# “Nuclear Energy – Australia’s Opportunity”

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### The big picture and the politics

Nuclear power generation has served the international community well and with remarkable safety for over 50 years. Today it is part of the portfolio of over 30 countries and growing with 440 civilian power reactors in service worldwide providing about 14% of the world’s electricity, with over 8 times more nuclear capacity installed than the total capacity of Australia. For France the figure is over 75% - with substantial exports to its neighbours. Around 45 new reactors are under construction, with over 300 more planned or proposed. A *nuclear renaissance* indeed!

Despite this exceptional record the *cognoscenti* insist (and are all too often believed) that nuclear power leads to bombs. But all five of the original nuclear nations (UK, USA, USSR, France and Japan) had bomb technologies before power – bombs led to power, not the other way round!

Nuclear power however is not part of Australia’s generation portfolio. Nor indeed can it be considered; despite having nearly 40% of the world’s easily won low cost uranium resources –yet another manifestation of ‘The Lucky Country’. Ironically Australia is the world’s second biggest exporter of semi-processed uranium ‘yellowcake’, fuelling much of the world’s reactor fleet.

Reasons for the lack of nuclear power take up in Australia are both economic and political. Economically Australia has an abundance of low cost coal resources close to load centres against which nuclear power cannot compete so long as carbon emissions are not costed; the sent out electricity cost being some 20-50% higher. Moreover the coal and associated power generation industries are major employers – and all employees vote.

Politically neither Commonwealth nor State Government policies yet permit nuclear generation while community attitudes, faced with conflicting ‘information’, are still uncertain. With community debate, such as this talk, the slowly growing understanding is that nuclear power is not the demon so often portrayed, but may yet be the low emission pathway of choice in the decades ahead. Indeed nuclear power generation, with its minimal carbon footprint, will almost certainly prove economically and hence politically attractive as carbon emission reduction pressures grow and costs begin to bite.

Australia was nuclear power ready in the early 1980s, with the Jervis Bay power station committed and the Australian Atomic Energy Commission (AAEC) among world leaders in technology development, including Synroc, and boasting a graduate school of nuclear engineering at the University of New South Wales. Today all that has gone. Did Australia miss an opportunity than? I for one believe we did.

## The nuclear fuel cycle – from uranium ore to spent fuel disposal

The nuclear fuel cycle, expressed simply, comprises the following steps: mining and milling (producing uranium oxide concentrate $U_3O_8$ sometimes known as ‘yellowcake’); conversion to gaseous uranium hexafluoride (loosely called ‘hex’); enrichment to increase the concentration of the fissile isotope $U_{235}$ in natural uranium from around 0.7% to between 3 and 5% - known as low-enriched uranium (LEU); fuel fabrication into small pellets; loading of pellets into fuel rod assemblies; loading into the reactor for some three years of controlled fission and heat release for conventional steam generation; cooling and radioactive decay of the spent fuel assemblies in deep water ponds; safe and permanent encapsulation and finally deep burial in engineered repositories some 500 to 2000 metres underground.

## Reactor technologies

As with most technologies nuclear power has developed over a series of ‘generations’. Generation I, now almost all removed from service, included the prototype gas cooled Magnox reactors of Britain commissioned in the 1950s, the last of which is to close down in 2010.

Generation II, from the mid 1960’s, comprised a range of commercial reactors of varying designs including LWR, PWR, BWR, CANDU, VVER and RBMK to name a selection. Many are still in service with some notable exceptions; the Soviet RBMK reactors at Chernobyl and other USSR sites have all been modified or decommissioned for reasons needing little further explanation.

Generation III, from the mid ‘90s, delivered today’s more advanced, safer and reliable light water reactors (LWRs) comprising the ABWR, System 80+, AP1000 and EPR designs being installed or on order throughout the world. Generation III+ designs, with even better fuel utilisation and safety features, enter service from 2010 onwards and, should Australia adopt nuclear power, this could well be the technology of choice. Capacity factors over 90% can confidently be expected with plant lives well over 40 years and more. Safety standards will be very high – rightly so.

Generation IV, comprising the fast reactors still under development, promises a whole new approach from around 2030. Five of the six candidate designs are so called ‘fast neutron’ types which extract some 50-60 times more energy from the uranium fuel by using both the $U_{235}$ and the far more plentiful $U_{238}$ unused by earlier generations and currently stockpiled for reprocessing or deep disposal. Australia is considering its commitment to their development through the Generation IV International Forum.

## Nuclear power for Australia?

The 2006 Uranium Mining Processing and Nuclear Energy Review (the UMPNER report) showed, on the basis of the best information then available, the earliest that nuclear electricity could be delivered to the Australian grid would be 10 years, with 15 years more probable, from the time of commitment to a nuclear program. However, as the report noted, the establishment of a single national regulator supported by an organisation with skilled staff is the first priority. Then a core of trained nuclear power industry scientists, engineers and technologists will be needed; human resources reported to be in increasingly short supply in the current worldwide ‘nuclear renaissance’. The challenge is huge; Australia is foolish to ignore it.

## The economics of nuclear electricity

The economics of nuclear power hinge on the cost of capital, the balance between (and ownership of) equity and debt and the means of managing financial risk.  Fuel costs are a relatively small proportion of sent out power costs which, apart from financing and regulatory costs, would include through a small levy on power sold for waste disposal and eventual decommissioning.

Capital costs comprise plant engineering, procurement and construction (EPC) and owner’s costs, typically land, cooling infrastructure, administration and associated buildings, site works, switchyards and project management. The term ‘overnight capital cost’ is used to mean EPC plus owner’s costs but excludes financing, cost escalation and inflation.

Many sources of cost data exist, not least the UMPNER report which showed on the basis of a commissioned independent report from the Electric Power Research Institute (EPRI) – see UMPNER Fig 4.7.  At that time the range of levelised cost of electricity (LCOE) from nuclear power lay between $40 and $65/MWh (or 4.0c and 6.5c/kWh) as compared with the LCOA for conventional pulverised coal power between $28 and $38/MWh (or 2.8c and 3.8c/kWh), figures which make no provision for emissions trading or plant needed for carbon capture and sequestration.  It must be noted that for nuclear power these are ‘settled down’ costs with the technology established. Inevitably ‘first of a kind’ (FOAK) costs are higher and Australia will be no exception.  However, as with any new technology having desirable attributes (in this case very low emission levels - carbon and otherwise), it is likely that some form of early taxpayer support will be provided, as has been the case with the introduction of all other low emission technologies to Australia - and indeed to most adoptive legislations.

An August 2008 paper of the World Nuclear Association (WNA) “The Economics of Nuclear Power” draws on much the same data as EPRI in 2006 but adds recent worldwide contract figures. Recent EPC costs recorded (and there are many) range from US$1530/kW (for China Guandong Nuclear Power Company’s 4x1080MWe CPR-1000 units at Hongyanhe) to US$3582/kW (for Florida Power and Light’s 2x1100MWe AP-1000 units at Turkey Point, Miami).  The average for the new contracts recorded recently lies between US$2,500 and US$3,000/kW.  Mid 2008 vendor EPC quotes are all around $US3,000/kW in a competitive worldwide market, but they are rising with growing manufacturing capacity constraints.  These figures are not significantly higher than those for conventional coal fired plants of similar capacity.  With the addition however of plant for carbon capture and sequestration, combined with the huge consequential increase in parasitic power to drive the plant and compress the $CO_2$, understood to be between 25 and 30% of the total plant output, the comparative economics of nuclear power begin to look much more attractive.  Moreover the technology is very well proven, compared to the remarkable notion of 'clean coal' upon which present hopes of major carbon dioxide reductions are based.

Fuel costs can be quite variable, especially on the spot market, although most operators lock in long term fuel supply contracts. Typical fuel costs at current world contract prices equate to US$5.0 to US$6.5/MWh. With new mines opening in Australia and overseas, contract prices are unlikely to increase dramatically. Even so fuel is but a small proportion (around 10%) of the sent out cost of electricity; thus sensitivity to fuel price variation (and hence inflation generally) is low. Moreover modern designs are increasingly fuel efficient.

Plant decommissioning costs are from 9 to15% of initial capital cost but lie so far in the future that a modest levy of around US$1.0 to US$2.0/MWh on electricity sent out is sufficient to provide adequate funds. Likewise spent fuel disposal costs are typically around US$1.0/MWh and can be dealt with similarly. The nuclear industry is one of very few industries offering this holistic approach to all of its costs, both internal and external.

## Low emission technologies

Turning to the low emission alternatives for power generation we have first the much loved solar and wind technologies. These are indeed wonderful and I hope they will continue to be strongly promoted. However both suffer from low 'capacity factors'; that is the ratio of continuous rated output to actual energy generation over a year. For wind worldwide this figure is a meagre 20%, although varying greatly between good and bad sites. But in general for every MW of wind generation installed, we need nearly 5MW to get the equivalent delivered energy over a full year as a 1MW baseload generator. But this is not all; at times of storm and gale this wind farm may deliver well over 5MW; at times of calm its output may be zero. However these highs and lows of wind speed do not coincide with electricity demand; thus another 5MW standby or part load plant is required to fill the gaps giving rise to acute problems of system control. This is an extraordinarily complex issue; energy storage, itself very expensive, is important but only part of the answer. Wind is still not a candidate for economic base load power.

Solar energy typical capacity factors are even lower at around 15% depending on latitude, but where air conditioning forms much of the daily load solar energy has a natural place, albeit still many times more costly per unit of output than coal or nuclear. Solar energy certainly has a space which is far from filled; private rooftops, remote dwellings, navigation lights and space vehicles all rely on solar energy, one of the most elegant of all technologies but quite unsuited to the provision of reliable bulk base load electricity at an acceptable cost – unless hugely subsidised.

### Nuclear power plant siting

Many sane people, apart from the pragmatic French, harbour irrational fears of nuclear power, giving rise to powerful NIMBY expressions when site locations are discussed. But in truth no-one really wants to live too near to any power plant, regardless of its primary energy source. Nevertheless the nuclear choice turns out to be not so bad when compared with its competitors provided plant safety, discussed below, is accepted as a given.

The land needed for a nuclear power station differs little from that for a coal fired power station of comparable output – say 1000MW. However to the coal station real estate must be added the chimneys (to remove and disperse the flue gas fine particulates spawned by coal combustion); the coal mine and its associated washeries and conveyors; and the relatively radioactive surface ash dam of ever increasing area. Typically a nuclear power station generates around 1,000W/m$^2$, far in excess of concentrating solar power at a modest 15W/m$^2$ or offshore wind around a yet more modest 3W/m$^{2.}$

Cooling water needs for nuclear power are a little higher than for coal due to slightly lower nuclear cycle efficiency. But the cooling water source can be once-through sea or estuary water, evaporative cooling towers with limited make-up water, or dry cooling with radiators – similar to cars and trucks.

Nuclear air pollution is far less than coal with no CO2 disposal. Solid nuclear wastes are also dramatically less in total pollutants - radioactivity and toxics combined. Plant access is comparable while safety is far better than coal. In short a nuclear plant can be located anywhere near the grid where there is adequate cooling water, assured security and plans for a long term future.

### Spent fuel and nuclear wastes disposal

Nuclear wastes arise in three broad categories – low level waste (LLW); intermediate level waste (ILW) and high level waste (HLW). LLW includes paper, glassware, tools and clothing which are very lightly contaminated and need no special shielding. ILW comprises reactor components, chemical residues and spent medical radioisotopes which do need shielding and special handling but not cooling. Safe LLW and ILW storage and disposal is already well demonstrated at sites worldwide, including at ANSTO's Lucas Heights facilities. At this stage the minimal HLW from the recently commissioned OPAL research reactor is reprocessed overseas.

Larger fission reactors worldwide produce spent fuel to be disposed of safely. Short term disposal (~ 30 years) in deep cooling ponds at the power station provides for heat and radioactivity decay. But eventually long term deep disposal is essential, as for many other of society's intractable wastes, and many nuclear nations are well advanced with such facilities. Australia is particularly well placed geologically with vast remote geo-stable regions ideal for deep (>500m) disposal which, at least for Australia, would not be needed until around 2050 should nuclear power be adopted.

Nevertheless spent fuel is indeed nasty dangerous stuff if not handled properly. Its reprocessing to retrieve uranium and plutonium for further use is highly complex and undertaken in costly plants in Britain, France, the USA and Japan.  But spent fuel volumes, even with today's fission reactors, are very small indeed, amounting to only 2 to 3 cubic metres per annum for a 1000MW base load nuclear power station if the fuel is reprocessed; about 10 cubic metres if not (about the same as a small ensuite bathroom!).  Compare this with the disposal of around 7 million tonnes of carbon dioxide for the most modern 1000MW coal plant, using as yet unproven carbon capture and sequestration (CCS) technology – the so called "clean coal" approach, not to mention the disposal of many tonnes of moderately radioactive ash.

Engineering of a spent fuel repository lies well within the skill base of Australian hard rock mining engineers.   It has been proposed (as a commercial opportunity) that Australia might lease its uranium to approved world users, taking it back after 30 years for permanent encapsulation and burial unless reprocessed.

## Health and safety

Nuclear power has unwarrantedly gained a reputation for dangerous radiation and resulting deaths.  However the truth, measured in the unattractive but illustrative units of "deaths per GWy", is that nuclear power, including the tragedy of Chernobyl, is by a huge margin less dangerous than all fossil fuel generation and also less than hydro and all renewables.  For the anti nuclear power plant lobby this is indeed an inconvenient truth.

## Conclusion

This short paper has touched on only some of the essentials of nuclear power.  Issues such as the management of nuclear proliferation; the creation and education of the cadre of scientists and engineers that will be needed should nuclear power be found to be the ugly duckling; the potential for Australia to take a stronger role in the nuclear fuel cycle and many others lie with the generations ahead.

In my view the need for moderate cost low emission base load generating technologies, along with the need for primarily electric transport, is clear.  But by the time the profound debate over the impact or otherwise of carbon in our atmosphere is resolved it may be too late for Australia to return to leadership in technologies that promise so much.

For Australia to ignore the potential of nuclear power may one day be shown to have been the height of foolishness.  Our grandchildren, and their children, will wonder how we could possibly have been so blind.