ADDITIONAL SUBMISSION TO THE INQUIRY INTO FUEL AND ENERGY

Comments by

The Australian Academy of Technological Sciences and Engineering

for

Senate Select Committee on Fuel and Energy

July 2009

Australian Academy of Technological Sciences and Engineering (ATSE)

SENATE COMMITTEE ON FUEL AND ENERGY

ADDITIONAL SUBMISSION FROM THE AUSTRALIAN ACADEMY OF TECHNOLOGICAL SCIENCES AND ENGINEERING

In a letter dated 2 July 2009, the Australian Academy of Technological Sciences (ATSE) was invited to make a further submission to the Inquiry into Fuel and Energy following the expansion of the Terms of Reference to include consideration of energy security, including issues associated with nuclear energy.

Concerns about energy security and about opposition to nuclear energy based on policy considerations which are not supported by current scientific and engineering knowledge have featured heavily in recent ATSE meetings and publications.

Energy security is a real issue for Australia.

Energy security for Australia requires a major increase in base load electric power generation capacity to meet the expected growth in demand. This growth is independent of climate change and will still occur even with a much greater focus made on energy efficiency and conservation measures. Rationing and blackouts are inevitable in future once economic growth picks up. Governments must establish the necessary long term, stable policy settings to ensure large scale investments are made in new generating capacity. The challenge is considerable as Australia now has a competitive electricity market with the generators mostly driven by commercial considerations rather than government directive.

There is an investment drought in respect to new base load plant. This is quite understandable while ownership issues of generating assets remain unresolved (particularly in NSW) and major uncertainties exist in regard to the form, timing and costs of any emissions trading scheme. There are even reports that in Victoria an operator has elected to defer major maintenance expenditure due to the uncertainties.

The provision of base load power is limited to a portfolio of a few technologies, all with problems. Carbon pricing uncertainty makes new coal, oil or gas capacity problematic; the technology is not ready for either CCS (carbon capture and sequestration) or geothermal, adequate resource is not available for hydro expansion and government policy prohibits consideration of nuclear. Intermittent renewables provide no short term solution to base load power security because of their intrinsic variability. The consensus within the Academy is that with current technology it would be unwise to rely on any more than 20% of requirements being derived from wind and solar sources. In the longer term, storage solutions may help overcome some of the variability of intermittent renewables and allow this figure to be raised marginally.

A more detailed evaluation of technologies is contained in the attached paper prepared by Mr Martin Thomas, a Fellow of ATSE and Chair of the ATSE Energy Forum.

Nuclear power must be considered as an option for Australia

The report of the Uranium Mining, Processing and Nuclear Energy Review (UMPNER) was a comprehensive evaluation of the worldwide state of the nuclear industry. It concluded that, with suitable safeguards and regulation, there was no reason that nuclear power should be banned in Australia. Since that Report there has been an increasing number of nuclear power plants being planned around the world and broad acceptance that they will be required to meet future base load generation needs.

Supporting this conclusion was a survey of ATSE Fellows, the leading applied scientists and engineers in Australia, which indicated 85% believed that nuclear energy could be considered as a safe option for electricity generation in Australia.

ATSE is not aware of any soundly based criticism of the findings of the UMPNER report and believes current government policy is not based on any known technology issues. Clearly there are significant (albeit diminishing) negative community attitudes towards nuclear energy which will need to be addressed. Under the auspices of the National Academies Forum (an initiative of the four Learned Academies in Australia), ATSE is participating in an ARC funded study aimed at better understanding what influences the formation of attitudes to nuclear power. A report on this study should be available by the end of this year.

Should the Australian Government believe that there are any remaining technical issues that need to be resolved before a change in policy can be made, and that these were not adequately addressed in the UMPNER report, ATSE strongly recommends that steps be taken immediately to commission high level studies to resolve them. If the remaining objection relates to the cost of nuclear power this should be left as a matter for the market to resolve rather than an excuse for maintaining the current ban.

Further observations on the question of nuclear power generation are contained in the attached paper.

The Australian Academy of Technological Sciences and Engineering
July 2009

Energy Security – Taken for granted?

“Power Generation Options”

Martin Thomas AM FTSE HonFIEAust*[*]

Synopsis

For a variety of reasons, not least the call for cleaner technologies, Australians need to evaluate the options from which to select the generation portfolio for 2050. A crucial part of that choice is recognition of the vital importance of the security of high quality electricity supplies to modern society, not only by 2050 but every year until then.

Many developing countries tolerate, because they have to, daily acceptance of outages, black-outs, brown outs and poor electricity ‘quality’. Less developed countries may not even offer this level of service; a secure supply of energy may be no more than a pile of firewood or heap of dung. Developed economies have no such strictures. Australians regard good quality reliable electricity of constant voltage and frequency as a given. Upon such certainties we build our families and our businesses.

But do we take this certainty for granted? Yes we do – and so we should in the Lucky Country, blessed with a superabundance of alternative energy sources. Can we be assured that certainty will continue untroubled? Well, perhaps…. but there are worrying signs, that the rocks upon which our certainty could founder are nearer the surface than they have been for some time.

The idea that electricity could simply ‘run out’ is fanciful. Governments would never, could never, let this happen. But do our governments see or understand the early warning signs? Do they predict or provide for the unexpected? Not really, as history has shown. More likely is the slow erosion of reserve plant margins, exacerbated by the inexorable growth of demand, the aging of plant and the lack of investment in new, all of which lead to the day when reserves are so dangerously low that the only possible response is to shed load; in other words to deprive customers of energy security they take for granted.

This paper does not address the challenges to investment in new generation assets and load management technologies. It simply presents the portfolio of

---

[*] Martin Thomas is Chair, Dulhunty Power Ltd; Consultant, Tyree Holdings Pty Ltd; ZBB Technologies Inc; Dir, EnviroMission Pty Ltd Formerly Principal, Sinclair Knight Merz Pty Ltd; MD, Australian CRC for Renewable Energy; Pres, The Inst of Eng, Aust; Pres, Aust Inst of Energy; Chair NSW Electricity Council; Member of the Uranium Mining Processing and Nuclear Energy Review

generation options available to investors with a brief summary of the attributes, capital and operating costs and appropriate market space. It takes a modestly speculative view of future trends in Australia's generation portfolio.

Australia's power generation options

Australia, with its abundant energy resources and innovative technologists and engineers, is fortunate to have a singular range of generation options from which investors, public and private, can select to meet their criteria. These include profitable investment, energy security, sustainability, first mover advantage or a judicious combination of these. Energy security is a fundamental commercial and political criterion.

The broad technology domains addressed, and the extent to which they may or may not meet a whole range of more detailed criteria, are discussed under headings which reflect their primary energy input. These are:

- Coal
- Oil
- Gas
- Nuclear
- Geothermal
- Hydro
- Biomass
- Solar
- Wind
- Waves and tides

The list is long; reflecting Australia's abundance of options but, as power engineers know, it offers 'horses for courses'. Each option has its own defining characteristics and its own economic domain. Energy storage is included as it can deliver electricity economically in some circumstances and is an enabling technology for others.

Before discussing the options in any detail it is worth briefly examining the attributes that distinguish the technologies and the parameters that compare them, as fairly as possible, on a 'like with like' basis. The words 'as fairly as possible' are used to reflect the author's experience. Such judgements are to a degree subjective and this paper is no exception, although every effort has been made to be objective and to rely on sound authority. But arguably there is no 'defining truth' or set of values upon which all can be agreed. To some investors project economics and investment profitability are paramount; others will put more weight on sustainability and externalities which lie beyond the envelope of market economics. Some can access the vast resources of global markets; others rely on nature's bounty.

All technologies depend on the load they are required to serve; some are well suited to big grid connected industrial and commercial demands where large scale low cost base load generation is essential to compete in world markets;

others are more suited to smaller distributed loads, sometimes off grid, where relative simplicity and modest cost are the drivers. Generally all interconnected electricity supply systems worldwide comprise a portfolio of technologies which, collectively, can and will deliver all of the attributes sought by the market.

Technology attributes

Introduction and context

This paper is written in the context of Australian power generation in late 2008. Concerns of climate change arising from energy conversion emissions, whether proven or not, are powerful drivers of community debate and political response.

Such concerns, taken with global economic issues, put at risk willingness to invest not only in low emission technologies but also in new capacity to meet load growth and plant retirement. Without substantial new investment energy security is threatened.

Before commenting on the options it is first useful to consider the attributes of the 2050 generation portfolio candidate technologies.

Capital cost

The paper expresses capital costs in $A/kW, regardless of output, using reasonably current figures based on sound authority and including generating plant and associated infrastructure up to the outgoing terminals. Transmission and distribution to customers is excluded, although such costs can be substantial.

Operating cost

Operating costs are expressed in $A/MWh and depend on many factors; primarily the energy source plus normal operation and maintenance.

Sent out cost

Sent out cost at the outgoing terminals is likewise expressed in $A/MWh. This includes for the lifetime cost of capital, risk management and profit, plus operating costs. Life cycle analysis (LCA) is typically used to ensure that all relevant costs from concept to decommissioning and site rehabilitation are fully accounted for.

Externality costs

Sometimes regarded as the ‘elephant in the room’, externality costs are those not currently brought into conventional cost accounting and investment analysis, but in future will be crucial to investment decisions. Externalities relevant to electricity generation include human safety, noise, water and airborne emissions, especially carbon dioxide, believed by many to be at the core of presumed climate change phenomena, and many others. The ATSE

Report “The Externalities of Electricity Generation in Australia” is a recent relevant authority.

Capacity factor

In comparing generation technologies it is important to distinguish between ***energy*** and ***power***. Power is the rate of production of energy. If, like some renewables, rated capacity can be provided for (say) only five hours per day the capacity factor is just over 20%. The ratio of generating capacity to energy actually produced, generally calculated over a full year, is known as the ***capacity factor*.**

Thus five times the power capacity must be installed for a generator of 20% capacity factor (typical for some renewables) as compared with a hypothetical generator of 100% capacity factor, although in practical terms no generators have annual capacity factors of 100%. Routine maintenance and occasional breakdowns, even in the best run plants, mean there are times of reduced or zero generation. Allowance is also needed for power to run the plant itself, called ***parasitic power****.* The ratio of the energy actually dispatched for sale to the nameplate rating of the generator is the ***sent out capacity factor.*** This is the context in which the term capacity factor is used.

The best base load plant, typically modern coal and nuclear, achieves capacity factors in the mid to high 90% range. Otherwise intermittent generators, for example many renewable technologies, lie typically in the range of 15% (for southern latitudes solar power) to 35% (for southern latitudes wind power). Although a renewable generator installation can use storage technologies to follow the load profile (demand), capacity factor remains unchanged. Thus for comparable base load performance considerably more installed name plate capacity is needed with low capacity factor plant.

Between generator delivery and customer end use is a lengthy transmission pathway along which energy losses can be considerable, reducing effective capacity factor. HV transmission losses are typically 5-8% of energy transmitted; LV distribution system losses are generally higher while losses at the point of use can be vast (leading to the fundamental imperative of improving dramatically the efficiency of end use technologies – but that is another story!). Nevertheless it is worth observing that distribution losses are minimal for localised (generally small scale) generation sources such as distributed cogeneration, rooftop solar PV units and the like.

Engineering, procurement and construction

Engineering, procurement and construction (EPC) costs are generally included in plant installed capital costs. Considerable specialist expertise is involved and costs can lie in the region of 5-15% of the final capital cost of the plant.

Siting

Siting costs and related issues, for example social and environmental impacts, are location and technology specific but need to be included in the real cost of power. Site related costs can range from solar panel roof top fastenings, exposed ridges for wind farms, estuaries or rivers for the cooling of thermal plant, high valleys for hydro schemes, coal mines and conveyors for coal plant - and so on. Each plant is near unique; each makes quite specific demands for supporting infrastructure.

Coal technologies

Technology context

Australia's coal reserves are vast; easily won from thick consistent seams of exceptional quality. It is not surprising then that coal remains by far the most important generation fuel source, as well as being one of Australia's most rewarding exports. Base load electricity costs from Australian steaming coal are amongst the worlds lowest while Australian coal mining and power generation industries are amongst the most efficient and sophisticated. Now coal is being challenged by growing GHG emission concerns; however the industry has replied vigorously with the 'clean coal' revolution and a number of emerging technologies.

Technology and primary energy source

Conventional black coal electricity generation is a mature technology. Thermal efficiencies typically range from 29% to 36%[†]. Efficiencies for brown coal, predominantly in Victoria's La Trobe valley, are lower due to its high moisture content which absorbs much available heat energy. Efficiencies can be increased by coal drying with various technologies under development.

However, these technology developments will be insufficient to meet emissions targets unless flue gas CO_2 is captured and stored underground – Carbon Capture and Storage (CCS). Relatively low concentration CO_2 is captured, compressed, transported by pipeline and injected into suitable underground storages using petroleum reservoir engineering technologies.

To increase CO_2 flue gas concentration to assist in capture, coal may be burnt or gasified using oxygen. Two possible technological pathways follow:

- coal-oxygen burners using recycled CO_2 and no nitrogen, and
- coal-oxygen gasification to produce carbon monoxide (CO) and hydrogen (H_2) to power an Integrated Gasification Combined Cycle (IGCC) plant.

Compared with retrofitting the facilities to remove CO_2 are reduced. However both technologies need costly air separation plants to produce oxygen.

Carbon capture and sequestration (CCS)

Captured CO_2 is ideally stored as a liquid in underground reservoirs. CO_2 is readily liquefied by supercritical compression rather than solidified at atmospheric pressure to so called "dry ice". Liquid storage requires deep

---

underlying porous rocks covered by an impermeable layer to prevent leakage, for example spent petroleum reservoirs. A rigorous demonstration project is currently being conducted by CO2CRC in the Victorian Otway Ranges.

Internationally CO_2 re-injection is used to enhance reservoir oil recovery. Large facilities re-inject about 1Mt/a, although this is only around one sixth the output of a 1,000MW power station. Moreover CCS - including capture, compression, pipelining and storage - needs some 25-30% more energy to drive it, with CO_2 rising to nearly 9Mt/a. Investment, including CO_2 transport over very long distances, is around \$3,500/kW compared with around \$1,500/kW for conventional plant.

CCS technology is complex but feasible. RD&D is required in the newer oxygen enhanced and ultra high pressure technologies. CO_2 capture employs conventional chemical engineering while supercritical compression, pipeline transport and injection are normal petroleum technologies, albeit on a very large scale.

Ongoing CCS RD&D is vital given the vast inventory of power stations worldwide. However the concept must first be fully proven, the purpose of the Otway trials, including monitoring against CO_2 escape. Locations must be characterised geologically; the storage rock for permeability and the cap rock for impermeability and freedom from escape fractures. Locations differ; each will require study using petroleum reservoir engineering skills. It has been estimated that \$1.5 to \$2.5B will be required to demonstrate fully CCS commerciality.

Coal technologies - the bad news

- Coal mining can sequester huge land areas of often good arable country
- Substantial carbon and other emissions (viz particulates, NOx and SOx)
- CCS looks promising - efficiency penalty is costly, yet to be fully proven
- Significant ash disposal and retention problems
- Significant water demand for cooling, although can employ dry cooling
- Inevitably heavy carbon footprint

Coal technologies - the good news

- Coal resources, black and brown, are vast, high quality and easily won
- Relevant technologies (mining, materials handling, preparation, combustion, gas cleanup and ash disposal) are well proven Australian skills
- Well suited to base load generation; capacity factors typically >90%
- Generation technology well proven and exportable
- Huge RD&D program promises further gains (IGCC, Oxy firing, etc)
- Australia has strong and exportable engineering capability

Oil and gas technologies

Technology context

Oil and natural gas bound the spectrum from heavy liquid to gaseous hydrocarbon fuels; a range including not only diesel oil and natural gas but also liquids derived from coal (CTL) as well as coal gases, increasingly coal seam methane (CSM).

Conversion technologies are twofold. For heavier liquids, and if necessary gas, the technology of choice is the medium speed diesel engine, commonplace throughout mining undertakings and Australia's small towns and cities, prior to the advent of the interconnected HV grid which made them uneconomic. Medium speed engines of 500-750 rpm have thermal efficiencies of 37-40% or more while the plant is relatively cheap at $600-750/kWe. Outputs range from 600kWe to 5MWe or more. Compared to coal, operating and maintenance costs are relatively high, as are fuel costs.

Open cycle gas turbines, essentially industrialised aero-derivatives, are widely used for modest generation capacities, typically 10-50MWe although larger units are made. They are used where fast installation and small footprints are important to meet load increments and defer major central facilities. They are valuable for industry where the high temperature exhaust waste heat can be used. They also follow varying loads with considerable flexibility. However efficiency is modest if waste heat is not used, especially in hot ambient conditions, while gas is becoming increasingly costly. Significantly improved efficiencies are achieved if waste heat generates steam to drive a steam turbine; a configuration known as combined cycle.

Oil and gas technologies – the bad news

- High fuel costs (both diesel oil and natural gas) - and rising
- High maintenance costs
- Noisy, smelly and polluting

Oil and gas technologies – the good news

- Diesel and gas turbine plant is well proven with numerous competitive suppliers and good service back up
- Diesel (medium speed) specific costs ($600-750/kW)
- Open cycle gas turbine costs ($900-1200 $/kW)
- Short construction times
- Carbon footprint much less than coal
- Readily follow variable loads

Nuclear technologies

Technology context

Nuclear power generation has served the international community with remarkable safety for over 50 years. Today nuclear forms part of the generation portfolio of some 30 countries (though not Australia) with over 439 civilian power reactors in service worldwide providing over 15% of the world's electricity. However Australia has nearly 40% of the world's easily won low cost uranium resources and is a major exporter of uranium 'yellowcake' to fuel the world's fast growing reactor fleet.

Reasons for the lack of nuclear take up in Australia are economic and political. Economically Australia has an abundance of low cost coal close to load centres against which nuclear electricity cannot yet compete; its sent out cost being some 20-50% higher. Politically neither Commonwealth nor State Government policies yet permit nuclear generation, while community attitudes remain uncertain, although observably changing. Whether and when the policies will change is a matter for community debate and better understanding; however nuclear power generation, with its minimal carbon footprint, is likely to prove economically and politically more attractive as carbon emission reduction pressures grow.

Technology and capacity factors

As with most technologies nuclear power has developed over a series of technological 'generations'. Generation I, almost all out of service, included the prototype Magnox reactors of Britain, commissioned in the '50s, the last of which will close in 2010.

Generation II from the mid '60's, comprised a range of commercial reactors of varying designs (LWR, PWR, BWR, CANDU, VVER and RBMK). Many remain in service with notable exceptions; the Soviet RBMK reactors installed at Chernobyl and elsewhere in the USSR have all been substantially modified or removed from service.

Generation III, from the mid '90s, ushered in new advanced, safer and more reliable light water reactors (LWRs) comprising the ABWR, System 80+, AP1000 and EPR designs, currently being installed or on order throughout the world. designs, with yet better fuel utilisation and improved safety features, are entering service from 2010 onwards. Should Australia embrace nuclear power Generation III+ is likely to be the technology of choice. Capacity factors over 90% can confidently be expected with plant lives of 40-60 years. Safety standards will be very high.

Generation IV, under development with six candidate technologies, is unlikely to be in service before 2030. Five designs are 'fast neutron' types which extract some 50-60 times more energy from uranium by using not only U_{235} but also the more plentiful U_{238} unused by earlier generations. Australia is currently considering its possible commitment to their development through the Generation IV International Forum.

Primary energy source and spent fuel disposal

The nuclear fuel cycle comprises the following steps: mining and milling (producing uranium oxide concentrate U_3O_8 known as 'yellowcake'); conversion to gaseous uranium hexafluoride; enrichment to lift the concentration of fissile isotope U_{235} in natural uranium from around 0.7% to 3-5% called low-enriched uranium (LEU); fuel fabrication into pellets; loading pellets into fuel rod assemblies; loading 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 deep burial in an engineered deep repository 500 to 200 metres underground.

Australia has numerous geo-stable regions suitable for such a repository which, in any event, would not be needed until around 2050 should nuclear be adopted. Moreover the quantities of high level waste, relative to the waste volumes of some other technologies, are small; amounting to only 2 to 3 cubic metres per annum for a 1000MWe base load nuclear power station if the fuel is reprocessed; about 10 cubic metres if not. Engineering of such a repository lies well within the skills of Australian hard rock mining engineers. It has been proposed that Australia might lease its uranium to approved world users, taking it back after 30 years for permanent encapsulation and burial unless reprocessed. It is postulated that if kept under Australian control the risks of proliferation are minimised.

Capital costs

Nuclear economics hinge on the cost of capital, the balance between and ownership of equity and debt and the managing of financial risk. Fuel is a small proportion of sent out power costs which, apart from financing and regulatory costs, would include, through a small power levy, all waste disposal and decommissioning costs.

Many cost data sources exist, not least the 2006 UMPNER report which showed on the basis of an independent report from the Electric Power Research Institute (EPRI) that the levelised (sent out) cost of electricity (LCOE) from nuclear power lay from $40-65/MWh (or 4.0-6.5c/kWh) as compared with pulverised coal power from $28-38/MWh (or 2.8-3.8c/kWh), figures which make no provision for carbon pricing or the costs of carbon capture and sequestration. For nuclear power these are ‘settled down’ costs with established technology in country. Inevitably ‘first of a kind’ (FOAK) costs are higher; Australia will be no exception. However, as with any new technology having desirable attributes (in this case very low emissions), it is likely that some form of early support will be provided, as with the introduction of all other low emission technologies to Australia and indeed most adoptive legislations.

Recent contract prices lie from US$2,500-3,000/kW. Mid 2008 vendor EPC quotes are around $US3,000/kW in the competitive worldwide market.

Operating costs

Fuel costs are variable, especially spot market, although most operators lock in long term contracts. Typical costs are between US$5.0-6.5/MWh. With new mines opening worldwide, contract prices are likely to stabilise. Fuel is a small portion of sent out cost; thus sensitivity to its price is low. Moreover modern designs are increasingly fuel efficient.

Plant decommissioning costs are typically 9-15% of capital, but lie so far in the future that a modest levy of around US$1-2/MWh (0.01-0.02c/kWh) on electricity sold would provide adequate funds. Likewise spent fuel disposal costs, typically around US$1.0/MWh, can be similarly dealt with. The nuclear industry is one of very few offering this holistic approach to whole of life internal and external costs.

Summary

The 2006 UMPNER report showed that the earliest nuclear electricity could feed the Australian grid would be 10 years from commitment, with 15 years more probable. A single national regulator supported by a skilled organisation is essential, likewise trained nuclear power industry scientists, engineers and technologists; human resources in increasingly short supply in the current ‘nuclear renaissance’.

Nuclear technologies - the bad news

- Technology still costly ($3,000-6,000/kWe)
- Australian regulatory environment inadequate
- Shortage of suitably qualified Australian engineers and scientists
- Significant water demand for cooling (although can employ dry cooling)
- Australian public concerns remain on:
    - *Spent fuel disposal technologies,*
    - *Potential for weapons proliferation, and*
    - *NIMBY siting issues.*

Nuclear technologies - the good news

- Australia has vast uranium resources (~40% world’s low cost supplies)
- Relevant technologies (mining, enrichment, reactor technology, spent fuel management and permanent disposal) all well proven
- Well suited to base load generation - capacity factors typically >90%
- Generation technology proven – similar to conventional steam plant
- Generation III and III+ reactors – improved and very safe
- Generation IV reactors inherently safe with far higher energy recovery
- Huge RD&D program promises further gains
- Australia has strong engineering capability

Geothermal technologies

Technology context

Harnessing hot water and steam for energy from shallow hydrothermal areas associated with volcanic activity has been practiced for centuries; in effect the active geothermal region being an underground boiler. Geothermal energy is not new; the Philippines for example, generates around 25% of its electricity from this source.

The deep technology known as hot fractured rock (HFR) is particularly attractive for Australia. The Cooper Basin has some of the world’s hottest dry rocks at 200-270^{o}C some 3-5km below the surface; the hottest spot on earth outside volcanic zones. The granites have natural radiogenic minerals producing their own heat, trapped by overlying insulating rock; in effect a natural nuclear reactor. Granites are effective heat sources but must be made permeable through fracturing, a complex technology.

To recover this heat an artificial hydrothermal field is established by drilling down into the hot rock, pumping very high pressure water down the borehole, forcing it through hydraulically fractured rock (a technique pioneered by the oil industry) and returning it as superheated water up a second borehole to a surface heat exchanger before recirculation. Steam generated drives a turbo-alternator. Demonstration facilities are being developed by companies in Australia and France.

HFR technology has significant advantages; the heat resource is immense and the environmental impact very low, producing no greenhouse gases and being classified as renewable. Recoverable heat under the USA is estimated as equivalent to 2,000 years of energy consumption at current rates. Australia's potential is comparable.

Capacity factor

HFR is the only known renewable energy source with capacity factors approaching 100%, a candidate for coal plant replacements, should the economics so warrant.

Capital costs

This emerging technology could yet be constrained by economics. Deep drilling is costly with many holes needed as fields grow. Known fields lie in remote regions so transmission costs and losses will be high. However HFR could supply large operations such as South Australia's Olympic Dam. In this context it is notable that over 10% of national electricity supply is used to grind Australian minerals.

Estimated costs, excluding transmission, are still high around $6,000/kW but should decrease with experience and plant scale up. Technology demonstration is warranted and Australian know-how and IP could provide significant export benefits.

Geothermal technologies - the bad news

- Hot fractured rock (HFR) technology still to be fully proven
- Technology costs still high
- Overall technology yet to be demonstrated in commercial service
- Geothermal resources generally remote from grid and load centres, requiring new transmission with associated losses

Geothermal technologies - the good news

- Huge resource at 200-270°C (>1,000y) at 3-5km depth
- Drilling technology well proven in oil industry
- Generation technology (conversion of heat to electricity) well proven
- Negligible carbon or other emissions
- Low water demand
- Real estate costs are low

Hydro technologies

Technology context

Hydro is one of the oldest known forms of generation, used to drive machinery long before the evolution of electricity. Although a mature technology no two plants are alike. Factors include catchment size and rainfall, topography, geology and proximity to load and the distribution grid. Dam technologies are sophisticated, especially for larger projects, and power generation is often only one of several purposes which may include pumped storage, flood mitigation and agricultural irrigation.

The primary energy source – water from rain, snow and ice melt – is ‘free’ although competing demands create real value. Water turbines are custom designed for each project to suit water head and flow volume available. Some machines operate in reverse as pumps to store water cheaply at times of conventional power excess, then releasing the water for generation at times of system peak.

Large hydro schemes are characterised by high to very high capital costs, typically $3,000-6,000/kW, although operating costs, aside from capital charges, are very low. Water is virtually free and operation and maintenance far lower than for equivalent highly stressed thermal plant although environmental issues like land ownership, wilderness preservation and flood mitigation are increasingly part of the decision process. Australia, being a dry and not especially mountainous continent, has limited hydro potential; most has been taken up by Hydro Tasmania, the iconic Snowy Mountains Scheme and smaller operators. The remaining potential is very limited.

Hydro technologies - the bad news

- High to very high site specific capital costs ($3,000-6,000/kW)
- Can pose significant environmental challenges
- Dependent on reliable rainfall

Hydro technologies - the good news

- Free primary energy – rain, snow and ice melt
- Very easy load following, useful for meeting system peaks
- Can provide pumped storage for load levelling
- Can co-exist with water storage, irrigation and flood control
- Environmental and recreational benefits can be significant
- Micro-hydro well suited to developing countries and small communities

Biomass technologies

Technology context

Biomass from sugar cane is widely used to generate process power and steam with excess power sold to the grid provided efficient high pressure boilers are used. Generation is seasonal, corresponding to winter-spring harvesting. Most generating plant is small-scale, the largest being a 68MWe unit at Queensland's Pioneer mill.

It is feasible to purpose-grow biomass for sustainable power generation. Biomass growth absorbs CO_2 . Combustion releases CO_2 emitted which is effectively recycled to new biomass, closing the CO_2 cycle to limit net long term emissions. Although described as "carbon neutral" the net carbon balance has yet to be calculated.

Other candidate biomass fuels include mallee trees, grown in SW Australia to help lower the water table to reduce salinity. Research to convert mallee to sustainable charcoal for minerals smelting is in hand. In principle almost any trees can be grown, harvested, dried and chipped to produce combustion biomass. Nevertheless it is expected that biomass combustion will remain a location specific technology in the under 100MWe range. At this scale the estimated capital cost for the fuel firing and steam raising component of biomass power generation is about $2,000-3,000/kW.

Biomass technologies - the bad news
- High site specific capital costs ($2,000-3,000/kW)
- Co-located with sugar or other agricultural product
- Output seasonal; poor load following limits electricity export value
- Plant sizes relatively small and process dependent
- Potential environmental issues.

Hydro technologies - the good news
- Primary energy 'free' from waste products (eg bagasse)
- Electricity export attracts relatively low additional capital cost through co-generation with factory process steam.

Solar technologies

Solar photovoltaics (PV)

PV technologies are many, broadly falling into flat plate and concentrating. Even within these technology categories the variations are many. Solar energy incidence in Australia peaks around 1.0-1.2kW/m². With typical commercial flat plate collector efficiencies of 8-12%, cell peak outputs range between 80-15Wp/m².

Australia has a proud record in PV development with world leading edge RD&D. Australian researchers, notably at UNSW and ANU, have pioneered much higher performing technologies. UNSW 'thin film' cells have exceeded 24% flat plate conversion efficiencies, at the time the world's highest. The ANU's 'SLIVER cell' technology, which dramatically reduces the silicon content of conventional wafer cells, promise efficiencies of 18-20% at much lower cost. Newer so called 'triple junction' cells are expected to have higher efficiencies yet, while the promise of concentrating PV, in which parabaloidal collectors concentrate up to 400 suns onto a single cell in a tracking configuration, promises well for large scale PV generation.

Capacity factor

Solar capacity factor depends on the hours of sunlight at the generator location, with flat plate collectors (eg rooftop) typically only about 15-20%. Tracking collectors, using parabaloidal dishes or troughs, are around 20-25%. Although direct solar technologies only operate for limited sunlight hours their output, especially in summer, can closely match demand peaks arising from refrigerative air conditioning. Electrical storage (ie batteries) or thermal storage for later energy delivery can increase system capacity factor but at significant additional cost. Several candidate storage technologies under development but are not discussed here.

Australian PV capacity factors typically range from 15% in Tasmania, through 20% in Adelaide and up to 25% in Central Australia and the North West, with around five peak sunlight hours. Large capacity plant, requiring significant real estate, will be located remotely with transmission to the grid giving rise to losses. DC transmission could serve very large installations but with higher infrastructure investment. The urban alternative of distributed solar PV ("a solar power station on every roof") is still expensive but increasingly attractive as collector costs fall and systems serve as the primary roofing material. However the potential Australian generating capacity with PV cells on every rooftop at present efficiencies is only around 5% of the national demand. PV generation, while exhibiting significant promise, is unlikely to enjoy a role in central power generation without continued subsidy. However it is an unusually attractive technology for a very wide range of smaller scale niche applications with huge export potential.

Capital cost

Capital costs are still high although intense RD&D combined with rapidly growing competitive markets and volume economics show year on year reductions. Installed costs, including system connection and inverters (to deliver 240V ac current), are $6,000-10,000/kWp, or more, typically serving small installations and private homes, although larger systems, encouraged by attractive grants, are becoming more commonplace. Emerging developments promise far lower system costs with industry targets in the region of $1,000-2,500/kWp. The measure "kWp" means peak kilowatts output; ie a normal incidence new cell output in full sunlight.

Solar photovoltaics (PV) - the bad news

- Technology installed still very costly ($6,000-10,000/kWp)
- Capacity factors low (15-20%) so unsuited to base load (eg industry)
- Power conditioning expensive and complex
- Energy storage expensive, alternatively needs standby (diesel, hydro or mains)
- Materials difficult to dispose of sustainably
- Poor use of real estate (unless household rooftop)

Solar photovoltaics (PV) - the good news

- Free primary energy – the sun
- Technology cost falling with advancing RD&D

- Feed-in tariffs increasingly accepted
- Well suited to distributed and remote generation
- Emerging technologies - thin film, SLIVER, concentrating and tracking PV
- Power conditioning and storage costs falling, lives extending, materials increasingly benign
- Negligible carbon or other emissions
- Zero water demand

Solar thermal (ST) technologies

For ST power (as distinct from solar hot water) the suns rays are focused by tracking reflectors onto a high temperature absorber comprising a heat exchanger to generate steam for power generation. Fluids other than water offer a range of downstream conversion options.

Reflectors range from parabolic troughs or Fresnel lens systems focussed on pipe heat exchangers to tracking flat mirrors focused on an elevated heat exchanger. Temperatures are >1000°C and can drive chemical processes, for example ammonia production and gas reforming. Mirrors can also focus onto PV cells to lift efficiency.

Some 350MW of trough mirror plants have operated commercially in California for over 20 years. 400MW more is either under construction or recently commissioned, primarily in Spain and the USA with a further 1200MW planned. While there are no commercial ST plants in Australia the CSIRO Newcastle Energy Centre large scale demonstration facility is the most advanced. Earlier plants include the ANU Big Dish and White Cliffs in far west NSW. The CSIRO concept comprises a 1MW plant with one ‘power tower’ and a number of solar tracking mirrors with a ‘packing factor’ of 50% to provide concentrating solar power (CSP). Larger power stations would simply comprise a multiple of such 1MW modules.

ST technologies can include integrated energy storage, for example large thermal capacity masses such as carbon blocks or molten inorganic salts such as sodium nitrate. Stored hot molten salts can generate steam for discretionary power delivery, for example evening peaks, to lift effective capacity factor.

ST generators will of necessity be larger centralised systems. An area some 50km square, with current ST technology, could deliver Australia’s total electricity requirements. The same issues identified for centralised solar PV apply, including transmission costs and low capacity factor without storage, hence high capital cost per unit of energy sent out. It is projected that ST costs, using a learning rate of 10% per doubling of capacity, will reduce from around $4,000/kW now to $3,000/kW in the next decade to $2,000/kWh in 25 years time, but this will depend on significant market penetration.

Solar thermal (STG) - the bad news

- Technology still very costly ($6,000-10,000/kWp)

- Capacity factor low (20-25%) - unsuited to base load (ie industry) without energy storage
- Energy storage expensive, alternatively needs standby (diesel, hydro or mains)

Solar thermal (STG) - the good news

- Free primary energy – the sun
- Technology costs falling with advancing RD&D – target ($4,000-2,000/kWp)
- Well suited to large scale generation with storage
- Materials well understood – disposal not complex
- Negligible carbon or other emissions
- Can use low value real estate
- Zero water demand

Wind technologies

Technology context

Wind power is well established and enjoying rapid growth worldwide, for example 27% in the USA in 2006. Denmark's has 3.1 GW installed, some 21% of all its capacity. Germany in 2006 had 20.6GW. Globally, in 2006 wind power supplied 0.9% of total world electricity consumption. In Australia over 800MW of capacity is installed, delivering 2,500GWh at a capacity factor of 35%.

Wind turbine technology is now based on aircraft designs with companies like GE in the USA manufacturing the turbine components. Blades now utilise sophisticated materials and designs. Average USA turbine size reached 1.6MW in 2006, with the largest at 3MW. USA installed costs had stabilised in 2006 in to about $1,500/kW, while efficiencies around 50% are to the theoretical maximum.

Costs depend significantly on wind intensity and duration. Steady strong winds, such as experienced in the 'Roaring Forties' (eg the west coast of Tasmania) provide high capacity factors and good investment returns, while variable winds of low average intensity offer much lower capacity factors. Other good Australian sites are hilltops (eg north Queensland) or coastal headlands (eg southwest WA or southern SA). The viability of offshore sites is balanced between increased costs and better winds.

Environmental issues matter. Visual disharmony, noise and possible bird strikes are cited. Nevertheless wind offers a low risk low pollution sustainable solution, provided suitable sites can be found. However it cannot replace base-load power at a realistic cost due to the vagaries of weather, low capacity factors without storage, transmission losses from remote sites and the lack of low cost storage technologies.

Wind technologies - the bad news

- Technology still costly ($4,000-8,000/kWp)

- Capacity factor limited (15-40%) and generation unrelated to demand pattern
- Windfarms often remote from grid
- Power conditioning expensive and complex
- Energy storage costly, alternatively needs standby (pumped hydro or mains)
- Not suited to base loads (ie industry)
- Regarded by some as noisy and visually intrusive
- Poor use of real estate – prime sites have other values

Wind technologies - the good news

- Free primary energy – wind, especially where > 8m/s
- Technology cost falling with advanced RD&D
- Manufacturers well established with quality production
- Feed-in tariffs increasingly accepted
- Emerging technologies include larger units, improved blades giving lower economic wind harvesting speeds
- Power conditioning and energy storage costs falling, lives extending
- Negligible emissions
- Zero water demand

Other renewable technologies

Wave and tidal power

Wave power devices capture abundant but diffuse wave energy. Technologies include rising and falling buoys and oscillating water columns which displace air at high velocity to drive turbines.

Many systems are developed. Portugal has three wave power machines generating 2.25MW with a further 28 machines forecast to be built for $120M to generate 72.5MW at a cost of $1,700/kW. A 3MW wave farm is to be built in Scotland and a UK “wave hub” has been announced for offshore north Cornwall generating 20MW. The USA is constructing a wave power park in Oregon using 40kW modular buoys. In Australia Oceanlinx has a prototype 450kW unit using Oscillating Water Column (OWC) technology powering an internal variable blade pitch air turbine, with plants up to 5MW planned for the UK, Australia and USA.

Challenges facing wave power include improving the conversion efficiency of intermittent mechanical movement to electricity and building plant that can survive the harsh marine environment. Wave power development needs innovation and demonstration at a variety of locations. However, like many natural renewables, it suffers from poor capacity factor, typically around 20-30%.

Tidal technologies convert tidal flow energy into electricity using large scale water turbines. Tidal barrages with differing water heads (high tide to low tide) generate from the head difference, large in temperate climes but negligible in the equatorial oceans. Tidal power sites are often remote from load centres, for example the Secure Bay – Walcott Inlet site in Western Australia which, although a site of very high potential, cannot find local economic application.

In Australia Tidal Energy Pty Ltd has successfully trialled a high efficiency shrouded turbine (efficiency > 60%) and plan a 3.5MW facility in north west Australia. Small (<1MW) propeller turbines are being demonstrated in the UK and Norway. A 1.2MW unit has been connected to the Northern Ireland grid since 2008. Other MW scale farms are foreshadowed internationally.

A 240MW barrage tidal power plant has been in operation in France since 2006, producing 600GWh at 28% capacity factor. Other such facilities operate at Canada’s Bay of Fundy (18MW) and Kislaya Guba in Russia (0.5MW). Tidal power scheme costs are site specific but are believed to range from $1,500-2,000/kWp.

Like wind power, wave and tidal power schemes raise environmental concerns including visual pollution of coastal seascapes and possible harm to marine creatures. Tidal power changes to estuarine ecosystems, turbidity, salinity and sediment movement may also limit their applicability.

Overall Conclusion

The portfolio options for 2050 are many. No one technology will dominate, although it is clear that considerable coal capacity, installed in the early part of this century, will almost certainly remain in operation, so great is demand and so limited still the investment or regulatory constraints. However pressures towards lower emission technologies are inexorable. By 2050 it is confidently forecast that the Australian generation portfolio, although still embodying coal, will include substantial gas, geothermal, nuclear and renewables. The proportions of those technologies will be fiercely debated; market economics will in the long run provide the answers.