THE COSTS OF INTRODUCING NUCLEAR POWER TO AUSTRALIA

Ben McNeil

Australia currently relies heavily on carbon-intensive fuel sources for its electricity needs. This dependence results in one of the world's highest *per capita* carbon dioxide emissions of any nation (Marland *et al*., 2003), leading to global warming (Houghton *et al*., 2001). To ameliorate Australia's carbon intensity from electricity, some have called for the development of nuclear-based electricity generation on the grounds that nuclear is a low-carbon form of energy. Most western nations (e.g. US, UK and Canada) have avoided new nuclear electricity generation over the past 30, years while some (Germany, Spain and Belgium) are actually phasing it out. Development of nuclear energy has a number of economic, environmental and political risks, so no such decision to introduce nuclear power for Australia should be taken lightly.

Over the last year the public debate over whether Australia should introduce nuclear energy has been heated and divisive. In March 2006, the Australian Nuclear Science and Technology Organisation (ANSTO) published an extensive commissioned report into the economic viability of introducing nuclear power (Gittus, 2006). This analysis claimed that nuclear power could compete with other fossil-fuel based electricity generation technologies (coal and natural gas), providing a catalyst for Prime Minister John Howard to set up an inquiry into the viability of introducing nuclear energy for Australia, headed by Ziggy Switkowski, which published its findings at the end of 2006 (UMPNER, 2006). It is therefore timely to examine the pressing economic, environmental and political issues arising from such a proposal.

This paper has three main goals. First, it briefly assesses the direct costs of electricity estimated by the Switkowski review (UMPNER, 2006) by drawing on international evidence not included in the final report. Second, it seeks to broaden the debate beyond a direct cost analysis by examining the environmental and political risks, and by discussing how to account for these in making a full assessment of nuclear power. Finally, it draws on the preceding analysis to make an overall judgment about whether nuclear power can contribute towards an environmentally sustainable energy policy for Australia's future prosperity.

Direct Costs of Nuclear Power: Recent International Experience

Levelised cost of electricity (LCOE) analysis (CERI, 2004; IEA, 2005) is the standard methodology used to assess the direct marginal costs of generating electricity, amongst a range of alternatives. For a given set of economic assumptions, the LCOE determines the price, in real terms of electricity per megawatt hour ($/MWh), that producers would need to charge to recover costs associated with electricity generation over the lifetime of the project (CERI, 2004). The benefit of LCOE calculations is that they can be compared across different types and sizes of energy projects to give an assessment of the direct costs. LCOE is calculated by estimating three main components of costs: construction (capital) costs, operations and maintenance (O&M) costs, and fuel costs. For nuclear power the costs associated with fuel waste and decommissioning must also be added to the analysis.

With the resurgence in debate over the potential use of nuclear power, a number of studies have been published internationally, using LCOE analysis for a range of energy options, including coal, natural gas, nuclear and wind. As with any economic forecast or model, a variety of differing assumptions have been used in each of these assessments.

Table 1 shows the principal cost estimates arising from seven recent international studies on the economics of nuclear power. The construction costs have a relatively small range but the range in LCOE is between $36 and $93/MWh.

Table 1: Comparison of Recent International Direct Cost Estimates of Nuclear Power (Australian Dollars)

	MIT, 2003	UKPIU, 2002	UOC, 2004	RAE, 2004	DGEMP, 2003	OECD, 2005	CERI, 2004	Gittus, 2006
Construction Cost ($/kWh)	2732	2732	2049	2732	2299	2122	2623	2846
Levelised Cost of Electricity($/MWh)	93.2	82.5	79	55.4	47.2	39-62	62	36.3
Real Internal Rate of Return (%)	11.5	12.5	12.5	7.5	8	5-10	8	5

Key: MIT: Massechusets Institute of Technology, UKPIU: United Kingdom Prime Ministers Innovation Unit, UOC:University of Chicago, RAE: Royal Academy of Engineering, DGEMP: French General Directorate for Energy and Raw Materials, OECD: Organisation for Economic Co-operation and Development, CERI: Canadian Energy Research Institute

The Switkowski report did not conduct a new LCOE analysis into the economics of nuclear power. Rather, it commissioned the US based non-profit Electric Power Research Institute (EPRI) to review several recent studies on the cost of generating electricity from nuclear energy. The EPRI found a broad range of cost estimates consistent with other international studies, as shown in Table 1. However, the two most relevant studies in the US – from a US Department of Energy funded study at the University of Chicago (UOC, 2004) and an independent multidisciplinary study at the Massachusetts Institute of Technology (MIT, 2003) – presented estimates in the range of A$75-100/MWh. The EPRI also found that nuclear energy in Australia would be 10-15% higher than the US, given 'Australia has no nuclear power experience, nor physical or regulatory infrastructure'.

Despite these EPRI findings, the Switkowksi review reports costs for Australian nuclear energy to be 35-50% lower, concluding: 'For settled down costs and moderate commercial risk akin to other basleload investment, nuclear power could fall within the cost range of A$40-65/MWh.' These Switkowski review cost estimates were on the lower end of the spectrum, despite Australia having a non-existent nuclear industry and regulatory environment and no skilled experience in nuclear construction. Nor did the Switkowski review report on the recent experience of nuclear energy economics in similar markets to Australia. So it is important to question the viability of those particularly optimistic cost estimates.

Real costings from previous new nuclear reactors are scarce, as there is no requirement to disclose this information to the public. Fortunately, however, the last reactor built in the UK, at Sizewell-B, publicly disclosed the cost of electricity from this facility (UKPIU, 2002; POST, 2003). Even when accounting for estimated ‘first of a kind’ technology costs at Sizewell-B, the cost of electricity from this most advanced nuclear facility is currently £60/MWh (~A$150/MWh using market exchange rates). That is more than triple the cost reported by the Switkowski review.

Sizewell-B was an advanced second-generation nuclear reactor (Pressurised Water Reactor). What about third-generation nuclear reactors, which are the type of reactors to be built in the future? Only two third-generation reactors have been constructed since 1996, both in Japan, and are known as Advanced Boiling Water Reactors (ABWR). According to the Uranium Information Centre (a nuclear energy advocate).

The cost of generating electricity from these advanced reactors is about US$70/MWh, or about A$100/MWh (Kashiwazaki Kariwa-6 & 7). These high costs are despite the large amount of direct and indirect subsidies to nuclear power given by the Japanese government over the last 25 years, with annual subsidies averaging over US$2 billion over that period, by far the largest of any country (WNA, 2006). The Japan Atomic Energy Agency (JAEA) employs 4400 scientists and has an annual R&D budget of over A$2 billion. Japan has also highly trained nuclear skills and experience in building reactors; and the cost of its latest third-generation reactor at $100/MWh gives some perspective at how difficult a task it is to reduce nuclear energy generating costs.

The Japanese experience shows that the Switkowksi review estimates of $45-60/MWh are misleading. It is disingenuous to suggest that energy produced by the first nuclear reactors in Australia will cost less than about $90/MWh, at best.

Assessing Environmental Externalities: Climate Positives versus Non-Climate Negatives

LCOE analysis is a typical neoclassical economic methodology for assessing choices within an energy market, focusing on direct changes in the marginal cost (i.e. LCOE) as the only factor driving how the energy market allocates differing types of electricity generation most efficiently. A more comprehensive analysis must also consider externalities. An externality (or external cost or benefit) is defined as an unpriced, unintentional and uncompensated side effect of one agent's actions that directly affects the welfare of another agent (Baumol & Oates, 1988). External costs or benefits of electricity generation relating to environmental effects, for example, are not reflected in the price-mechanism of the energy market. Nuclear energy has both positive and negative environmental externalities; and it is important to try and assess these, in addition to the LCOE analysis, for decision makers to make a full assessment of introducing nuclear power to Australia.

Estimating the level of externality from electricity is particularly difficult, with wide ranges due to the complexities of environmental issues and the potential problems of attempting to assign a dollar value to an environmental cost or benefit (Sundqvist, 2004). Most assessments of environmental externalities from nuclear energy are based on estimating an impact 'damage function' or an 'impact pathway' approach, which attempts to identify the externality as a cost (in $/MWh) that can be compared and added to the direct costs from LCOE analysis (EC, 1998; ORNL, 2000; NEA, 2003).

Increasing carbon dioxide concentrations in the atmosphere the main physical driver of human-induced climate change (sometimes referred to as global warming). The long term economic, environmental and social implications of climate change make it one of the most pressing of all global challenges. According to the Inter-governmental Panel on Climate Change, global temperatures are likely to increase by between 1-6°C by the year 2100, sea-level could rise up to 2m, extreme weather events (drought, floods and cyclones) will be enhanced, along with a rapid deterioration in ecosystems like coral reefs, rainforests, and species extinctions due to rapid climate reorganisations beyond natural bounds

(Houghton *et al*., 2001). Although some agricultural nations may benefit from warmer and longer growing seasons, on balance the negative impacts far outweigh the beneficial ones. A recent study commissioned by the British Treasury suggests that climate change impacts may reduce global economic growth by up to 20% of GDP over the coming decades (Stern, 2006) and even suggests the possibility of an economic downturn as big as the last depression (Button, 2006).

Fossil fuel power plants are a significant contributor to carbon dioxide emissions. Their full 'costs' are currently not passed on to the electricity price. Nuclear and renewable energies emit negligible amounts of CO_2 over their full life-cycle (5-30 g CO_2/KWh) in comparison to fossil fuel energy sources, particularly coal-base power plants (800-1100 g CO_2/KWh) (Gagnon *et al*., 2002; British-Energy, 2005; Diesendorf, 2005; Storm van Leuwen & Smith, 2005; Tokimatsu, 2006). There is no doubt that nuclear power has a significant advantage over fossil fuel CO_2 emissions (particularly coal) if some sort of carbon price signal is to be introduced to the Australian energy market in order to 'internalise' these climate costs. Since the early 1990's, a burgeoning number of economists have attempted to estimate the social cost of carbon (SCC) or the marginal damage cost of carbon, defined as a monetary indicator of the global damage done by emission of one extra tonne of carbon today (see Clarkson & Deyes, 2002; Pearce, 2003; Tol, 2005; Guo et al., 2006; Icyk, 2006). However, from an environmental perspective, there are other costs not related to carbon emissions or climate change that also need to be accounted for.

Owen (2006) defines two separate types of environmental externalities in relation to electricity generation – 'climate' and 'non-climate' externalities. Nuclear energy has both positive 'climate' externalities in the form of low-carbon electricity and negative 'non-climate' externalities arising from nuclear waste, the decommissioning of power stations and problems of nuclear proliferation.

Externality costs of nuclear or any other form of energy are the sum total of both 'climate' and 'non-climate' externalities, if both are weighted evenly. This way of assessing the external costs has considerable implications for assessing the externalities of nuclear energy, particularly if the non-climate externalities outweigh the climate externalities.

Climate change goals are important, but are only part of the goal toward achieving environmentally sustainable development, defined as ‘development which meets the needs of the present without compromising the ability of future generations to meet their own needs’ (Brundtland, 1987).

In relation to environmental externalities, the policy treatment of nuclear energy in the UK, for example, is markedly different to that of renewable technologies, even though both would have equally positive climate externalities due to low-carbon electricity generation. Currently, in the UK, there is a renewable energy obligation to electricity providers, similar to Australia’s Mandatory Renewable Energy Target (MRET), along with a climate change levy on those producers that rely on fossil-fuel generation (Richardson & Chanwaim, 2003). However, nuclear producers are not exempt form the climate change levy, as is the case for renewable energy sources, even though both have positive climate externalities. The reason for this different policy treatment is that nuclear power gives rise to other substantial negative ‘non-climate’ externalities that more than compensate for the positive ‘climate’ externalities, as judged by the British government (Richardson & Chanwaim, 2003; MacKerron, 2004).

Direct costs of nuclear power in Australia are estimated to be at least \$90/MWh, going by recent overseas experience, whereas the government estimates wind and biomass renewable energies that cost between \$30-80/MWh (Prime Minister, 2004). A carbon price signal (or positive climate externality) would benefit nuclear and renewables to the same degree. However, the ‘non-climate’ externalities could be viewed to outweigh the likely positive benefits associated with ‘climate’ externalities. These ‘non-climate’ externalities include the environmental damage associated with uranium mining, the environmental and economic legacy of high level nuclear waste disposal and reactor decommissioning, substantial risk of catastrophic accident / terrorist attack and water constraints of nuclear power. The ‘non-climate’ externalities from renewables are substantially lower from an environmentally sustainable point of view, so these technologies can gain the full benefit from the positive climate externality. Wind and biomass energy would be cheaper than nuclear energy, so taking environmental externalities into consideration significantly benefits the appeal of renewable energy but not nuclear energy.

A similar assessment of the lower environmental externalities arising from renewables (particularly wind power) was found in a recent synthesis (Sundqvist, 2004). Moreover, the Kyoto Protocol follows a similar logic, with nuclear power currently not allowed to be used for carbon offsets due to these other significant ‘non-climate’ externalities. For Australia, a carbon-price signal could be introduced to account for the full external climate cost. However, if a time exists when nuclear power is introduced to Australia, the carbon price signal could either be imposed on nuclear utilities, such as is the case in the UK or altered to reflect the ‘non-climate’ externalities associated with nuclear power generation. In both of these assessments, the use of renewable energies is the preferred energy option from a total environmental externality standpoint.

Some people argue that nuclear power is a necessity because it can provide a steady flow of power with limited interruption. This steady flow is known as baseload power. However, Australia is gifted with a number of other options for baseload power, including natural gas, coal with carbon capture and storage, biomass and a large future potential with geothermal energy. Natural gas power generation emits 60% less greenhouse gas than coal fired power stations. Although it does have a slight negative ‘climate’ externality, the ‘non-climate’ externalities are far less than those of nuclear. Natural gas is also half the direct cost of nuclear so, taking into account of both ‘non-climate’ and ‘climate’ externalities in comparison to nuclear may result in natural gas being a preferred option, particularly given the vast reserves of natural gas in Australia (Saddler *et al*., 2004). Natural gas could be prioritised to provide Australia with baseload electricity in the coming decades.

Any decision on future energy supply will need to consider both climate and non-climate externalities. Diversifying Australia’s energy supply with natural gas and renewable sources, along with the longer-term option of coal with carbon capture and storage technology, will enable Australia to move away from less carbon intensive sources of electricity in the coming decades without imposing the significant ‘non-climate’ externalities of nuclear power.

What Level of Nuclear Subsidies to Expect in Australia?

The International Energy Agency defines a subsidy as ‘any government action that concerns the energy sector that lowers the cost of energy production, raises the price received by energy producers or lowers the price paid by energy consumers’ (UNEP, IEA, 2002). Subsidies can stimulate the production or consumption of electricity above that which the market would have naturally allowed. Subsidies on their own are not necessarily undesirable, and are in many cases essential for creation of incentives in a new area with large potential public good. A myriad of government initiatives is typically provided to a range of goods and services across the economy for the benefit of both public and private industry.

Disparity over a long period of time between the levels of subsidy for nuclear energy and other energy sources in the international context provides an important means of assessing the viability of nuclear energy in Australia. First, the magnitude of direct subsidies, like government grants or tax credits/incentives, provides an indication of the level of government support required to financially ‘sustain’ a given energy technology. Electricity comes from known point sources and governments rarely allow the failure of electricity supply because of the economic and political consequences of blackouts. Therefore government subsidies can provide an indirect indication of the economic fragility of electricity generation from a particular technology. Second, the level of indirect government subsidies via research and development (R&D) can help to show the incremental technology gains and what technologies are best poised for advances for a given level of R&D funding.

Before the first nuclear energy reactor was ever built, insurance agencies were unwilling to provide adequate liability and indemnity for nuclear utilities in the event of a catastrophic accident, simply because of the devastating magnitude of such an event. Governments had to provide limited liability for nuclear utilities for anyone to even consider building a reactor. In 1957 the US government legislated the Price-Anderson Act, which limited the liability of private operators for a nuclear accident. The Act was recently renewed up to the year 2025. The Price-Anderson

Act requires private nuclear power licensees to provide a maximum primary liability of US$300 million. If claims exceed this primary liability, the Price-Anderson Fund requires all licensees to pay a maximum of $96 million (totaling $9.5 billion if all 106 reactors were required to pay the maximum) at the time of the accident. Beyond the Price-Anderson Fund, the US Congress covers an extra $9.5 billion for liabilities. The economic consequences of a catastrophic nuclear accident are in the order of hundreds of billions (Heyes, 2003), depending on the geographical location of the nuclear facility. The Price-Anderson Act therefore provides for a direct subsidy, reducing the real insurance premiums paid by the nuclear industry (Heyes, 2003).

In the international context, the Vienna Convention on Civil Liability for Nuclear Damage (1963) was also formulated, with a limited liability for individual licensees set at US$400 million, and was ratified in 1997. It is difficult to directly estimate the effect of limited liability on LCOE, with estimates ranging anywhere between $1 and 30/MWh (Dubin & Rothwell, 1990; Heyes, 2003; Kammen & Pacca, 2004). A recent analysis of Canada's nuclear liability Act of 1970, which limits liability to nuclear utilities to $75million, suggests a direct subsidy of up to $4/MWh (Heyes & Heyes, 2000). Although it is difficult to determine the exact level of subsidy to the costs of nuclear energy, limited liability provisions are without doubt fundamental in reducing the risk environment for nuclear utilities. As stated by US Vice-President Dick Cheney, without the Price-Anderson Act 'nobody's going to invest in nuclear power plants' (Reuters, 2001).

Limited liability provisions, however, could actually increase the likelihood of an accident, because they serve as a disincentive for nuclear reactor utilities to put in place more comprehensive safety measures (Heyes, 2003). Given that governments mostly underwrite the damages of a nuclear accident, the utility could shift resources towards profit seeking activities rather than safety measures. Limited liability does not reduce the risk, but shifts the risk to the government. This then results in continuous governmental monitoring of nuclear facilities. In the US, after the Three Mile Island nuclear accident in Pennsylvania in 1979, regulatory measures and monitoring by government authorities surged, resulting in time delays and an average 60% increase in capital costs for new nuclear reactors built after 1979 (Nivola, 2004). Nuclear power plants are also targets for terrorists, but these acts are not covered in the current insurance liability provisions, and the government has to pick up the entire financial liability of such an event. Given the international experience, the Australian government needs to consider whether it is willing to accept these significant liability risks required in introducing nuclear power to Australia.

A simple cost analysis can show how even the subsidies required for nuclear power would be disproportionately large in comparison to other technologies. Gittus (2006) outlines two financial plans in introducing nuclear power in Australia. The first requires government to take 56% of the risk of construction by issuing a risk-free loan which would amount to about $2 billion. The second financial plan requires the government to provide a direct grant of about $420 million for construction and to provide 21% of the entire cost of electricity for the first 12 years of operation (about $70 million per year), along with providing limited liability for the nuclear utility (about $4/MWh if taking the Canadian liability model from Heyes & Heyes, 2000). The total direct governmental subsidy estimated by Gittus (2006) in the second financial plan is $420 million for construction and about $100 million each year for 12 years (about $1.6 billion over 12 years), notwithstanding a limited liability subsidy discussed previously.

It was shown recently that direct annual Australian government subsidies (excluding Research & Development) were $255 million for coal and $260 million for natural gas (Riedy, 2003). Taking into account the level of electricity generated by each fuel source (Prime Minister, 2004), direct subsidies equate to $8/MWh for natural gas and $2/MWh for coal. There are very few estimates of the level of direct subsidies for renewable energy, but the Australian National Institute of Economic and Industry Research estimated a figure of about $43.1 million, although this was before the federal Mandatory Renewable Energy Target (NIEIR,1996). Assuming $43.1 million is the total direct subsidy and, comparing that to the proportion of electricity generated by renewables in Australia (Prime Minister, 2004), the subsidy to renewable energy amounts to about $3/MWh. Using the estimates from Gittus (2006), the subsidy of the first nuclear power plant (assuming an output of

1150MW) would require a government subsidy of $60/MWh. The government would therefore be required to provide between 7 and 30 times the level of subsidy for the first nuclear power reactor than is currently provided for for either coal, natural gas or renewable energy.

Crowding-out Other Low-emission Energy Options

Technology 'crowding out' is the phenomenon by which limited governmental Research and Development (R&D) budgets are disproportionately allocated to one technology, leaving little room for expenditure on other technologies (Frey & Jegen, 2001). Historically, R&D expenditure on nuclear power represents a perfect example of technological 'crowding out'. Global R&D expenditures over the last 30 years show nuclear to be funded by $120 billion, compared with $19.7 billion for renewable energy – a ratio of 6 to 1 (IEA, 2002). The economic return from the disproportionate allocation of R&D funds for nuclear is unclear. The nuclear technology learning rate, defined as the percent reduction in cost resulting from a doubling in production, between the 1970s and 1990s (~5.8%), was four times lower than for renewable technologies (15-20% for wind turbines) (McDonald & Schrattenholzer, 2001). Despite an R&D investment of 6 to 1, this provides evidence that the investment has not been the most effective. Given these huge R&D investments in nuclear power, it suggests that any future incremental technology improvements will be minimal in comparison to technology improvements of other forms of energy provision.

Even after the decades of support, with little gain in improving nuclear energy in comparison to other energy sources, the federal government in the US committed 29% to nuclear, 29% to fossil fuels and 19% to renewables within the 2004 energy R&D budget (DOE, 2006). What is remarkable is that, over the last 30 years, capital costs for nuclear reactors have not decreased despite the disproportionate R&D expenditure (Thomas, 2005).

The global energy market is in the midst of a long-term low-carbon transformation, so the question arises as to how Australia should position itself within this burgeoning market for low-carbon emission energy technologies. R&D expenditure by government will play a crucial role in shaping and positioning Australia to benefit, economically and environmentally, from the new and more advanced low-emission technology market. Although nuclear is a low-emission technology, countries like Japan, France, the UK and the USA have a 40-50 year head start on Australia in terms of developing the relevant labour skills, research and nuclear investment. It will take another 15 years at least for a nuclear reactor to be built in Australia and, from this perspective, it is clear that we have a comparative disadvantage with the rest of the world in nuclear technology. Furthermore it is unclear if nuclear power will play an important role in global energy supply, as many countries in the European Union (Germany, Spain, Denmark and Sweden) are phasing out nuclear power, while other western economies (like the US, UK and Canada) have not ordered a new nuclear reactor since the early 1980's. Investing heavily in nuclear power R&D to the detriment of other low-emission technologies is a misguided option simply on grounds of comparative advantage.

Australia has a sophisticated coal and gas industry and an existing international comparative advantage in its production and supply of energy. However, this advantage for coal is beginning to shift because of concern over its intense greenhouse gas emissions. This is why cleaner natural gas energy production is the fastest growing baseload option in the world. Given Australia's reliance on coal, it would be in Australia's best interest to provide R&D and incentives for new low emission coal technologies that are at the start of their development. The demand for lower emission coal technologies, along with natural gas, will continue well into the future, where Australia has a considerably advantage over other countries in terms of skills and existing knowledge base. Like cleaner coal and natural gas energy production, renewable technologies like wind, solar, geothermal and biomass are set to undergo considerable growth in global energy markets over the coming decades. Most developed countries (Guardian, 2007), and even countries like China (Xiaohua, 2007), are setting ambitious goals for renewable energy to make up at least 20% of domestic energy production by 2020.

Nations that position themselves as renewable energy leaders will stand to gain considerably from technology exports, with substantial economic and employment growth benefits. Australia's diverse environmental resources from intense solar radiation, high regional wind strength, geothermal capability and biomass potential, coupled with its large land mass, position it to become potentially the world's leader in research, development and deployment for a range of renewable low-emission energy technologies. Australia must therefore choose to invest and subsidise technologies that not only provide Australia domestic cost-effective low emission energy technologies but also position Australia to benefit from the future international low-emission global energy market. The funds required to invest and sustain a nuclear industry would siphon direct and indirect government funds away from other low-emission technologies that have a brighter global market potential than does nuclear power.

Energy Market Liberalisation and Nuclear Power: Can they co-exist?

Many nuclear advocates suggest that simply allowing free access to energy markets will ensure the existence of nuclear power in Australia (Levendis *et al.*, 2006), yet the majority of the current 440 reactors in the world were built in energy markets that are or were centralised regulated monopolies. As the Australian energy market is increasingly liberalized, the question then arises – can nuclear power play a role in fully or partially liberalised energy market?

The constitutional status of providing energy in Australia falls on the States. Consequently, up until the 1990s the energy market was entirely owned and controlled by State governments (Sharma, 2003). In the early 1990s, reform of Australia's electricity industry was pushed forward to target economic efficiency and to lower marginal electricity prices. In 1991, State governments agreed on a reform package, which included the creation of a national electricity market (NEM). In principle, the NEM is to provide freedom of choice for electricity buyers, limit regulation on electricity generators and retailers, and reduce the barriers to inter-State electricity trade. To conform with the NEM, States underwent considerable but varied reform in the mid-late 1990s, but in general have introduced competition among generators and retail sectors (Sharma, 2003). In Victoria and South Australia, for example, the energy sector was privatised. In the NEM all generators (whether from coal, gas or renewables) compete to supply electricity to a common market pool.

The old centralised, regulated monopoly energy market introduced inherent biases towards capital-intensive electricity generation technologies, as electricity was classed as a public good with known economic returns for long periods of time (Averch & Johnson, 1962). In increasingly liberalised markets, however, the motive is profit, with risk shifted to private investors with a preference for smaller, modular projects with quicker returns. As pointed out by Roques *et al*. (2006), even if the direct costs of nuclear were comparable to that of other technologies, the redistribution of risk and long payback period make nuclear projects unattractive to investors, as demonstrated by the complete lack of private investment in nuclear power globally in fully or partially liberalised markets over the last 30 years.

These overseas trends provide an important perspective on the prospects of nuclear power in Australia's partially liberalised energy market. In 1989, the UK energy market was completely privatised. In response to the concerns over fossil fuel externalities from the European Commission, the UK government passed a non-fossil fuel obligation, which required public electricity utilities to purchase a certain amount of electricity from non-fossil fuel sources (Mitchell, 2000). A fossil fuel levy (FFL) on all electricity sales was imposed to compensate these utilities for the new obligation. Between 1990 and 1998, however, the government used 75% of the £9.4 billion accumulated from this levy to subsidise the nuclear industry, as no private investors were willing to purchase the public nuclear utilities (Mitchell, 2000: 293). The FFL added 10% to electricity bills; yet, even with the FFL subsidising nuclear reactors, investors substantially moved towards renewable technology investments, particularly wind power because of its lower risk and shorter payback periods (Mitchell, 2000). Eventually British Energy, which owns most of Britain's new nuclear plants, was provided with the equivalent of a $1.5 billion bailout by the government due to the inability of nuclear utilities to compete in a more volatile privatised energy market (BBC, 2002).

A history of state deregulation in the US found that, in many cases, energy liberalisation initiatives have actually increased electricity prices by up to 30% (Johnston, 2006). Even in this scenario not a single reactor has been planned for 30 years. From overseas experience, even if the government allowed free market access to nuclear energy in Australia, the increasingly liberalised (fully liberalised in Victoria and SA) energy market will probably discriminate against investing in nuclear reactors, as opposed to other more agile, less risky technologies (particularly natural gas).

Even if substantial government subsidies are assured, it would still be unlikely that the market will be attracted to nuclear power in Australia. The Standard & Poor rating agency recently declared that 'the nuclear industry's legacy of cost growth, technological problems, cumbersome political and regulatory oversight, and the newer risks brought about by competition and terrorism may keep credit risk too high for even federal legislation that provides loan guarantees to overcome' (*The Economist*, 2005).

The only way that the Australian federal government could effectively lock in nuclear power generation to the Australian market is to mandate a percentage requirement of nuclear power, in a similar way to its current Mandatory Renewable Energy Target (MRET). Whereas other countries have set MRET between 10-20% by 2020, Australia's target of 2% is the lowest in the modern world. One of the main reasons for this low target are the pro-liberalisation preferences within the current federal government, where there is a belief that government should not 'interfere' with energy markets. This leaves the government in a particular political dilemma, given the lack of investment in nuclear power in liberalised energy markets overseas. It seems that the government would be required to 'intervene' in Australia's energy market and impose a mandatory nuclear energy target (MNET) to ensure its use, but given their current misgivings on increasing firm targets for renewable energy use under MRET, it would be a considerable policy shift. Furthermore, it would be hard to envision the Australian public accepting an MNET to the detriment of MRET.

The Proliferation Domino in the Asia-Pacific Region

The core of a nuclear reactor is fueled by uranium, with plutonium produced as a by-product of uranium fission, both of which can be used to develop nuclear weapons upon further enrichment. Historically, nuclear weapons programs have been intimately linked with nuclear reactors, as political leaders see the potential positive by-product of nuclear weapons capabilities. In 1974 for example, India detonated its first atomic bomb, using plutonium from a nuclear reactor given by the Canadian government for peaceful nuclear energy use (Martin, 1984). Unfortunately, the intentions of countries who state their purpose to develop peaceful nuclear energy can never be guaranteed.

Most countries treat the development of civil nuclear reactors as a signal to build nuclear weapons. Even today Iran and North Korea’s nuclear weapons programs are inextricably linked with ‘civil’ nuclear reactors. Recently, a former US vice-president stated, ‘during my 8 years in the White House, every nuclear weapons proliferation issue we dealt with was connected to a nuclear reactor program’ (Gore, 2006). Undoubtedly, both national allies and enemies of Australia will take the news of a new nuclear program with skepticism, based on previous guarantees by foreign leaders to use nuclear reactors for peaceful purposes only to acknowledge later that they have facilitated the development of nuclear weapons.

The pursuit of civilian nuclear energy will also have foreign diplomacy and security implications. In 2005, Westinghouse, a US company that designs nuclear reactors, was bidding against French and Russian companies for a Chinese nuclear contract. According to *The Economist*, ‘the House of Representatives, fearful of giving China access to American nuclear know-how, voted down a $5 billion loan from America's Export-Import Bank’ (*The Economist*, 2005). From a regional perspective, a good relationship with Asia-Pacific nations is most important for Australia, particularly with respect to nuclear proliferation. It is critical that Australia sends a signal to its regional neighbours that does not create confusion or unwanted diplomatic implications in relation to developing nuclear energy. It is not inconceivable that Indonesia, for example, would believe that Australia is fulfilling a clandestine nuclear weapons capability by building a civil nuclear reactor, especially given the range of energy options on offer in Australia. It is then not inconceivable that Indonesia or any other nation could subsequently pursue its own clandestine nuclear plans while still under the auspices of the nuclear non-proliferation treaty. A paranoid domino effect may occur in the Asia-Pacific region, leading to a dangerous regional escalation of 'nuclear capabilities'. This risk of a detrimental outcome for regional non-proliferation and security must be thoroughly examined before advocating development of nuclear energy for Australia.

Australian Energy Policy: Is There a Role for Nuclear?

Fortunately, Australia has many options in developing an energy policy that addresses the economic, social and environmental challenges of the future. Taking into account a full cost assessment of both direct and external costs imposed by each energy source is essential. Climate change will have widespread global consequences and cause particular harm in developing nations, since their economies depend significantly on agriculture and fisheries that are particularly climate-sensitive activities. In developing an environmentally sustainable energy policy, 'climate' externalities should therefore be weighted more than 'non-climate' externalities, since in general 'non-climate' externalities are more localised. However, the 'non-climate' externalities of nuclear energy (such as nuclear waste, uranium mining, potential catastrophic accidents and water constraints) cannot in any way be classified as environmentally sustainable.

The main priority for a sustainable energy policy for Australia must therefore be to work towards reducing carbon emissions by 50-60% by the year 2050, as suggested by the scientific community (Houghton *et al*., 2001), while causing the least environmental damage from 'non-climate' externalities. Many advocates of nuclear energy seek to justify it as having an important role in moving Australia towards this 'sustainable' energy policy. However, this assumes that there are no other options to generate electricity that have positive 'climate' externalities and neutral 'non-climate' externalites, something that cannot be said for nuclear. All forms of renewable energy, particularly wind power, have both a net positive environmental benefit and are equivalent to nuclear on a marginal cost perspective.

Some countries do not have the luxury of energy choices and may require utilising nuclear energy, particularly with the need to reduce greenhouse gas emissions to meet international climate agreements like the Kyoto Protocol. Australia, however, is fortunate to have a multitude of energy choices that do not require it to chose nuclear. This is illustrated by a substantial study undertaken by Saddler *et al*., (2004), setting out to develop an energy policy for Australia with the goal of reducing carbon emissions by 50% by the year 2040 (Saddler *et al*., 2004). The study showed how this goal could be achieved by using a mixture of energy sources that included: 32% combined cycle natural gas turbines, 26% biomass, 20% wind turbines, 9% black coal, 7% hydro, 5% solar / photovoltaics and 1% oil. The analysis showed that nuclear energy was not required, thereby minimising negative non-climate externalities.

Two other technologies that have positive 'climate' externalities similar to nuclear, without the negative 'non-climate' externalities, are known as carbon capture and storage (CSS) and geothermal energy. Neither of these featured in the final analysis of Saddler *et al*., (2004). CCS refers to the capturing of carbon emissions from smokestacks at coal fired power stations (or natural gas power stations), liquefying it and pumping it into geological features like coal seams or depleted oil reservoirs. Given Australia's reliance on coal fired power and Australia's large coal reserves, this option has potential but it could only contribute to energy policy in the longer-term, as it would be at least one decade before the technology would be commercially available for coal-fired power stations. Geothermal energy is that created by pumping water deep underground, where hot rocks return the water as steam, thereby driving turbines to create electricity. Geothermal energy could also have considerable potential, based on Australia's geology (Prime Minister, 2004). However, in reality these two particular technologies are still in the infancy of development; so the subsides that would be required for nuclear power development in Australia would be far better spent on these and other renewable energy technologies in order for push Australia along a more environmentally sustainable path.

Conclusion

In light of the increasing awareness of global climate change, it is no surprise that the energy debate in Australia is currently receiving considerable attention. Fortunately for Australians, we are in the enviable position of having access to numerous different energy technologies and resources. Yet nuclear energy has taken centre-stage for the current federal government which presents it as the principal solution to our energy policy dilemma. This article has shown that the direct and external costs of introducing nuclear energy to Australia greatly exceed those used by the government to justify its position.

The most recent available international costs calculations and the Switkowski commissioned EPRI review both suggest that the direct costs of nuclear energy are likely to be at least $90/MWh. Australia's lack of experience with the necessary economic, labour and regulatory environment could drive the costs yet higher. From a marginal cost perspective, the Switkowksi report's conclusion that nuclear energy is the 'least cost low-emission baseload technology option' is particularly dubious, given that costs of other baseload options like biomass, carbon capture and storage and geothermal technologies were not reviewed. Moreover, an examination of the likely subsidies required to ensure nuclear energy viability in Australia's partially liberalised energy market suggests considerable political and economic risk in comparison to other more agile and less risky energy options.

When assessing energy supply options, external costs related to their use also need careful consideration in the decision making process. For nuclear energy and other forms of energy, these can be broadly separated into climate externalities (associated with climate change) and non-climate externalities (any environmental effect not related to climate change). An effective and genuine environmentally sustainable energy policy must take both categories into account. Although nuclear energy has a substantial climate benefit via low-carbon electricity, it also imposes substantial environmental costs in relation to the legacy of nuclear waste, uranium mining, decommissioning, accident risk, water use and proliferation concerns which cannot be considered as environmentally sustainable.

Other technologies, such as renewable energy (wind, solar, biomass, geothermal), also provide low-carbon electricity but are not fraught with the significant negative non-climate externalities associated with nuclear energy. Renewable energy technologies (particularly wind and biomass) have also demonstrated direct economic viability. These other technologies, along with carbon capture and storage, could be used in conjunction with other baseload energy sources (particularly natural gas) to move Australian energy policy towards a sustainable future that genuinely addresses climate change, without the need to introduce the significant economic costs, strategic problems (of proliferation and terrorism) and environmental / health risks associated with nuclear energy.

Ben McNeil is a lecturer and research fellow at the Climate Change Research Centre of the University of New South Wales.

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b.mcneil@unsw.edu.au

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