ELECTRICITY GENERATION ALTERNATIVES FOR AUSTRALIA

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by

Jim Brough and Jim Fredsall

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1. INTRODUCTION

We were reminded by the unfortunate accident at the Longford gas plant in Victoria some two years ago that caused two plant operator deaths, a two-week interruption in natural gas supply across the whole state (losing some $A100M in industrial production per day and disruptions to some one million households), that reliable supplies of energy are essential to operation of the country. Other lessons of the Victorian tragedy were that that the supply of any form of energy is not only a dangerous endeavour but that in this instance there was too great a reliance placed on a source of energy that could be stopped by a single event (i.e. an explosion).

This latter lesson also applies to electricity supplies (recent examples being the power outages in WA and SA caused by strike and lack of adequate supply). In Australia about 88% of electrical energy comes from coal fired power plants. Not only is this supply sensitive to a single event such as a national strike, but as was seen at the Kyoto Conference and its aftermath, another emerging factor of vulnerability is the international concern over the use of greenhouse gas emitting technologies such as coal, oil and gas fired electricity.

At that Conference Australia tried to stave off any appreciable near term restriction on the use of coal for electricity generation, but the stage has now been set for firm worldwide restrictions to be applied to CO2 generating technologies – especially in the high per capita use countries such as Australia. If this were to happen, not only would our exports of natural gas and coal be reduced but also our domestic use of these fuels would have to be limited. What options do we have then to ensure that sufficient electric power supplies are available to continue the economic development of the country? A discussion of the options for electricity production for both central station and small-scale facilities is the purpose of this paper.

2. CURRENT ELECTRICITY SUPPLY PROFILE AND TRENDS

Australia is placed in a relatively unique position in the world with regard to electricity production and energy resources. In fact, ignoring other constraints, Australia could generate electricity at the current level for the next 1000 years before its black coal resources were exhausted (assuming exports were discontinued, see table 2.0-2 below). Electricity production by source and state are shown in Table 2.0-1 (attached). As can be seen, generation by coal predominates with 88%, hydro at 10% and gas turbines most of the remainder. The 88% from coal comes 55% from black coal, mainly in Queensland and NSW, and 23% from brown coal mainly in Victoria. The major electricity producing states are New South Wales 34%, Victoria 23%, and Queensland 20%.

Table 2.0-2: AUSTRALIA'S ENERGY RESOURCES & CONSUMPTION
Petajoules (ref. 1)

	Resources	Use/yr*
Black Coal	1,323,000	1,374
Brown Coal	398,000	630
Oil	15,650	1,657
LPG	4,611	7
U (LWR)	444,000	0

* 1997-1998 (domestic only)

It is no coincidence that these latter three states are also the most populous since experience shows that total electricity demand is broadly proportional to population. Thus it can be anticipated that the demand for electricity will increase as the future brings increases in the Australian population. Nobody seems to know how the population will grow because for one thing there is no consensus on immigration policy, but it is reasonable to assume that growth will continue. In addition, the current the annual per capita consumption of electricity is about 9000kWhe – almost double what it was 25 years ago (ref 2). Factors that would lead to even higher per capita demand are greater applications of electricity in industry (e.g. aluminium, magnesium refining) and in the home (e.g. electric cars), whereas factors that would lead to less percapita demand in both domains are energy conservation, direct use of fuels and restrictions on electricity use - economic or legislated.

Over the past 25 years total generation has increased by a factor of 2.7 (a compounded annual increase of 4%) while the only important renewable source, hydro, increased just 33% - mainly because of a lack of suitable (technically and politically) new large scale sites. New on the scene is wind power, but installations totaled just 2.2 MWe in 1995 (see Table 2.0-1, attached).

On current trends it can be expected that electricity demand will continue to increase along with increases in per capita consumption and population. Further, most of this, as at present, will be supplied from central power stations, and without any other constraints, coal will continue to provide the major source of energy.

3. WORLD AND LOCAL DEVELOPMENTS

In 1994 the world electricity generation was 12,852TWhe, an increase of some 36% from the previous 10 years (ref 1) which is equivalent to a compounded annual increase of 3.1% and an increase in annual per capita consumption from approximately 1960kWhe to 2200kWhe (i.e. a compounded annual increase of 1.1%).

According to ref. 3 "Electricity is expected to remain the fastest growing form of end-use energy worldwide through 2010. Indeed, about 42 percent of the increase in total worldwide fuel consumption projected for the 1992-2010 period is expected to be for electricity generation." World usage is expected to continue to increase at 2% per annum to 2010 with the highest growth in the non-OECD countries, which have 75% of World population but roughly half of this presently does not have access to electricity. Average annual per capita consumption in the developing countries is 660 kWhe compared with 10,500 kWhe in the US and about 6,000 kWhe in the OECD Europe and Japan (it is worth noting here that if the non-OECD countries were to rise to the OECD average percapita primary energy consumption level, World energy demand would increase by a factor of about five).

As for World population trends ref. 3 estimates that by 2010 the total will exceed 7 billion people. Thus the growth between 1990 and 2010 will be nearly twice as great as the growth between 1970 and 1990.

The consumption of primary energy for electricity generation given by ref. 3 is:

Table 3.0-1: WORLD SOURCES OF PRIMARY ENERGY
BY REGION AND FUEL
(Quadrillion BTU)

	1990	1992	2000	2010
OECD	71.7	73.9	85.2	97.3
Oil	5.7	5.7	5.9	6.2
Natural Gas	6.0	6.4	10.1	15.0
Coal	28.0	28.3	30.6	33.4
Nuclear	16.2	17.4	18.8	18.7
Renewables	15.7	16.1	19.8	24.0
Non-OECD	52.6	51.0	64.4	79.7
Oil	6.4	6.2	8.6	10.6
Natural Gas	10.4	10.3	12.3	15.1
Coal	21.2	19.7	25.7	31.3
Nuclear	4.1	4.0	5.0	5.6
Renewables	10.5	10.7	12.8	17.1
World	124.2	124.9	149.7	177.0
Oil	12.1	11.9	14.5	16.8
Natural Gas	16.4	16.8	22.5	30.2
Coal	49.2	48.0	56.3	64.6
Nuclear	20.3	21.4	23.7	24.4
Renewables	26.2	26.8	32.6	41.1

As can be seen coal contributes the largest share of energy to the world's electricity generation and this is expected to continue to 2010. Oil use is expected to increase especially in the non-OECD countries whereas in the OECD the use of natural gas should increase instead. Nuclear is projected to remain relatively static reflecting the long running lack of orders. Renewables, on the other hand will increase, especially in the non-OECD countries.

Estimates in 1991 of worldwide energy reserves are given by reference 4. It states that the ratio of proven reserves to current production rates was: coal 239 years, natural gas 59 years, oil 43 years and uranium 100 years (the latter without breeding). Reference 3 gives similar totals with 200 years for coal, 100 years for oil, and 65 years for natural gas. (It must be noted that such comparisons suffer from the nonuniformity of assessing energy reserves between types and regions, and thus are gross estimates only.)

3.1 Coal

Australia's reserves of coal amount to 8.7% of the World total (ref. 3). Most of Australia's black coal reserves lie in NSW and Queensland. Victoria has extensive brown coal reserves (lignite) and its electricity generation comes almost solely from this source. In relation to CO_2 emissions however, it suffers from a 26 to 47% higher generation rate than black coal because of the energy that is devoted to drying the brown coal to make it suitable as a power station fuel.

A paper by Topham and Hennessy (ref.5) provides interesting comments on Australia's current dependence on coal mining and local concerns over possible restrictions that might accrue to alleviate environmental effects

> "Australia accounts for only 5% of world hard coal production ... However Australia accounts for 34% of World trade in coal, and coal is 12% of Australia's commodity exports ... Coal comprises 42% of primary energy demand compared with only 21% in the OECD as a whole".
>
> "48% of Australia's 1993 exports were to Japan and 35% to non-Annex I countries such as Korea and Taiwan." 70% of Australia's black coal is exported [i.e. leaving all brown coal and 30% of black coal to be used domestically].
>
> Greenhouse gas emissions from the use of coal in Australia were 24% from coal (compared with 19% of CO_2 in NZ and 20% worldwide). Coal mining accounts for about 1% of Australia's CO_2 emissions and 12% of its methane emissions.

> “If global warming is proven, then greenhouse gas emissions in 2250 would need to be half of today’s level for stabilisation at about twice the current concentration. This would require substantial technological change, most likely to nuclear power, ‘solar energy’ and other renewables. History teaches us that the long-term future is largely unpredictable, but such a scenario would almost certainly involve much lower coal use.”

> “The bottom line is that the future of coal is unpredictable as it depends on uncertain science and technology and unpredictable policy responses. However, if wise policies are adopted, coal will play a vital role in the transition to an energy future in which there is less dependence on fossil fuels.”

Another view from the HEC Tasmania (ref.6) “Coal is the world’s most important fuel source for the generation of electricity. It is likely to continue in this role despite environmental concerns over emissions of carbon dioxide and other chemicals. Carbon dioxide has been associated with the Greenhouse Effect and global warming. Coal-fired power stations in the Northern Hemisphere have also been blamed for pollution of inland lakes and waterways. A lot of progress has been made in recent years in using coal more efficiently to make electricity and in reducing the environmental problems associated with its use."

Problems with coal, aside from just the greenhouse gas emissions include acid rain gases and ash disposal. Hans Blix, former head of the IAEA pointed out (ref. 7), “a 1000 MWe coal plant with optimal pollution abatement equipment will annually emit into the atmosphere 900 tonnes of SO_2, 4500 tonnes of NO_x, 1300 tonnes of particulates and addition to 6.5 million tonnes of CO_2. Depending on the quality of the coal up to 1 million tonnes of ashes containing hundreds of tonnes of toxic heavy metals (arsenic, cadmium, lead, mercury) will have to be disposed of.” Another view of the magnitude of the solid waste problem in the UK is illustrated by the output of gypsum generated from the same sized plant fitted with their required SO_2 removal system: “one station can produce enough gypsum to satisfy the UK building industries' needs on its own" (ref. 8). But lucky (or unlucky) for Australia such removal equipment is not used here – partly because of the low sulfur content of Australian coal and partly because there is not such a concentration of generating stations here.

The array of trace elements in Australian coals is discussed in references 9 and 10 and is summarised in the attached table 3.1-1. The concentration and mobilisation of these elements in the fly ash – including both the 99% of the ash collected and dumped and rest that escapes airborne – is a serious problem in safe operation of coal fired generating plants. It should also be noted that the elements uranium and thorium are both also contained in both brown and black Australian coals (as are even greater amounts of the heavy metals). These elements of course, produce decay chains of radioactive daughter products that are mainly alpha emitters - a type of radiation particularly harmful to the lungs. Section 4.3.2 below discusses the radiation safety aspects of these emissions.

Also as a point of interest, it turns out that the concentration of uranium in Australian black coal is sufficiently high so that if it were removed from the coal and burned in breeder reactors it would generate an amount of electricity about equivalent to the coal (ref. 1). Further, if the thorium were also removed and converted in breeders, the nuclear generation would be two to three times that of the coal. Altogether the black and brown coal fired plants in this country release some 100 t of uranium and 240 t of thorium per year (and along with the coal we export goes about 180 t of uranium and 520 t of thorium), but even so this would be an expensive source of nuclear fuel, uncompetitive with present uranium mines. In a similar vein reference 11 estimates that the cumulative releases worldwide for the century ending in 2040 would be 0.8 Mt of uranium and 1.9 Mt of thorium.

3.2 Natural Gas

Australian gas reserves are about 20 trillion ft3 as compared with world gas reserves of about 4800 trillion ft3, or 0.4% (ref. 12). (In relation to oil it says about 1000 billion barrels worldwide with 1.6-1.9 billion barrels in Australia {ie. <0.2%}.)

"Australia also has large reserves of natural gas (ref.13). However, this fuel is less cost effective than coal due to the costs associated with transporting gas the large distances between reserves and major centre of consumption. Some 78 percent of proven and probable gas reserves are situated on Australia's North West Shelf, far from the majority of electricity consumers on the south east coast, and 94 per cent of the country's gas is offshore. Consequently, less than 10 percent of total electricity output is sourced from natural gas, and less than 15 percent of Australia's emissions of carbon dioxide are accounted for by natural gas."

There will be a move to cogeneration plants such as that at Smithfield (162 MWe, NSW). Cogeneration has become popular and there are many small units in hospitals providing heating, cooling and electricity. Cogeneration is indeed a more efficient use of energy. The Australian Cogeneration's 1998 report (ref. 14) gives the current capacity as follows.

TABLE 3.2-1: COGENERATION PLANTS IN AUSTRALIA

Type of Project	MW	MWe
Natural Gas	826.7	126

(Table 3.2 Continued)

Bagasse	295.8	0
Coal	285.2	0
Waste Gas	211.5	87
Liquid fuel	115.5	0
Other Gases	12.5	?

Cogeneration plants of many descriptions benefit the environment by making more efficient use of energy resources to minimise CO2 output during heat or electricity production.

It is the authors' opinion that however laudable the projects may be, the bagasse, coal and liquid should not be classed as cogeneration. Bagasse should be classed as biomass.

Electricity production from coal seam methane is established in NSW at Appin (56 MWe) and Tower (41 MWe) collieries in NSW with the potential for 10 MWe from Westcliff. The very large coal deposits under Sydney have the potential to provide a significant contribution to Sydney's regional supply, but technology may have to be developed to cope with high CO2 concentrations in the gas. Queensland coal seams will almost certainly provide a similar resource. The authors feel that these resources will be highly significant but need proving.

Underground coal gasification is another option currently being examined by the CSIRO (ref. 15). In this process air and steam are injected into a coal seam to feed a controlled combustion situation that produces hydrogen, methane, carbon monoxide and carbon dioxide that are piped to the surface to fuel electric power plants. According to the CSIRO the prospects are bright through the essential elimination of underground mining and the lessening of CO2 emissions during power generation.

In addition, recent research suggests that there are huge reservoirs of frozen methane in marine sediments 500 - 2000m underwater, as the headline puts it "Beneath the ocean bed lies enough frozen fuel to power the planet for centuries", which is fine, but still releases significant amounts of CO2 and inevitably lead to leakage of methane (ref. 16). The article suggested that the methane "burp" from one such deposit 7000 years ago caused a tsunami which engulfed the north of Scotland. Frankly, I'd rather play with nuclear reactors.

Fuel cells are still another contender for producing cleaner electricity by "burning" hydrogen derived by catalytic conversion of a variety of feedstocks such as natural gas, LPG, and other gaseous fossil fuels. Fuel cells come in various sizes with the largest being a few megawatts electric capacity, but in most cases the cost of hydrogen production has been too high for the units to compete economically in all but specialised applications (e.g. space flight). Fuel cells are mentioned as part of a paper promoting an alternative hydrogen economy (ref. 17), but (of course in this case) there the hydrogen was to come by electrolysis using electricity from CANDU nuclear reactors! Still, fuel cells may be significant for reducing greenhouse gas emissions even if used mainly in electric vehicles – where the use of rechargable batteries has proven not entirely satisfactory. Although the technology is proven to be more than twice as thermally efficient as conventional steam-based systems, it is still expensive and we doubt that it is mature enough to satisfy other ordinary small-scale needs let alone provide a major source of electricity for the electricity grid.

3.3 Renewables

Following the major reassessments of the World energy scene that were occasioned by the oil crisis in the early 70s, much hope was held out for renewable sources (e.g. wind, tidal/wave, solar) to supply a major share of the World's energy and even a major share of the electricity. Of course up until the industrial age the World had used renewable sources almost solely, so in one sense this was a return to the past but utilising modern technologies to obtain better utilisations. Appendix 1 discusses a review of renewable energy potentials for Denmark, the USA and Canada as conducted by the Australian Atomic Energy Commission in 1976-77 (ref. 2). As can be seen from the appendix the predictions at that time were quite overly optimistic probably in part due to the lower electricity growth that eventuated and partly because of R&D difficulties.

Nevertheless a review of the current status of renewable energy sources is important in order to evaluate its potential to supplement or supplant more conventional sources of electricity generation.

3.3.1 Hydro

Of the 160,000 GWhe produced in 1995, 9.9% came from hydro. Of this Tasmania accounted for 54.7%, Snowy Mountains for 35.2% (i.e. at a 16% capacity factor – see Table 2.0-1), Victoria 6.6% and Queensland 2.5%.

It is extremely unlikely that there will be any major hydro schemes in the future because of their acknowledged environmental problems. Developments will be small scale and related to the use of existing water supply dams such as Glenbawn 5.5 MWe and Kembla Grange 6.4 MWe (cost $10M) (ref. 18). Also a recent newspaper article (ref. 19) referred to "Two massive dams will produce 7MWe of clean power, a huge saving on harmful greenhouse gas emissions" – well, hardly massive or huge but a step in the right direction, provided the electricity is not too costly.

3.3.2 Wind

An interesting view of the situation in the UK says (ref. 20) in effect that if every wind farm in the world were moved to Britain, their combined output would just about meet the commitment to generate 10 percent of the country's electricity from renewable sources – but only on a windy day.

According to the Sustainable Energy Development Authority, wind energy potential in NSW could be as high as 3300 GWhe/y, as compared with total Australian electricity production in 1996 of 167,543 GWhe. The 1995 output was 6.5 GWhe before installation of Newcastle and Crookwell. The current annual output should be approximately 17 GWhe.

TABLE 3.3-1: AUSTRALIAN WINDPOWER STATIONS

Station	Rating, MWe	Output,GWhe/y
Breamlea Vic]	?	0.100
Esperance WA	2.5	5 (approx)
Crookwell, NSW	4.8	9
Newcastle, NSW	0.6	1.126
Coober Pedy, SA	?	0.551
Huxley Hill, Tas	?	1.58

In addition there will be a number of other very small units that are of minor significance (not to mention the inoperable unit at Malabar which has been an eyesore on the Sydney scene for many years).

Of course windpower has its problems just as does any other source of power. Some complain about it on the grounds of aesthetics, noise, interference with telecommunications and bird movements. In addition are the technical problems of needing wind and attachment to the power grid for when there isn't any. In fact, if a constant load is created to be supplied by a wind generator, then an equivalent increase in the grid capacity must be provided, but this disadvantage is common to any such intermittent source of power even base load power stations.

3.3.3 Solar

The first major solar thermal unit was installed at White Cliffs (NSW) some years ago was proved too expensive to operate and has now been replaced by PV (photovoltaic) cells of 25kWe giving some 70MWhe per year (ref. 21)

Australia's largest solar farm using PV has been built at Singleton (NSW) and is expected to produce 287 MWhe/y on a capacity of 200kWe. South Australia also has a 100 kWe farm with an estimated production of 0.143 GWhe/y (ref. 22). This station is not grid connected and supplies Wilpena Pound tourist resort with approximately 40% of its electricity.

The cumulative installed capacity in Australia is given by the Energy Research and Development Corporation (ERDC) (ref. 23) and is shown in the table below:

TABLE 3.3-2: CUMULATIVE INSTALLED PV CAPACITY (kWe)

Submarket	1990	1991	1992	1993	1994	1995
Off-grid Domestic	760	1140	1560	2030	2600	3270
Off-grid non-Domestic	3840	4760	5740	6865	8080	9380
On-grid Distributed	0	0	0	5	20	30
On-grid Centralised	0	0	0	0	0	20

PVs have been successful to power telephones, navigation aids and for other devices in remote locations where power lines are out of the question. In this situation, their high cost is not a problem.

Just as an example, to make enough electricity to heat the water used annually by the Brough household, solar panels costing $29500 would be needed. Alternatively to install a solar hot water heater to provide the same amount of hot water, cost $2900 (ref. 24).

PVs are being actively marketed in cities and without subsidy the cost per kWhe is about 69¢/kWhe (levelised at 5%/yr and including 5.4¢/kWhe O&M).

The Sustainable Energy Development Authority (SEDA) offers a rebate of $5760 on the above PV unit and the energy supplier gives an additional 5% discount of $1475. SEDA does not offer a rebate on the hot water heaters, some local councils do but not all. It is our opinion that the encouragement of solar hot water heaters makes much more environmental sense than subsidising PVs.

3.3.4 Tidal and Wave

Schemes to use the tides and waves to generate electricity have been investigated for many years but little has been achieved worldwide. Both methods suffer from having to handle a hostile seawater environment over the long term without incurring significant maintenance costs, and in addition both have to extract energy from rather modest changes in water level.

Tidal schemes also suffer from having to accommodate the tidal cycle and can only be sited in the few places worldwide where the tidal range is large enough to be put to practical application. About the only existing practical plant was built in 1966 in Brittany on the river Rance. This has a reservoir of some 20 square kilometers and the 240 MWe generating plant delivers about 700 MWhe per tide (i.e. every 12.5 hrs, which is equivalent to the average output of a 77 MWe thermal plant over this time). Another plant of 8.6 GWe has been proposed for the Severn but at a cost of £10 billion the government decided to leave it to the private sector (ref. 25). And although this barrage plant would have provided some 7% of Britain's electric energy it has also been heavily criticized by the bird lobby (ref. 20).

A proposal has also been put forward for a 48 MWe tidal plant near Derby in Western Australia (ref 26). This is to have eight 6 MWe turbines. Tenders are to be called at the end of January 1999. Apparently there are several other suitable sites along the WA coast for tidal power plants, but it is unlikely that such plants will supply a significant fraction of WA generation over the next 20 years.

Wave power schemes also have the complication that all substantially sized plants proposed have been for shore locations where wave power is much diminished. In short, no plant with a power of more than a few hundred kilowatts has been constructed. Of course other problems with these types of plants is that their existence would not exactly enhance the seashore aesthetics or environment, and if they were to be placed in remote sites away from the power grid they would incur additional capital costs for connection.

3.3.5 Biomass

Biomass has been extensively touted for Australia for heat and electricity production, but apart from bagasse, information is sparse.

Wood is sourced from forestry residues, sawlogs pulpwoods and occasionally forest logging and is used in industrial boilers, dryers, cooking and home heating. This constitutes about 6 MT/y (i.e. 100 PJ/y).

Bagasse is the fibrous residue from sugar production, and is used as fuel to provide process energy in sugar mills in NSW and QLD (according to the ABS, ref. 27). It is burnt and the heat converted into electricity, providing about 70 PJ. The Australian Co-Generation Association's annual report (ref 14) shows that all the bagasse units are for steam and process heat, not electricity generation.

There is an interesting development reported from the UK, which has, three stations fuelled by chicken-litter totalling 64.7 MWe. The editor of the Journal of Power and Energy (ref. 28) commented that this was equivalent to 1600 300 kWe wind turbines each of which produces only about 40 kWe on average.

In general, we do not believe that growing plantations to produce biomass will be viable because its energy density is low and an unacceptably large proportion of its energy may have to be expended in harvest and transport. Also, there must be environmental concerns regarding the nutrients required for sustainable silviculture or any other biomass production. This option also is not entirely green, because although it contributes to greenhouse gas stabilisation, it also leads to stabilisation at a higher average concentration of such gasses in the atmosphere. This is so because at equilibrium, approximately half the carbon attributable to a totally dedicated biomass is held by the atmosphere.

Methane gas is produced by the putrefaction of organic matter in landfill, and the first Australian unit was installed in 1992. Current capacity is 72 MWe and DPIE estimates 100 MWe by the year 2000. Methane has 24 times the greenhouse effect of CO2 thus, apart from producing energy, burning it makes a significant contribution to greenhouse mitigation.

The UK's current output is 150 MWe, with a potential up to 1000 MWe. The Australian Group Energy Developments who are also active in coal seam methane, have landfill gas contracts for 60 MWe in UK and are active in USA with 100+ MWe from landfill sites.

Methane can be produced from human and animal sewage and as we grow more environmentally aware we will produce more from such sources. There is no hard information on the potential production but the authors believe this source will not make a large contribution to energy production, although such developments will make a major contribution to minimising our greenhouse emissions through methane removal.

A recent example is of a pig farmer in Ballarat who will recoup his investment of $2M in 6 years while minimising the effect of piggery effluent on the environment. An old example from Brough’s student days was a sewage treatment plant built in the 20's, feeding gas into the local supply and selling the dried spent sludge to gardeners. A more recent local example was a Water Board treatment plant flaring off its gas because the gas company had a supply monopoly. These sources are classed as biomass.

3.4 Nuclear

3.4.1 World

There has been considerable investment in nuclear power throughout the developed world. Currently there are 437 reactors installed generating 2276 GWe (see table 3.4-1 attached, as taken from ref. 29). This constitutes a contribution of 17% of the world’s total generation and is about 12 times the total electrical generation in this country. Altogether there are 32 countries that have nuclear power plants and 13 of these that use nuclear power for 30% or more of their total electricity generation. Top of the list is France (at 78%) which is heavily reliant on nuclear generation and even exports some of this to its neighbours. Altogether over 8000 reactor years of operating experience has been accumulated by the world's power reactors (ref. 12).

At current consumption rates proven uranium resources should last about 100 years if used in thermal reactors. However if fast breeder reactors are used then the amount of energy available in uranium increases by a factor of about 60. This is about 4 times greater than the energy contained in the World reserves of coal, gas and oil combined. In addition the use of thermal reactors designed to operate on the thorium – U233 breeding cycle, would more than triple the nuclear total (ref. 30). As an interesting footnote, the uranium already exported to the US, UK and France was sold essentially for its U235 energy content, which was removed by the enrichment process leaving the majority in storage as depleted uranium. This depleted uranium, when used in the future in breeder reactors, constitutes a substantial energy resource for these countries - all essentially for free!

In spite of the advantages of the nuclear option, many countries have decided against its use or are not planning to expand its application. Most of the reason for this is found in the mistaken assumptions that nuclear power leads to nuclear weapons or is otherwise unsafe thereby producing controversy that leads politicians to avoid the issue. A recent Canadian reference commented, "Nuclear Energy is currently in a paradoxical situation. Although it is the only technology so far to have produced large reductions in GHG [i.e. greenhouse gas] emissions in Canada and the world, nuclear energy is relegated in the emissions debate either to be ignored [as at Kyoto] or dismissed. Yet it is the only non-carbon source whose increased use is capable of replacing carbon (coal, oil and gas) sources. The pure renewables will gradually grow within the energy mix but without additional nuclear capacity, it will be impossible even to hold greenhouse gas emissions near current values without enormous economic disruption. Nuclear electric is the largest proven on non-carbon emitting source in the world" (ref. 17). The latter reference to increased use of nuclear relates to the need to provide additional nuclear generation as the non-CO2 producing means to back up the renewables.

This year the OECD (ref. 78) commented: "Efforts to combat climate change could alter the perception of, and the prospects for nuclear power. Electricity generation accounts for about one-third of emissions of man-made carbon dioxide. Nuclear power is a potential contributor to reducing those emissions. A strong commitment to reduce emissions of carbon dioxide could have dramatic positive effect on the prospects for nuclear power over the coming decades. A focus on nuclear power's potential benefits in relation to climate change could put concerns about nuclear plant safety and environmental protection in a different perspective."

3.4.2 Australia

Australia has about 33 to 40% of the world's reserves of uranium and its exports constitute about 10% of the world market (but less than 1% of merchandise exports from Australia). However, it has no nuclear power plants of its own. It has a nuclear research establishment at Lucas Heights, Sydney, but in recent years the Australian Nuclear Science and Technology Organisation (ANSTO, formerly the AAEC) has not taken an active interest in the application of nuclear power in this country.

The first flirtation Australia had with nuclear power was by the Playford government in South Australia and concerned a proposal for a 200 MWe Magnox plant at Wallaroo in South Australia. This proposal was made in 1963 by the UKAEA. The capital cost of this plant was to be about £A34M ($A 578M today) or 170 £A/kWe (2890 $A/kWe today). Two variants were offered, one with the boilers surrounding the core and the other with boilers on top of the reactor. This proposal was dropped, however.

The most serious proposal to date was the Jervis Bay plant. This was to be about 600 MWe and was to cost about $A 200M ($A 1365M today) or 333 $A/kWe (2273 $A/kWe today) with an estimated generating cost of about 0.6 ¢A/kWhe (4.1 ¢A/kWhe today) (ref. 31). By June 1970 most of the world's major reactor vendors submitted bids including: Westinghouse, GE, KWU, AECL and TNPG. The main reactors proposed were proven commercial designs, i.e. PWRs, BWRs and CANDUs, except for TNPG's SGHW. AAEC gained valuable experience during the assessment of these tenders (all of which has now disappeared at ANSTO), but an ill-founded judgement about the integrity of reactor pressure vessels effectively eliminated all PWRs and BWRs. Subsequently the preference became the SGHW, which was the only design that was not commercially proven. The Government then essentially cancelled the project. In hindsight this decision was correct from the viewpoint that the design of choice, the SGHW, never did become a commercial design (none beyond the 100MWe prototype was built), whereas those eliminated, the PWRs, BWRs and CANDUs have dominated the world market. It probably was unwise too to have a Federal Government agency such as the AAEC heavily involved in what should have been primarily a commercial project – where the electric utilities are the experts.

Australia's energy future was the subject of an inquiry by the Senate Standing Committee on Industry, Science and Technology in 1991 (ref. 32). In a report section on "Alternatives to conventional coal based electricity generation" the Committee concluded that "Whilst the Committee took evidence about the possibilities of nuclear power it considers that best returns will be made from funds invested in increasing the efficiency of energy conversion by existing infrastructure and through demand management whilst at the same time developing the renewable and advanced technologies as recommended [herein]."

Clearly at this time and since at the federal political level there was no inclination to stray far from coal based generation while the supporters of the “soft” technologies were to be kept happy through increased federal subsidies for R&D.

The introduction of nuclear power in this country would require some infrastructural changes with respect to the establishment of a national reactor regulatory authority and the need to develop a cadre of qualified personnel within the lead utility. Neither of these is a particularly difficult task and given properly qualified personnel initially, appropriately trained staff for these functions could be in place in advance of actual operation. The regulatory function would require national legislation, but the forerunner to this is the nuclear regulator ARPANSA (Australian Radiation Protection and Nuclear Safety Authority), which regulates only Federal activities, and could provide the basis for the formation of a truly national regulator.

An often quoted problem with nuclear is disposal of radioactive wastes. We differ from most authors on this subject in that we do not see any point in attempting to devise waste storage schemes that will maintain integrity for more than about 500 to 1000 years at which time its specific activity is approximately the same as the original ore (see ref. 1). Most of mankind’s important written records and substantial structures have lasted longer – thus even 1000 years hence mankind will know where a waste depository is and what’s in it. Further, history has shown that technology has not regressed, so we should not discount the ability of future generations to use or, if necessary, redispose of the waste. Thus in our view radioactive waste disposal is really a non-problem that has been blown out of proportion by anti-nuclear elements, supported by those conducting research on geologic storage systems and abetted by nuclear regulators leaning to the political breezes.

4. PROS AND CONS OF ALTERNATIVES

4.1 Economic Cost

For this country there is very little in the open literature by way of comparative cost studies for central station generating plants – particularly in relation to nuclear. None was available from the Jervis Bay Program but the SECV did publish a comparison in the early 1970s in conjunction with the Loy Yang project planning. This study was carried out by JE Hayes and others and showed that nuclear had an approximately 8% levelized generating cost advantage over coal. However, this advantage was deemed too small to compensate for the uncertainties associated with actually constructing and licensing a nuclear plant.

Another study by the SECV about 10 years later for the Portland plant, compared nuclear with a brown coal station and a station burning $US45/tonne black coal imported from NSW. Of course the brown coal station won, but the generating cost ratio of nuclear to black coal was quoted at 1.56 (which looks very high considering the results of the next mentioned OECD study).

In 1990 one of us (Fredsall) published a paper (ref. 33) which discussed the 1990 OECD (IEA)/NEA cost survey results and attempted to project the results of the Japanese estimates (nuclear/coal = 0.78) back to Australia. In this the cost of imported coal to Japan, $US45, was simply reduced to $US40 to allow for its non-export to Japan. The nuclear to coal ratio then changed to 0.88 – or better than that for the USA, UK or the FRG burning their domestic coal. In other words, assuming the other generating costs in Japan are applicable to this country, then coal-fired generation using the same coal would produce electricity 14% higher in cost.

Hayes later provided a reanalysis of the situation to the IEAust Nuclear Panel in an address in Sydney in November 1995 (ref. 34). This information showed that the breakeven costs of nuclear and coal (1995 costs, 5% discount rate) would be at coal costs of approximately $A71/tonne for no FGD (flue gas desulphurisation) and $A52 with FGD, whereas the typical range of coal costs is from $A20 to 40. Hayes noted that FGD was common in North America, Europe and Japan but has not been required in this country because of the low sulphur content of local coals and a low total coal based generating capacity. Hayes summarized his presentation by saying, “there would appear therefore to be little or no prospect of economic justification and public acceptance of the introduction of nuclear power in Australia for the next 20 years or so.”

An extrapolation of Hayes’ results by Fredsall indicates that his levelized costs would have been about:

TABLE 4.1-1: 1995 ESTIMATES OF AUSTRALIAN GENERATING COSTS (in ¢A/kWhe)

	Capital	O&M	Fuel	Total
Nuclear (2X600 MWe)	2.1	1.2	1.0	4.3
Coal no FGD (2X660 MWe)	1.0	0.5	1.4	2.9
Coal FGD (2X660 MWe)	1.5	0.8	1.4	3.7

using a coal cost of $A35/tonne. This yields cost ratios of nuclear to coal with no FGD of 1.48 and 1.16 with FGD. However, using coal at a value of $US35/tonne (the non-exported cost of coal currently sold to Japan) i.e. $A50/tonne, the coal fuel costs increase by 0.6¢A/kWhe leading to the ratios nuclear to coal with no FGD of 1.2 (i.e. coal at 3.5¢A/kWhe) and 1.0 with FGD. It is worth noting too that on the figures of the table, the cost of FGD amounts to about 0.8¢A/kWhe – in other words this is about the price paid by northern hemisphere countries to counteract the environmental effects of SO2 emissions.

(Note: the "levelized" costs referred to are calculated by dividing the present worth of the cost stream by the present worth of the generation stream. This is usually done at an interest rate of 5% which is about the real cost of money, thus producing results that are in non-inflationary terms.)

In 1993 the OECD (IEA)/NEA (ref. 35) released a study of comparative generating costs for plants to be installed in the year 2000 (See table 4.1-2 attached). In this study real escalation to the startup date was allowed, a 5% discount rate was used but the costs are quoted in 1991 $US. Generating cost ratios were predicted to be:

TABLE 4.1-3: 1993 OECD ESTIMATED GENERATING COST RATIOS

	Nuclear/Coal	BE Coal	Nuclear/Gas	BE Gas
Belgium	0.91	0.83	0.88	0.82
Canada	0.88	0.73	0.57	0.46
Finland	0.86	0.74	0.85	0.80
France	0.65	0.39	0.60	0.49
Japan	0.85	0.73	0.69	0.59
UK	1.02	1.04	1.11	1.15
US	0.85-1.19	0.88-1.61	0.86-0.90	0.83-0.87
China	0.86	0.75		
CSFR	0.87	0.68	0.80	0.72
Hungary	0.73	0.51	0.79	0.75
Korea	0.75	0.54		

(note: e.g. BE Coal is the factor that the price of coal would have to change for break even generating costs.)

Conclusions of this study were that nuclear was cheaper than coal except in the UK, Western US and Western Canada and nuclear was cheaper than gas in all countries except the UK. The study also discussed the shift toward generation with natural gas and noted that further such installations, especially in Europe, could lead to substantial rises in gas prices.

The most recent study by the OECD (IEA)/NEA (ref. 36) gives the following cost ratios nuclear to coal (online 2010, lifetime of 30 years, discount rate 5%) (note the figures were obtained by interpreting the graphical representation):

TABLE 4.1-4: 1998 OECD ESTIMATED GENERATING COST RATIOS

	Nuclear/Coal	Nuclear/Gas
Canada	0.59 - 1.02	0.82 – 0.99
Finland	1.17	1.07
France	0.70	0.68
Japan	1.01	0.71
Korea	0.90	0.72

(Table 4.1-4 Continued)

Spain	0.98	0.86
Turkey	0.83 - 1.28	1.09
US	1.32	1.22 – 1.43
Brazil	0.60 – 1.03	1.12 – 1.29
China	0.81 - 0.97	-
India	0.89 - 1.01	-
Russia	0.60	0.75

This study showed that the base capital costs for nuclear ranged from 1000 to 2500 $US/kWe – the average being about 1500 $US/kWe. This study also showed that generating costs of coal and gas have reduced relative to those shown by the previous study and attributed this primarily to lower fuel costs – costs that contribute greater shares of total generating costs than is the case with nuclear.

The UIC recently attempted to sum up the situation with nuclear power based on the 1993 OECD study (ref. 37): "The relative costs of generating electricity by coal, gas and nuclear plants vary considerably from country to country, due to location. Coal is and will probably remain an economically attractive option in countries such as Australia where there is access to abundant domestic coal resources. Gas is also competitive for base-load power in many places, but this depends greatly on future gas prices." This comment about coal, of course misses the point that it is not so much the amount of coal that a country has that determines relative generating costs, but the relative cost of the coal, and as is discussed below, this is not necessarily just the cost of digging the coal and transporting it to the power station.

From the above discussion it can be seen that nuclear, coal and gas based plants are the most economic for use as central power stations, and across the OECD countries generating costs fall generally within about ± 20% of each other.

Unlike most other countries, Australian electric generating costs have never been made available in a form that allows transparent comparisons between the state generating authorities or with generating costs overseas. Mainly this has been for political reasons. Since the selling price of electric power is two or three times the generating cost there is plenty of scope to distort the picture. For instance in at least one state it was common practise to shift part of the capital cost to O&M, thus making plants appear to be cheaper to build than they really were. The picture in relation to coal costs is also obscured by the state owned utilities not having to pay royalties on crown land coal, making the value of coal in the ground zero rather than assigning its open market worth. This costing approach incorporates a hidden subsidy and ignores the cost to society for not using a valuable resource in the most cost efficient manner. Further, the practice of not requiring flue gas desulphurisation, as in most other parts of the world, has also biased the equation towards coal generation by about 20%.

However, with the strengthening of the southeast power grid allowing substantial interstate trade in electricity, and the privatisation of the generating authorities together with the need for publicly accountable regulation, it can be expected that more cost efficient generation will result and hopefully that comprehensive and consistent cost figures will become available. Presumably these should be comparable to the OECD figures discussed above, but with suitable adjustments for the real prices of local coal and gas and no FGD. The net result of such an exercise would be to place Australian costs within the ± 20% band shown by the rest of the OECD countries. The only exception to this might be with the lignite stations in Victoria where the value of the coal in the ground really is essentially zero and where the most recently built plants are reputed to be the lowest cost generators in the country

Typical generating costs in the UK from various renewable energy sources are given below (converted at 45p/$A, and levelized generating costs recalculated at 5% discount, ref. 25):

TABLE 4.1-5: ESTIMATED GENERATING COSTS FOR THE UK 1995

Source	Capital $A/kWe	O&M $A/kWe/yr	CF,%	Life years	Gen Cost ¢A/kWhe
Solar PV	7800	78	11	25	64
Large Hydro	4500	11	50	40	6.2
Small Hydro	2500	67	60	20	5.3
Tidal	3100	18	22	50	9.8
Wave	4500	111	20	30	23
Wind	3100	22	25	20	12
Landfill Gas	1800	195	88	10	5.8

(notes: O&M = operation and maintenance; CF = capacity factor; the comparison of levelized cost for plants of short lifetimes is somewhat misleading since the capital investment component is undervalued; for comparison from table 4.1-2 the mid-range generating costs for the UK in 1992 were nuclear= 5.7, coal= 6.6, gas= 6.0 ¢A/kWhe.)

Comparable costs for commercial solar PV units in Australia are available from Integral Energy (ref. 38). Looking at their largest unit, the SP11 (5.04 kWe) which delivers 7241 kWhe per year (a 16.4% CF), the capital cost is $57,315. On a levelized cost basis for a 20 year life at a 5% discount rate, gives 64 ¢A/kWhe. Then if the same O&M cost is used as in the British figures above, the total estimated cost comes out at 72 ¢A/kWhe, or some 5.3 times higher than the Southern Energy's quoted retail cost of electricity at 13.5 ¢A/kWhe (Energy Australia quotes 10.2¢A/kWhe).

As another example, a Solahart domestic water heater in Australia costs $2950, has a life of 17 years and a yearly output of 3220 kWh. Assuming equivalence for electric heating (i.e. kwh = kWhe), on a levelized cost basis over this lifetime the unit cost comes out to be 8.1 ¢A/kWhe.

A recent article on the prospects of tidal power stations around the world (ref. 39) shows that many concepts and sites have been considered, but that little has been done – often because supporting funding has not been made available or has been withdrawn. This reference points to a recent feasibility study for a plant in the Orkney and Shetland islands where the generating costs were estimated to be 5-10p/kWhe (i.e. 11-22¢A/kWhe).

As has been discussed, there is little scope for the wide use of hydro, wave, tidal, or landfill gas, in Australia. Moreover the remaining forms, wind and solar PV have generating costs some three to fifteen times those of nuclear, coal or gas. Thus if wind or solar PV were to be installed on a scale large enough to provide a substantial share of electrical consumption there would have to be a substantial increase in the retail cost of electric power with a consequent substantial reallocation of consumer spending. Furthermore, even if such renewable generation were used, this would not mean that it would displace much base load central station generation because electricity supply must be maintained at all times (ref. 1). This does not mean that renewables should not be used at all. For instance installation of a wind farm in a location where the capacity factor would be high and grid connection costs were low would be a logical choice, and solar PV has already proved itself for special purpose low capacity remote situations.

Thus from a purely generating cost mininmisation point of view, the major share of electricity generated in Australia should come from central nuclear, coal or gas stations. These plants are all reasonably competitive and the use of any or all of them would not appreciably alter the wholesale or retail cost structures of electric power in this country. While it is true that the price of coal has decreased in more recent times thereby driving down the relative cost of coal based generation worldwide, this tends to be offset by environmental/political considerations as are discussed below.

4.2 Environmental Impact

4.2.3 Land Use

It is instructive to examine the “footprints” of various land use activities to get some appreciation of their relative impacts. The table below shows agriculture occupies the most land, and even just the land devoted to crops is more than 100 times that given to mining.

TABLE 4.2-1: LAND USE IN AUSTRALIA

LAND USE	sq km
Total area (a)	7,682,840
Grazing (a)	4,200,000

(Table 4.2-1 continued)

Marine Parks (g)	426,000
Parks, Nat., Wildlife, Rec. (g)	328,000
Pastures and Grasses (a)	300,000
Crops (a)	180,000
Roads (a)	24,000
Serrated tussock grass (i)	9,000
Housing (6.5 million dwellings) (b)	6,500
All mining (f)	1,500
Reservoirs (c)	860
Suburban driveways (b)	312
Snowy Mountains Hydro roads (c)	48
Sydney sewer mains (h)	40
Melbourne - Sydney gas pipeline (j)	14
Uranium mines (incl. Jabiluka) (e)	12
Proposed cycle way NSW coast (b)	6
PV producing 163 TWhe/y (d)	1,000

{table references: a = ABS yearbooks, b = Brough, c = SMH & Tasmanian Hydro, d = from Integral Energy data (area does not include mines for materials), e = WMC and ERA environmental studies, f = Australians and the Environment, p180, 1996 (ABS 4601.0), g = Zoos, Parks and Gardens Industry 1996-7 (ABS 8699.0)}, h = Sydney Water newsletter 20/10/99, i = CSIRO reported in Weekend Australian Aug 14-15, 1999, j = From Brough

As a miscellaneous point of interest, the big threat to the Kakadu National Park is not Jabiluka uranium mining, it is the advance of the imported big-headed ant from the Darwin area (ref. 40), the advance of imported cane toads from the east (ref. 41), plus feral cats, pigs, and weeds (ref.42). The control of one weed in NSW is reported to cost $600M/y (ref. 43). Cane toads have already spread over half a million square kilometres (ref. 44) and have been found around Kakadu (ref. 42).

Other aspects of land use which are less easy to quantify involve the usual necessity to connect the local generating station to the electricity grid in order to provide backup when the local station is unavailable (e.g. down for maintenance). This involves building a transmission line to the site, and although we believe that the health effects of the attendant electrical fields is and overrated problem, such lines do have a negative aesthetic impact. Facilities for transport of fuel to, or waste from the site can also affect aesthetic values. Also the mere presence of a generating station may degrade the aesthetics or the value of the site for recreation - for example, a tidal station on the coast.

4.2.2 Greenhouse Gases

Australians use 5.1 t of coal per head every year to produce electricity for industrial and domestic use, producing about 13.8 t of CO_2 per head. (Brough's est). Included in this total is the amount derived in the production of electricity for aluminium refining. Every kilogram of refined aluminium produced releases 27 kg of CO_2 (ref. 76). In 1995 Australia exported 1.3 Mt of aluminium (5.5% of world production) equivalent to 35.1 Mt of CO_2 or 10.5% of the nation's total CO_2 emissions from coal.

TABLE 4.2-2: CARBON DIOXIDE PRODUCTION WITH VARIOUS FORMS OF GENERATION (including indirect generation by coal fired plants)

Generator	Grams CO_2 per kWhe					
	Ops.	Fuel	Total	IAEA R46	R47	R48
Coal	88	902	990	860-1290	960	900
Oil	44	689	733	689-890	860	750
Gas (LNG)	147	506	653	460-1234	720	500
Ocean - Thermal	132		132			
Tidal	128		128			
Wave	92		92			
Photo-voltaic	59		59	30-279	110	45
Wind	37		37	11-75	20	6.5*
Geo-thermal	22		22			
Hydro	18		18	16-410	40	3-10
Nuclear	11-22		11-22	9-30	20	8
Biomass				37-116		

(notes: first 3 columns ref. 45, ref. 49 says 860g CO_2/ kWhe for NSW coal, whereas Energy Australia uses 950g CO_2/kWhe. Comparable figures for brown coal are 1.2 to 1.4g CO_2/ kWhe), *refs 76 and 77

Table 4.2-2 shows the amount of CO_2 associated with electricity generation by various means – assuming the primary source of electricity for materials, etc. is from coal. As can be seen, all modes shown involve the production of CO_2, some in substantial amounts. Nuclear is low however, indicating the fact that the energy payback time of nuclear plants is about two years.

As was noted earlier, the OECD estimates that worldwide about one-third of all man made CO_2 comes from the generation of electricity (ref. 78). In Australia the figure is estimated by the Australian Greenhouse Office to be approximately 53% (ref. 79) because of our heavy reliance on coal-fired generation - one of the highest in the world.

The Australian Bureau of Agricultural and Resource Economics (ABARE) not long ago did some background work on the impact of the reductions of CO_2 emissions for Australia (ref. 13). In this study they looked at the effect of introducing nuclear power plants in 450MWe units starting in 2005 (even though they state that "Australian government policy precludes this as a real option"), but found that under the method of calculation used, that is optimisation for least cost, the incentive to reduce CO2 specific emissions from the remaining fossil plants is diminished, thereby reducing the total benefit one would expect. This seems an odd result, but of course the condition of least cost is not necessarily what one would pursue to solve what is basically an environmental/political problem. Also ABARE's choice of nuclear plant size seems odd in that the southeast power grid could certainly handle larger plants – thereby obtaining the economy of scale, plus the authors comment that "It should be noted that the CANDU [i.e. a Canadian design] nuclear option is relatively low cost compared with larger sized light water reactor nuclear plants currently used in Europe" begs the question of why so few CANDUs have been built. Although the CANDU design has some advantages over the more popular light water reactors, the fact is that only 5% of the world installed capacity comes from CANDUs (plus no 450 MWe CANDUs have ever been built), thus ABARE's choice of plant and the theoretical costs assumed may also have biased the results of their study.

4.4 Health and Safety

4.4.1 General

The Senior Expert Symposium on Electricity and the Environment report (ref. 48) presented a table of severe energy-related accidents, which we summarise below. Note that for local Australian purposes we have included the fatalities caused during the construction of the Snowy Mountains scheme and some other data as noted.

TABLE 4.3-1: FATALITIES ASSOCIATED WITH VARIOUS ENERGY SOURCES

SOURCE	FATALITIES	
	Workers	Public
Coal mining and waste	799(b)	144(a)
Oil,production	187	0
transport	48	2(e)
Amoco Cadiz	0	0
Exxon Valdez	0	0
Nigeria pipe		500+
Gas, storage	2	>500
transport	0	316
pipeline	0	>1438
Hydro	121(s)	21259
Nuclear, TMI	0	0
Chernobyl	31+	0(t)

(a); Aberfan disaster only, no estimate for transport accidents or pollution effects.

(b); Mining accidents involving >62 deaths
(e); Excludes road tanker accidents
(s); Snowy Mountain Scheme only.
(t); Unknown. No increase in leukaemia, 1800+ cases of treatable childhood thyroid cancer. [refs. 50,51,52]

Also taken from reference 48 is Figure 4.3-1 which summarises the relative risks of various energy technologies. This figure illustrates that even so-called benign technologies such as wind, tide and solar technologies have some risk mainly from the production of materials. In addition how many people die from falls every year? Can we estimate how many will die during the installation of rooftop solar cells? In 1990, 88 Australian males died in accidental falls

Further illustrating the risks from the most common energy industries are the following fatality figures for the US 1998: coal mining = 30, oil & gas mining - 76, gas production & distribution = 6, electric services = 27 (ref.80)

4.4.2 Coal vs Nuclear – Direct Risks

Coal and nuclear are the major components of the world's electricity generation capacity so it is reasonable to look at their relative risks as are provided in the attached figure 4.3-1.

Bromley (ref. 53) compared the hazards of coal - mining in Britain with the hazards of uranium mining and found that fatalities for coal were 9 to 250 times greater than for uranium when based on the number of deaths per GWey of electricity produced (that includes public risk). If only the radiation risk is considered, coal is 6 to 386 times that for uranium.

TABLE 4.3-2: RISKS OF COAL AND URANIUM MINING

	RISK RATIO COAL/URANIUM	
URANIUM MINE	Total Risk	Radiation Risk
Rossing	45	52
Nabarlek	170	343
Key Lake	250	310
France	48	45
Cluff Lake	23	12
Ontario	12	6
Energy Fields	43	46
France	9	8
Everest	170	386

(Note: we think that the hazards of radon are overestimated by regulators and that the radiation hazards are less than they appear to be for both coal and uranium mining)

The mix in Germany is approximately 60% coal and 30% nuclear. Coal mining kills 40 to 50 miners per year, injures thousands and is subsidised by Dm 10 billion per year (ref. 54). Environmentalists have kept a brand-new reactor from operating on a legal technicality since 1987, but at what cost in coal-mining deaths and injuries, health effects and environmental effects of burning coal? The use of this reactor would have avoided the release of 9 Mt of CO_2 per year.

The following table illustrates the Japanese experience in coal mining (ref.55):

TABLE 4.3-3: FATALITIES from COAL MINING IN JAPAN

YEAR	FATALITIES TOTAL	FATALITIES PER Mt	PRODUCTION Mt
1960	615	12.1	51
1965	640	13.1	49
1970	170	4.3	40
1975	70	3.7	19
1980	25	1.4	18
1985	45	2.8	16
1986	18	1.3	14
1987	10	0.8	13

Coal mining fatalities in the USA have also been well documented. The data shown in the following table illustrate the differences between surface and underground mining and the improvements obtained over the years (ref.56).

TABLE 4.3-4: FATALITIES FROM COAL MINING IN THE US

YEAR	TOTAL (per Mt)	UNDER-GROUND (per Mt)	SURFACE (per Mt)	PRODUCT-ION Mt
1935	1242(3.2)	NA	NA	385
1940	1388(3.0)	NA	NA	465
1945	1068(1.9)	NA	NA	574
1950	643(1.3)	NA	NA	511
1955	420(0.94)	NA	NA	446
1960	325(0.82)	NA	NA	395
1965	259(0.54)	NA	NA	479
1970	260(0.47)	NA	NA	554
1975	155(0.28)	NA	NA	555
1980	125(0.17)	102(0.34)	23(0.053)	725
1985	65(0.082)	53(0.17)	12(0.025)	785
1990	60(0.065)	48(0.13)	12(0.022)	926
1995	42(0.044)	26(0.072)	16(0.028)	938
1997	28(0.028)	22(0.058)	6(0.010)	993

NA = not available. In addition the data to 1977 showed that non-fatal disabling injuries in ratio to fatalities remained in the range of about 50 to 100.

Comparable figures for Australia are shown in Table 4.3-5 below as taken from references 57, 58 and 59.

TABLE 4.3-5: FATALITIES FROM BLACK COAL MINING IN NSW + QLD

FINANCIAL YEAR	TOTAL (per Mt)	UNDER-GROUND (per Mt)	SURFACE (per Mt)	PRODUCT-ION Mt
1979-80	23(NA)	23(NA)	0(NA)	(NA)
1980-81	19(NA)	17(NA)	2(NA)	(NA)
1981-82	5(NA)	5(NA)	0(NA)	(NA)
1982-83	9(NA)	9(NA)	0(NA)	(NA)
1983-84	8(NA)	7(NA)	1(NA)	(NA)
1984-85	9(NA)	7(NA)	2(NA)	(NA)
1985-86	8(NA)	6(NA)	2(NA)	(NA)
1986-87	20(0.11)	18(0.31)	2(0.017)	176
1987-88	2(0.012)	2(0.041)	0(0)	161
1988-89	6(0.034)	5(0.098)	1(0.008)	177
1989-90	3(0.016)	2(0.034)	1(0.008)	189
1990-91	11(0.056)	9(0.15)	2(0.015)	196
1991-92	7(0.033)	6(0.10)	1(0.007)	210
1992-93	5(0.023)	3(0.049)	2(0.013)	214
1993-94	2(0.009)	1(0.017)	1(0.007)	213
1994-95	13(0.057)	13(0.20)	0(0)	228
1995-96	2(0.009)	1(0.015)	1(0.006)	231
1996-97	10(0.039)	9(0.12)	1(0.006)	253
1997-98	2(0.007)	1(0.012)	1(0.005)	269

figures are for raw coal; NSW + QLD currently produce about 97% of black coal mined in Australia; NA means QLD production figures unavailable in refs. for these years.

As can be seen the fatality rates for Australia are generally lower than those in the US (assuming the same statistical basis). The average number of mining fatalities from black coal mining over the last 10 years shown is 6.1 per year, with 82% of these occurring in underground mines – mines that produced only 29% of the coal.

4.3.3 Radiation Hazards

105 years ago, Becquerel discovered that uranium was radioactive and shortly after that Marie Curie started the work which was to earn her 2 Nobel Prizes. Many others followed her lead and during the next 70 years their work has identified over 80 natural radioisotopes in the environment. Cosmic radiation creates 13 radioisotopes of these in the earth's atmosphere. Consequently there is no such thing as a radiation-free environment, and it is sad to reflect that even in societies with good educational standards maybe only 2% of the population are aware of this fact. Also, since the nuclear industry had its beginnings in weapons production, and is an industry that produces and uses radioactive materials, many people have a gut feeling that all radiation is deadly. This helps to explain the great fear of anything to do with radiation.

Radiation from natural and anthropogenic sources has been studied extensively over many years and a literature survey revealed more than 7000 references on the natural radioactive Radon gas over a recent period of 7 years, and the survey did not cover newspapers or non-technical magazines. In spite of the enormous amount of data on radiation levels considerable controversy rages as to what it means in terms of human health and we will attempt to explain.

We know a great deal about the cancer risks produced by high doses of radiation received by the Japanese A-bomb survivors, and from medical and accidental exposures. We know that at such high doses there appears to be a linear relationship between dose and effect so in the absence of evidence of harmful effects of radiation at background or moderately elevated levels, it was assumed by the radiological protection community that the effects could be extrapolated back to zero dose. By making this assumption it made it extremely unlikely that potential harmful effects would be underestimated and it is known as the Linear No-threshold Theory (LNT). This assumption has been liberally interpreted by many to mean "there is no safe dose of radiation".

In spite of the LNT theory having no epidemiological basis in low dose situations, it is used widely today. This is not just an academic exercise for there are significant consequences – such as the $US85 billion to be spent on cleaning up the Hanford site, money spent to reduce radon levels in homes (ref. 60) - all with little or no likelihood that there ever will be any positive health benefits. Although there is currently a move to rationalise this situation through recognition that as with many other environmental factors there is a threshold effect with low level radiation, it will be some time before this could be adopted internationally (see ref. 61). Thus evidence to the contrary such as the fact that major studies of large populations of nuclear workers show them to have lower cancer levels than other workers are often dismissed as the "healthy worker effect," and the radon exposure results discussed below continue to be ignored. (Another incentive to keep the LNT as stated by some radiological protection practitioners has been simply that it is conservative and easy to use.)

The LNT assumption means that for every increment in radiation dose it is possible to calculate the number of theoretical additional deaths in the population, a prime example being for the Chernobyl accident where, as reported in reference 60, 10,000 to 20,000 deaths were estimated (compare with the most recent assessment of "no evidence of a major public health impact attributable to radiation exposure fourteen years after the accident" (ref. 52)). The British Medical Association's book 'Living with Risk'(ref. 62) can be interpreted as follows. Out of every million deaths in the UK, 250,000 will be from cancer. If the linear assumption is correct, about 2500 of those will be caused by background radiation, 250 from man-made radiation and 25 from nuclear power stations.

The radiation doses received by people from the natural background vary markedly depending on local geologies, altitude, latitude and exposure to indoor radon gas. Table 4.3-6 (ref. 63) shows the radiation doses for 17 European countries. In addition to this, the human body is radioactive because we live in a radioactive environment. The major component of the internal radiation dose is potassium-40 (half-life 1.3 trillion years), plus about 90µg of uranium (ref. 64) plus carbon 14, tritium and polonium 210.

TABLE 4.3-6: Natural Radiation Dose, mSv/y

COUNTRY	RADON	COSMIC & EXTERNAL	TOTAL*
Austria	3.55	0.71	4.60
Belgium	2.61	0.62	3.58
Denmark	2.50	0.70	3.55
Finland	6.26	1.01	7.62
France	4.00	0.95	5.3
Germany	2.33	0.8	3.48
Greece	3.44	0.89	4.68
Ireland	2.89	0.78	4.02
Italy	2.73	0.99	4.07
Luxembourg	3.43	0.86	4.64
Netherlands	1.35	0.69	2.39
Norway	2.89	0.93	4.17
Portugal	3.55	1.03	4.93
Spain	4.07	0.88	5.3
Sweden	4.73	1.12	6.2
Switzerland	3.13	1.05	4.53
UK	1.01	0.66	2.02

*Total includes 0.35 mSv/y from natural radionuclides in the body.

If we accept the no safe dose concept we should be able to discern harmful effects in populations because they are exposed to varying doses of natural environmental radiation, but studies of cancer rates in very large populations do not support the linear or no safe dose concept. Cohen (ref. 65) found a negative correlation between radon dose and lung cancer in both men and women. Brough found a similar negative lung correlation in a cruder study of Europe (unpublished) which also strongly suggested negative correlations for breast, colon and bladder cancers and no effect for stomach, prostate and lymphatic cancers or leukaemia. Another large population study of other cancers by Cohen found no increase within the radiation doses experienced from natural background radiation (ref. 66).

If radioactivity from nuclear power stations is dangerous to the health of the environment, consider the radiation doses from the natural environment and the range of other common human activities as measured by the United Nations Environment Program in its reports of 1986 and 1991 (ref. 67). The following Table 4.3-7 is derived from these reports.

TABLE 4.3-7: RADIATION DOSES FROM VARIOUS ACTIVITIES
(collective effective radiation dose in person-Sieverts)

ACTIVITY	1986 Report	1991 Report
Natural Background	12,000,000	12,000,000
Phospho-gypsum	300,000	300,000
Phosphate industry	6000	10,000
Coal, heat & cooking	100,000	20,000 – 40,000
Coal ash, building		50,000
Coal power stations	2000	2000
Air travel	2000	4000
Nuclear, public	500	800
Nuclear, occupational	2000	2000
Medical, X-Rays, etc.	1,600,000	2,000,000 – 5,000,000

Ranger Mine workers have an average radiation exposure of 5.2 mSv/y compared with the average Swedish person 5.47mSv/y and lower than the average Finn, 6.94mSv/y (refs. 68, 63).

Various modes of electricity generation also produce radiological effects. In 1979 K. Okamoto, of the UNI of NSW (ref. 69) calculated the relative radioactive hazards from various power plants of 1000MWe size, as shown in table 4.3-8.

TABLE 4.3-8: RADIOLOGICAL EFFECTS OF ROUTINE OPERATION FOR VARIOUSLY FUELLED 1000MWe PLANTS IN AUSTRALIA

PLANT TYPE	RADIOACTIVE HAZARDS	
	Soluble	Insoluble
Aust. Black Coal (99% dust removal)	320-700	110-450
Oil	7	2.5
Natural Gas	>9	>9
Nuclear	0.3-40	0.3-40

These estimates are “relative radioactive hazards” and were calculated by comparing the releases with the MPC (maximium permissible concentrations) adopted by the International Commission on Radiation Protection. The reason the coal plant figures are so high is that the emissions are mainly of α emitting isotopes such as uranium, thorium (see section 3.1), radon and their daughters. The range of figures for the coal plant corresponds to 1% and 100% release rates for such isotopes. Thus even from a radioactive hazard point of view for routine airborne releases, nuclear plants are much safer than plants burning Australian black coal.

Reference 11 points out that on the basis of studies by the US National Committee on Radiation Protection "The population effective dose equivalent from coal plants is 100 times that from nuclear plants" (i.e. routine releases). Further, it is not just the immediate airborne releases that can cause problems because the uranium and thorium spread over the countryside from the stacks do not disappear, but accumulate for as long as the plants operate. In addition the uranium and thorium concentrated and mobilised in the discarded coal ash constitute a radiological waste discharge problem that would not be tolerated for US nuclear power plants.

4.4 Political

Politics plays an important part in determining the methods used in generating electric power in any country. Here an example is the Snowy Mountains Scheme, which was a reasonable success in providing water for irrigation and jobs for new migrants but a limited success in generating electricity (only 3.4% of total generation in 1995). Another hydro project to suffer from political input was the proposed Franklin Dam in Tasmania. As most readers will recall this project was heavily criticised on environmental grounds with such success that it would be unlikely that another hydroelectric project will be built in this country – unless the "clean, green and renewable" rhetoric prevails.

Another was the Jervis Bay project – which was killed by politics (in our view rightly so), but which also served, along with the Fox Inquiry, to stimulate the political forces against nuclear power and uranium mining. The latter, in particular, has been a long running debate in this country founded on the rather peculiar notion that Australia should save the rest of the world from "nuclear power" (deliberately confused with nuclear weapons) by denying it Australian uranium. The consequent restrictions placed on the mining and export of uranium from this country have been a great boon to foreign producers to the extent that Australia with 30 - 40% of the world reserves supplies 10% of the demand while Canada with 10% of the reserves supplies 40% of the demand – all of which has restricted nuclear developments overseas not one iota.

Another manifestation of anti-nuclear politics has been the passage of anti-nuclear legislation in Victoria {Nuclear Activities (Prohibitions) Act 1983} and NSW {Uranium Mining and Nuclear Facilities (Prohibitions) Act 1986} which prohibit prospecting for uranium, mining uranium and prohibition of the construction or operation of nuclear reactors and other facilities in the nuclear fuel cycle, etc. And now the Labor Government in Queensland is promising to pass comparable legislation in that state. Aside from the possibility that further commercially significant uranium deposits may exist in Queensland, these pieces of legislation should be of little consequence to these states as long as they remain committed to coal for electricity generation. If they want to go nuclear however, the acts mean little (similar to "Nuclear Free Zone ordinances) since they simply could be revoked.

Which brings us to the primary energy source for almost 90% of the electricity generated in this country, coal. Coal has several advantages, the major one being that there is plenty of it. Also, there is a large associated industry that has been built up over the years, not only to construct, operate and maintain coal fired power stations, but to produce coal (25,000 employees and 6.1 deaths per year) for domestic use and export (exports worth about $A8 billion annually or 10% of merchandise exports). This industry obviously has political clout to the extent that it would take a tremendous amount of political counter pressure for any change to occur in the methods employed to generate electric power.

True, some small investments have come from governments to subsidise correspondingly small generating plants using solar PV or wind power (presumably as a sop to the environmentalists) but, as discussed above, by their very nature these methods will never contribute a significant fraction of electric energy demand, unless we wish to regress to an agrarian idyll, that is. But there is a counter pressure looming that could cause enough political pressure to be brought to bear to change the preferred method of generation in favour of nuclear. That is, limitations on greenhouse gas emissions – namely CO2 – coal generation's got a lot and nuclear doesn't Australia was probably fortunate to be able to achieve agreement at Kyoto to its near-BAU plan for reforming coal usage, land clearance and carbon sinks as a trade off to continuing to burn coal and increasing CO2 emissions to 8% above the 1990 level by 2008 - 2012 (reference 70). This was in contrast to the other developed countries that undertook to reduce such emissions by more than 5% mainly because they had access to nuclear electricity. Still, at this date the outcome of the Kyoto conference awaits ratification by most of the countries that attended, so this global plan may wind up as just more wishful thinking.

Aside from the moral issue of Australia not setting a very good example at Kyoto because it's hooked on coal, the real question is what will happen next? If more conclusive evidence becomes available that CO2 emissions are definitely leading to global warming and/or if the developing nations successfully demand that the advanced nations actually reduce CO2 emissions so they can increase theirs to the same per-capita level, then nuclear will be the only real option left (world energy consumption would have to increase by a factor of three to bring everyone up to the current OECD average). At this point one can well imagine the politicians in this country saying, "well if that's the case we'll just start burning our own lovely Australian uranium".

In the meantime it appears that Australia will continue as is, with occasional well-publicised and subsidised installations of minor renewable energy electric plants. An interesting commentary by Alan Moran on the situation appeared recently in the press (ref. 71). This article presents estimated generating costs in Australia for various fuels. These show that nuclear generation would be about 6 to 50% greater than coal. But the article goes on to point out that if ABARE's estimate of the $A208/tonne carbon tax required to achieve our Kyoto goal were included it would increase generation costs by present methods some 70%, whereas nuclear would become the lowest cost option by about a factor of one half. Moran concludes by saying "But proposals to build nuclear generation would bring a chorus of ill-informed opposition. No Australian government has demonstrated a willingness to take this on......It is just as well that the Kyoto undertakings will be quietly abandoned."

5. SUMMARY AND CONCLUSIONS

All energy/electricity generation systems release CO2 into the atmosphere to varying degrees. If we believe that CO2 is the major component of global warming the options we have are:

(1) Return completely to nature, rely on biomass (what you can grow), because that is the only CO2-neutral option. This is something that most city-based environmentalists would like to achieve but somehow they forget to perform an environmental impact assessment of such a policy on the existing population. Brough had a brief discussion of this approach when he raised the proposal that Australia's population should be limited to 6 million. There was an enthusiastic response from ACF members, but this changed to bewilderment when asked where they were going to live. Obviously, somebody else would make the sacrifice on their behalf. NIMBY.

One could also ask how many of the people in Europe could survive the winter on the philosophy of grow your own? Back to the pre-industrial revolution conditions.

Somehow, "alternative" energy sources don't need EIA's because they are assumed to be environmentally friendly.

(2) Choose technologies based on minimum CO2 generation, cost and environmental impact. As we have seen, all of the renewable energy sources entail some CO2 generation, but are generally too expensive and suffer from limitations in siting and availability (e.g. where is solar when the sun goes down?). These generation methods also require backup from the grid and consequent commitment of a portion of central station generation.

The remaining commercially proven system for base load generation that is comparable in cost to the present system but generates minimal CO2, is nuclear power.

(3) Choose a mix of technologies. Use all forms of electricity generation where it is most advantageous to do so, in terms of cost, and total environmental impact (including CO_2 generation), and have these supported by an interconnected grid that primarily would be fed by nuclear power stations.

It should be clear from the above examination that all forms of electricity generation have positive and negative aspects. These are summarised below.

Table 5.0-1: ASPECTS OF ELECTRICITY SOURCES FOR THE AUSTRALIAN CONTEXT

Method	Pluses	Minuses
Coal	commercially developed, large reserves near population, low energy costs	CO_2, acid and radioactive emissions, ash disposal, mining and transport deaths and injuries
Gas	commercially developed, large reserves, low energy costs	reserves remote, dependent on pipeline grid, radioactive emissions, production and transport deaths
Biomass	can increase carbon sink	low energy value fuels, half carbon in atmosphere, see 3.3.5
Hydro	low energy costs, creation of reservoirs for recreation	high capital costs, few sites available, high environmental impacts, danger from dam failures
Tidal/ Wave	seashore locations available	not commercial, adverse impact on environment, high costs, few sites, uneven availability
Solar Thermal	high temperatures achievable (but house water heaters economic)	high energy costs, not commercial
Solar PV	reliable commercial modules available	high energy costs, daytime availability
Wind	reliable commercial units available, costs moderate	small unit size, few sites near population available, visual & bird impacts, noisy, TV interference, wind availability.
Nuclear	largest domestic fuel reserves, low energy costs, proven technology, safe in operation, essentially no CO_2 emissions	very low risk of serious accident, political risk for community leaders

It should also be clear that the alternatives of wind, solar PV, tidal/wave and biomass can be employed in special circumstances, but in general these options suffer from intermittent availabilities (still necessitating base load backup to maintain supply) and high generating costs. Considering these aspects alone, none of these will make a significant contribution to national generation in the near future and probably never.

Hydro is also limited in the number of feasible sites remaining and even these can be ruled out because of potential or real political opposition based on environmental impact.

Thus the only options remaining for future expansion of base load generation are coal, gas and nuclear; all have comparable generation costs and are proven technologies. The first is the mainstay of present generation and certainly has the impetus and political clout behind it to serve in this way well into the future. However, the rising worldwide interest in limiting CO_2 emissions will probably eventually lead to internationally based demands that are strong enough to counter even the entrenched position of coal.

Gas is in a similar position to coal except that its CO_2 emissions are less, but this is at least partially offset by its limited availability to the eastern states power grid.

Nuclear then, is the remaining option for base load generation because it is the only one that is not significantly CO_2 producing, and has the proven capacity and reliability to satisfy the needs for future growth. Nuclear is marginally more expensive than coal in this country (about +0.8 ¢A/kWhe generating costs, depending on assumptions), which is certainly a lot cheaper than the other minor alternatives such as wind or solar PV and is approximately equivalent to the price paid by northern hemisphere countries to reduce SO_2 emissions to lessen their consequent environmental effects. Further, as discussed in the previous section, the anti-nuclear political forces in this country have succeeded in neutralising any attempts since the aborted Jervis Bay project to introduce nuclear power. This was not of great economic concern, however, since local coal based generation costs are comparable with that overseas. However, international pressure to limit CO_2 emissions may well serve to neutralise the local anti-nuclear political forces and enable the politicians to break out of this “politically correct” mold to once again countenance the use of nuclear power.

On this thesis, and speaking realistically, nuclear power should be introduced as soon as politically acceptable to ensure that it is available in sufficient capacity to meet the majority of future demands for electricity growth. This change in acceptability will probably occur a few years later than optimum from a technical viewpoint, in order to give time for the reality of the situation to be politically understood, but this should not prove to be an insurmountable hurdle since there need not be a long lead-time for the first station. Since this technology is already commercially developed overseas, the requirements for trained staff and local equipment supplies could be met through overseas training/recruitment and direct purchases until qualified local expertise and suppliers develop. Of course it would be better to introduce the nuclear option in a more orderly fashion as soon as is required by projected electricity capacity requirements, and it is hoped that the politicians in power at the time have this foresight.

APPENDIX 1: RETROSPECTIVES ON RENEWABLES

The Power and Energy Assessment Unit of the Australian Atomic Energy commission compiled renewables forecasts in 1976-79 (ref 2), which are given below together with an update of progress. A summary is provided in the table.

Denmark

In 1900, 100,000 windmills were milling wheat, pumping water and making some electricity. "Previous reports rated wind 2-3 times more expensive as oil and nuclear, but recent studies gave wind a favourable edge taking onto account price increases and uncertainties of supply for fossil fuels and uranium over the next 25 years (Oct 76).

Planned for 23% of total primary to be derived from nuclear by 1995, but public concern and discussion led to emphasis on solar space and water heating, wind electricity and combined power/district heating. The alternative energy plan was for 11% from wind by 1995 (Oct 77). In 1996, 5000 wind turbines produced 1232GWhe, 2.22% of electricity generation (50). Installed capacity is now 959MWe with an estimated output of 1920GWhe/y (ref. 72).

Denmark also claims to have 70% of the world market for wind turbines (ref.73).

USA

Ocean thermal was projected to be 1 - 5% of net generation by yr 2000, but none is being produced. Major developments were expected in photovoltaics with 3% by 2000. 1996 production by utilities was 3 GWhe, or 0.000086% of total electricity production. Solar thermal fared better with 0.03%, geothermal with 0.44% and wind 0.1%. It is interesting to note that 88% of the USA's electricity from the above sources is produced in California (refs. 74 and 75).

CANADA

It was expected that by 1990 4000GWhe would be produced by tidal hydro in the Bay of Fundy. This may have been reduced to a demonstration unit of 4.6MWe in 1991. Wind was stated to have the potential to supply double Canada's winter needs, but current production is 0.015% of the total. Biomass was estimated to be able to produce 19% of energy needs, but with the most recent information (1994) says that the mix was 16% nuclear, 62% hydro and 22% thermal does not leave much room for biomass production. For comparison, current biomass electricity generation in the USA is 1.7% out of 69% thermal production.

TABLE A1: AAEC FORECASTS FROM 1976/77
(see ref. 2)

COUNTRY	MODE	FORECAST (&DATE)	ACTUAL (&DATE)
Denmark	Wind	11% of energy (1995)	2.2% of energy (1996)
USA	Ocean Thermal	1-5% (2000)	0 (1996)
	PV	3% (2000)	? (1996)
	Solar Thermal	NF	0.03% (1996)
	Wind	NF	0.1 (1996)*
	Geothermal	NF	0.44 (1996)*
	Biomass	NF	1.7 (1996)*
Canada	Tidal	4000GWhe (1990)	4.6MWe (1991)
	Wind	60GWe	0.015% of total (1991)
	Biomass	19% of energy	?

Notes: NF = no forecast, * = approx 88% of this production is in California (ref. 75)

REFERENCES

1. “Nuclear Electricity”, I. Hore-Lacy, Uranium Information Centre, 6th ed., 2000.

2. Australian Atomic Energy Commission, Power and Energy Quarterly Information Bulletin, NSTB/PEQR 1 (4/76) through NSTB/PEQR 6 (10/77).

3. International Energy Outlook, 1995, Energy Information Administration, USDOE, Website: eia.gov/oiaf/ieo95/.

4. “The Economic Competitiveness of Nuclear Power”, Peter M.S. Jones, the Uranium Institute Annual Symposium 1993.

5. “Coal: The Industry, Trade and the Future”, F. Topham and W. Hennessy, pp 538-553 of “Greenhouse - Coping with climate change”, ed. W. Boumal et.al., CSIRO 1996.

6. “Water Power” A. Scanlon, published by the HEC Tasmania, 1995.

7. "Nuclear energy in the 21st Century", H. Blix, p34-39, Nuclear News September 1997.

8. "Fuel Economics in Power Generations", G. Reynolds, International Directory of Power Generation, 1998.

9. "The Analysis of Coals and Fly Ash for Trace Elements and Natural Radioactivity", J.J. Fardy, G.D. McOrist and Y.J. Farrar, CSIRO, Presented at Australian Coal Science Conference 1984.

10. Coal Geology and Coal Technology, C.R. Ward Ed., Blackwell Sci. 1984, p5-288.

11. "Coal Combustion: Nuclear Resource or Danger", A. Gabbard, ORNL Review Vol. 26 No.3&4, 1993.

12. World Almanac 1997.

13. "Meeting Greenhouse Targets in Australia – Implications for coal use", A. Dickson, et.al., ABARE Conference Paper 94.34.

14. The Australian Co-Generation Association, Plant Register, Members Directory and Annual Review 1998.

15. "Underground Seams a Gas" C. Murphy, The Australian 12/6/99.

16. The Guardian, September 8, 1998.

17. "Hydrogen and Nuclear Energy", R.B. Duffy, A.I. Miller and W.T. Hancox, D.R. Pendergast, CNS Bulletin, Jan-March 1999.

18. Mould, R. (of Kembla Grange Water Treatment Plant), Private Communication, 1998.

19. "Dams Switch to Power Production", J. Albert, The Weekend Australian 27-28/2/99.

20. "Squandering our Energies", A. & E. Fells, New Scientist 16 May 1998.

21. "Outback Town Gets Solar Boost", Powerhouse Magazine, May-June 1988.

22. SunPower at Wilpena, Newsletter of the Primary Industries and Resources, South Australia, (PIRSA) p 15, July 1998.

23. "Photovoltaics in Australia", G. Watt & M. Watt, Energy Research and Development Corporation report ERDC 295, 1977.

24. Commercial Quotation, SOLAHART, Aug 1998.

25. "Energy A Guidebook", J. Ramage, Oxford U press, 1997.

26. "Can Nature Help Solve Our Energy Needs", P. Garcia, Readers Digest October 1998.

27. Australian Bureau of Statistics Yearbook 1997, p451.

28. Editorial, M.J. Moore, Journal of Power and Energy, Vol. 212 part A, 1998.

29. Nuclear Europe Worldscan, July-August 1999.

30. "A Fresh Look at Thorium Fuel Cycles in Candu Reactors", P.G. Bocazar, P.S.W. Chan, G.R. Dyck, J.D. Sullivan, P. Taylor, and R.T. Jones, AECL, Presented at 11th PBNC May 3-7 1998.

31. "Australia's Uranium Opportunities" K.F. Alder 1996

32. "Rescue the Future – reducing the impact of the greenhouse effect", a report by the Senate Standing Committee on Industry, Science and Technology, 1991.

33. J.R. Fredsall, "Estimated Nuclear and Coal Generation Costs Overseas and In Australia", Nuclear Australia, Feb 1990.

34. J.E. Hayes, "Nuclear Power For Australia???", an address to the Nuclear Power Group, IEAust. November 1995.

35. "Projected Costs of Generating Electricity, Update 1992" OECD.

36. "Can Nuclear Power Stay Competitive?",NEA Newsletter No.1 1998.

37. "The Economics of Nuclear Power", Uranium Information Centre Nuclear Issues Briefing Paper 8, March 1998.

38. Integral Energy data sheets 8/98.

39. "Catching the Tide", F. Pearce, p 38-41, New Scientist, 20 June 1998.

40. Big-Headed Ants March on Darwin, p 36 Ecos 95, April-June 1998.

41. Invasion North, W.J. Freeland, Australian Natural History 22(2) p69, 1988.

42. Northern Territory Government, web site coburg.nt.gov.au/paw/fauna/bau/guc

43. Sydney Morning Herald, 28/11/98, p11.

44. Listen, Our Land is Crying, p 204, M.E. White, Kangaroo Press, 1997.

45. Industry, Japan, Atoms in Japan, p8 Jan 1998.

46. Comparing Energy Options", H. Rogner and A. Khan, "IAEA Bulletin Vol. 40, No. 1 1998.

47. "The Power To Choose", p18, New Scientist 6/9/97.

48. Senior Expert Symposium on Electricity and Environment, Helsinki, Finland 13-17 May 1991.

49. Pacific Power Annual Report 1996.

50. Chernobyl, Ten Years On – Radiological and Health Impacts. An appraisal by the NEA Committee on Radiation Protection and Public Health, 1996.

51. Ten Years After Chernobyl: What do We Really Know? IAEA/WHO/EC Conf., Vienna, April 1996.

52. "Radiological Consequences of Chernobyl Accident: UNSCEAR Confirms Earlier IAEA Estimates", IAEA press release 13 June 2000.

53. Bromley J., "Comparison of the Hazards of coal and uranium mining". ATOM, March !987, p 3-9.

54. The European, 13-19 March 1997, p4.

55. Japan's Coal Mining Industry Today, 1988, Japan CMRC.

56. "Historical Data 1931-1977 and Historical Data 1978-1997 All Coal Mines," Mine Safety and Health Administration US Dept. of Labor, Net address: msha.gov/STATS/PART50/WQ/ etc.

57. "Lost Time and Fatal Injuries, Queensland Mines and Quarries Statistical Report," Queensland Department of Mines and Energy 1 July 1997 to 30 June 1998, pub. 30/9/98.

58. Australian Black Coal Statistics 1996 (&1998), Joint Coal Board and Queensland Coal Board.

59. Lost Time Injuries and Fatalities in NSW Coal Mines 1994-5, Joint Coal Board.

60. Cohen, B.L. Validity of the Linear No-Threshold Theory of Radiation Carcinogenesis at Low Doses, Uranium Institute 23rd Annual Int. Symposium 1998.

61. J. Graham, D. Higson, Jae-Shik Jun, S. Kobuyashi, R.E.J. Mitchel, "Low Doses of Ionizing Radiation at Low Dose

Rates," Radiation Protection in Australasia 1999, V16, No.1.

62. Living with Risk, The British Medical Association Guide, Wiley 1987.

63. Radiation Atlas, Natural Sources of Ionising Radiation in Europe, Green, B.M.R., Hughes, J.S. and Lomas, P.R. European Union Publication EUR14470 1993.

64. Taylor,D.M., Environmental Plutonium in Humans. Appl Radiat & Isotop, V46, p1245-1252, 1995.

65. Cohen, B L, Test of the linear-no threshold theory of radiation carcinogenesis for inhaled Radon decay products Health Phys. 68:157-174; 1995.

66. Cohen, B.L., "Relationship Between Exposure to Radon and Various Types of Cancer," Health Physics 65 (5):529-531; 1993.

67. United Nations Environment Programme reports of 1986 (pp 46, 47) and 1991 (pp 29, 63): RADIATION; Doses, Risks, Effects.

68. UIC Report July/August p3, 1997.

69. "Radioactive Emission from Thermal Power Plants and Related Problems", K. Okamoto, Proceedings of AIE National Conference 5-9 Feb 1979.

70. "Terms and Impacts of the Kyoto Protocol", P. Kay, Current Issues Brief 10 1997-98, Australian Parliamentary Library, 9/3/98.

71. "Go nuclear, but only if you can handle the hate", A. Moran, Institute of Public Affairs, The Australian 23/3/99.

72. Larson, J.L., "Scandanavian Business News" p20, April 1998.

73. Energy in Denmark 1998, Energy Policies and Results, Danish Energy Agency.

74. US Energy Information Administration, Electric Power Industry at a Glance, 1996. Web site: eia.doe.gov/cneaf/electricity.

75. California Energy Commission, California Energy Facts, 1996. Web site: energy.ca.gov/html/calif_energy_facts.html.

76. "Forest Facts", NSW State Forests. Original source Dr Willima R. Lawson, "Timber in Building Construction; Ecological Implications," UNSW July 1996.

77. Private Communication to Brough, VESTAS Turbines Dec. 1998 (bill of materials for 600 kWe turbine).

78. "Nuclear Power in the OECD," IEA 2001

79. "National Greenhouse Gas Inventory, Part 3 Sectorial Contributions to Emissions, 1997" National Greehouse Office 6 April 2001.

80. US Department of Labor, Bureau of Labor Statistics.

TABLE 2.0-1: Gigawatt-Hours Generated in Australia (Capacity MWe), Financial 1995

(Source: Electricity Australia 1996, ESAA)

Type of Plant	NSW	VIC	QLD	SA	WA	TAS	NT	SMA	Total
Hydro	145 (345)	1,042 (469)	401 (632)	0 (0)	4 (2)	8,679 (2,263)	0 (0)	5,582 (3,756)	15,855 (7,466)
Steam	54,189 (11,536)	36,831 (6,220)	31,219 (6,065)	8,130 (1,905)	10,820 (2,040)	0 (0)	0 (0)	0 (0)	141,191 (28,006)
Internal Combustion	2 (0.91)	0 (0)	49 (29.2)	19 (175)	281 (0)	15 (5.9)	151 (95.5)	0 (0)	519 (329)
Gas Turbine	2 (295)	301 (466)	0.2 (170)	6 (321)	1,064 (739)	0 (0)	472 (221)	0 (0)	1,846 (2,211)
Combined Cycle	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	3 (0.9)	692 (101)	0 (0)	695 (102)
Wind	0 (0)	0 (0)	0 (0)	0.3 (0.15)	6 (2.02)	0.2 (0.06)	0 (0)	0 (0)	6.5 (2.23)
Total	54,339 (12,177)	38,174 (7,155)	31,670 (6,896)	8,156 (2,248)	12,177 (2,957)	8,697 (2,509)	1,316 (417)	5,582 (3,756)	160,114 (38,116)

Table 3.1-1: Trace Elements in Australian Coals
(arithmetic means, ppm)

Elements	Black Coals		Brown Coals		Earth's Crust	NSW & Qld. Coals
	Coal	Fly Ash	Coal	Fly Ash		
Na	570	4000	950	16400	28300	*
Al	28000	127000	3000	109000	81000	*
Cl	360	*	780	*	*	*
K	1800	13000	75	5750	26000	*
Ca	4000	11000	*	*	36000	*
Sc	5.1	19	0.4	12	22	3
Ti	1700	6400	400	4760	4400	*
V	32	130	3.5	120	135	20
Cr	12.5	50	2.2	96	100	6
Mn	120	630	21	870	950	150
Fe	8300	31000	1750	97000	50000	*
Co	5.9	16	0.60	224	25	4
Zn	27	110	3.5	600	70	25
Ga	6.5	35	*	*	*	4
As	2.4	5.1	0.17	80	1.8	3
Se	0.81	1.5	0.59	*	0.05	0.79
Br	3.6	*	12.8	*	*	*
Sr	140	280	82	740	375	100
Cd	*	*	*	*	*	0.1
Sb	0.84	3.4	0.08	2.2	0.2	*
Cs	1.2	4.8	0.04	6.3	3	*
Ba	210	520	63	2240	425	<100
La	12	62	1.30	77	30	10
Ce	23	110	10.3	140	60	*
Nd	11	40	1.78	35	*	*
Sm	2.3	11	0.32	11	6	*
Eu	0.41	2.2	0.055	2.4	1.2	*
Tb	0.34	1.7	0.08	1.6	0.9	*
Dy	2.2	*	0.22	11	*	*
Ho	0.43	*	*	*	*	*
Yb	1.2	7.8	0.15	5.7	3.4	*
Lu	0.23	1.1	0.028	0.7	*	*
Hf	2.2	12	0.25	5.0	3	*
Ta	0.27	1.5	0.12	1.2	2	*
W	2.5	5.5	0.45	3.5	1.5	<10
Au	0.005	0.01	*	*	*	*
Hg	*	*	*	*	*	0.1
Pb	*	*	*	*	*	10
Th	3.7	24	0.29	9.9	7.2	2.7
U	1.3	7.3	0.35	3.6	1.8	2
Ref.	a	a	a	a	a	b

* = no value quoted.
Ref. a = "The Analysis of Coals and Fly Ash for Trace Elements and Natural Radioactivity", J.J. Fardy, G.D. McOrist and Y.J. Farrar, CSIRO, Presented at Australian Coal Science Conference 1984.
Ref b = Coal Geology and Coal Technology, C.R. Ward Ed., Blackwell Sci. 1984.

Table 3.4-1

World nuclear power status in 1998 (IAEA figures)

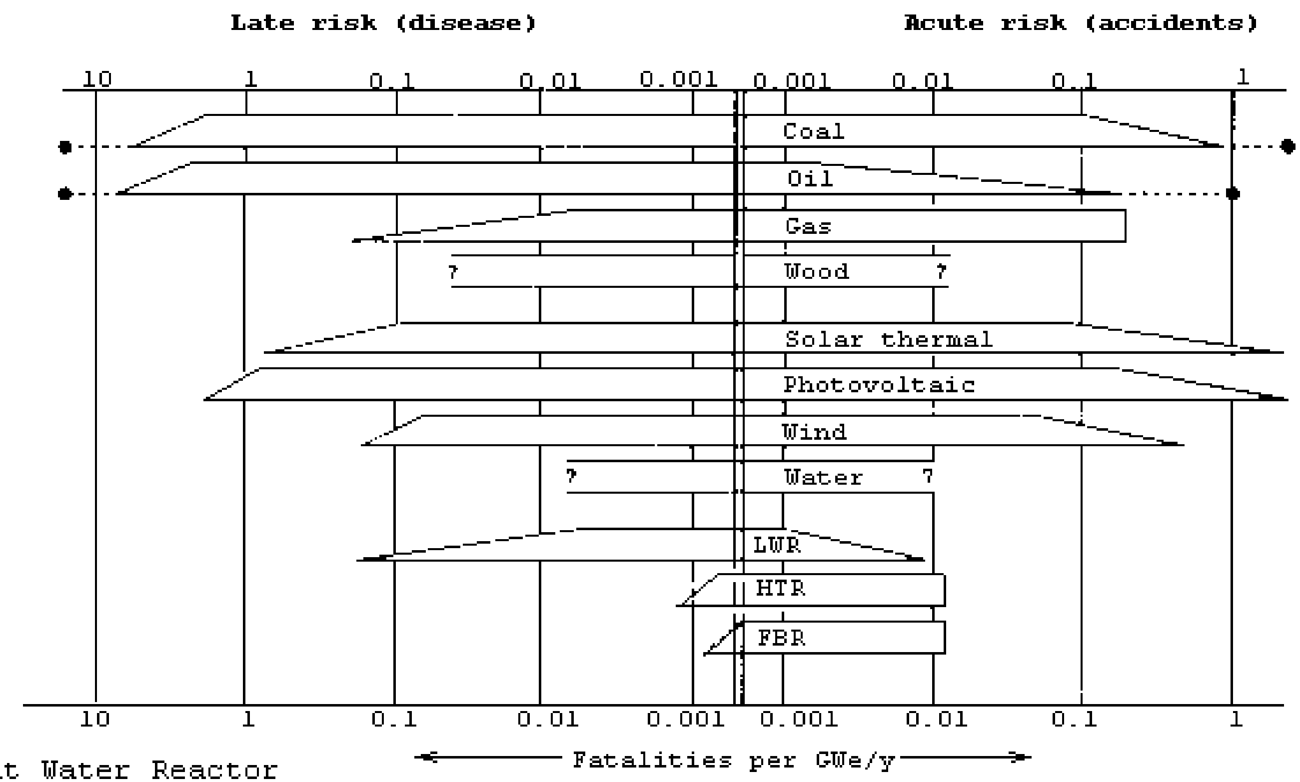
	Operation	Construct	'98 TWh	%Share
Argentina	2	1	6.93	10.04
Armenia	1	-	1.42	24.69
Belgium	7	-	43.89	55.16
Brazil	1	1	3.27	1.08
Bulgaria	6	-	15.49	41.50
Canada	14	-	67.86	12.44
China	3	6	13.46	1.16
Czech Rep.	4	2	12.35	20.50
Finland	4	-	20.98	27.44
France	58	1	368.40	75.77
Germany	20	-	145.20	28.29
Hungary	4	-	13.12	35.62
India	10	4	10.15	2.51
lran		2	–	–
Japan	53	2	306.94	35.86
Kazakhstan	1	-	0.09	0.18
South Korea	15	3	85.19	41.39
Lithuania	2	-	12.29	77.21
Mexico	2	-	8.83	5.41
Netherlands	1	-	3.59	4.13
Pakistan	1	1	0.34	0.65
Romania	1	1	4.90	10.35
Russia	29	4	95.38	13.08
Slovak Rep.	5	3	11.39	43.80
Slovenia	1	-	4.79	38.33
South Africa	2	-	13.58	7.25
Spain	9	-	56.68	31.66
Sweden	12	-	70.00	45.75
Switzerland	5	-	24.37	41.07
Taiwan	6	1	35.41	24.77
UK	35	-	91.14	27.09
Ukraine	16	4	70.64	45.42
US	104	-	673.70	18.69
Total	**434**	**36**	**2291.41**	**~22.0**

TABLE 4.1-2: OECD/NEA PROJECTED GENERATING COSTS 1992

(1991 US¢/kWh, Startup in 2000, 5% discount)

COUNTRY	Nuclear				Coal				Gas			
	Cap.	O&M	Fuel	Total	Cap.	O&M	Fuel	Total	Cap.	O&M	Fuel	Total
Belgium	2.02	0.75	0.83	3.59	1.32	0.50	2.12	3.94	0.91	0.52	2.66	4.08
Canada	2.28	0.53	0.18	2.98	1.08-1.44	0.41-0.75	0.75-1.66	2.54-3.82	0.82	0.22-0.31	1.75-4.18	2.88-5.22
Finland	1.89	0.54	0.58	3.01	0.98	0.67	1.86	3.50	0.58	0.40	2.55	3.53
France	1.45	1.00	0.83	3.28	1.17	0.95	2.94	5.06	0.70	0.42	4.36	5.48
Germany	2.96	1.27	1.08	5.31	1.69	1.51	3.54-4.81	6.74-8.01	-	-	-	-
Japan	2.44	1.09	1.83	5.37	2.06	0.79	3.45	6.30	1.27	0.69	5.77	7.73
UK	3.06-3.23	0.97-1.13	0.81	4.84-5.16	1.61-19.4	1.13-1.29	1.94	4.68-5.16	0.65	0.65	3.23	4.52
US	2.05-2.21	1.64	0.52	4.21-4.37	1.68-1.77	0.73-1.02	1.12-2.40	3.53-5.13	0.62	0.25	3.90-4.24	4.77-5.11
China	1.50	0.66	0.91	3.07	1.03	0.52	2.02	3.57	-	-	-	-
CSFR	1.21	0.74	0.94	2.89	1.23	0.75	1.33	3.31	0.66	0.28	2.69	3.63
Hungary	1.89	0.45	0.69	3.03	1.40-2.14	0.47-1.10	1.94-2.26	4.13-5.18	0.36	0.23	3.25	3.84
India	1.72	1.19	0.71	3.61	1.25	0.41	2.55	4.21	-	-	-	-
Korea	1.67-1.94	0.73-1.18	0.30-0.53	3.15-3.20	1.08	0.88	2.29	4.25	-	-	-	-

Figure 4.3-1 Public Mortality Due to Electricity Production (all steps of the fuel cycle; without severe accidents)



LWR: Light Water Reactor
HTR: High Temperature Reactor
FBR: Fast Breeder Reactor

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