centres (e.g., large cities such as Sydney and Melbourne). Some think that Distributed Generation (DG) could be one solution to this problem. Instead of investing large funds into new large scale power plants and long distance transmission lines a local point of consumption DG system can accommodate for demand growth and at the same time not increase overall greenhouse gas emissions. With regard to the centralised generation versus distributed generation issue the range of technologies available (fossil and renewable) can be implemented for both systems, the only real exception is that of nuclear power (Rukes and Taud, 2004:1855). Apart from technical criteria such as high reliability, high efficiency, and low emissions a low as possible life-cycle costs is a requirement for any power plant technology (Rukes and Taud, 2004).

Having considered the above it is also pertinent to note that two major energy challenges facing the world are (1) replacing oil consumption and (2) reducing greenhouse gas emissions (Forsberg, 2009). Even though Forsberg (2009) did not directly mention an easy path to reduce greenhouse gas emissions (GHG) newer power generation technologies are now more likely to be gas- instead of coal-fired. However, gas-fired power generation technologies still have GHG emissions, around one-third to one-half that of coal-fired, their use as a larger scale base load source of power whilst being limited a few years ago will increase. Other options can be to move towards distributed power generation, that is generating power at or very close to the point of consumption. This allows for the use of renewable technologies such as solar photovoltaic (PV) and wind. For all of these options there are social and institutional barriers that need to be overcome or convinced of the benefits of switching to lower or zero carbon power generation technologies. Indeed the CEO of the US Electric Power Research Institute (EPRI) recently stated that in the USA to achieve an 80% reduction in GHG emission by 2050 it would be wrong to prematurely classify any technology as a winner or loser; CCS and nuclear must not be discarded (Specker, 2009). A similar outlook must be held for Australia's desire to reduce GHG emissions.

The latest Intergovernmental Panel on Climate Change (IPCC) Report published in 2007, the Fourth Assessment Report on Climate Change stated there is no "one size fits all solution" to the global issue of climate change and the need to reduce GHG emissions (Barker et al., 2007:27). The solutions to this global issue will be regional, or country specific especially if we consider Australia, an "isolated" island continent. The role of technologies is important to the solutions that will be needed (Barker et al., 2007). Switching fossil fuel from coal-fired to gas-fired reduces CO_2 emissions, gas-fired power plants have 40% - 45% of the emissions intensity of black coal power plants, as expressed in t CO_2/MWh (Chappin, Dijkema, de Vries, 2009). The electricity sector possesses significant mitigation potential across a range of power generation technologies combined with end-use energy conservation and efficiency (Barker, et al., 2007).

In all of the debate on climate change and GHG emission reductions the continued use of fossil fuels for power generation has been a major issue. Globally the electricity sector contributes 41% of global energy related CO2 emissions. (IEA, 2008a) and this is mainly due to the heavy reliance on the burning of fossil fuels. For the next twenty years to 2030 world population growth combined with vast reserves of fossil fuels suggests that this dependency must inevitably continue, particularly for the generation of base-load electrical energy supplied through centrally controlled and coordinated networks (IEA, 2008a). There have been recent arguments for and against the continued dominant use of fossil fuels for electricity (power) generation. The "… plans for the end of the fossil-fuel economy are now being laid" proclaimed The Economist (2008:13). However, such plans might need to convince a sceptical portion of the general population that feels indifferent to the benefits of a cleaner source of electricity. The International Energy Agency (IEA) *World Energy Outlook 2008* highlights that coal will remain as the leading fuel input for power generation to the year 2030 (IEA, 2008b). Announcements in 2009 such as the plan for a low-carbon future for the UK, the 'Desertec' Industrial Initiative in northern Africa, a possible nuclear power expansion in the EU, and calls for increasing the use of distributed generation suggest that a new look electricity sector is coming. Of course these changes will need time, money and some impetus to overcome several barriers to the uptake of these next technologies (Jamasb, Nuttall, Pollitt, Maratou, 2008). 'Decarbonisation' is the key to achieving the goals of large GHG emissions reductions by 2050. The product of two factors can be used to express decarbonisation (1) carbon emissions per unit of energy consumption and (2) the energy requirements per unit of value added, often known as energy intensity (Nakicenovic, 1996:99).

The climate change debate and its relation to the electricity supply industry can be thought of as having the following major elements (Grubb, Jamasb and Pollitt, 2008):

1. Establishing emission and technology targets. The setting of emission targets should come with an emission trading scheme that is adopted in Australia. The Carbon Pollution Reduction Scheme (CPRS) as it is known is the centre-piece of a suite of policies aimed at reducing Australia's GHG emissions in line with Kyoto Protocol obligations.
2. Incorporating the externalities of conventional and alternative generation sources in electricity prices. This area has seen an increase in publications/studies, calculating a reasonable price for such externalities is always going to be difficult.
3. Expedite energy efficiency improvements. An area that has been under-promoted in Australia until recently.
4. Support the use of alternative fuel sources for power generation. There are some support mechanisms for this in Australia, the Federal government's Renewable Energy Target, essentially guarantees a market for high-cost new power generation technologies that have greatly reduced or zero GHG emission intensities.

3. Nuclear Power and Centralised Power Generation Technologies

From a regional perspective it is prudent to investigate what can be done to mitigate greenhouse gas emissions in a high per capita emission country such as Australia. Is it just the case that technology will simply change from coal- to gas-fired, or for Carbon Capture and Storage (CCS) to become the dominant design? Can we utilise the solar energy striking the surface of Australia's vast tracts of land? And what social and institutional barriers will be present that hamper technological change? Implementing low-carbon technologies can be impeded by the lack of human and instructional capacity (IPCC, 2007); the marketplace left to its own devices will just keep selecting the cheapest technological options for power generation and not consider the costs of the damage caused by using such technologies. Normally the cheaper options are coal-fired and in some cases gas-fired technologies. Within the developing world the use of coal- and gas-fired power generation technologies will continue unabated as these countries further industrialise and move toward developed status; the demand for coal for power generation use is expected to double by 2030 (IPCC, 2007).

Most modern technologies display increasing returns to adoption in that more adoption means more experience and consequently improvements occur (Arthur, 1989). A technology used in an industry that has an early lead may eventually corner the market and 'lock-out' other technologies (Arthur, 1989); this had been the general case for coal-fired power generation technologies until the reform/restructuring process began in the mid-1990s. So, those technologies that are locked-out cannot gain a foothold in the marketplace due not only cost competitiveness but also technical competitiveness or other issues. For example, hydro-electric power can become more costly as dam sites become scarcer and less suitable (Arthur, 1989).

The latest IPCC Fourth Assessment Report on Climate Change (Barker, et al., 2007) stresses that the multitude of GHG emission scenarios all assume that technological changes occur during this 21st century. The electricity/power generation sector globally contributes 41% of energy related global GHG emissions per year at present (IEA, 2008). In Australia the electricity/power generation sector contributes 35% of the country's total yearly GHG emissions (Garnaut, 2008). Australia's per capita GHG emissions are amongst the highest of OECD nations and around the globe as a matter of fact (Garnaut, 2008). And Australia's share of global GHG emissions in 2005 was 1.5% of the total (Garnaut, 2008). Thus, one could argue that it does not matter if Australia progresses towards a low-carbon power generation sector.

Australia's traditional ties with the United Kingdom (UK) did in part see both countries' ESIs resemble each other since the end of the Second World War. Both countries established large centralised systems based primarily on coal-fired power plants. The onset of privatisation/reform for the UK ESI in 1990 then saw similar reform process being followed in the various Australian state based ESIs. The UK has embarked on a Low-Carbon future; various goals have been identified for the UK in the quest for this to occur (Grubb, Jamasb and Pollit, 2008). Australia's position on a low-carbon future has been clouded by the delay in the passage of legislation that introduces a nationwide emissions trading scheme. As previously mentioned the passage of this legislation has now been postponed until 2013.

Whatever the outcome for Australia with respect to nuclear power, it is still unclear what the best method is to dispose of nuclear waste and how this 'externality' can be costed. In a way this is similar to how the costs of greenhouse gas emissions shape the social costs and competitiveness of fossil fuel stations. Nuclear power plants need large amounts of water for cooling purposes so the location of these plants on the eastern Australia seaboard would be a major challenge for any potential new project. In addition there is not a vast supply of nuclear qualified engineering/technical staff residing in Australia so this would have to be developed quickly if nuclear power was approved. For Australia nuclear power is currently not an option as the Australian Labor Party (which is in government federally and in nearly all states) prohibits the development of a nuclear power industry (Rudd, 2009). This sentiment was reinforced by the Australian Climate Change Minister who ruled out the possibility of the current Labour Government wanting to have nuclear power generation in Australia (Bloomberg New Energy Finance, 2010). As part of this statement the Minister said that Australia should concentrate on renewable energy and also the storage of emissions from coal-fired plants (Bloomberg New Energy Finance, 2010. So, where does this leave the issue of using nuclear power in Australia as part of a suite of zero/low-carbon power generation technologies to meet ambitious greenhouse gas emission reductions by 2050?

Another recent media report highlighted that coal mining and coal-fired power station emissions of dust particles and noxious gases has caused increased health problems for some 40,000 resident in the Hunter Valley of New South Wales Australia (ABC, 2010). The issue of human health damage effects from the mining and combustion of coal is very important, but seems to have taken a back-seat to the greenhouse gas emissions issue. One comprehensive study that explored the issue of human health damage costs was that by the Australian Academy of Technological Sciences and Engineering (ATSE) (2009). This study was a follow on from the European ExternE study (2005) which mainly explored the externalities of the energy sector in Europe.

A recent presentation by Angwin (2010) and commentary by Toohey (2010) suggests that for nuclear power to be adopted:

1. Australia has infrastructure support for the mining, processing, power generation, and disposal of waste components of the uranium life cycle.
2. For Australia the decision to adopt nuclear power needs:
   a) Political support from Federal and State governments. At present the level of support for nuclear power is ambivalent at best.
   b) Financial support from the federal government. This follows on from recent US news that the latest 3rd generation Light Water Reactors to be approved for construction in the Unites States cost more than expected and the Obama administration has offered loan guarantees for the power companies investing in these plants. These guarantees amount to a considerable part of the initial capital cost. For example, for a 2200 MW expansion of an existing plant that will at present cost $US14.5 billion the US government's loan guarantee amounts to $US8.3 billion.
   c) People with the necessary skills and training in the operation of nuclear power plants. Australia does have limited experience with smaller nuclear reactors, the Australian Nuclear Science and Technology Organisation (ANSTO) operated a 10kW reactor (then expanded to 100kW) from 1961 to 1995 (Reztsov, 2010), and a 10MW reactor was shut down in 2007 after almost 50 years service. ANSTO now operates a 20MW reactor (ANSTO, 2010a). These three reactors have been used mainly for producing isotopes for medical and industrial use, materials science research, and for irradiating silicon ingots which are subsequently used in electronic semiconductor devices. And ANSTO and selected contractor staff have now had not only operational experience but also decommissioning experience. Therefore there might be a perceived lack of necessary skills in Australia but this is not justified.
   d) A comprehensive regulatory framework to cover the various components of the uranium life cycle. Because of the small nuclear reactors located at the ANSTO facility the Australian government has established the Australian Radiation Protection and Nuclear Safety Authority (ANSTO, 2010b). This authority regulates nuclear facilities in Australia via the *Australian Radiation Protection and Nuclear Safety Act 1998* (ANSTO, 2010b). However, the establishment of large scale nuclear reactors in Australia will necessitate much further and more stringent regulation than presently established.

e) A good business case for investors. The business case for investment into power generation plants has been around since the privatisation of the United Kingdom's electricity supply industry in 1990. The main factor that would differentiate the decision to adopt nuclear power for large scale application (e.g., 1000MW) is the appropriate level of risk premium. Nuclear power investment is not really possible without government support.

f) Public support is a crucial issue on whether or not to adopt nuclear power and is discussed in the last section of this chapter.

With regards to the business case for power generation investment discussion on the restructuring of electricity supply is now presented. Before climate change became a major issue the power generation sector was part of a vertically integrated government owned monopoly electricity supply industry. The reform process that began in the 1980s had a major assumption that restructuring and liberalisation of these industries would result in greater economic efficiency (Skoufa, 2006; Skoufa and Tamaschke, 2008). The three major forces that drove change within utility industries such as electricity supply (and electricity generation) included (Weiner, Nohria, Hickman, Smith, 1997; Lomi and Larsen, 1999):

1. Market Change – liberalisation, that is, the establishment of competition introduced consumer choice, price and product differentiation, asymmetric information between firms and regulators, and new entrants trying to capture capacity share from incumbents.
2. Regulatory and Political change – the objectives of the regulator (seen as 'watchdogs') and the regulated (profit or shareholder maximising firms) tended to become less co-operative in some instances.
3. Technological Change – technological change ended the traditional advantage of having economies of scale derived from possessing large-scale coal-fired generation plants. For example, coal-fired plants that were scale efficient at approximately 1000MW were replaced with gas-fired combined-cycle plants with scale efficiency at approximately 400MW.

These forces are still relevant in other ways for the power generation sector. Some lessons and suggestions for Australia's power generation sector can be learned from the experiences of the European Union's Emissions Trading Scheme (EU ETS); although the United States has had an ETS for SO_2 emissions since the 1970s (Klaassen, 1996). The EU ETS was launched in January 2005 and has become a reference point for greenhouse gas (GHG) emissions trading schemes in other parts of the world including Australia. If nothing else the EU ETS is a start at trying to address the potentially damaging effects of climate change. As three years have now passed published work on the effectiveness of the EU ETS has grown in volume within the areas of economic analysis and policy issues. From a business perspective Egenhofer (2007) identified that up to now the EU ETS has not encouraged investment into new and low-carbon power generation technologies due to various uncertainties. One of these uncertainties is the international indecision on what will replace the Kyoto Protocol which expires at the end of 2012.

Electricity supply has the unique distinction of being classed as an essential service and security of supply (i.e., keep the lights on at all costs) is of paramount importance (AEMO, 2009). However, to guarantee security of supply cost effectiveness and environmental criteria may be comprised (Sims, et al., 2007).

According to Dyner, Larsen and Lomi (2003) there are three broad categories of risk facing companies involved with electricity supply (specifically the generation sector); *organisational risks, market risks, and regulatory risks*. *Organisational risks* are those mainly associated with inertia within an organisation, that is, the tendency of established companies to resist change (both the content of the change and the process by which it is done). *Market risks* are those related to issues brought on by competition such as customer choice, price volatility, asymmetric information, new and possibly aggressive new entrants to the industry, and variable rates of return. *Regulatory risks* come about because even after restructuring and deregulation regulatory body/bodies have been established to oversee the electricity supply industry. Regulatory bodies have to choose how to balance controls on such issues as prices, anti-competitive behaviour and now with climate change and greenhouse gas emissions being of importance there will be uncertainty in policy and regulations and thus increased risk. Another way to view the major risks facing investors in power generation sectors is shown below in Figure 1.

Plant Risk	Market Risk	Regulatory Risk	Policy Risk
Construction costs	Fuel cost	Market design	Environmental standards
Lead time	Demand	Regulation of competition	CO_2 constraints
Operational cost	Competition	Regulation of transmission	Support for specific technologies (renewables, nuclear, CCS)
Availability/ performance	Electricity price	Licensing and approval	Energy efficiency

Fig. 1. Major Risk Factors for Investors in Power Generation

<u>Source:</u> Nguyen, Stridbaek, and van Hulst, 2007, *Tackling Investment Challenges in Power Generation*, p. 134

Even if the technical and economic criteria make a generation technology viable the level of support for adopting these technologies; by governments, generation companies, or the public is a strong component to be considered. Technological choices are shaped in part by social political factors (Jamasb, et al., 2008). To 'decarbonise' the electricity generation sector multiple dimensions of technical, economic, social and political are needed to be addressed (Pfaffenberger, 2010). Additionally various barriers to the adoption of various power generation technologies has been identified for the UK ESI (Jamasb, et al., 2008). These five barriers should also apply to the situation facing Australia, if a low-carbon electricity system is to be established. The five barriers are:

1. Technical – an obvious factor for both large scale (coal, nuclear) and distributed generation (DG). It is suggested that a wide adoption of DG systems in Australia

would present control, voltage and power flows issue for the current centralised system. If the systems are considered separately then the issue of fuel availability is a factor of high importance. Australia has vast reserves of coal, gas, uranium and its solar intensity is one of the highest in the world.

2. Regulatory – the Australian Renewable Energy Target encourages the use of new, higher cost renewable sources of power generation and these can be implemented in both centralised and DG systems. This is seen to be a barrier to the continued dominance of coal-fired technology and to some extent the gas-fired technology. An emissions trading scheme would also present itself as a barrier to coal-fired technologies as the short-run and long-run costs would be increased, quite significantly for the high CO_2 emitting brown-coal fired power stations in Victoria.
3. Existing planning and approval procedures – for example the current Queensland State Government has stipulated that no new coal-fired power stations would be approved for Queensland unless (1) the proposed station uses the world's best practice low emissions technology, and (2) it is CCS ready and can fit that technology within five years of CCS becoming commercially viable (Queensland Office of Climate Change, 2009. For a region with a plentiful supply of coal reserves this could see problems in the future if older large-scale coal-fired plant is not replaced by other technologies that provide similar scale. Obviously with no nuclear power industry in Australia the planning and approval procedures would have to be established and most likely follow that of the United States system of procedures.
4. Lack of standards – this is more applicable to nuclear power and small scale DG technologies in Australia at this time. For instance, standards need to be in place for safe operation of nuclear power plants and then for subsequent radioactive waste disposal and storage. The selection of sites for disposal would have to be heavily regulated via appropriate standards.
5. Public opposition/lack of awareness – especially relevant for nuclear power stations in Australia; the Not In My Back Yard (NIMBY) feeling amongst the public is strong. However this can also occur for other technologies like wind power (the large tall turbines), coal-fired power stations, and solar (PV and/or concentrated).

Rothwell and Graber (2010) state that for nuclear power to have a significant role in global GHG mitigation four countries that already have nuclear power are crucial; China, India, the United States and Russia. It is foreseen that if these four countries build substantial numbers of new nuclear power stations then GHG emission reduction could also be substantial. So where does this leave Australia? It is envisaged that this would delay or cancel out the nuclear power option for Australia, the fission option anyway. For nuclear fusion only time will tell.

In 2009 MIT updated its 2003 *The Future of Nuclear Power* study. The main conclusions of what has changed between 2003 and 2009 were (MIT, 2009):

1. That nuclear power will diminish as a viable generation technology in the quest to reduce GHG emissions. This is due to the lack of support for the technology from the US Government. However, in March 2010 President Obama pledged funding, reportedly $US 8 billion, for underwriting new investment into nuclear power stations.
2. The renewed interest in the United States for using nuclear power stems from the fact that the average capacity factor of these plants in the US has been around 90%. Also, the US public support has increased since 2003.

3. US government support via such instruments as financial funding is comparable to those given to wind and solar technologies. Such support can bring nuclear more into line with coal- and gas-fired technologies on a long-run marginal cost (LRMC) basis. And this is before carbon pricing is included in LRMC calculations.

Australia's position on the use of nuclear power has been mired in controversy for several decades. The latest data shows that Australia is the country with the highest proportion of identified uranium reserves, this was at 23% in 2007 (OECD, 2008). The key advantages and disadvantages of currently available electricity generation technologies for use within Australia's NEM are summarised in Table 1.

Technology	Generating Cost (US c/kWh)- Based on AUD/USD 0.9093 average for 2010	CO_2 Emissions (g/kWh) (Lifecycle)	Major Advantages	Major Disadvantages
Coal	3-5 (no carbon price) 6-8 (for a carbon price of USD18/tCO_2)	900 average - for brown and black coal plants	Abundant reserves in Australia Clean coal technologies are being developed but 10-15 years from commercialisation Lower operating (private) costs relative to gas	Relatively high emissions and emission control (social) costs (use of CO_2 scrubbers, carbon sequestration) Location problems for new plants Takes 8-48 hours to bring online for dispatch from cold
Natural Gas	4-6 (no carbon price) 5-8 (for a carbon price of USD18/tCO_2)	450 average (combined and open cycle)	Abundant reserves in Australia Low construction cost Lower environmental damage relative to coal (lower social cost) Takes 20 minutes to bring online for dispatch from cold Coal Seam Methane can be used for power generation (with potential Greenhouse Gas Credits to be paid)	Higher fuel (private) cost than coal Export market demand has driven up prices recently, and will do so in the future Can drive up gas prices for other non-electricity users
Nuclear	3-7 (Probably closer to 7 based on 2010 capital costs estimates for new plants in the USA)	65	Australia has 38% of global low-cost uranium deposit No air pollutants Low operating (private) costs Non-sensitive to world oil prices Proven technology 40 – 60 year lifetime, possibly 100 years with appropriate maintenance	Safety concerns (operational plants) High capacity (investment) cost with long construction time Approval process expected to be protracted Potential severe public backlash at its introduction in Australian and ultimate location of plant (on coastline for large amounts of water for cooling) Disposal of waste (where and also potential for

				weapons use)
Hydro-electric	4-20	45-200 (large and small hydro plants)	No air pollutants Low economic costs Takes 1 minute to bring online for dispatch from cold	Limited capacity expansion Volatile and increasingly scarce availability of water in Australia
Renewable(e.g. solar, wind, geothermal)	3-20 (wind is generally cheapest, then geothermal and then solar)	65-200 (inclusive of manufacturing emissions)	Minimal fuel-price risk Environmentally benign (low social costs) Stable or decreasing costs	Intermittent and other reliability concerns High economic capital costs

Table 1. Characteristics of different generation technologies for use in Australia's NEM

Based on: Commonwealth of Australia (2006); Costello (2005); Gittus (2006); Graham and Williams (2003); Lenzen (2009); Mollard, et al. (2006); Naughten (2003); NEMMCO (2007); Rothwell and Graber (2010); Rukes and Taud (2004); Sims, et al. (2003)

4. Is It Possible in Australia?

One previous study (Macintosh, 2007) looked at several criteria for the siting of nuclear power plants in Australia. In that study Macintosh (2007) proposed 19 locations in four Australian states. These locations were basically all coastal, the need for seawater cooling as opposed to freshwater cooling is important given Australia's relatively dry climate. Apart from the need for a coastal location other criteria such as minimal ecology disruption, closeness to the current transmission grid, appropriate distance away from populated areas, and earthquake activity were amongst several criteria considered by Macintosh (2007).

Recent public opinion polls in Australia on nuclear power were published by The Sydney Morning Herald (2009) and Newspoll (2007). The 2009 poll found that 49% of the survey said they would support using nuclear power as a means of reducing carbon pollution and 43% said they did not support using nuclear power for reducing carbon pollution (The Sydney Morning Herald, 2009). The 2007 poll found that whilst 45% of the survey favoured the use of nuclear power for reducing greenhouse gas emissions only 25% of the survey was in favour of a nuclear power plant being built in their local area (Newspoll, 2007). In general the NIMBY feeling remains strong in Australia, it is suggested this is in part due to the fact that large scale major coal-fired power stations are well away from major cities such as Sydney, Melbourne and Brisbane. Similarly the public attitudes to nuclear power reflect those of Australian surveys in the United States, Germany France and Japan to name a few (Rothwell and Graber, 2010). Maybe half the population might support using nuclear power plants to reduce/mitigate GHG emissions, but less would accommodate those plants in their local area. By way of some contrast there is some government support, mainly in from China and the United States, for using nuclear power in a clean energy scenario (World Nuclear News, 2010).

It might be easy to reject the use of nuclear power in Australia due to 'competition' from other sources of power generation such as coal-fired, gas-fired and renewables (solar, wind, geothermal, and so on). Interestingly enough Australia generally has abundant supplies of all 'fuel sources' for power generation. However, in Australia the abundance of uranium ore and of thorium (which is increasingly another fuel option for nuclear) may mean that when a breakthrough comes along that greatly reduces the radioactive danger for nuclear fission the apparent Australia myopia in not establishing a nuclear power industry might turn out to be a big misguided fallacy. In other words, Australian has not until now fully considered the merits of using nuclear power.

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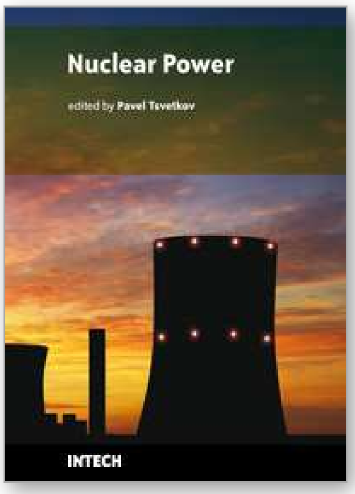

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The world of the twenty first century is an energy consuming society. Due to increasing population and living standards, each year the world requires more energy and new efficient systems for delivering it. Furthermore, the new systems must be inherently safe and environmentally benign. These realities of today's world are among the reasons that lead to serious interest in deploying nuclear power as a sustainable energy source. Today's nuclear reactors are safe and highly efficient energy systems that offer electricity and a multitude of co-generation energy products ranging from potable water to heat for industrial applications. The goal of the book is to show the current state-of-the-art in the covered technical areas as well as to demonstrate how general engineering principles and methods can be applied to nuclear power systems.

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