4

Greenhouse gas emissions and nuclear power

Responsible and balanced policy would strive for a mix of low-greenhouse energy sources: CO2-free nuclear for baseload power in countries with high ambient power demand; low-CO2 coal, because coal is abundant; natural gas for peaking loads; hydro, wind, tidal, solar where suitable and appropriate. Achieving better energy efficiency in product design and use and reducing excessive consumption in the developed world through better electricity pricing are also important strategies. There is no single panacea, but no likely remedy should be arbitrarily rejected. Windmills and reactors each have parts to play.[1]

… I am a Green and I entreat my friends in the movement to drop their wrongheaded objection to nuclear energy. Even if they were right about its dangers, and they are not, its worldwide use as our main source of energy would pose an insignificant threat compared with the dangers of intolerable and lethal heat waves and sea levels rising to drown every costal city in the world. … civilisation is in imminent danger and has to use nuclear – the one safe, available, energy source – now or suffer the pain soon to be inflicted by our outraged planet.[2]

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1 Paladin Resources Ltd, *Submission no. 47*, p. 7.

2 Sir James Lovelock, 'Nuclear Power is the only green solution', *The Independent*, 24 May 2004, viewed 15 May 2006, <http://comment.independent.co.uk/commentators/article61727.ece>.

Key messages —

- **Electricity generation is the largest and fastest growing contributor to global carbon dioxide (CO_2) emissions, responsible for 40 per cent of global emissions in 2003—10 billion tonnes of CO_2. Emissions from electricity are projected to contribute approximately 50 per cent of the increase in global CO_2 emissions to 2030.**
- **Nuclear power is a CO_2-free energy source at point of generation.**
- **Over the whole fuel cycle, nuclear power emits only 2–6 grams of carbon (or up to 20 grams of CO_2) per kilowatt-hour of electricity produced. This is two orders of magnitude less than coal, oil and natural gas, and is comparable to emissions from wind and solar power.**
- **A single nuclear power plant of one gigawatt capacity offsets the emission of some 7–8 million tonnes of CO_2 each year if it displaces coal. A nuclear plant will also offset the emission of sulphur dioxide, nitrous oxide and particulates, thereby contributing significantly to air quality.**
- **Nuclear power currently avoids the emission of 600 million tonnes of carbon per year. If the world were not using nuclear power, CO_2 emissions from electricity generation would be at least 17 per cent higher and 8 per cent higher for the energy sector overall. By 2030, the cumulative carbon emissions saved due to the use of nuclear power could exceed 25 billion tonnes.**
- **Australia's uranium exports currently displace at least 395 million tonnes of CO_2 per year, relative to use of black coal. This is equivalent to 70 per cent of Australia's total greenhouse gas emissions for 2003. Australia's total low cost uranium reserves could displace nearly 40 000 million tonnes of CO_2 if it replaced black coal electricity generation.**
- **The capacity of uranium to mitigate production of greenhouse gases depends on the extent to which nuclear power displaces carbon-based energy sources in electricity generation. In the future, nuclear power may also have the capacity to reduce emissions from the transport sector through the production of hydrogen.**
- **For the generation of continuous, reliable supplies of electricity on a large scale, the only alternative to fossil fuels is nuclear power.**
- **Nuclear power is cost competitive with gas and coal-fired electricity generation in many industrialised countries. Nuclear plants offer**

very low operating costs, security of energy supply and electricity price stability.

Introduction

4.1 This chapter addresses the greenhouse gas emissions avoided by the use of nuclear power, emissions across the whole nuclear fuel cycle, the contribution from renewable energy sources, and the relative economic attractiveness of nuclear power for baseload power generation.

4.2 In turn, the Committee considers:

- the nature of the enhanced greenhouse effect and the potential consequences of climate change;
- projections for global energy and electricity demand and associated carbon dioxide emissions; and
- the contribution that nuclear power makes to the mitigation of greenhouse gas emissions, the quantity of emissions displaced by export of Australia's uranium, and the possible future emission savings from expanded use of nuclear power.

4.3 The Committee then considers arguments critical of nuclear's greenhouse gas mitigation potential, including claims about emissions across the whole nuclear fuel cycle compared to other electricity generation chains, the energy used to enrich uranium and the energy required to extract uranium as ore grades decline. The Committee then addresses arguments associated with the claim that nuclear power is too limited, slow and impractical to 'solve' climate change. Discussion follows on the limitations of renewables and efficiency measures, and the need for a mix of low-emission energy sources.

4.4 The chapter concludes with an overview of the economics of nuclear power and its competitiveness relative to other baseload alternatives and renewables.

The enhanced greenhouse effect

4.5 The greenhouse effect is the term used to describe the retention of heat in the Earth's lower atmosphere. The enhanced greenhouse effect refers to the rise in the Earth's surface temperature (global warming) which is considered likely to occur because of the increasing concentration of certain gases in the atmosphere due to human activities. These gases are referred to as greenhouse gases.[3]

4.6 Greenhouse gases absorb infrared radiation reflected back from the Earth's surface and trap heat in the atmosphere. The principal greenhouse gases are carbon dioxide (CO_2), methane, halocarbons and nitrous oxide. While some greenhouse gases exist in nature, such as water vapour, CO_2 and methane, others are exclusively human-made, such as gases used for aerosols.

4.7 Atmospheric concentrations of greenhouse gases have increased significantly during the last century and most of this increase is attributed to human sources; that is, of anthropogenic origin. Human activities that generate greenhouse gases include burning fossil fuels (coal, oil and natural gas), agriculture and land clearing.[4]

4.8 Carbon dioxide is considered the most significant anthropogenic greenhouse gas (GHG) and fossil fuel combustion is known to be responsible for the largest share of global anthropogenic GHG emissions, accounting for 80 per cent of emissions in industrialised countries in 2003. The second largest source of GHG emissions is agriculture, which contributes seven per cent (mainly methane and nitrous oxide).[5]

4.9 The atmospheric concentration of CO_2 is now at 380 part per million by volume (ppmv), which is the highest level for at least 420 000 years, and possibly the highest concentration for 20 million years.[6]

4.10 In addition to historically high concentrations, the rate of increase is also unprecedented during at least the past 20 000 years.[7] Evidence emphasised that 'of the non-catastrophic sources of quick CO_2 emissions into the atmosphere, it appears that the rate of change in the last 150 years has been greater than that previously witnessed.'[8] That is, although major volcanic events such as Krakatoa have introduced large volumes of CO_2 into the atmosphere in shorter time frames, the current rise is the fastest increase of anthropogenic origin.

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3 Uranium Information Centre (UIC), *Global Warming*, Nuclear Issues Briefing Papers No. 24, UIC, Melbourne, 2003, viewed 11 May 2006, < http://www.uic.com.au/nip24.htm>.

4 Australian Greenhouse Office (AGO), *Climate Change Science – Questions Answered*, Australian Government Department of the Environment and Heritage, Canberra, 2005, p. 5, viewed 12 January 2006, <http://www.greenhouse.gov.au/science/qa/index.html>.

5 International Energy Agency (IEA), *CO_2 Emissions from Fossil Fuel Combustion 1971–2003*, OECD/IEA, Paris, 2005, p. xvii.

6 B Pittock (ed), *Climate Change: An Australian Guide to the Science and Potential Impacts*, AGO, Canberra, 2003, p. 23.

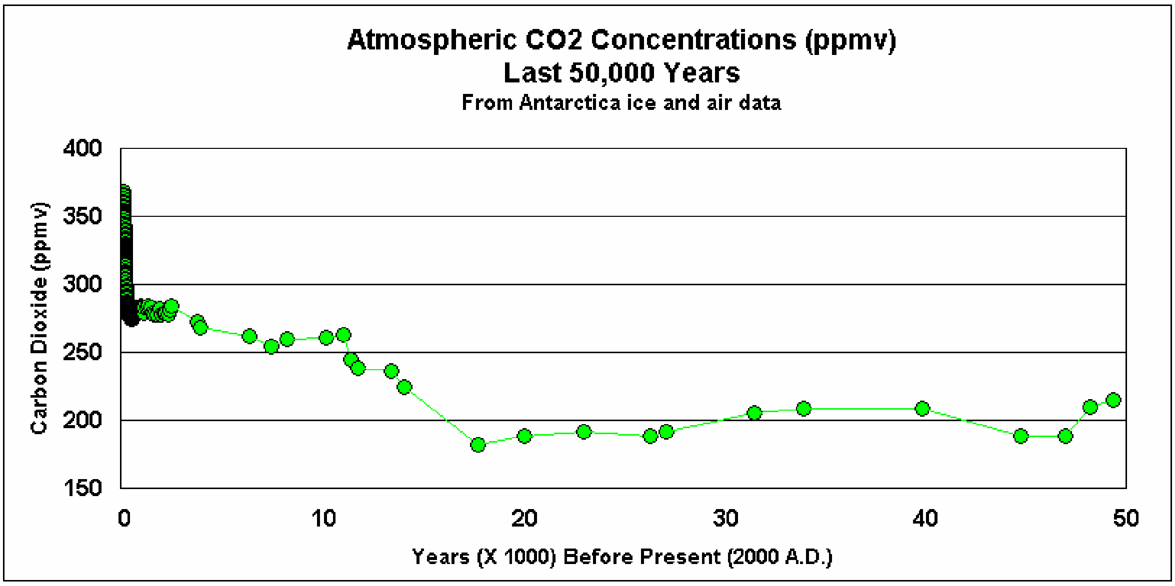
7 Nova Energy Ltd, *Submission no. 50*, p. 18.

8 Dr Rod Hill (CSIRO), *Transcript of Evidence*, 19 August 2005, p. 8.

4.11 The increase in atmospheric concentrations of CO_2 during the past 250 years is depicted in figure 4.1. Over the period from 50 000 years ago to the last hundred years, concentrations remained in the range of 200 to 270 ppmv. However, the Australian Nuclear Science and Technology Organisation (ANSTO) argued that since the industrial revolution CO_2 concentrations have increased dramatically.[9] In 1750, CO_2 concentrations were approximately 280 ppmv, but by 2000 they had risen to 370 ppmv—an increase of 32 per cent.[10]

4.12 The rate of increase has been pronounced even over the span of a few decades. In 1959, CO_2 concentrations were 316 ppmv, but had risen to 375 ppmv by 2003—an 18.8 per cent increase over just 44 years.[11]

Figure 4.1 Atmospheric concentrations of CO_2 over the last 50 000 years (parts per million by volume)



Source ANSTO, *Exhibit no. 74, Presentation by Dr Ron Cameron and Dr Ian Smith*, p. 17.

4.13 The Committee's inquiry was concerned with the potential implications for global GHG emission reductions from the further development of Australia's uranium resources. Comment was not explicitly sought on the link between GHG emissions and global warming, or the possible severity of climate change. Nevertheless, most submitters were convinced that 'carbon dioxide is driving … global climate change. The greenhouse effect

9 Dr Ian Smith (ANSTO), *Transcript of Evidence*, 13 October 2005, p. 5.

10 Dr Michael Goldsworthy (Silex Systems Ltd), *Transcript of Evidence*, 9 February 2006, p. 2. In addition, nitrous oxide levels have increased by 17 per cent and methane concentrations have more than doubled. See also: AGO, *op. cit.*, p. 6.

11 Nova Energy Ltd, *loc. cit.*

is real' and global warming will have 'potentially catastrophic consequences.'[12]

4.14 Drawing on findings published by the International Panel on Climate Change (IPCC), it is widely reported that the global average surface temperature increased by about 0.6 degrees Celsius (°C) over the past one hundred years (0.7°C in Australia).[13] Carbon dioxide is estimated to contribute some 60 per cent of the warming effect.[14]

4.15 In its Third Assessment Report (2001), the IPCC concluded that 'there is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities.'[15] According to all IPCC emissions scenarios, CO_2 concentrations, global average temperature and sea-level rise are all projected to increase in the coming decades without additional mitigation action.

4.16 ANSTO commented that the world cycles between glacial and warmer inter-glacial periods over about 100 000 years. During each cycle, sea level changes by about 120 metres and the temperature changes by approximately five or six degrees. A change in cycle is thought to be triggered by about 180 ppmv CO_2 to 260 ppmv CO_2. As noted above, atmospheric concentrations are now at about 380 ppmv and are projected to rise to at least 450 or even 550 ppmv. ANSTO argued that:

> … the world is now into a cycle that has been going on for a period of 150 years. We are making the kinds of change in CO_2 level that triggered that change happening in just 100-odd years.[16]

That is, climatic changes that would previously have been experienced over a 100 000 year glacial-interglacial cycle are projected to occur in a mere 100 years.

4.17 In addition to global temperature change and sea level rise, ANSTO noted that increased CO_2 concentrations acidify the oceans which will have potentially disastrous effects on coral reefs and marine life.[17]

4.18 The potential consequences of global warming were emphasised by the Chief Scientific Adviser to the British Government, Sir David King, who attributed half of the severity of the 2003 heatwave in Europe, which killed 30 000 people, to global warming with a 90 per cent statistical certainty.[18]

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12 Dr Michael Goldsworthy, *loc. cit*; Nova Energy Ltd, *op. cit.*, p. 19.

13 B Pittock, *op. cit.*, p. 3; AGO, *op. cit.*, p. 4.

14 UIC, *loc. cit.*

15 Cited in IEA, *op. cit.*, p. xviii.

16 Dr Ian Smith, *op. cit.*, p. 6.

17 *ibid.*

18 *ibid.*

4.19 While the Committee notes that there are uncertainties in the science of climate change, the Australian Government reports that climate models, based on a range of emission scenarios, indicate that increasing atmospheric concentrations of greenhouse gases could cause average global temperatures to rise by between 1.4 and 5.8°C by 2100.[19] The consequences of a temperature rise of this magnitude could be dramatic:

> This rate and magnitude of warming are significant in the context of the past 400,000 years. History has shown us that a warming of 1–2°C can have dramatic consequences. Even the 0.6°C warming in the past 100 years has been associated with increasing heat waves and floods, fewer frosts, more intense droughts, retreat of glaciers and ice sheets, coral bleaching and shifts in ecosystems. A further warming of 1.4 to 5.8°C could challenge the adaptive capacity of a range of human and natural systems.[20]

The global energy situation and carbon dioxide emissions

4.20 Global primary energy demand is projected to grow at a rate of 1.6 per cent per year in the period 2003 to 2030. This would see demand for energy increase by 52 per cent over the period and reach 16.3 billion tonnes of oil equivalent (toe) by 2030.[21]

4.21 Fossil fuels are expected to continue to meet the overwhelming bulk of the world's energy needs. Oil, natural gas and coal are expected to account for 83 per cent of the increase in world energy demand over 2003–30 and account for 81 per cent of energy demand in 2030 (up slightly from 80 per cent in 2003).[22]

4.22 Electricity consumption, which uses some 40 per cent of the world's primary energy supply, is forecast to grow at a faster rate than overall energy demand. Electricity consumption is projected to grow at an annual rate of 2.5 per cent and rise from 15 000 terawatt-hours (TWh) currently, to

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19 AGO, *op. cit.*, p. 5; Nova Energy, *op. cit.*, p. 19. Media reports claim that the IPCC's Fourth Assessment Report, to be issued in 2007, will find that temperature rises will be between 2 and 4.5°C by 2100. See: M Warren, 'Science tempers fears on climate', *The Australian*, 2–3 September 2006, p. 1.

20 AGO, *loc. cit.*

21 IEA, *World Energy Outlook 2005*, OECD/IEA, Paris, 2005, p. 80.

22 *ibid.*; ANSTO, *Exhibit no. 74, Presentation by Dr Ron Cameron and Dr Ian Smith,* p. 26.

24 000 TWh by 2025.[23] The growth in demand is likely to be driven by the industrial modernisation of India and China.[24]

4.23 In 2003, fuel for world electricity production was provided 39.9 per cent by coal, 19.2 per cent by natural gas, 6.9 per cent by oil (for a total of 66 percent from burning fossil fuels), 16.3 per cent by hydro, 1.2 per cent by combustible renewables (such as biomass), and 0.7 per cent from geothermal, solar and wind combined. Nuclear was the fourth largest fuel source for electricity generation at 15.7 per cent.[25] It is anticipated that the majority of the growth in electricity consumption will be fuelled by coal.[26]

4.24 World CO_2 emissions from fossil fuel combustion reached 25 billion tonnes (gigatonnes, Gt) in 2003, an increase of 20 per cent on the 1990 level of 20.7 Gt. Of these emissions, around 38 per cent comes from coal, 21 per cent from gas and 41 per cent from oil.[27] Energy-related CO_2 emissions are projected to increase by 1.6 per cent annually between 2003 and 2030, reaching 37 Gt of CO_2 emitted annually by 2030—an increase of 52 per cent over the 2003 level.[28]

4.25 According to the IEA, the largest and fastest growing contributor to global CO_2 emissions is the electricity and heat sector, which contributed 40 per cent of world CO_2 emissions in 2003—10 Gt of CO_2. Emissions from electricity generation grew by 44 per cent over the 13 years to 2003 and are projected to contribute approximately 50 per cent of the increase in global emissions to 2030. Other major contributors to world CO_2 emissions are the transport sector (24 per cent) and manufacturing and construction (18 per cent). Transport will contribute a quarter of the emissions increase to 2030.[29]

23 IEA, *Electricity Information 2005*, OECD/IEA, Paris, 2005, p. I.4; UIC, *Submission no. 12*, p. 7; Summit Resources Ltd, *Submission no. 15*, p. 27; Heathgate Resources Pty Ltd, *Exhibit no. 57, Energy for the World – Why uranium?*, p. 2.

24 Dr Michael Goldsworthy (Silex Systems Ltd), *Transcript of Evidence*, 9 February 2006, p. 2; UIC, *loc. cit*.

25 IEA, *Electricity Information 2005*, *op. cit*., pp. I.39, I.43. See also: World Nuclear Association (WNA), *Sustainable Energy – Uranium, electricity and greenhouse*, March 2006, viewed 16 March 2006, <http://world-nuclear.org/education/ueg.htm>; Cameco Corporation, *Submission no. 43*, p. 6; Mr Bernie Delaney (BHP Billiton Ltd), *Transcript of Evidence*, 2 November 2005, p. 26.

26 Dr Michael Goldsworthy, *loc. cit*. Association of Mining and Exploration Companies (AMEC), *Submission no. 20*, p. 7.

27 WNA, *Sustainable Energy – Uranium, electricity, and greenhouse*, March 2006, viewed 16 May 2006, <http://world-nuclear.org/education/ueg.htm>.

28 IEA, *CO_2 Emissions from Fossil Fuel Combustion 1971–2003, op. cit*., p. xxiii; IEA, *World Energy Outlook 2005*, *op. cit*., p. 92.

29 IEA, *CO_2 Emissions from Fossil Fuel Combustion 1971–2003*, *op. cit.,* pp. xxiii, xxviii; IEA, *World Energy Outlook 2005, loc. cit.*

4.26 While industrialised countries have been overwhelmingly responsible for the build-up in fossil fuel-related CO_2 concentrations to date, much of the future increase in emissions is expected to occur in the developing world, where economic development and energy demand is predicted to be supplied primarily with fossil fuels. Developing countries' emissions are expected to grow above the world average at 2.7 per cent annually to 2030. Developing countries will be responsible for 73 per cent of the increase in global CO_2 emissions to 2030 and surpass the OECD as the leading contributor to global emissions in the early 2020s. The increase in emissions from China alone will exceed the increase in all OECD countries and Russia combined.[30]

4.27 ANSTO amplified the significance of the forecast growth in energy demand in developing countries, explaining that during the last 30 years some 31 per cent of the growth in energy production was in the OECD, with 59 per cent in the developing world. In the next 30 years however, there is predicted to be only three per cent growth in the OECD, but 85 per cent growth in the developing countries:

> If you take Nigeria, for instance, the average electricity consumption per person is 70 kilowatt hours per year. If you want to quantify it, that is the equivalent of leaving your television set on stand-by for the year. The average use in Europe is 8,000 kilowatt hours per person. So as these people develop, we are going to have a greater energy demand.[31]

4.28 The IEA also notes that in 2003 some 1.6 billion people were without access to electricity. If future energy demand is met by fossil fuels, the implications for CO_2 emissions are dramatic, as indicated in the forecasts above.[32]

4.29 With these forecasts in mind, a number of submitters argued that nuclear power will be essential to reduce emissions from electricity generation. For example, Cameco argued that:

> Numerous studies have noted the generation of electricity from fossil fuels, notably coal and natural gas, is a major and growing contributor to the emissions of carbon dioxide – a greenhouse gas that contributes significantly to global warming. There is a scientific consensus that these emissions must be reduced, and a growing opinion the increased use of nuclear power is one of only

30 ANSTO, *Exhibit no. 74, Presentation by Dr Ron Cameron and Dr Ian Smith*, p. 28; IEA, *World Energy Outlook 2005, op. cit.*, pp. 92, 93.

31 Dr Ian Smith, *op. cit.*, p. 7.

32 IEA, *CO_2 Emissions from Fossil Fuel Combustion 1971–2003*, *op. cit.*, p. xvii.

a few realistic options for reducing carbon dioxide emissions from electricity generation.[33]

4.30 Similarly, Areva argued that stabilising emissions will require mitigation policies. It was noted that in order to stabilise emissions at a target of 550 ppm of CO_2 will require that emissions be limited to 10 billion tonnes of carbon (GtC) per year by 2050. Achieving this target will require avoiding about 6 GtC per year from the current trend by 2050 and even more after that. Areva argued that human adaptation systems to climate change will need to be developed but that this capacity is limited, particularly in developing countries: 'We thus need to implement mitigation policies to avoid unbearable costs for economies.'[34]

4.31 The Committee now turns to a consideration of the GHG emissions from use of nuclear power and the extent to which nuclear power mitigates emissions from other sources.

Nuclear power's contribution to greenhouse gas mitigation

4.32 Most submitters to the inquiry who expressed a view on this issue argued that the use of nuclear power reduces GHG emissions and that 'the export of uranium helps reduce greenhouse emissions in other countries to the extent that nuclear power produced replaces higher emission sources.'[35] A sample of the observations made on this issue follows:

- 'Realistic assessment shows that nuclear energy is indispensable in abating the intensification of greenhouse gases resulting from the inexorable rise of global energy consumption.'[36]
- 'There is incontrovertible evidence that from an emission standpoint uranium is a clean fuel.'[37]

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33 Cameco Corporation, *op. cit.*, p. 7.

34 Areva, *Submission no. 39*, p. 4.

35 Minerals Council of Australia (MCA), *Submission no. 36*, p. 10. See also: ANSTO, *Submission no. 29*, p. 8. Some 30 submitters expressed this view. See for example: Mr Robert Elliott, *Submission no. 1*, p. 1; Mr John Reynolds, *Submission no. 5*, p. 3; Summit Resources Ltd, *Submission no. 15*, p. 25; Deep Yellow Ltd, *Submission no. 16*, p. 2; Australian Nuclear Association, *Submission no. 19*, p. 3; Submarine Institute of Australia, *Submission no. 21*, p. 7; Mr Robert Parsons, *Submission no. 24*, p. 2; Anonymous, *Submission no. 25*, p. 1; Mr Alan Parker, *Submission no. 35*, p. 12; CSIRO, *Submission no. 37*, p. 10; Heathgate Resources Pty Ltd, *Submission no. 49*, p. 1; Southern Gold Ltd, *Submission no. 54*, p. 4; Energy Resources of Australia Ltd, *Submission no. 46*, p. 4.

36 Cameco Corporation, *op. cit.*, p. 9.

37 Compass Resources NL, *Submission no. 6*, p. 3.

- 'Nuclear power plants are the single most significant means of limiting increased greenhouse gas emissions while enabling access to economic electricity and providing for energy security.'[38]
- 'Nuclear power is mankind's single greatest opportunity to combat the looming environmental threat of global warming.'[39]
- 'Nuclear power is essential to attaining the goal of reducing the emission of greenhouse gas while at the same time maintaining access to electricity.'[40]
- 'Nuclear energy appears to be the only source which can provide safe, reliable and substantial base-load power without producing large quantities of greenhouse gases.'[41]
- 'Nuclear power is the only proven large scale technology for baseload power supply which does not release substantial amounts of carbon dioxide.'[42]

4.33 Nuclear power produces no GHG emissions during electricity generating operations. A nuclear power plant does not emit combustion gases when producing steam and therefore 'a nuclear power plant is a CO_2-free energy source at point of generation.'[43]

4.34 On a fuel basis, coal releases some four tonnes of CO_2 for every tonne of oil equivalent burned, oil releases some 3.2 tonnes of CO_2 for every tonne burned and natural gas releases 2.3 tonnes of CO_2 for every tonne of oil equivalent burned. Nuclear plants emit no CO_2.[44]

4.35 Uranium is also a highly concentrated source of energy when compared to fossil fuels. Uranium contains some 10 000 times more energy per kilogram of fuel than traditional fossil fuel sources. The typical energy output per kilogram of various fuels are listed in table 4.1.

38 UIC, *Submission no. 12*, p. 14.

39 Arafura Resources NL, *Submission no. 22*, p. 1.

40 Areva, *Submission no. 39*, p. 2.

41 Mr Robert Parsons, *Submission no. 24*, p. 2.

42 AMEC, *loc. cit*.

43 Paladin Resources Ltd, *Submission no.47*, p. 5. See also: Australian Government Department of the Environment and Heritage (DEH), *Submission no. 55*, p. 5; Geoscience Australia (GA), *Submission no. 42*, p. 26.

44 Cameco Corporation, *op. cit*., p. 8.

Table 4.1 Energy output per kilogram of various fuels

Rank	Fuel source	Energy output per kilogram of fuel (megajoules)
1	Uranium	500 000
2	Crude oil	45
3	Natural gas	39*
4	Black coal	30
5	Firewood	16
6	Brown coal	9

Source Arafura Resources NL, *Submission no. 22*, p. 4. * per cubic metre

4.36 Fuel derived from one tonne of natural uranium can produce more than 45 000 megawatt-hours (MWh) of electricity. To produce this amount of electricity from fossil fuels would require burning 20 000 tonnes of black coal, 80 000 barrels of oil or 13 million cubic metres of gas.[45] However, burning one tonne of black coal emits approximately 2.75 tonnes of CO_2. Hence, to generate the same amount of electricity that can be produced with one tonne of uranium, a coal-fired station would emit some 55 000 tonnes of CO_2. To operate a typical coal-fired power plant with 1 000 megawatts electrical (MWe) capacity requires some 3 million tonnes (Mt) of black coal, which emits some 7–8 Mt of CO_2 per year.[46]

4.37 According to the Minerals Council of Australia (MCA) and other submitters, every 22 tonnes of uranium (equivalent to 26 tonnes of uranium oxide—U_3O_8) used in generating electricity saves the emission of one million tonnes of CO_2, relative to using coal with current technologies.[47]

4.38 While precise estimates of the global emissions avoided due to the use of nuclear power vary, submitters generally agreed that nuclear energy avoids more than 600 million tonnes of carbon emissions or some 2.5 billion tonnes of CO_2 per year.[48] That is, nuclear power currently saves about 10 per cent of total CO_2 emissions from world energy use.[49] The

45 See for example: UIC, *Submission no. 12*, pp. 10, 21; Cameco Corporation, *loc. cit.* AMP Capital Investors Sustainable Funds Team provided a similar estimate in *Exhibit no. 65, The Nuclear Fuel Cycle Position Paper*, p. 13. The amount of energy produced depends on the type of reactor and the enrichment level of the fuel.

46 AMEC, *op. cit.*, p. 7.

47 Mr Mitch Hooke (MCA), *Transcript of Evidence*, 5 September 2005, p. 20. See also: Southern Gold, *Submission no. 54*, p. 9; AMEC, *op. cit.*, p. 8.

48 UIC, *op. cit.*, p. 14. See also: Compass Resources NL, *Submission no. 6*, p. 3; Nova Energy Ltd, *op. cit.*, p. 19; Professor Leslie Kemeny, *Exhibit no. 7, Nuclear Energy and the Greenhouse Problem*, p. 1; AMEC, *loc. cit*; Cameco Corporation, *op. cit.*, p. 9. Cameco estimates savings of 2.2 Gt of CO_2 per year, while AMEC estimates savings of 2.3 Gt.

49 Professor Leslie Kemeny, *ibid*.

World Nuclear Association (WNA) estimates that the emissions avoided are equivalent to approximately one half of the CO_2 emitted by the world's motor vehicles.[50]

4.39 If the electricity currently generated by nuclear power were instead generated by fossil fuels, the increase in global CO_2 emissions would be dramatic. AMP Capital Investors Sustainable Funds Team (AMP CISFT), which is opposed to the use of nuclear power, conceded that:

> If modern fossil fuelled plants produced the electricity that is currently generated by nuclear power plants, then CO_2 emissions would be 8% higher from the energy sector and 17% higher from the electricity generation sector.[51]

4.40 Evidence also revealed that countries with a higher proportional share of nuclear energy in their electricity generation mix are the world's lowest emitters of greenhouse gasses.[52]

4.41 In relation to electricity generation in the US specifically, ANSTO noted that if that country had *not* adopted nuclear power, total emissions of CO_2 would be 29 per cent higher than they currently are. That is, the US nuclear program is saving the equivalent of almost 30 per cent of the country's total emissions.[53]

4.42 ANSTO observed that of the emission-free energy sources in the US; that is, sources that produce little or no CO_2, nuclear produces some 72 percent of the total, hydro about 26 per cent, with small amounts contributed by wind, geothermal and solar. For ANSTO, this means that 'if you take the fossil fuel side out of it then nuclear forms a big part of the ability to have emission-free generation.'[54]

4.43 These conclusions have also been reached in international fora. The International Ministerial Conference, *Nuclear Power for the 21st Century*, held in Paris during March 2005, noted that:

> The health of the planet's environment, including action to reduce air pollution and address the risk of global climate change, is a serious concern that must be regarded as a priority by all Governments.[55]

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50 WNA, *The environment needs nuclear*, viewed 14 May 2006, <http://www.world-nuclear.org/pdf/The_Environment_Needs_Nuclear.pdf>.

51 AMP CISFT, *Exhibit no. 65, The Nuclear Fuel Cycle Position Paper*, p. 13. See also: The Hon Alexander Downer MP, *Submission no. 33*, p. 6.

52 Nova Energy Ltd, *op. cit.*, p. 20.

53 Dr Ron Cameron (ANSTO), *Transcript of Evidence*, 13 October 2005, p. 5. See also: Northern Land Council, *Submission no. 78*, p. 4.

54 Dr Ron Cameron, *op. cit.*, p. 2.

55 Cited in the Hon Alexander Downer MP, *loc. cit.*

The Conference affirmed that nuclear power could make a contribution to meeting energy needs and sustaining the world's development in the 21st Century because nuclear 'does not generate air pollution or greenhouse gas emissions'.[56]

Australia's uranium exports displace global emissions

4.44 In terms of the emission savings attributable to Australia's uranium exports, the Australian Government Department of the Environment and Heritage (DEH) noted that Australia's uranium exports of 9 593 t U_3O_8 in 2002–03 could have produced some 413 640 gigawatt-hours (GWh) of electricity. If this amount of electricity was produced from black coal generation, more than 395 Mt of CO_2 would be emitted and 'this represents around 70% of Australia's total greenhouse gas emissions for 2003'.[57]

4.45 Assuming that Australia's uranium does not displace uranium sourced from other countries, DEH estimated that:

> Australia's total inferred, low cost, uranium reserves could displace nearly 40,000 Mt CO2e if it replaced black coal electricity generation. This represents almost 5 years of emissions from world public electricity and heat production at 2002 levels …[58]

4.46 To place these GHG displacement estimates in the context of specific uranium mine production, Heathgate Resources (owners of Beverley, Australia's smallest uranium mine) submitted that its annual production generates the same amount of electricity as 16 Mt of coal and thereby avoids 33 Mt of CO_2 that would be emitted by coal-fired plants.[59]

4.47 Paladin Resources argued that Australia's uranium industry complements the coal industry because uranium exports 'neutralise' the carbon content of Australia's thermal coal exports, 'by generating in our customer countries an amount of carbon-free electricity to balance the inevitable carbon emissions of burning the coal equivalent.'[60] Moreover, Paladin Resources suggested that 'a good argument can be made that uranium exports should earn credits against CO2 taxes imposed on coal combustion in some jurisdictions.'[61]

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56 *ibid*.

57 DEH, *loc. cit*. See also: Dr Clarence Hardy (ANA), *Transcript of Evidence*, 16 September 2005, p. 53.

58 *ibid*.

59 Heathgate Resources Pty Ltd, *Exhibit no. 57, loc. cit*.

60 Paladin Resources Ltd, *op. cit*., p. 4.

61 *ibid*., p. 5.

4.48 DEH noted however that under current international arrangements, the emissions from producing uranium would be attributed to Australia, but the emissions savings from its consumption in electricity generation would accrue to the country that uses it. Nonetheless, as Nova Energy argued, 'the growth of uranium exports will contribute to global greenhouse gas and CO_2 emissions reductions.'[62]

Future emission savings from use of nuclear power

4.49 To the extent that uranium is used in nuclear power plants which are constructed instead of fossil fuel plants, further export of Australia's uranium will prevent additional emissions of greenhouse gasses.[63]

4.50 As noted above, evidence stated that use of nuclear power avoids the emission of approximately 600 million tonnes of carbon per year (MtC).[64] This estimate is based on the assumption that, in a hypothetical non-nuclear world, all non-nuclear sources would expand their contributions proportionately, with the exception of hydropower which is more constrained than other sources of electricity.[65]

4.51 The IAEA stated in its 2003 study, *Nuclear Power and Climate Change*, that compared with the carbon avoidance promised by the Kyoto Protocol, which will reduce annual carbon emissions in 2010 by less than 350 MtC:

> … nuclear power *already* contributes reductions more than twice the likely reductions from the Kyoto Protocol seven years down the road.[66]

4.52 In terms of the quantity of carbon that will be avoided by use of nuclear power in the future, estimates vary depending on forecasts for the future evolution of the electricity generating mix and the likely reductions in the carbon intensity of different generation options. For its projections, the IAEA adopted the conservative assumptions of the IEA in its *World Energy Outlook 2002* report; that no new nuclear plants will be constructed beyond those currently being built or seriously planned, and that reactors will be retired as previously scheduled. If the world develops along this path, by 2030 cumulative carbon emissions avoided that are attributable to nuclear power could be some 17 billion tonnes (GtC).[67]

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62 Nova Energy Ltd, *loc. cit*.

63 ANSTO, *Submission no. 29*, p. 8.

64 The Hon Alexander Downer MP, *loc. cit*. This is the elemental carbon component of carbon dioxide.

65 H Rogner, *Nuclear Power and Climate Change*, IAEA, Paris, 2003, p. 4.

66 *ibid*., p. 8. Emphasis in original. Cameco Corporation, *loc. cit*.

67 *ibid*., p. 6.

4.53 If nuclear power expands its contribution to world energy supplies in the future, rather than contracts as in the IEA scenario presented above, then emissions avoided that are attributable to nuclear power could be far greater. Adopting the emissions scenarios developed by the IPCC, the IAEA has estimated that cumulative carbon emissions avoided by nuclear power will exceed 20 GtC by 2030 under all scenarios.[68] This amounts to some 74 Gt of CO_2 avoided due to use of nuclear power.

4.54 Cameco observed that in some emissions scenarios, the cumulative carbon savings from nuclear over the three decades to 2030 will actually exceed 25 GtC.[69]

Nuclear power's other environmental benefits

4.55 In addition to displacing emissions of CO_2, it was argued that nuclear power relieves general air and surface pollution. Several submitters emphasised that the environmental impacts of coal and gas-fired power stations are significantly greater than those of nuclear power plants.[70] A comparison between coal, gas and nuclear plants of equal capacity follows.

4.56 A coal-fired power station with a capacity of 1 300 MWe will consume approximately 3.3 Mt of black coal per year and require a transport component of 82 500 rail cars each of 40 tonnes capacity. The land use requirement for a plant of this size, including fuel storage and waste disposal, will be around 415 hectares. Depending on the quality of the coal and other factors, the emissions will be in the order of 10 Mt of CO_2, 2 300 tonnes of particulates, 200 000 tonnes of sulphur dioxide and 7 000 tonnes of nitrous oxide. The plant would also produce some 250 000 tonnes of fly ash containing toxic metals including arsenic, cadmium, mercury, organic carcinogens and mutagens and naturally-occurring radioactive substances.[71]

4.57 A gas combined cycle plant of the same capacity will consume 1.9 billion cubic metres of gas per year and emit 5 Mt of CO_2, 30 tonnes of sulphur dioxide, 12 700 tonnes of nitrous oxide and 410 tonnes of methane.[72]

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68 *ibid*., p. 8.

69 Cameco Corporation, *loc. cit*.

70 Mr John Reynolds, *Submission no. 5*, p. 5; Energy Resources of Australia Ltd, *Exhibit no. 82, Ranger overview presentation*, p. 16; Southern Gold Ltd, Submission no. 54, pp. 9–10.

71 Professor Leslie Kemeny, *op. cit*., p. 3. See also: Professor Leslie Kemeny, *Exhibit no. 28, Renewable energy debate makes little sense*; Energy Resources of Australia Ltd, *loc. cit*. Precise quantities of emissions would depend on the coal quality, power plant design, thermal efficiency, effectiveness of the abatement system and the operational performance of the plant.

72 Professor Leslie Kemeny, *Exhibit no. 7*, *op. cit*., p. 4.

4.58 In contrast, a 1 300 MWe nuclear power plant, which requires a land area of some 60 hectares, will consume some 32 tonnes of enriched uranium per year, produced from around 170 tonnes of natural uranium in the form of uranium oxide concentrate. The plant would produce some 4.8 cubic metres of used fuel per year.[73] The wastes produced in the operation of nuclear power plants and in the various stages of the fuel cycle are further described in chapter five.

4.59 In comparing the environmental consequences of using fossil fuels with nuclear power, Cameco restated British environmentalist Sir James Lovelock's suggestion that people try to imagine they are a government minister required to decide what fuel to use for a new power station being built to supply half a large city:

> Every year, there are the following environmental consequences: using coal requires a 1,000 kilometre line of railway cars filled with coal which will emit billions of cubic feet of greenhouse gases, creates dust and more than 500,000 tonnes of toxic ash; using oil needs four or five-super tanker loads of heavy oil imported from unstable parts of the world, emits nearly as much greenhouse gases as coal plus huge volumes of sulphur and other deadly compounds that turn into acid rain; importing natural gas over long distances by ships and pipelines prone to accidents and leaks, emissions are highly polluting and the gas supply is vulnerable; or about two truckloads of cheap and plentiful uranium with essentially no emissions.[74]

4.60 While natural gas emits less CO_2 than coal, several submitters expressed reservations about its expanded use for baseload power generation on the grounds that there are relatively small global resources and these are said to be poorly located relative to centres of high potential economic growth. AMEC also raised concerns about the opportunity cost in using gas for large-scale electricity generation and inter-generational equity.[75]

4.61 The Committee also received evidence suggesting that nuclear power causes virtually the least environmental damage of all major energy technologies. Based on estimates of the unit cost of various pollutants (carbon dioxide, lead, nitrous oxide, particulates, sulphur dioxide and so on) in US dollars per tonne, Lucent Technologies have determined the damage to the environment per kilowatt-hour in dollar terms for a range

73 *ibid.*, p. 3. Maintenance of a nuclear reactor of this size would also produces some 531 cubic metres of low level waste and 47 cubic metres of intermediate level waste per year.

74 Cameco Corporation, *loc. cit.*

75 Arafura Resources NL, *op. cit.*, p. 5; AMEC, *op. cit.*, p. 6; Mr Keith Alder, *Transcript of Evidence*, 16 September 2005, p. 80.

of energy technologies. These environmental damage costs are listed in table 4.2. According to this estimate, wind power causes the least environmental damage, followed by nuclear power. Fossil fuel energy sources cause by far the most environmental damage in dollar terms.[76]

Table 4.2 Life cycle damage cost from major energy technologies (1999)

Technology	Damage cost (USc/kWh)
Wind	0.005 – 0.008
Nuclear	0.04
Hydro	0.073
Solar PV	0.231 – 0.376
Natural gas	1.04
Coal	1.59 – 6.02

Source ANSTO, *Exhibit no. 74, Presentation by Dr Ron Cameron and Dr Ian Smith*, p. 34.

A moral responsibility to export uranium?

4.62 As noted in the discussion of energy demand above, forecast levels for energy use would trigger a significant increase in CO_2 emissions, with the IEA predicting that energy-related CO_2 emissions will reach 37 Gt annually by 2030—an increase of 52 per cent over the 2003 level.

4.63 Arafura Resources explained that while world economic growth to 2010 is forecast to average 3.5 per cent, India and China are forecast to grow at 6 per cent and 9.5 per cent respectively. Combined, these countries currently have some 37.5 per cent of the world's population. However, Arafura argued that India and China:

> … already have environmental conditions that are approaching crisis point. China has 9 out of the 10 most polluted cities in the world. Approximately 70% of China's energy needs come from brown coal, the least efficient and dirtiest fossil fuel for energy generation.[77]

4.64 Summit Resources also spoke of the imperative for countries like China to have their energy requirements supplied by non fossil fuel sources:

> … what we have to face is that China's economy is growing and they want to improve their standard of living. The biggest thing that the Chinese are going to consume is not KFC and not Coca-Cola but energy. If we sit here and just keep letting them build more coal-fired power stations, we are all going to suffer.[78]

76 Dr Ian Smith, *op. cit.*, p. 14.
77 Arafura Resources NL, *Submission no. 22*, p. 2.
78 Mr Alan Eggers (Summit Resources Ltd), *Transcript of Evidence*, 3 November 2005, p. 14.

4.65 For Nova Energy, nuclear power is a means for these and other developing nations not bound by the Kyoto Protocol, to meet their energy demands in a way which reduces their reliance on fossil fuels:

> Australia's uranium is, potentially, a way to meet the energy demands of these developing countries that obviates their need to depend on fossil fuels and delivers a positive global outcome—more energy for less carbon.[79]

4.66 Similarly, Compass Resources argued that:

> … the only realistic alternative available to meet the increased energy demand is coal or nuclear. Despite likely improvements to coal power plant emissions through geosequestration, use of coal will increase greenhouse gas emissions as the industry is asked to fill the world's energy needs.[80]

4.67 Noting that nuclear electricity has the lowest CO_2 emissions per kilowatt hour of the alternatives for baseload power generation, the Australian Nuclear Forum (ANF) argued that:

> In those countries that are serious about global warming, nuclear will expand and will need fuel. We think that the greatest contribution Australia can make to the global reduction of CO_2 is to maximise the export of uranium to responsible countries.[81]

4.68 AMEC submitted that the Federal 'government now has a moral responsibility to contribute to reducing global greenhouse emissions' and that 'Australia is well placed to make a significant contribution to greenhouse gas emission reduction targets through increased production and supply of uranium.'[82]

4.69 Cameco was also emphatic that given nuclear power's value as a carbon-free electricity supply technology, the further exploration and development of Australia's uranium resources should be supported and 'Australia should throw the world a climate lifeline.'[83]

4.70 In view of the potential greenhouse benefits, Professor Ralph Parsons argued that 'Australia should encourage those of our major trading

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79 Nova Energy Ltd, *op. cit.*, p. 19.

80 Compass Resources, *op. cit.*, p. 3.

81 Mr James Brough (ANF), *Transcript of Evidence*, 16 September 2005, p. 42. Baseload power generation is defined as that part of electricity demand that is continuous and requires reliability.

82 AMEC, *op. cit.*, p. 7.

83 Cameco Corporation, *loc. cit.*

partners which currently produce large quantities of greenhouse gases to use uranium rather than carbon based fuels wherever possible.'[84]

Prominent environmentalists support nuclear power

4.71 The Committee was also informed that a number of prominent environmentalists, who were foundational figures in the environment movement and previously adamantly opposed to nuclear, now support use of nuclear power to avert global environmental calamity. These individuals include Dr Patrick Moore, Bishop Hugh Montefiore and Sir James Lovelock. Excerpts from their writings cited in evidence follow:

- Dr Patrick Moore, one of the co-founders of Greenpeace in 1971 and subsequently its president, has argued that 'nuclear energy is the only non greenhouse gas-emitting power source that can effectively replace fossil fuels and satisfy global [energy] demand.'[85] Dr Moore has also argued that environmental activists who oppose nuclear power have 'abandoned science in favour of sensationalism'.[86]
- Sir James Lovelock, an independent scientist and author of the Gaia hypothesis, has argued that:

> … by all means, let us use the small input from renewables sensibly, but only one immediately available source does not cause global warming and that is nuclear energy. Opposition to nuclear energy is based on irrational fear fed by Hollywood-style fiction, the Green lobbies and the media. These fears are unjustified, and nuclear energy from its start in 1952 has proved to be the safest of all energy sources. We have no time to experiment with visionary energy sources; civilisation is in imminent danger and has to use nuclear — the one safe, available, energy source — now or suffer the pain soon to be inflicted by our outraged planet.[87]

- Bishop Hugh Montefiore, a trustee of Friends of the Earth (FOE) for two decades and chairman of the organisation between 1992 and 1998, argued that:

> The dangers of global warming are greater than any others facing the planet. In the light of this I have come to the conclusion that the solution is to make more use of nuclear energy … Nuclear energy provides a reliable, safe, cheap, almost limitless form of pollution free energy. The real reason why the government has not

84 Professor Ralph Parsons, *Submission no. 24*, p. 2.

85 Cited in Professor Leslie Kemeny, *Exhibit no. 8, A power too good to refuse.*

86 *ibid*.

87 Cited in UIC, *op. cit.*, p. 14.

> taken up the nuclear option is because it lacks public acceptance, due to scare stories in the media and the stonewalling opposition of powerful environmental organisations. Most, if not all, of the objections do not stand up to objective assessment.[88]

4.72 For Cameco, the reason these environmentalists have taken this stance is that they rightly recognise that the enhanced greenhouse effect poses a far more serious threat to humankind than the risks associated with use of nuclear energy, notably its relatively small quantities of waste.[89] Indeed, Sir James Lovelock has argued that:

> … I am a Green and I entreat my friends in the movement to drop their wrongheaded objection to nuclear energy.
>
> Even if they were right about its dangers, and they are not, its worldwide use as our main source of energy would pose an insignificant threat compared with the dangers of intolerable and lethal heat waves and sea levels rising to drown every costal city in the world.[90]

4.73 Similarly, the Australian Nuclear Association (ANA) argued that while the perception of risks may vary, 'the cost is that the greenhouse gas problem could be more dangerous in the future … than the risks of radioactive waste if we use nuclear power.'[91]

4.74 The significance of prominent environmentalists taking pro-nuclear positions was disputed by FOE, who argued that most environmentalists remain opposed to use of nuclear power.[92] Similarly, the Environment Centre of the Northern Territory (ECNT) argued that:

> They are still only a tiny, tiny proportion of the people who have ever considered themselves to be, or have been called, environmentalists. The environment groups around the world are extremely solid in saying that we should not be wasting our time going back to nuclear; we should be going forward to renewable energy and energy efficiency.[93]

4.75 In response to the environment movement's continued opposition to nuclear power, Dr Moore argued before the US Senate Committee on Energy and Natural Resources in April 2005 that:

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88 Cited in Jindalee Resources Ltd, *Submission no. 31*, p. 2. See also: H Montefiore, 'Why the planet needs nuclear energy', *The Tablet*, 23 October 2004, viewed 15 August 2005, <http://www.thetablet.co.uk/cgi-bin/register.cgi/tablet-00946>.

89 Mr Jerry Grandey, Cameco Corporation, *Transcript of Evidence*, 11 August 2005, p. 10.

90 J Lovelock, 'Nuclear Power is the only green solution', *loc. cit.*

91 Dr Clarence hardy (ANA), *Transcript of Evidence*, 16 September 2005, p. 57.

92 Dr Jim Green (FOE), *Transcript of Evidence*, 19 August 2005, p. 60.

93 Mr Peter Robertson (ECNT), *Transcript of Evidence*, 24 October 2005, p. 9.

> I believe the majority of environmental activists, including those at Greenpeace, have now become so blinded by their extremism that they fail to consider the enormous and obvious benefits of harnessing nuclear power to meet and secure America's growing energy needs. These benefits far outweigh the risks. There is now a great deal of scientific data showing nuclear power to be an environmentally sound and safe choice.[94]

4.76 Despite media reports of a shift in perspective by WWF Australia, several environmental groups in Australia that submitted to the Committee's inquiry remain opposed to uranium mining and use of nuclear power.[95] The following section summarises the range of criticisms of nuclear power's contribution to GHG emission mitigation.

Arguments critical of nuclear's contribution to greenhouse gas mitigation

Emissions across the whole nuclear fuel cycle

4.77 While it was widely conceded that nuclear power emits virtually no CO_2 at point of generation, numerous submitters argued that the balance of emissions across the whole nuclear fuel cycle is significant. That is, by adding the emissions produced from all other fuel cycle stages—mining and milling, enrichment, fuel fabrication, transport, plant construction, plant decommissioning and waste disposal—to the electricity generation stage, nuclear power produces a relatively large quantity of GHG emissions.

4.78 Examples of statements by submitters making this argument follow:

- 'Nuclear power also contributes to global carbon dioxide production. Huge quantities of fossil fuel are expended for the "front end" of the nuclear fuel cycle, to construct the massive reactor buildings and cooling towers, and to mine, mill, and enrich the uranium fuel.'[96]
- 'While the production of steam in a nuclear reactor is essentially greenhouse-free, the same is not the case for, the mining, transport and enrichment of the uranium concentrate and the decommissioning of the plant … The amount of fossil fuel required in the mining, enrichment,

94 P Moore, *Nuclear Statement to the United States Senate Committee on Energy and Natural Resources*, 28 April 2005, viewed 11 April 2006, <http://www.greenspirit.com/logbook.cfm?msid=70>.

95 See for example: A Hodge, 'WWF boss to push N-power at meeting', *The Australian*, 9 May 2006, p. 3.

96 Ms Janet Marsh, *Submission no. 2*, p. 2.

construction and decommissioning stages ruins the argument that nuclear power is a valid answer to climate change.'[97]

- 'Nuclear power, despite being depicted as "clean and green" by its advocates, is neither. Throughout the exploration and mining phases, the milling and processing, the transporting of processed ore, the building of reactors, the global movement of spent and treated fuel rods, the passage of radioactive wastes … and the final decommissioning of reactors past their use-by date, fossil fuels are extensively used.'[98]
- 'The case for presenting nuclear power as an alternative source of power generation that is less likely to contribute to global warming is very flawed as it does not take into account the whole nuclear power cycle.'[99]
- 'While nuclear power is "environmentally greener" than any other current energy resource, the infrastructure needed to access and mine the ore plus the construction of reactors and waste disposal sites might result in increased levels of greenhouse gas, cancelling the good effects at the power production level.'[100]

4.79 Life cycle emissions analysis presented in evidence refuted these claims. While estimates of the quantity of emissions released from electricity generation sources across their life cycles vary, it is clear that nuclear power emits orders of magnitude *less* CO_2 than fossil fuels and is equivalent to renewables in most cases:

> Nuclear power creates the lowest amount of CO_2 emissions compared with coal (highest), gas, solar photovoltaic, and in some cases wind. The only rival to nuclear is hydro.[101]

4.80 Several estimates of the emissions from electricity generation chains were submitted in evidence and some of these are listed below. Life cycle emissions are generally quoted in terms of grams of carbon dioxide emitted per kilowatt-hour of electricity produced (gCO_2/kWh). The range of estimates are comparable:

- UIC estimated that nuclear emits some 20 gCO_2/kWh, while black coal emits 950 gCO_2/kWh and gas emits 500 gCO_2/kWh.[102]

97 Wind Prospect Pty Ltd, *Submission no. 4*, p. 3.
98 Medical Association for the Prevention of War—WA Branch, *Submission no. 8*, p. 8.
99 Mr John Schindler, *Submission no. 10*, p. 2.
100 Ms Caroline Pembroke, *Submission no. 81*, p. 2.
101 Paladin Resources Ltd, *op. cit.*, p. 5.
102 UIC, *op. cit.*, p. 14.

- Areva estimated that nuclear emits 12 gCO_2/kWh, while lignite emits 1.1kg of CO_2/kWh, coal emits 932 gCO_2/kWh, oil emits 777 gCO_2/kWh, gas emits 439 gCO_2/kWh, hydro (dam) emits 12.5 gCO_2/kWh, wind emits 9 gCO_2/kWh and hydro (river) emits 5.1 gCO_2/kWh.[103]
- Geoscience Australia (GA) estimated that nuclear emits 5 gCO_2/kWh.[104]
- CSIRO estimated that nuclear emits less than 40 gCO_2/kWh, compared to 760 gCO_2/kWh from a 'state-of-the-art pulverised fuel fired station firing black coal at around 41 per cent overall thermal efficiency.'[105]
- Australian Institute of Nuclear Science and Engineering (AINSE) estimated that nuclear, hydro and wind emit under 10 gCO_2/kWh, while solar emits approximately 100 gCO_2/kWh.[106]

4.81 These various estimates suggest that fossil fuels emit between 18 and 92 times the CO_2 of nuclear power across the full electricity production chains, while nuclear is comparable to—and in some cases less than—renewables.

4.82 Groups critical of nuclear power cited other studies, such as those published by the German Oko Institut, which were said to have found that nuclear emits between 34–60 gCO_2/kWh over its full fuel cycle, while wind emits approximately 20 gCO_2/kWh. Similarly, the Medical Association for the Prevention of War (Victorian Branch) argued that on a full life cycle basis nuclear produces between 1.5 and 3 times as much CO_2 as wind generation.[107]

4.83 The Australian Conservation Foundation (ACF) and Dr Helen Caldicott cited research by Jan Willem Storm van Leeuwen and Philip Smith claiming that nuclear power emits only three times less GHG than modern natural gas power stations.[108]

4.84 Some environmental groups conceded that nuclear power is far less carbon intensive than fossil fuel alternatives. For example, FOE stated that electricity from fossil fuels is far more greenhouse intensive than nuclear.

103 Areva, *op. cit.*, p. 5. Areva cite estimates published by the World Energy Council in 2004.

104 GA, *Submission no. 42*, p. 26.

105 CSIRO, *op. cit.*, p. 10.

106 AINSE, *Submission no. 77*, p. 3.

107 Medical Association for the Prevention of War—Victorian Branch (MAPW), *Submission no. 30*, p. 10.

108 ACF, *Submission no. 48*, p. 13; Dr Helen Caldicott, *Exhibit no. 73, Nuclear Reactions*, p. 2; Dr Helen Caldicott, *Transcript of Evidence*, 16 September 2005, p. 15. See also: Mr Justin Tutty, *Submission no. 41*, p. 2; Wind Prospect Pty Ltd, *op. cit.*, p. 3. For a critique of the van Leeuwen and Smith study see: UIC, *Energy Analysis of Power Systems*, Nuclear Issues Briefing Paper No. 57, UIC, Melbourne, 2006, viewed 18 May 2006, <http://www.uic.com.au/nip57.htm>.

However, it was argued that nuclear power emits more GHG than most renewables, but again FOE conceded that the difference is small.[109]

4.85 AMP CISFT, which argued that nuclear power is not environmentally sustainable, conceded that nuclear's major benefit is that it 'is one of the least carbon intensive generation technologies.'[110] AMP CISFT estimated that nuclear emits between 9.2–20.9 gCO_2/kWh, compared to 385g–1.3kg CO_2/kWh for fossil fuel chains and 9.2–278.7 gCO_2/kWh for renewables.[111]

4.86 The range of greenhouse gas emissions emitted across electricity production chains for different sources of electricity as determined by the IAEA are depicted in figure 4.2. As with the estimates above, these figures include emissions across the entire nuclear power chain—from mining uranium ore to nuclear waste disposal and reactor construction. Emissions range from 366 grams of carbon equivalent per kilowatt-hour (gC_{eq}/kWh) for lignite, to between 2.5 and 5.7 gC_{eq}/kWh for nuclear power. Wind ranges between 2.5 and 13.1 gC_{eq}/kWh, and solar photovoltaics between 8.2 and 76.4 gC_{eq}/kWh. The IAEA has concluded that:

> The complete nuclear power chain, from resource extraction to waste disposal including reactor and facility construction, emits only 2-6 grams of carbon equivalent per kilowatt-hour. This is about the same as wind and solar power including construction and component manufacture. All three are two orders of magnitude below coal, oil and natural gas.[112]

4.87 Studies have also been made of the carbon emissions by fuel source for specific countries. Table 4.3 lists the life cycle emissions for various sources of electricity generation and fuel types in Japan, Sweden and Finland—countries which have produced authoritative figures. The variation in emission levels for nuclear across the three countries reflects the method of uranium enrichment used (gaseous diffusion or gas centrifuge) and whether the power for enrichment comes from nuclear sources or from fossil sources.

4.88 The data reveals that, other than hydro, nuclear power emits the least CO_2 of all generation methods in each of the countries. Nuclear emits less than one-hundredth of the CO_2 of fossil fuel based generation in Sweden.

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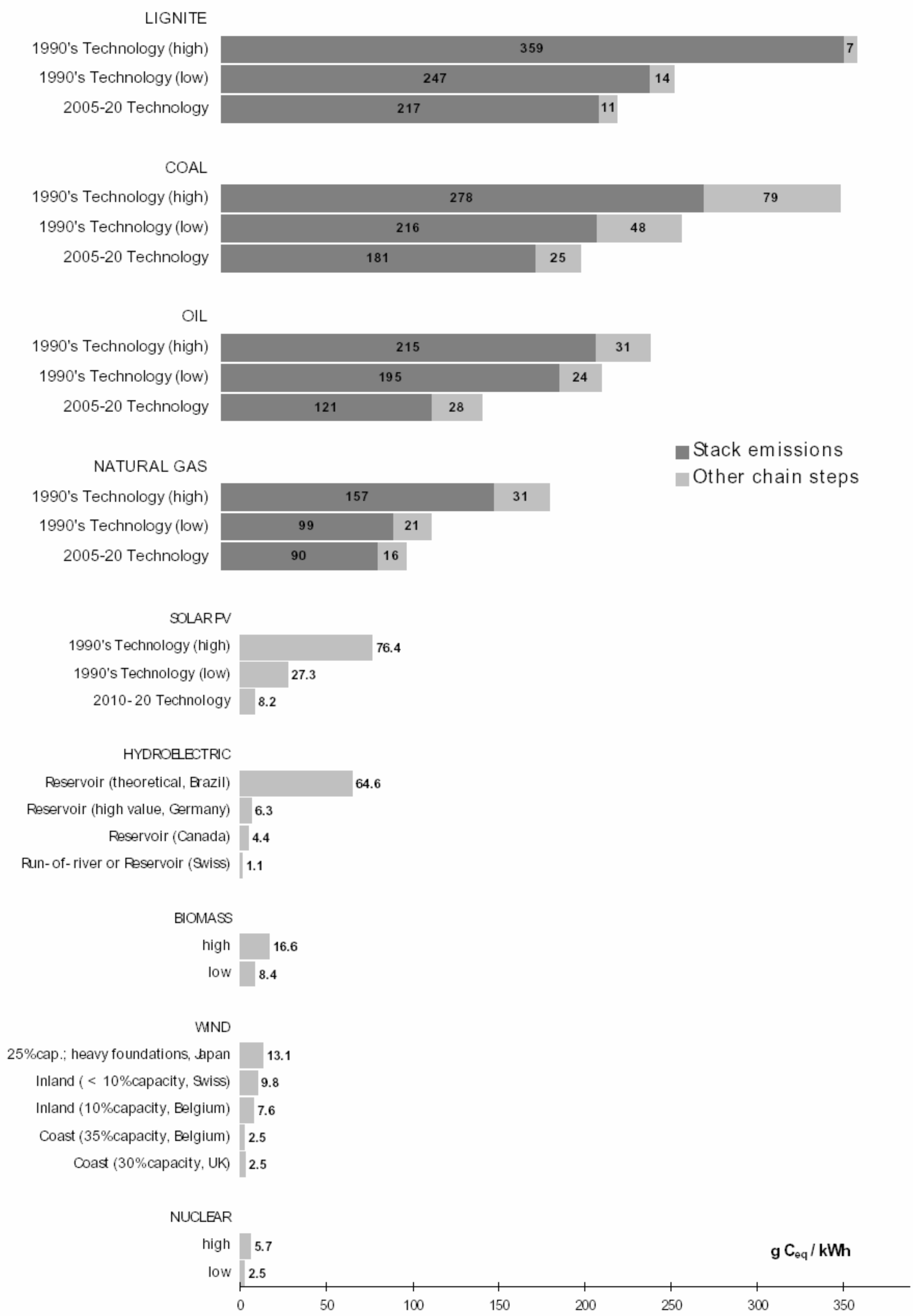
109 FOE, *Submission no. 52*, p. 5.

110 AMP CISFT, *op. cit.*, p. 13.

111 *ibid*.

112 Cited in the Hon Alexander Downer MP, *op. cit.*, p. 2.

Figure 4.2 The range of total greenhouse gas emissions from electricity production chains (measured in grams of carbon equivalent per kilowatt-hour of electricity generated)



Source Hans-Holger Rogner, et. al., *Nuclear Power: Status and Outlook*, IAEA, Vienna, 2002, p. 5.

4.89 The ANA argued that emissions from nuclear are below wind in Japan and marginally above wind in Sweden and Finland. The reasons for this are that wind and solar are diffuse sources of energy and they have a low capacity factor. In addition, solar and wind both produce CO_2 during the construction process for the towers, turbines and generators.[113]

Table 4.3 Grams of carbon dioxide emitted per kilowatt-hour of electricity produced by different generation methods in Japan, Sweden and Finland

Generation method	Japan	Sweden	Finland
Coal	975	980	894
Gas $_{Thermal}$	608	1170	—
Gas $_{Combined\ Cycle}$	519	450	472
Solar photovoltaic	53	50	95
Wind	29	5.5	14
Nuclear	22	6	10 – 26
Hydro	11	3	—

Source ANSTO, *Exhibit no. 74, Presentation by Dr Ron Cameron and Dr Ian Smith*, p. 32. UIC, *Submission no. 12*, p. 15.

4.90 GA submitted the life cycle emissions data contained in table 4.4, which lists the GHG emissions for different sources of electricity generation and fuel types for France and other European countries. The table lists the emissions released at the point of generation or operation, emissions across the remainder of the electricity production chains and the total for each source of electricity.

4.91 In this data, natural gas releases 182 times more CO_2 over its full electricity production chain than nuclear, and coal releases over 200 times more CO_2 than nuclear. Nuclear and hydro have the same life cycle emissions per unit of electricity produced and wind is marginally lower.

113 Dr Clarence Hardy, *op. cit.*, p. 54.

Table 4.4 Greenhouse gas emissions for different sources of electricity generation and fuel types, typical for France and other European countries (2004)

Energy source	**Operation** grams of CO_2 equivalent per kW hour	**Remainder of cycle** grams of CO_2 equivalent per kW hour	**Total** grams of CO_2 equivalent per kW hour
Coal 600 MWe	892	111	1 003
Fuel oil	839	149	988
Gas turbine	844	68	912
Diesel	726	159	895
Hydro-pumped storage	127	5	132
Photovoltaic	0	97	97
Hydroelectric	0	5	5
Nuclear energy	0	5	5
Wind generation	0	3	3

Source Geoscience Australia, *Submission no. 42*, p. 26.

Enrichment and declining uranium ore grades

4.92 Critics of nuclear power's GHG mitigation potential raised the issues of the energy required to power uranium enrichment plants and the additional energy that may be required to mine and mill uranium as ore grades decline. That is, as higher grade ores are exhausted, a greater amount of energy may need to be expended for extraction and processing, and hence overall CO_2 emissions may increase.

4.93 In relation to uranium enrichment, which is discussed further in chapters seven and twelve, there are currently two enrichment technologies in large scale commercial use: gaseous diffusion and newer gas centrifuge enrichment plants. There are currently two of the older gaseous diffusion plants remaining in operation—one in France (operated by Areva) and another in the US (operated by the US Enrichment Corporation, USEC). These plants account for approximately 40 per cent of world enrichment capacity.[114]

4.94 It was argued that enrichment plants consume enormous quantities of electricity and emit large quantities of chlorofluorocarbons (CFCs), which are ozone depleting as well as being significant greenhouse gases.[115]

4.95 Silex confirmed that the first generation gaseous diffusion enrichment technology consumes large amounts of electricity. The gaseous diffusion plant in Paducah, Kentucky, consumes one-half of one per cent of all

114 UIC, *Uranium Enrichment*, Nuclear Issues Briefing Paper No. 33, UIC, Melbourne, 2006, viewed 19 May 2006, <http://www.uic.com.au/nip33.htm>.

115 Dr Helen Caldicott, *Exhibit no. 24, Nuclear power is the problem, not a solution*, pp. 1–2; People for Nuclear Disarmament NSW Inc, *Submission no. 45*, p. 6; Ms Janet Marsh, *loc. cit.*

electricity generated in the US. The Paducah plant also operates with CFCs and has a dispensatory license allowing it to do so. Areva and USEC have indicated their intention to phase out these plants.[116]

4.96 ANA stated that while gaseous diffusion plants consume a large amount of electricity, these are being replaced by centrifuge enrichment plants which use less than one-tenth of the electricity previously required.[117] Whereas a gaseous diffusion plant would use 2 500 kWh per unit of production (a separative work unit, SWU), a centrifuge plant would only require between 50 and 100 kWh per SWU.[118]

4.97 Mr Keith Alder, formerly the General Manager and then a Commissioner of the Australian Atomic Energy Commission, also dismissed arguments critical of the energy balance in relation to enrichment plants, arguing that centrifuge technology has dramatically reduced the amount of energy required, down by a factor of 20 compared to gaseous diffusion plants.[119]

4.98 GA observed that the whole of life cycle emission rate for nuclear power in France listed in table 4.4 (5 gCO_2/kWh) is lower than the industry average cited by the UIC (20 gCO_2/kWh) because nuclear reactors are used to power the enrichment plants in France, whereas in other countries the electricity for enrichment is supplied by coal-fired power stations.[120]

4.99 The ANA agreed, noting that the gaseous diffusion plant in France, which is to be replaced by centrifuge technology, is powered by four dedicated nuclear power plants and so the enrichment process in that country emits no CO_2.[121] The gaseous diffusion plant operating in the US is powered by coal. However, the ANA and Silex estimated that within ten years all existing gaseous diffusion plants will be replaced by centrifuge enrichment plants. There are now four of the newer plants worldwide, with two currently in operation, and there are plans to build more.

4.100 The UIC observed that while enrichment can be greenhouse intensive, it still accounts for a small share of carbon emissions:

> [Enrichment] can also account for the main greenhouse gas impact from the nuclear fuel cycle if the electricity used for enrichment is generated from coal. However, it still only amounts to 0.1% of the carbon dioxide from equivalent coal-fired electricity generation if

116 Dr Michael Goldsworthy (Silex Systems Ltd), *Transcript of Evidence*, 9 February 2006, p. 8.

117 Dr Clarence Hardy, *op. cit.*, p. 53.

118 UIC, *Uranium Enrichment*, *loc. cit.*

119 Mr Keith Alder, *Transcript of Evidence*, 16 September 2005, p. 87.

120 GA, *op. cit.*, p. 26.

121 Dr Clarence Hardy, *op. cit.*, p. 58.

modern gas centrifuge plants are used, or up to 3% in a worst case situation.[122]

4.101 It was also argued that over coming decades increased energy inputs will be required to extract and process lower grade uranium ores, and that the energy required to extract uranium will rise to the extent of making the net energy yield from nuclear power very small. It was argued that as energy inputs increase, CO_2 emissions will rise to near fossil fuel levels.

4.102 A number of submitters advanced this argument. For example, DEH argued that the GHG emission benefit of nuclear power may indeed diminish as the quality of uranium ores decline: 'The lower the quality of the ore, the more greenhouse gas intensity increases.'[123] Similarly, Dr Gavin Mudd claimed that:

> If you look at Olympic Dam, both its current operations and its future operations, and Ranger et cetera, there will be at least one millions tonnes of CO_2 released a year. If those operations expand, that figure will obviously increase. One of the issues is that to get the uranium out in the future is going to require more energy, so there will be more relative CO_2 emissions.[124]

4.103 The argument was also made by other witnesses, including FOE, ACF, the Public Health Association (PHA), MAPW and Greenpeace who issued a joint statement, *Nuclear Power: No Solution to Climate Change*. This statement claimed that:

> … the mining of lower grade ores is likely to have significant implications in relation to energy usage and greenhouse gas emissions. The energy required to extract uranium from low grade ores may approach the energy gained from the uranium's use in power reactors. Likewise, the increased greenhouse gas emissions from mining and milling low grade ores will narrow nuclear's greenhouse advantage in relation to fossil fuels, and widen nuclear power's deficit in comparison to most renewables energy sources.[125]

4.104 The argument draws again on a study by Storm van Leeuwen and Smith (SLS), now comprehensively critiqued, which purports to compare the energy inputs and outputs for nuclear power, and asserts that mining and

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122 UIC, *Uranium Enrichment, loc. cit.*

123 Mr Barry Sterland (DEH), *Transcript of Evidence*, 10 October 2005, p. 14.

124 Dr Gavin Mudd, *Transcript of Evidence*, 19 August 2005, p. 42.

125 FOE et. al., *Exhibit No. 71, Nuclear Power: No Solution to Climate Change*, section 2.2. The argument was also made by: Wind Prospect Pty Ltd, *op. cit.*, p. 3; Mr Alan Parker, *Submission no. 35*, p. 11; Mr Justin Tutty, *Submission no. 41*, p. 3; Dr Helen Caldicott, *Transcript of Evidence, loc. cit.*

milling uranium are major energy costs. SLS argue that although the production of electricity leads to 'considerably less' CO_2 emissions than fossil fuels:

> In the course of time, as the rich ores become exhausted and poorer and poorer ores are perforce used, continuing use of nuclear reactors for electricity generation will finally result in the production of more CO_2 than if fossil fuels were to be burned directly.[126]

4.105 The UIC, WNA and academics from the School of Physics at the University of Melbourne, among others, have published detailed responses to the SLS study and emphatically rebutted the claims made.[127] In brief, the UIC argued that the SLS 'assertions ignore hard data and misunderstand the concept of mineral resources.'[128]

4.106 It was argued that a typical life cycle analysis of nuclear energy shows that total energy inputs are only about two per cent of outputs (which is comparable to wind generation), or less.[129] An audited life cycle analysis of the Forsmark nuclear power plant in Sweden showed that energy inputs are in fact 1.35 per cent of output. It was argued that if uranium with much lower ore grades is used, the total energy inputs rise to only about 2.5 per cent of outputs.

4.107 Similarly, the Melbourne University physicists group have argued that the SLS paper 'grossly over estimates the energy cost of mining low-grade ores'.[130] Employing the SLS calculations, the group predicted that the energy cost of extracting Olympic Dam's annual uranium production would require the energy equivalent to almost two one-gigawatt power plants running for a full year (two gigawatt-years). In fact, this is larger than the entire electricity production of South Australia and an order of magnitude more than the measured energy inputs for the mine.[131]

4.108 The UIC argued that the energy costs of uranium mining and milling are well known and published. The energy cost are said to form a small part

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126 The Storm van Leeuwen and Smith paper, *Nuclear Power: the Energy Balance*, is available online, viewed 19 May 2006, <http://www.stormsmith.nl/>.

127 For detailed critiques of the Storm van Leeuwen and Smith studies see: UIC, *Energy Analysis of Power Systems*, Nuclear Issues Briefing Paper No. 57, UIC, Melbourne, 2006, viewed 18 May 2006, <http://www.uic.com.au/nip57.htm>; and by physicists at Melbourne University available online at 'nuclearinfo.net', viewed 18 May 2006, <http://www.nuclearinfo.net/Nuclearpower/TheBenefitsOfNuclearPower>.

128 UIC, *Submission no. 12.1*, p. 1.

129 Compare UIC, *Submission no. 12.1*, p. 1, with Wind Prospect Pty Ltd, *loc. cit*.

130 See: Nuclearinfo.net, *loc. cit*.

131 *ibid*.

of the overall total and 'even if they were ten times higher they would still be insignificant overall.'[132]

4.109 The UIC also argued that by suggesting the need to mine low grade ores is imminent, SLS misunderstand the nature of mineral resources:

> We can be confident that known economic resources of uranium (as of other metal minerals) will increase in line with exploration effort. While ore grades may well decline to some extent, the energy required to utilise them will not become excessive.[133]

Nuclear power 'too limited, slow and impractical to solve climate change'

4.110 Environment groups argued that nuclear power cannot solve climate change because it is too limited, slow and impractical. Nuclear was said to be a limited response to climate change because nuclear power is used almost exclusively for power generation, which is claimed to be 'responsible for less than a third of global greenhouse gas emissions.'[134] As noted above, other anthropogenic sources of GHG emissions include transport and agriculture, and thus:

> Switching the entire world's electricity production to nuclear would still not solve the problem. This is because the production of electricity is only one of many human activities that release greenhouse gases.[135]

4.111 MAPW also argued that the IPCC has concluded that CO_2 emissions must be reduced by at least 70 per cent over the next century to stabilise atmospheric CO_2 concentrations at 450 ppm. It was therefore argued that:

> Reducing CO2 emissions from electricity generation by itself would be insufficient to achieve this target; thus even massive expansion of nuclear power could not by itself be sufficient.[136]

4.112 ACF argued that to reduce emissions by the public energy sector according to the targets of the Kyoto Protocol would require that 72 medium sized nuclear power be built in the EU-15 nations by the end of the first commitment period, 2008–12:

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132 UIC, *Energy Analysis of Power Systems*, *loc. cit.*

133 UIC, *Submission no. 12.1*, *loc cit.*

134 FOE et. al., *Exhibit no. 71*, *op. cit.*, section 2.1. As described in the section in this chapter entitled 'The global energy situation and carbon dioxide emissions' above, the IEA states that the electricity and heat sector contributes 40 per cent of global CO_2 emissions and is the fastest growing sector. FOE argued that electricity is responsible for less than a third of CO_2 emissions, while the ACF stated that electricity accounts for 39 per cent of emissions.

135 ACF, *op. cit.*, p. 13.; PHA, *Submission no. 53*, p. 3.; Ms Jo Vallentine, *Submission no. 73*, p. 2.

136 MAPW (Victorian Branch), *Submission no. 30*, p. 9.

> Leaving aside the huge costs this would involve, it is unlikely that it is technically feasible to build so many new plants in such a short time, given that only 15 new reactors have been built in the last 20 years.[137]

4.113 FOE also argued that a 'nuclear solution to climate change' was impractical because for nuclear to account for 70 per cent of electricity by 2100 would allegedly require 115 reactors to be built each year. In any case, it was claimed that this would 'result in emission reductions relative to fossil fuels of just 16 per cent.'[138]

4.114 FOE and People for Nuclear Disarmament NSW asserted that a doubling of nuclear power output by 2050 would reduce global greenhouse emissions by about 5 per cent, allegedly 'less than one tenth of the reductions required to stabilise atmospheric concentrations of greenhouse gases.'[139]

4.115 Research provided by Dr Helen Caldicott argued that, in addition to being a limited response to climate change, nuclear power is also 'about the slowest option to deploy (in capacity or annual output added)'.[140] It was argued that efficiency gains combined with decentralised sources of energy 'now add at least ten times as much capacity per year as nuclear power.'[141]

4.116 Professor Richard Broinowski expressed scepticism that nuclear power could even be part of the solution to the greenhouse emissions problem:

> The most compelling reasons are that: firstly, electricity generation accounts for only approximately one-third of greenhouse gas emissions; secondly, at least 1,000 nuclear reactors of at least 1,000 megawatts each would have to be constructed, beginning immediately, to make any dent on the contribution power generation makes to global warming; and, thirdly, these would in turn generate enormous quantities of hydrocarbon emissions in the mining and enrichment of the additional uranium, rapidly exhaust economically significant deposits of uranium and significantly increase the problems of disposal of spent nuclear fuel.[142]

4.117 In terms of emissions currently avoided, FOE argued that nuclear avoids some 312 Mt CO_2 per year in the EU countries, relative to use of fossil

137 ACF, *loc. cit.*

138 Dr Jim Green, *op. cit.*, p. 60.

139 FOE, *Submission no. 52*, p. 5; People for Nuclear Disarmament NSW Inc, *op. cit.*, p. 5.

140 Dr Helen Caldicott, *Exhibit no. 68, Nuclear power: economics and climate-protection potential*, p. i.

141 *ibid*.

142 Professor Richard Broinowski, *Transcript of Evidence*, 16 September 2005, p. 17.

fuels. However, FOE argued that the savings drop to half if the comparison is with natural gas cogeneration and zero if compared with hydroelectricity. There are allegedly net costs if nuclear is compared with investment in energy efficiency measures and renewables such as wind generation.[143]

4.118 ACF argued that nuclear is not an answer to the climate change problem because of the 'very long lead time and the high capital investment that is required for nuclear options.'[144] ACF also pointed to the significant opportunity cost involved for countries that choose to build or expand nuclear power. Because resources are finite, countries would necessarily have to forgo other options should it choose to adopt nuclear power. ACF also stressed that the economic competitiveness of renewables would improve over the next 10 to 15 years.

4.119 Similarly, MAPW (WA Branch) pointed to the long-lead times for the construction of nuclear power plants:

> The 10 years needed to plan and build a nuclear power plant, together with the high capital cost, makes the nuclear response to accelerating global warming particularly inappropriate. In fact, I think it would be a recipe for disaster because of the greenhouse gases produced in building those power stations.[145]

4.120 Critics of nuclear power argued that nuclear cannot solve the climate change problem. For example, FOE argued that 'nuclear power is being promoted as *the* solution to climate change, but it is no such thing.'[146] However, no witness or submitter—particularly those from industry—presented evidence to the Committee alleging that nuclear power *alone* could 'solve' climate change, or that nuclear power *alone* could reduce emissions sufficient to prevent further global warming.

4.121 Industry presented a consistently measured response in relation to nuclear power's potential to assist in reducing GHG emissions. For example, the ANA argued that:

> … if you are operating 400 or so nuclear power stations around the world, you are producing less CO_2 per unit of electricity than if you were operating coal or gas stations. Nuclear power, in that sense, can contribute to reducing the greenhouse effect but … nuclear power is not the solution to the greenhouse problem because it can only contribute a small amount as one of several

143 FOE, *op. cit.*, p. 6.

144 Mr David Noonan (ACF), *Transcript of Evidence*, 19 August 2005, p. 81.

145 Dr Peter Masters (MAPW – WA Branch), *Transcript of Evidence*, 23 September 2005, p. 36.

146 FOE, *op. cit.*, p. 5. Emphasis in original.

> energy resources. In general, we in the world are unfortunately very reliant on fossil fuels. We cannot possibly phase them out over a short period, and possibly not even over 20 to 50 years. We will be dependent on them, but we can do everything possible to conserve electricity and use more efficient end-use applications. We can conserve it in that sense and we can supplement it with new baseload and distributed generation from nuclear and renewables which have much lower contributions. That is the point.[147]

4.122 Areva also argued that:

> No-one will ever suggest, and we certainly would not, that nuclear should be the only fuel source, but there is no doubt that it is the most efficient and one of the cleanest sources of energy …
>
> Nuclear power is just one of the many aspects. In a relative sense it is a clean fuel. It does not produce CO_2 which … is creating global warming … Nuclear power will help to reduce that, but there have to be other ways as well. It is not going to stop it, but it will help to reduce it.[148]

4.123 Similarly, BHP Billiton argued that:

> No, [nuclear power] is not the solution, because I do not think there is one solution. I think more efficient carbon capture, better use of fossil fuels, more use of renewables as appropriate and more use of nuclear fuels are all part of the case.[149]

4.124 Heathgate Resources stated that nuclear power is 'one part of the answer' and the ANF argued that nuclear power is 'not going to solve [the climate change] problem by itself', but that 'by having nuclear reactors you certainly could do something to ameliorate it.'[150] Similarly, Nova Energy stated that nuclear 'is only part of that solution.'[151]

4.125 Nonetheless, BHP Billiton noted that while the energy used to mine uranium in Australia is carbon based, a global perspective is needed and use of Australia's uranium makes a significant contribution to GHG mitigation worldwide:

> You have to take a global picture … about 40 per cent of Australia's current greenhouse gas emissions are saved, if you

147 Dr Clarence Hardy, *op. cit.*, p. 54.

148 Mr Stephen Mann (Areva), *Transcript of Evidence*, 23 September 2005, pp. 1, 8.

149 Dr Roger Higgins (BHP Billiton Ltd), *Transcript of Evidence*, 2 November 2005, p. 23.

150 Mr Mark Chalmers (Heathgate Resources Pty Ltd), *Transcript of Evidence*, 19 August 2005, p. 105; Mr James Brough (ANF), *Transcript of Evidence*, 16 September 2005, p. 50.

151 Mr Richard Pearce (Nova Energy Ltd), *Transcript of Evidence*, 23 September 2005, p. 71.

> like—internationally, not in Australia—by virtue of the amount of uranium produced. So it is a major contributor … and a legitimate part of the greenhouse gas debate, but there is no magic solution.[152]

4.126 In terms of the emissions avoided by use of nuclear compared to those saved by renewables, in testimony before the US Senate Committee on Energy and Natural Resources Dr Patrick Moore argued that 'in 2002, carbon emissions avoided by nuclear power were 1.7 times larger than those avoided by renewables.'[153]

4.127 While it was conceded that nuclear power currently avoids emissions in the electricity and heat sector, which contributes 40 per cent of global CO_2 emissions, submitters also argued that nuclear power has the potential to significantly reduce emissions in the transport sector, which is the second largest CO_2 contributor at 24 per cent of the global total.[154]

4.128 Paladin Resources and Cameco, among others, pointed out that nuclear power, particularly reactors currently being developed, could play a significant role in producing hydrogen which may eventually have widespread use in transport and for desalination:

> Looking ahead there is an expectation that hydrogen will play a more important role in energy supply, especially as a transportation fuel to replace greenhouse gas-emitting petrol. Industrial-scale production of hydrogen by electrolysis will require large amounts of electricity, which itself must be generated by a CO2-free source if the total greenhouse loading is to be reduced. Large nuclear power plants obviously have a key role in future hydrogen manufacture. Nuclear power plants are also ideally suited for large scale water desalination plants which may become necessary in some parts of the world as water resources become severely over taxed by social demand.[155]

4.129 CSIRO also observed that:

> … large-scale nuclear energy production allows you an easy route to electrolysis of water to produce oxygen and hydrogen, without

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152 Dr Roger Higgins (BHP Billiton Ltd), *loc. cit*.

153 P Moore, *Nuclear Statement to the United States Senate Committee on Energy and Natural Resources*, *loc. cit*.

154 Detailed descriptions of non-electricity uses of nuclear power, including for hydrogen production, are available in the OECD Nuclear Energy Agency publication, *Non-Electricity Products of Nuclear Energy* (2004), viewed 21 May 2006, <http://www.nea.fr/html/ndd/reports/2004/non-electricity-products.pdf>.

155 Paladin Resources Ltd, *op. cit*., p. 6. See also: Mr Jerry Grandey (Cameco Corporation), *Transcript of Evidence*, 11 August 2005, p. 14.

> producing greenhouse gas emissions in any significant way and without the need, as you do in the similar production of hydrogen from coal, to sequester the CO_2.[156]

4.130 The Final Statement from the International Ministerial Conference, *Nuclear Power for the 21st Century*, also observed that nuclear power could make a valuable contribution to sustainable development through the production of hydrogen and potable water (desalination).[157]

4.131 ANSTO informed the Committee that the US Department of Energy (DOE) is moving towards a concept of producing hydrogen by nuclear power through a 'Nuclear Hydrogen Initiative'.[158] The aim of the Initiative is to:

> … demonstrate the economic commercial-scale production of hydrogen using nuclear energy by 2015, and thereby make available a large-scale, emission-free, domestic hydrogen production capability to fuel the approaching hydrogen economy.[159]

Renewables and energy efficiency measures

4.132 Submitters opposed to the use of nuclear power argued that the world's energy needs can be met and major reductions in GHG emissions can be achieved by promoting the use of renewable energy sources, decentralising power generation, adopting energy efficiency measures and significantly reducing energy consumption per capita in industrialised countries.[160] In particular, ACF, FOE, MAPW (WA Branch) and others drew on a study by Keepin and Kats, published in 1988, to argue that:

> … energy efficiency demand management is the most cost effective way of addressing greenhouse gas emissions … for every dollar invested in energy efficiency … realises seven times more

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156 Dr Rod Hill, *op. cit.*, p. 5. See also: Mr John Reynolds, *op. cit.*, p. 7; ANF, *op. cit.*, p. 4.

157 Cited in the Hon Alexander Downer MP, *op. cit.*, p. 7.

158 Dr Ron Cameron, *op. cit.*, p. 10; ANSTO, *Exhibit no. 74, Presentation by Dr Ron Cameron and Dr Ian Smith*, p. 47.

159 US DOE, *Nuclear Hydrogen Initiative*, Office of Nuclear Energy, Science and Technology, viewed 20 April 2006, <http://www.ne.doe.gov/infosheets/hydrogenfactmarch2003.pdf>.

160 See for example: Associate Professor Tilman Ruff (MAPW), *Transcript of Evidence*, 19 August 2005, p. 39; Dr Gavin Mudd, *Transcript of Evidenc*e, 19 August 2005, pp. 42, 43, 55; Dr Jim Green (FOE), *Transcript of Evidence*, 19 August 2005, p. 73; Dr Peter Masters (MAPW – WA Branch), *Transcript of Evidence*, 23 September 205, pp. 36, 38. Mr Justin Tutty, *op. cit*., p. 7; Uniting Church in Australia (Synod of Victoria and Tasmania), *Submission no. 40*, pp. 14–15; Mr David Addison, *Submission no. 59*, p. 1.

> savings in energy and in greenhouse gas emissions than if the same single dollar had been invested in a nuclear proposal.[161]

4.133 Keepin and Kats assert that:

> Opportunities for efficiency gains are so compelling that they suggest that global warming can best be avoided by concentrating on efficiency rather than on a rapid expansion of nuclear power.[162]

4.134 FOE cited a number of alternative studies which assert that energy efficiency and conservation measures, in combination with use of renewables, can deliver reductions in emissions required to stabilise atmospheric concentrations of greenhouse gasses. FOE also argued that reducing growth in energy demand will be essential to reduce emissions, regardless of whether there is a large expansion of nuclear power or renewables. It was argued that the choice of which renewable energy source to deploy (for example, solar or wind) would vary depending on the circumstances of the particular country.[163]

4.135 In the Australian context, FOE and the ECNT cited two studies which propose methods to achieve 'deep cuts' in Australia's GHG emissions:

- Clean Energy Future Group (2004), which concludes that Australia can meet its energy needs from various commercially proven fuels and technologies while cutting greenhouse emissions by 50 percent by 2040 in the stationary energy sector; and an
- Australia Institute study (2002), which claims to show how Australia can reduce greenhouse emissions by 60 per cent by 2050, through a combination of:

> … a major expansion of wind power, modest growth in hydroelectricity, significant use of biomass, niche applications for solar photovoltaics, and a shift away from large-scale thermal generators isolated from load centres towards distributed cogeneration of electricity and heat.[164]

4.136 The ECNT argued that:

> … there are more immediate, cost-effective and environmentally and socially sustainable options that can be pursued, rather than wasting time, money and resources heading off towards the nuclear dead end.[165]

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161 Mr David Noonan, *op. cit.*, p. 82. See also: Dr Gary Scott (ECNT), *Transcript of Evidence*, 24 October 2005, p. 4; MAPW (WA Branch), *op. cit.*, p. 7; Ms Jo Vallentine, *Submission no. 73*, p. 2.

162 Cited in FOE et. al., *op. cit.*, section 6.2.

163 FOE, *op. cit.* pp. 6–7. See also: FOE, *Submission 52.3*, pp. 1–11; FOE et. al., *op. cit.*, appendix 1.

164 FOE, *Submission no 52. loc. cit.*

165 Dr Gary Scott, *loc. cit.*

It was argued that nuclear should be replaced by efficient combined cycle gas as a transition away from fossil fuels to generate baseload power.[166]

4.137 The ECNT also argued that it would:

> … be negligent of the committee to endorse an expansion of uranium exports to, say, China, without conducting a thorough examination of the opportunities for, and benefits of, renewable energy technologies and energy efficiency measures, both in Australia and overseas. Indeed, we would go further and encourage the committee to recommend the redirection of Commonwealth funding currently aimed at facilitating the expansion of the coal and uranium sectors towards the renewable sector as well as into reducing baseload electricity demand.[167]

4.138 The Uniting Church in Australia (Victorian and Tasmanian Synod) also recommended that the Australian Government should assist in transferring renewable technologies to developing countries to assist with their greenhouse gas emission reductions and to significantly increase the provision of subsidies for research, development and implementation of renewables.[168] The ECNT also alleged that Australia was 'getting left behind' by failing to export renewable technologies to China.[169]

4.139 In a project of potential significance in Australia, Geodynamics described the GHG displacement potential of the company's 'hot fractured rock' geothermal resources in the Cooper Basin, which could enable Australia to avoid some 38 Mt of CO_2 per year relative to fossil fuelled plants and generate baseload power (estimated at 3 500 MWe). It was argued that the company's geothermal energy project is unique within the renewable sector 'because it can produce low cost, baseload power on a large scale'.[170]

Nuclear power — an essential component in a low-emission energy mix

4.140 Industry argued that nuclear power can make a significant contribution as part of a low-emission energy mix, which should also include renewables and clean coal technologies:

> Australia's uranium producers do not say that nuclear is the only answer to the world's energy needs but they do say that it needs to

166 *ibid.*, p. 5.

167 *ibid.*, p. 3.

168 Uniting Church in Australia (Synod of Victoria and Tasmania), *op. cit.*, p. 3.

169 Dr Gary Scott, *op. cit.*, p. 4.

170 Geodynamics Ltd, *Exhibit no. 64*, pp. 1, 3.

> be regarded as an important part of the mix, which should also include renewable sources where they are available, economic and efficient. We also support the coal industry's endeavours to dramatically reduce carbon dioxide emission from the use of their product and to achieve this economically.[171]

4.141 Energy Resources of Australia (ERA) emphasised that:

> … nuclear power is an essential component of any mix of low-emission power generation technologies required to reduce greenhouse gas production.[172]

4.142 Paladin Resources stated that:

> Responsible and balanced policy would strive for a mix of low-greenhouse energy sources: CO2-free nuclear for baseload power in countries with high ambient power demand; low-CO2 coal, because coal is abundant; natural gas for peaking loads; hydro, wind, tidal, solar where suitable and appropriate. Achieving better energy efficiency in product design and use and reducing excessive consumption in the developed world through better electricity pricing are also important strategies. There is no single panacea, but no likely remedy should be arbitrarily rejected. Windmills and reactors each have parts to play.[173]

4.143 Likewise, Ms Pepita Maiden, a former employee of British Nuclear Fuels, argued that:

> … nuclear power should not necessarily be embraced as the sole solution to climate change issues, it should be accepted and supported as an important part of the world's energy mix.[174]

4.144 The Committee notes that while the IEA has emphasised the key role of energy efficiency measures in reducing global emissions, the Agency has argued that there is no one technology or policy which can stabilise atmospheric GHG emission concentrations. The IEA has concluded that the global energy mix for a sustainable future will require a 'portfolio approach' to policy, technology development and R&D in which nuclear power plays an important part.[175]

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171 Mr Ian Hore-Lacy (UIC), *Transcript of Evidence*, 19 August 2005, p. 89.

172 ERA, *Submission no. 46*, p. 4.

173 Paladin Resources Ltd, *op. cit.*, p. 7.

174 Ms Pepita Maiden, *Submission no. 56*, p. 1.

175 Mr Claude Mandil, Executive Director, IEA, 'The Energy Mix of a Sustainable Future', *Delhi Sustainable Development Summit*, New Delhi, 2–4 February 2006, viewed 22 March 2006, <www.iea.org/textbase/speech/2006/Mandil/DSDS.pdf>.

4.145 In a similar vein, the Final Statement from the International Ministerial Conference, *Nuclear Power for the 21st Century*, noted that:

> A diverse portfolio of energy sources will be needed in the 21st century to allow access to sustainable energy and electricity resources in all regions of the world. Efforts will be needed as well to improve energy efficiency, while limiting air pollution and greenhouse gas emissions.[176]

4.146 Emphasising the importance of a mix of energy sources, the World Energy Council concluded at its World Energy Congress held in Sydney in September 2004 that:

> All energy options must be kept open and no technology should be idolised or demonised. These include the conventional options of coal, oil, gas, nuclear and hydro (whether large or small) and the new renewable energy sources, combined of course with energy efficiency.[177]

4.147 The view that the optimum energy supply mix must include nuclear power was also supported by Wind Prospect, a wind energy developer, constructor and operator, working in Australia, UK, Hong Kong and Ireland, who submitted that:

> It is our belief that the optimum energy supply solution, both for Australia and internationally, involves a mix of many energy sources, and that there exists a place for nuclear energy as a source of baseload electricity.[178]

4.148 The MCA emphasised that nuclear power should not be seen as a substitute for coal, renewables or other energy sources because the rate of growth of energy demand globally requires a contribution from all energy sources and, second, the required reductions in greenhouse emissions will not be achieved by energy efficiency measures alone:

> The rate of growth in demand of energy is increasing and, particularly in the industrialised and urbanising countries of China and India and other parts of Asia, there is going to be demand for all sources of energy. We are not looking at uranium as a substitute for coal or other sorts of energy, we are looking across the board and that includes some of the variable load capacity of renewables and maybe also the baseload of hydro …

176 Cited in the Hon Alexander Downer MP, *op. cit.*, p. 6. See also: International Ministerial Conference, *Nuclear Power for the 21st Century*, Final Statement, Paris, 21–22 March 2005, Viewed 16 May 2006, <http://www-pub.iaea.org/MTCD/Meetings/PDFplus/2004/cn122-final-statement.pdf>.

177 Cited in UIC, *Submission no. 12*, p. 14.

178 Wind Prospect Pty Ltd, *op. cit.*, p. 1.

> because we are not going to get within a bull's roar of what the scientists are telling us we have to do in terms of [greenhouse gas emission] reductions just through energy efficiency …[179]

4.149 However, research cited by Dr Helen Caldicott disputed the argument that a mix of energy options is required or even possible:

> The claim that 'we need all energy options' has no analytic basis and is clearly not true; nor can we afford all options. In practice, keeping nuclear power alive means diverting private and public investment from the cheaper market winners—cogeneration, renewables, and efficiency—to the costlier market loser.[180]

4.150 The IEA concludes that to meet global energy demand and stabilise CO_2 concentrations will require unprecedented technology changes during this century.[181] Potential strategies to avoid one billion tonnes of CO_2 per year (a three per cent difference) as posited by the IEA are listed in table 4.5. For example, to avoid one billion tonnes of CO_2 would require the replacement of 300 conventional 500 MW coal power stations with 1 000 Sleipner carbon sequestration plants (currently being deployed in the North Sea at a cost of US$59/tonne), the installation of 200 times the current US wind generation, or the construction of 1 300 times the current US solar generation. Alternatively, 140 one-gigawatt nuclear power stations would need to be constructed. Dr Ian Smith, Executive Director of ANSTO, argued that 'I believe you have to do all those things; you cannot do just one of those things.'[182]

Table 4.5 Strategies to avoid one billion tonnes of carbon dioxide per year

Coal	Replace 300 conventional, 500-MW coal power plants with 'zero emission' power plants, or …
CO_2 Sequestration	Install 1 000 Sleipner CO2 sequestration plants
Wind	Install 200 times the current US wind generation in lieu of unsequestered coal
Solar PV	Install 1 300 times current US solar generation in lieu of unsequestered coal
Nuclear	Build 140 1-GW power plants in lieu of unsequestered coal plants

Source Claude Mandil, *International Ministerial Conference, Nuclear Power for the 21st Century, March 2005* cited in ANSTO, *Exhibit no. 74, Presentation by Dr Ron Cameron and Dr Ian Smith*, slide no. 30.

179 Mr Mitch Hooke, *op. cit.*, p. 28. FOE and others conceded that 'energy efficiency measures alone are insufficient' to achieve necessary emissions reductions. See: FOE et. al., *op. cit.*, section 6.3.

180 Dr Helen Caldicott, *Exhibit no. 68, op. cit.*, p. ii.

181 Mr Claude Mandil, *loc. cit.*

182 Dr Ian Smith, *op. cit.*, p. 8.

4.151 Silex Systems argued that potential solutions to climate change include a combination of the following:

- decreasing fossil fuel consumption;
- increasing reliance on nuclear power;
- increasing reliance on renewables, at least for peak load power;
- accelerating the hydrogen economy via nuclear power, particularly to replace fossil fuels in transportation; and
- improving energy efficiency.[183]

Silex argued that no one option will solve the greenhouse problem:

> We believe that an integrated mix of nuclear, renewables, hydrogen and energy efficiency measures is required and is inevitable.[184]

4.152 Moreover, in relation to the development of clean coal technologies, development of uranium reserves and renewables/hydrogen, Silex argued that Australia needs a 'bipartisan energy strategy for there to be a coherent and forceful approach. A unique opportunity for political leadership exists'.[185]

4.153 DEH, the MCA and the ANA stressed the importance of addressing GHG emissions by focussing on clean coal technologies given Australia's comparative advantage in coal and the likelihood that the world will remain reliant on fossil fuels, particularly coal, for decades to come:

> … in the longer term the world is going to be reliant on fossil fuels. There is no doubt about that; it is the dominant fuel … So it does make sense to look at technologies by which you can clean up that use of coal in terms of greenhouse emissions.[186]

4.154 DEH emphasised that while uranium exports can reduce emissions if they displace high-intensity sources, Australia has a keen interest in technologies that can produce low emissions from coal and so 'it is in Australia's interests not to set them against each other but to talk about the contribution both can make.'[187] Furthermore, in addition to clean coal technology, it was submitted that Australia has a comparative advantage in solar photovoltaics and hot dry rocks (geothermal) and is best able to contribute in these areas of technology.

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183 Silex System Ltd, *Exhibit no. 88, Presentation by Dr Michael Goldsworthy*, p. 7

184 Dr Michael Goldsworthy, *op. cit.*, p. 3.

185 *ibid*.

186 Mr David Borthwick (DEH), *Transcript of Evidence*, 10 October 2006, pp. 5, 6; MCA, *op. cit.*, p. 10; Dr Clarence Hardy, *op. cit.*, p. 56.

187 Mr Barry Sterland (DEH), *Transcript of Evidence*, 10 October 2005, p. 15.

The limitations of renewable energy sources

4.155 While industry welcomed the contribution that renewable energy sources can make and readily conceded that nuclear power alone could not 'solve' climate change, it was consistently argued that nuclear power is the only low-emission alternative to fossil fuels capable of providing baseload supply of electricity on a large scale. For example, the UIC submitted that:

> While the UIC has a positive view of the role of wind and solar power in the overall electricity supply, we wish to emphasise that the main demand in any urbanised country is for continuous, reliable supply on a large scale, and these intermittent renewables simply cannot meet that, let alone on an economic basis. Nor is there any prospect of them doing so.[188]

4.156 The capacity of nuclear power to provide baseload power with low emissions was emphasised as being particularly important in the context of rapidly growing global energy demand. For example, Paladin Resources argued that:

> It is difficult to see how the world's voracious appetite for energy, and particularly electricity, will be met without compromising greenhouse gas limits unless there is an increasing reliance on nuclear power for baseload, high volume electricity production.[189]

4.157 Similarly, AINSE argued that:

> … of the methods of power generation which contribute least to CO_2 emissions nuclear fission is the only one suited to the provision of a stable baseload … The projected increase in energy demands requires a solution now. Nuclear fission will be one component of multiple strategies, including renewables.[190]

4.158 AMEC also observed that nuclear power is part of the answer to the energy demand and GHG emission problem for the medium term:

> With the growing demand for energy and the dangers that global warming presents … at least in the short to medium term we have to develop uranium deposits throughout this country.[191]

4.159 It was emphasised that renewable energy sources and energy efficiency measures are limited and will not be sufficient to meet growing energy demand and reduce emissions. The SIA argued that the limitations of renewables need to be acknowledged:

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188 UIC, *Submission no. 12.1*, p. 1.

189 Paladin Resources Ltd, *op. cit.*, pp. 5–6.

190 AINSE, *op. cit.*, p. 1.

191 Mr Alan Layton (AMEC), *Transcript of Evidence*, 23 September 2005, p. 21.

> Yes, we must achieve better efficiencies. We must maximise the use of renewable energy—wind, solar and hot rocks—and clean up coal, but we have to be realistic about the risks, the costs and the real limitations of some of these measures. These measures alone will not suffice. The paradox for me is that the very people who would protect the environment have caused and continue to cause such damage by their blind rejection of the realities.[192]

4.160 On the potential for renewables to address global GHG emissions, replace fossil fuels and nuclear power, and meet the growing global demand for energy, CSIRO argued that:

> The question is can renewable technology keep pace with the increasing need for energy? At the moment it does not appear that the technology is advancing at a rate and at a scale that allows it to replace existing fossil fuel and nuclear fuel based energy production … The scenario planning that CSIRO has done so far projects out 50 years or so, and that has fossil fuel based sources of energy still in the mix at that point. At the end of the day, the models must take into account the economic situation as well as the demand situation. It projects increases in electricity production requirements of the order of two per cent growth a year, and we just cannot keep pace with that with any silver bullet technology that might come in.[193]

4.161 Submitters noted that the proportion of world energy demand that will be supplied by renewable sources in the future is highly contested. Nova Energy asserted that without resolving a series of technical challenges, 'there is general acceptance that it will not be possible to meet all future energy demands from renewable energy sources.'[194]

4.162 In general, it was argued that renewable energy sources cannot provide the baseload capacity required by industrial societies and large cities, such as the emerging 'megacities' of Asia.[195] Renewables, such as solar, wind and wave power, were said to be intermittent, provide fluctuating supply and present energy storage issues.[196]

4.163 Nova Energy argued that while renewables are certainly required to complement other energy sources, it is not possible to derive sufficient electricity or liquid fuels from renewables to sustain the present high per

192 Rear Adm. Peter Briggs AO CSC (Retired) (SIA), *Transcript of Evidence*, 10 October 2005, p. 27.

193 Dr Rod Hill (CSIRO), *Transcript of Evidence*, 19 August 2005, p. 5.

194 Nova Energy Ltd, *op. cit.*, p. 23.

195 See for example: Mr John Reynolds, *op. cit.*, p. 3; Compass Resources NL, *op. cit.*, p. 3; Deep Yellow Ltd, *op. cit.*, p. 2.

196 Summit Resources, *op. cit.*, p. 26.

capita rates of consumption, let alone additional growth requirements. The reasons cited for these limitations were:

- Large fluctuations in energy production, for example variability and intermittency of wind energy or limited solar energy efficiency caused by winter solar incidence or night time.
- Need to store energy to cope with timing inconsistencies of supply and demand, for example storage of solar energy for night use. Large storage volumes are required to store significant quantities of energy.
- Significant loss factors during the process, including on transmission, inversion from DC to AC current and conversion for storage.
- Many potential locations from where renewable energy, such as wind, hydro and thermal, may be sourced are significant distances from power grids making transport difficult and expensive.
- Infrastructure requirements are expensive to install and maintain.
- Low efficiency rates, for example solar energy generated compared to actual energy falling on solar panels.
- Current technology requires large amounts of land to house infrastructure.
- It is difficult to extend the use of renewables on a large scale unless significant government policies are implemented, for example reducing carbon-emitting energy sources on the environment and subsidies.
- Renewable energy is not expected to compete economically with fossil fuels in the mid-term forecasts.[197]

4.164 Nova Energy argued that the limitations of wind power are clearly demonstrated by the German experience, which now has over 17 000 wind turbines with capacity exceeding 14 350 MW—the largest installed wind capacity in the world. In 2003, the turbines were said to provide just four percent of Germany's demand for electricity. The operator of Germany's transmission grid, E.ON Netz GmbH, has pointed out that periods of maximum demand often coincide with periods of minimum wind power (for example, summer heatwaves). E.ON estimates that 80 per cent back-up power (nuclear or carbon-based) is required to meet demand at all times. Thus, wind power reduces fossil fuel consumption but does not remove the need for conventional baseload power sources.[198]

4.165 Similarly, Deep Yellow submitted that:

> Evidence to date is that wind, wave and solar power cannot provide the scale of electricity required without a backup facility

197 Nova Energy Ltd, *op. cit.*, p. 24.

198 *ibid.*

> powered by reliable fossil fuels. Geothermal energy is not yet proven on large scales.[199]

4.166 Mr Keith Alder also welcomed the contribution being made by renewables but argued that their limitations needed to be better understood:

> There is a lot of urging that the use of [renewables] be increased—looking for subsidies, of course—from the present one or two per cent up to about 20 per cent … That figure of 20 per cent is one of the limits, I believe. I do not think you can put more than about 20 per cent of renewable energy such as solar and wind into a major electricity grid, for the simple reason that it is unreliable … If the wind does not blow … your wind generator drops out and, if the sun does not shine—and it certainly does not shine at night—you lose your solar energy. There is a natural limit to what the grid can stand. If it drops out and you do not want blackouts, then something else has to pick up the load. No electricity generating authority in the world which believes it can supply reliable energy will tolerate more than about 20 or maybe 30 per cent, at the most, of its input in one piece of machinery. This is why there is a natural limit on the renewables ...[200]

4.167 Mr Alder argued that the key question is:

> … where we get the other 80 per cent. That is where uranium comes into the picture. As far as I can see, there are only two possible ways to generate that 80 per cent, or the baseload—which is more than half and, more likely, 70 per cent—of that 80 per cent. The two alternatives are coal and nuclear; there is nothing else. It is an absolutely inescapable fact that you have to burn coal or use nuclear reactors to generate baseload electricity. You can use oil or gas, but they are both very desirable resources to be retained for other purposes.[201]

4.168 Although opposed to use of nuclear power, AMP CISFT conceded that that renewables cannot meet baseload power requirements, either in Australia or internationally.[202]

4.169 CSIRO submitted that while considerable research is going into energy storage devices for renewables, aside from geothermal there are no renewable sources of energy that provide inherent baseload power.[203] In

199 Deep Yellow Ltd, *loc. cit.*

200 Mr Keith Alder, *Transcript of Evidence*, 16 September 2005, p. 80.

201 *ibid.*

202 Dr Ian Woods (AMP CISFT), *Transcript of Evidence*, 16 September 2005, p. 34.

203 Dr Rod Hill, *op. cit.*, p. 6. CSIRO also note that the heat content in the granites that could be used for geothermal energy are radiogenic in origin.

surveying the range of future renewable electricity generation options, including photovoltaics, Dr Rod Hill observed that:

> There is certainly a significant research effort in these longer term technologies, but the reality of it is that we need to make the existing dependence on coal more efficient and we need to make sure that people feel comfortable about nuclear, because they are the short-term options.[204]

4.170 The MAPW (WA Branch), who promoted use of renewables such as wind and solar, also conceded that energy storage is a problem for wider deployment of renewables.[205] The ANA also argued that intermittent renewable sources—solar, wind and wave—will not be able to make a major contribution until electricity storage systems are developed to produce a 'smooth, efficient source at reasonable cost. That is the key to renewables.'[206] In the meantime, the ANA expressed support for the Australian Government's efforts to develop clean coal technologies.

4.171 Dr Gavin Mudd observed that geothermal has potential as a future renewable baseload energy source, but being remote from population centres means that significant energy losses can be expected in transmission.[207]

4.172 In summary, Nova Energy argued that:

> … to develop systems in which the majority of energy is sourced from renewables, provision must be made for large fluctuations in energy production and for the need to store large quantities of energy. These problems make a significant difference to the viability of renewables due to the impact on efficiencies and costs.[208]

4.173 Nova Energy also argued that even if renewables could supply baseload power needs, the capital investment that would be required would be 'absolutely enormous'.[209] The UIC also noted that to conform with current German policy, another 30 000 MWe of renewable capacity will need to be added by 2020, which will cost some €80 billion.[210]

4.174 Heathgate Resources pointed to the impracticality of providing baseload power via renewables by comparing the fuel requirements to generate

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204 *ibid.*, p. 11.
205 Dr Stephen Masters (MAPW – WA Branch), *Transcript of Evidence*, 23 September 2005, p. 37.
206 Dr Clarence Hardy, *op. cit.*, p. 56.
207 Dr Gavin Mudd, *Transcript of Evidence*, 19 August 2005, p. 56.
208 Nova Energy Ltd, *loc. cit.*
209 Dr Timothy Sugden (Nova Energy Ltd), *Transcript of Evidence*, 23 September 2005, p. 70.
210 UIC, *Exhibit no. 49, Nuclear Industry in Europe*, p. 3.

1 000 MW, the typical size of a single nuclear reactor, which would require 150 tonnes of natural uranium per year. Given the low energy densities of renewables, to generate this amount of electricity would require 60 to 150 square kilometres of solar panels (in France), 150 to 450 square kilometres of wind mills in a favourable area, 6.2 Mt of garbage, or 4 000 to 6 000 square kilometres of biomass plantations. The fuel requirements for an equivalent capacity fossil fuel plant, discussed above, are 2.3 Mt of coal, 1.9 Mt of oil or 1.4 billion cubic metres of natural gas.[211]

4.175 Concern about the potential of renewables is shared by Dr Mohamed ElBaradei, Director General of the IAEA, who has stated that while nuclear and renewable sources could both have larger roles to play in meeting rising energy demands over coming decades:

> The problem is that no 'renewable' source has been demonstrated to have the capacity to provide the 'baseload' amounts of power needed to replace large fossil fuel plants. Wind power, for example, may be an excellent choice for sparsely populated rural economies, particularly if they lack modern electrical infrastructure; on the other hand, it seems unlikely that wind power will be able to support the electricity needs of tomorrow´s mega-cities.[212]

4.176 Compass Resources argued that as oil production eventually declines, 'the only realistic alternative to meet the increased energy demand is coal or nuclear.'[213] However, it was suggested that despite geosequestration and other improvements, coal is likely to increase greenhouse emissions as demand grows. SIA also argued that geosequestration is 'perhaps 10 years off' and that 'the technical and economic viability have yet to be demonstrated.'[214]

4.177 In addition to comparing the life cycle emissions of electricity generation chains, assessing the contribution that nuclear power can make to GHG abatement necessarily involves an analysis of the costs of generating nuclear power. Although the Committee did not request evidence on this matter, information was provided by some submitters and the Committee presents an overview of this evidence in the section which follows.

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211 Heathgate Resources Pty Ltd, *Exhibit no.57, op. cit.*, p. 3.

212 Cited in the Hon Alexander Downer MP, *op. cit*., p. 7. See also: Dr Mohamed ElBaradei, *Nuclear Power: Preparing for the Future*, 21 March 2005, viewed 12 May 2006, <http://www.iaea.org/NewsCenter/Statements/2005/ebsp2005n004.html>.

213 Compass Resources NL, *op. cit.*, p. 3.

214 SIA, *Submission no. 21*, p. 7.

The economics of nuclear power

4.178 A central consideration in assessing nuclear power's viability as a GHG emission mitigation option relates to the economic attractiveness of nuclear generation of electricity relative to other baseload alternatives.

4.179 The OECD Nuclear Energy Agency (OECD-NEA) states that the economics of nuclear power are characterised by high capital investment costs; low fuel, operating and maintenance costs; insensitivity to variations in fuel prices; and long operational life but significant regulatory costs.[215]

4.180 The costs of producing nuclear electricity are typically broken down into three major categories:

- capital investment costs, including plant construction, major refurbishment and decommissioning;
- operation and maintenance (O&M) costs, including staff costs, training, security, health and safety, and cost of managing low and intermediate level operational waste; and
- fuel cycle costs, including the cost of the uranium, its conversion and enrichment, fuel fabrication, used fuel disposal and reprocessing.[216]

4.181 Capital costs account for approximately 60 per cent or more of the total costs of nuclear electricity production, with O&M and fuel cycle costs accounting for some 20 per cent each of the total cost.[217]

4.182 Compared to nuclear power, coal-fired plants are said to be characterised by mid-range capital and fuel costs, while natural gas-fired plants are characterised by low capital investment costs but significant fuel costs. Renewable sources of energy, such as wind and hydropower, are similar to nuclear in having high capital and low generating costs per unit of power produced.[218]

Studies of the comparative costs of generating electricity

4.183 There have been several respected studies of the economics of nuclear power published in recent years, including the following:

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215 OECD-NEA, *Nuclear Energy Today*, OECD-NEA, Paris, 2003, p. 59, viewed 23 May 2006, <http://www.nea.fr/html/pub/nuclearenergytoday/welcome.html>. See also: MCA, *op. cit.*, p. 10.

216 *ibid.*, p. 60.

217 *ibid.*

218 *ibid.* See also: Dr Ian Smith, *op. cit.*, p. 8; Mr Donald Kennedy (Jindalee Resources Ltd), *Transcript of Evidence*, 23 September 2005, p. 62.

- IEA and OECD-NEA (2005), *Projected Costs of Generating Electricity*[219]
- University of Chicago (2004), *The Economic Future of Nuclear Power*[220]
- Royal Academy of Engineering (2004), *The Cost of Generating Electricity*[221]
- Canadian Energy Research Institute (CERI) (2004), *Levelised Unit Electricity Cost Comparisons of Alternative Technologies for Baseload Generation in Ontario*[222]
- General Directorate for Energy and Raw Materials (DGEMP) of the French Ministry of the Economy, Finance and Industry (2003), *Reference Costs for Power Generation*[223]
- Massachusetts Institute of Technology (MIT) (2003), *The Future of Nuclear Power*[224]

4.184 While these studies come to differing conclusions about the costs of generating nuclear power, in the main they reveal that nuclear power is economically competitive with other baseload alternatives in many countries. This accords with the argument advanced by the MCA, Areva, UIC and others that: 'In many industrialised countries, nuclear energy is cost competitive with coal-fired electricity and gas–fired generation'.[225] The Committee makes observations about the possible economic competitiveness of nuclear power in the Australian context in chapter 12.

4.185 The most recent study, published by the IEA and OECD-NEA, estimated the costs of generating electricity by baseload power plants that are expected to be commercially available by 2015 or earlier. Ten countries submitted data on nuclear plants which were compared with coal and gas generation in the same countries. Some data was also collected on renewable energy generation options.

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219 IEA and OECD-NEA (2005), *Projected Costs of Generating Electricity*, viewed 24 May 2006, <http://www.nea.fr/html/pub/ret.cgi?id=new#5968>.

220 University of Chicago (2004), *The Economic Future of Nuclear Power*, viewed 24 May 2006, <http://www.anl.gov/Special_Reports/>.

221 Royal Academy of Engineering (2004), *The Cost of Generating Electricity*, viewed 24 May 2006 <http://www.nowap.co.uk/docs/generation_costs_report.pdf>.

222 CERI (2004), *Levelised Unit Electricity Cost Comparisons of Alternative Technologies for Baseload Generation in Ontario*, viewed 24 May 2006, <http://www.cna.ca/pdf/CERI_LUEC_Report_August_27_2004-ed.pdf>.

223 DGEMP (2003), *Reference Costs for Power Generation*, viewed 24 May 2006, <http://www.industrie.gouv.fr/energie/electric/cdr-anglais.pdf>.

224 MIT (2003), *The Future of Nuclear Power*, viewed 24 May 2006, <http://web.mit.edu/nuclearpower/>.

225 MCA, *loc. cit*. UIC, *The Economics of Nuclear Power*, Briefing Paper No. 8, April 2006, viewed 24 May 2006, <http://www.uic.com.au/nip08.htm>.

4.186 The principal findings, which include the average plant construction costs, average construction times and levelised electricity generation costs for the electricity generation options employed in the survey countries are listed in table 4.6. The levelised generation cost figures incorporate capital, O&M and fuel costs relevant to each technology. The levelised cost is the price needed to cover both the operating (fuel and O&M) and annualised capital costs of a plant. The calculations do not include costs of transmission and distribution, or costs associated with residual emissions including greenhouse gases from coal and gas-fired plants.

Table 4.6 Construction costs, construction time and levelised costs of electricity generation

Generating technologies	**Construction costs** (per plant, US$/kWe)	**Construction time** (years)	**Levelised generation costs** (US$/MWh @ 5% discount rate)	**Levelised generation costs** (US$/MWh @ 10% discount rate)
Coal-fired	1 000 – 1 500	4	25 – 50	35 – 60
Gas-fired	400 – 800	2 – 3	37 – 60	40 – 63
Nuclear	1 000 – 2 000	5	21 – 31	30 – 50
Wind (onshore)	1 000 – 2 000	1 – 2	35 – 95	45 – >140*
Solar	2 775 – 10 164	1	~150	>200
Hydro	1 500 – 7 000	3	40 – 80	65 – 100

Source IEA and OECD-NEA, *Projected Costs of Generating Electricity: 2005 Update*
* Does not include specific costs associated with wind or other intermittent renewable energy source for power generation, such as the need for backup power to compensate for the low average availability factor

4.187 The study found that despite relatively high capital costs, nuclear power is competitive with fossil fuels for electricity generation in many countries. Construction costs for nuclear power plants range from US$1 000 per kW in the Czech Republic to $2 500 per kW in Japan. Coal-fired plants range from $1 000 to $1 500 per kW and gas-fired plants are significantly less costly at between $400 and $800 per kW.[226]

4.188 At the five per cent discount rate, nuclear power is revealed to be generally the lowest cost option with costs ranging from US$21 to $31 per MWh. Nuclear is cheaper than coal in seven of the ten countries and cheaper than gas in nine. The lowest costs for nuclear production were recorded in Korea, the Czech Republic, Canada and France and the highest in Japan. At the 10 per cent discount rate, the levelised costs for nuclear range from $30 to $50 per MWh. Despite this, nuclear is cheaper than coal in five of the ten countries and cheaper than gas in eight.[227]

4.189 DEH expressed some reservations about the cost estimates, cautioning that the study fails to specify the level of finance allocated to

226 IEA and OECD-NEA, *op. cit.*, pp. 43, 35, 39.

227 *ibid.*, p. 47.

decommissioning (although the estimates do explicitly incorporate decommissioning costs). The study was also criticised for not including complete insurance risk and the cost of permanent waste storage, which it was argued 'may raise the levelised cost considerably'.[228]

4.190 The IEA and OECD-NEA make clear that although the cost estimates do not substitute for detailed economic evaluations required by investors and utilities at the stage of project decision and do not take business risks in competitive markets adequately into account, nonetheless they 'provide a robust, transparent and coherent set of cost estimates … and may be used to assess alternative options at the stage of screening studies.'[229]

4.191 The IEA and OECD-NEA concluded that the generating technology preferred in each country will depend on the specific circumstances of each project. Further, the ranking of technologies in each country is sensitive to the discount rate employed and the projected prices of natural gas and coal.[230]

4.192 DEH also argued that the cost of electricity from nuclear compared to coal will vary according to 'the generation plant's proximity to its fuels source, the quality of fuel and the age of competing infrastructure.'[231]

4.193 The UIC and the MCA observed that the comparative costs of nuclear and coal depends on the locality of the proposed plant. If a power station is far removed from sources of coal and global transport is required then nuclear becomes more attractive.[232] Similarly, AMEC observed that nuclear is competitive with other forms of electricity generation, except where local access to low cost fossil fuels exist.[233]

4.194 The study by the Royal Academy of Engineering (2004), *The Costs of Generating Electricity*, compared the present day costs of generating electricity in the UK from available technologies, including coal, oil, gas, nuclear, wind and biomass. The study considered what was regarded as best estimates of what it costs to build, maintain and operate various power stations. That is, the study incorporated the costs of construction, O&M and fuel for each plant. It also included an estimate of decommissioning costs for nuclear plants, but assumed that decommissioning costs for other plants are neutral. The study's findings are depicted in figure 4.3.

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228 DEH, *loc. cit.*

229 IEA and OECD-NEA, *op. cit.*, p. 16.

230 *ibid.*, p. 14.

231 DEH, *op. cit.*, p. 6.

232 Mr Robert Rawson (MCA), *Transcript of Evidence*, 5 September 2005, p. 31.

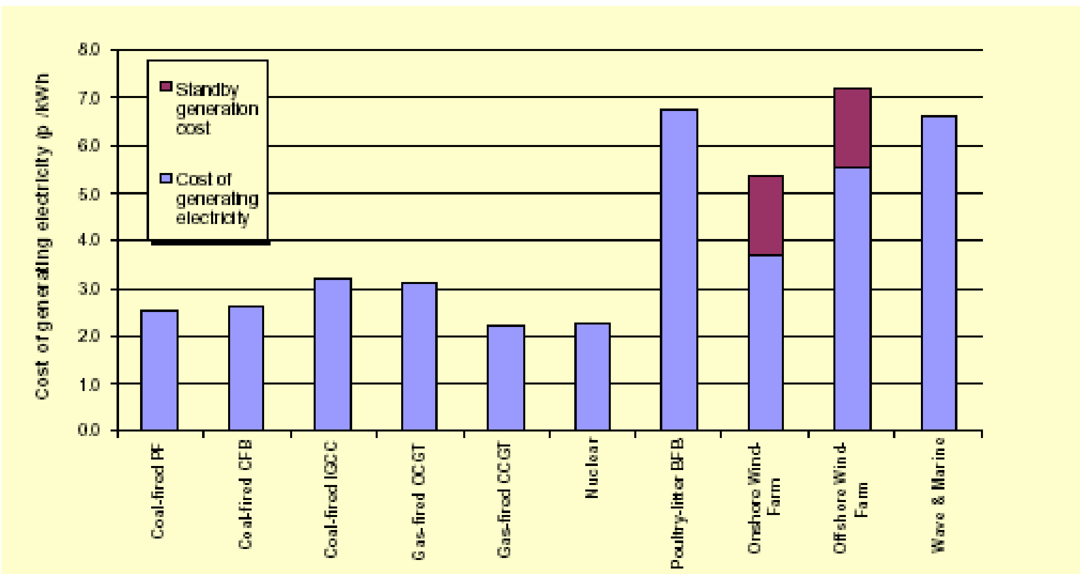
233 AMEC, *op. cit.*, p. 6.

4.195 The study concluded that for baseload operation, generating costs are 2.2 pence per kWh for combined-cycle gas turbine (CCGT) plants, 2.3 pence per kWh for nuclear plants and between 2.5 and 3.2 pence per kWh for coal plants.[234]

4.196 Renewable energy sources, which offer intermittent power, were found to be markedly more expensive, with onshore wind generation costing 3.7 pence per kWh and offshore wind costing 5.5 pence per kWh. However, when the additional cost of standby generation was added, the costs became 5.4 and 7.2 pence per kWh respectively.[235] The effect of including standby generation costs is also depicted in figure 4.3.

4.197 The Academy's study also examined the sensitivity of electricity generation costs to variations in fuel prices and emission costs. As the cost of carbon emissions increases, nuclear and renewables become more competitive and the gap between CCGT plants and coal-fired technologies widens (because of the greater level of carbon found in coal compared with natural gas and the lower efficiency of steam plant). It was found that if fuel prices rise by 20 per cent or carbon taxes are introduced, nuclear becomes the cheapest option to deploy.[236]

Figure 4.3 Cost of generating electricity (pence per kWh) in the UK



Source The Royal Academy of Engineering, *The Costs of Generating Electricity*, p. 4.

234 Royal Academy of Engineering, *op. cit.*, p. 5.
235 *ibid.*, p. 6.
236 *ibid.*, p. 7.

4.198 The University of Chicago (2004) study, *The Economic Future of Nuclear Power*, which was sponsored by the US DOE, found that new nuclear plants coming online in the next decade will initially have a levelised cost of electricity of US$47 to $71 per MWh. In comparison, coal plants will be in the range of $33 to $41 per MWh and gas-fired plants will be in the range of $35 to $45 per MWh. However, it was found that once early costs are absorbed, levelised costs for nuclear plants will fall to the range of $31 to $46 per MWh.[237] Thus, the DOE concluded that 'the future cost associated with nuclear power production is comparable with gas and coal-based energy generation', and that 'nuclear power can be a competitive source of energy production in the future and will help meet our environmental goals.'[238]

4.199 The CERI (2004) study, *Levelised Unit Electricity Cost Comparisons of Alternative Technologies for Baseload Generation in Ontario,* found that in the majority of scenarios considered, coal-fired generation is the most attractive option. However, if CO_2 emission costs of C$15 per tonne are included, deployment of 'first of a kind' nuclear technology (the twin ACR-700 reactor) becomes either the least-cost generating option or competitive with coal-fired generation depending on financing assumptions. For later deployments of the technology, cost savings are expected to reduce the levelised cost so that nuclear is competitive with coal even in the absence of CO_2 emission costs. Given forecast increases in the price of natural gas, gas-fired generation for baseload supply was found to be uncompetitive in most scenarios considered.[239]

4.200 The DGEMP study (2003), *Reference Costs for Power Generation*, found that using an eight per cent discount rate, nuclear power will be the cheapest option at 2.84 euro cents per kWh, followed by coal plants at 3.37 euro cents per kWh and the CCGT at 3.50 euro cents per kWh. At higher discount rates, nuclear's advantage is reduced. Nuclear power's competitiveness improves even further if CO_2 emission costs are included. Figure 4.4 illustrates the main conclusions of the study, showing the basic costs of the technologies estimated for 2015 and the effect of additional CO_2 costs.[240]

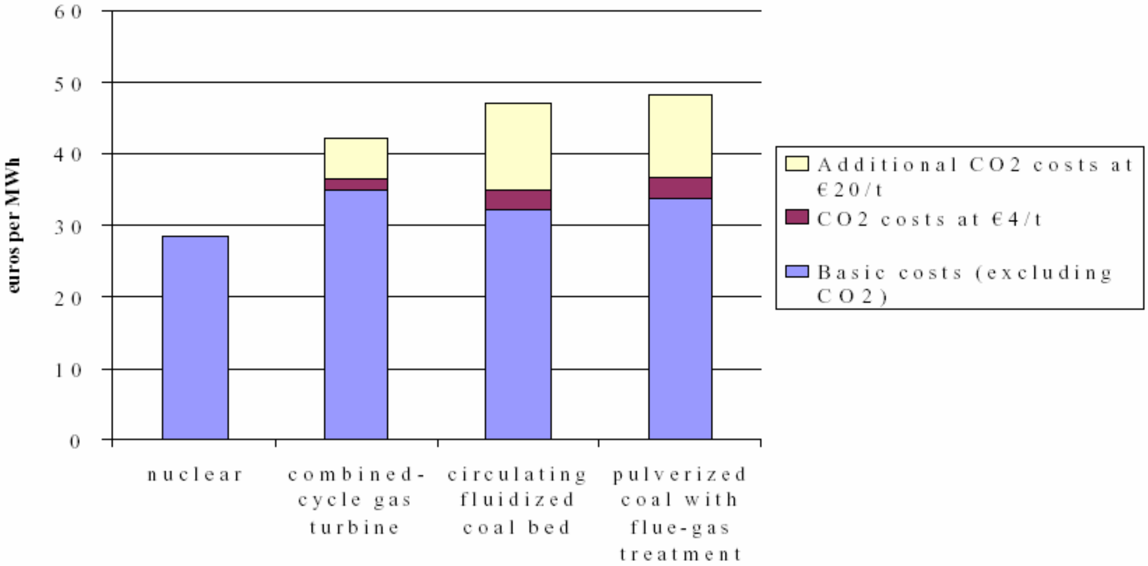
237 University of Chicago, *op. cit.*, pp. xi–xii.

238 Argonne National Laboratories, *Study shows future cost of nuclear power is comparable with gas- and coal-fired energy*, Media Release, 20 September 2004, viewed 25 May 2006, <http://www.anl.gov/Special_Reports/>.

239 CERI, *op. cit.*, pp. 3–4.

240 DGEMP, *op. cit.*, p. 2.

Figure 4.4 Costs (including tax) of baseload alternatives in France in 2015, based on an 8 per cent discount rate and showing CO_2 costs



Source DGEMP, *Reference Costs for Power Generation*, p. 1.

4.201 In contrast to the generally positive assessments of nuclear power's economic competitiveness in the studies summarised above, the MIT study (2003), *The Future of Nuclear Power,* found nuclear power to be an unattractive option. The study, which used construction and financing cost assumptions the industry considers demanding for nuclear, found the levelised cost for nuclear power to be US6.7 cents per kWh, compared to 3.8 to 5.1 cents per kWh for gas and 4.2 cents per KWh for coal.[241]

4.202 Even with the imposition of a cost for CO_2 emissions of US$50 per tonne of carbon (tC), nuclear power was still found to be uncompetitive against gas and coal in a base case scenario. With carbon taxes in the range of $100/tC to $200/tC, nuclear power would be an economic baseload option.[242]

4.203 DEH stated that, as with the IEA and OECD-NEA study, it was unclear whether MIT accounts for the costs of decommissioning, insurance risk and permanent waste disposal. Again, these factors could raise the levelised cost considerably.[243]

4.204 Notwithstanding its conclusion that nuclear 'is just too expensive', particularly in regions where electricity suppliers have access to natural gas or coal, the MIT study concluded that:

241 For a plant with a 40 year life and 85 per cent capacity factor. MIT, *op. cit.*, p. 42. WNA, *The New Economics of Nuclear Power*, WNA, London, December 2005, p. 25, viewed 24 May 2006, <http://www.uic.com.au/neweconomics.pdf>.

242 MIT, *loc. cit.*

243 DEH, *loc. cit.*

> If in the future carbon dioxide emissions carry a significant 'price' … nuclear power could be an important—indeed vital—option for generating electricity … *we believe the nuclear option should be retained, precisely because it is an important carbon-free source that can potentially make a significant contribution to future electricity supply*.[244]

Reducing capital costs

4.205 In relation to the high capital costs for nuclear plants, ANSTO observed that efforts are now being made, for example through the 'Nuclear Power 2010' initiative in the US, to reduce capital costs, including by establishing more efficient licensing and approvals processes.[245]

4.206 Technological developments in reactor designs are also promising to reduce construction costs and construction times. For instance, ANSTO noted that 'pebble bed' reactors, which are fourth generation designs, are intended to be modular; that is, of various sizes from, say, 180 MW upwards. The costs for these reactors, which are thought to be appropriate for desalination and to supply power in remote communities, will be a fraction of the cost of a large 1 000 MW reactor, roughly proportional to the amount of power they produce. Thus, a 100 MW reactor would cost in the order of $250 million to construct.[246]

4.207 According to information published by academics from the School of Physics at the University of Melbourne, Westinghouse claims that its advanced reactor, the AP1000, will cost US$1 400 per KWh for the first reactor and fall to $1 000 for subsequent reactors. It is also claimed that the AP1000 would take only three years to construct. For the Melbourne University group:

> If the AP1000 lives up to its promise of $1000 per KW construction cost and 3 year construction time, it will provide cheaper electricity than any other Fossil Fuel based generating facility, including Australian Coal power, even with no sequestration charges.[247]

4.208 In addition to new and simpler reactor designs and more predictable licensing processes, the WNA has suggested that other areas of potential capital cost reductions include: replicating several reactors of one design on one site, which can bring major unit cost reductions; standardisation of

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244 MIT, *op. cit.*, pp. 40–41, 3. Emphasis in original.
245 Dr Ron Cameron, *op. cit.*, pp. 9, 10.
246 *ibid.*, p. 14.
247 Nuclearinfo.net, *loc. cit.*

reactors and construction in series; and larger unit capacities which provide substantial economies of scale.[248]

Low operating costs

4.209 ANSTO and the AMP CISFT argued that one of nuclear power's clear advantages is low operating (i.e. fuel and O&M) costs. For example, in the US operating costs for nuclear plants continue to decline and in 2004 were US1.72c per kWh, slightly lower than coal at 1.8c per kWh and substantially lower than oil at 5.53c per kWh and gas at 5.77c per kWh. The operating costs for oil and gas were said to have increased substantially in recent times.[249]

4.210 Cameco also observed that 'from a cost perspective, nuclear power has been the lowest cost generator of electricity in the United States for four years running, marginally under coal, with one exception—that is, hydro-generated electricity'.[250]

4.211 Table 4.7 lists the comparative operating costs for nuclear, coal and gas generation for a range of countries projected for 2010 onwards, produced by the IEA and OECD-NEA. The data forecasts that costs of nuclear power will be below those for coal and gas in all countries, except the US and Korea where the cost of nuclear will exceed that of coal by a small margin. Costs for coal and gas generation in Australia have been included for an indicative rather than direct comparison. ANSTO observed that operating costs vary depending on whether a country has indigenous supplies of the particular fuel, the cost of importation and the cost of a country's regulatory systems.

4.212 A key factor in nuclear power's improved competitiveness has been a steady increase in nuclear plant availability and productivity. In particular, nuclear generating capacity has improved markedly in recent years. In 1990, nuclear plants on average were generating electricity 71 per cent of the time, but by 2005 reactor capacity reached a record average of 91.5 per cent in the US.[251] According to the IAEA, the global increase in generating capacity over the past 15 years represents 'an improvement in productivity equal to adding more than 25 new 1 000 megawatt nuclear plants—all at relatively minimal cost.'[252]

248 WNA, *The New Economics of Nuclear Power*, *op. cit.*, p. 19.

249 ANSTO, *Exhibit no. 74, Presentation by Dr Ron Cameron and Dr Ian Smith*, p. 11; AMP CISFT, *Exhibit no. 65*, *op. cit.*, p. 14.

250 Mr Jerry Grandey, *op. cit.*, p. 7.

251 Professor Leslie Kemeny, *Exhibit no. 9, Power to the people*, p. 2.

252 Dr Mohamed ElBaradei, *Nuclear Power: Preparing for the Future*, 21 March 2005, viewed 12 May 2006, <http://www.iaea.org/NewsCenter/Statements/2005/ebsp2005n004.html>.

Table 4.7 Comparative electricity production cost projections for 2010 onwards (US 2003 cents per kWh)

Country	Nuclear	Coal	Gas
Finland	2.76	3.64	—
France	2.54	3.33	3.92
Germany	2.86	3.52	4.90
Switzerland	2.88	—	4.36
Netherlands	3.58	—	6.04
Czech Republic	2.30	2.94	4.97
Slovakia	3.13	4.78	5.59
Romania	3.06	4.55	—
Japan	4.80	4.95	5.21
Korea	2.34	2.16	4.65
USA	3.01	2.71	4.67
Canada	2.60	3.11	4.00
Australia*	—	3.00 – 3.50 (black coal) 3.60 – 4.00 (brown coal)	3.50 – 4.50

Source ANSTO, *Exhibit no. 74, Presentation by Dr Ron Cameron and Dr Ian Smith,* slide 12; ANSTO, *Submission no. 29.1*, p. 3.
US 2003 cents/kWh, Discount rate 5%, 40 year lifetime, 85% load factor
* Australian cents per kWh in 2010.

4.213 Additional generating capacity has also been obtained through up-rating the power output of nuclear reactors, by up to 15–20 per cent in some cases. This has been a particular focus in the US, Sweden and Eastern European countries. Owners of nuclear plants are also seeking to obtain permission from regulatory authorities to extend the operational life of their plants, thereby generating additional output per plant. In the US, 30 nuclear plants have already been granted 20-year life extensions.[253]

Electricity price stability

4.214 In general, fuel costs represent a relatively large proportion of fossil fuel-based generating costs that are, as a result, sensitive to fuel price variations. Areva submitted that this is one of nuclear power's main advantages over other baseload alternatives: nuclear power has low fuel costs as a proportion of the overall cost of the electricity production, which means that the price of nuclear electricity is insensitive to fuel price rises and therefore relatively stable:

> … unlike its fossil fuel competitors, nuclear power is relatively immune to changes in fuel prices, which represent approximately

253 WNA, *The New Economics of Nuclear Power*, *op. cit.*, p. 12.

> 15% of its production cost. Based on current prices, natural uranium itself represents approximately 5% of the cost of nuclear electricity.[254]

4.215 Drawing on a Finnish study published in 2004, Areva argued that:

> … a 50% increase in the cost of natural uranium would raise the cost of nuclear generated electricity from €23.70 to €24.30. A 50% increase in the cost of natural gas or coal would raise the cost of electricity produced with these sources of energy from €31.20 to €42.40 for natural gas and from €32.90 to €41.85 for coal.[255]

4.216 Similarly, the AMP CISFT argued that:

> … doubling the price of uranium would increase the cost of [nuclear] power plant electricity by 20%. Doubling the price of coal would increase coal power plant electricity by 58%. The figure is 90% for gas power plants.[256]

External costs — carbon dioxide emissions, waste management and decommissioning

4.217 The UIC explained that external costs are those which are actually incurred in relation to the health and the environment but not paid directly by the electricity producer or consumer.[257] For fossil fuel plants these externalities include the unpriced costs of carbon dioxide emissions into the atmosphere.

4.218 It was argued that, unlike nuclear power, the environmental costs of fossil fuel power generation are not factored into the cost of the electricity produced.[258] Thus, if the external costs of carbon emissions into the atmosphere were internalised in fossil-fuel electricity generation through the imposition of a carbon tax, the economic competitiveness of nuclear power could improve significantly.[259]

4.219 Several of the studies cited above noted that the introduction of a cost of carbon emissions (e.g. carbon taxes) would raise the levelised cost of fossil fuel electricity generation and thereby enhance the competitiveness of nuclear power, rendering nuclear the lowest cost option in many cases.

4.220 The UIC argued that international pressure will continue for limits to be imposed on carbon emissions and for costs of carbon to be internalised:

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254 Areva, *op. cit.*, p. 5.

255 *ibid.*

256 AMP CISFT, *Exhibit no. 65, op. cit.*, p. 14.

257 UIC, *Nuclear Electricity*, Chapter 2, viewed 28 May 2006, <http://www.uic.com.au/ne2.htm>.

258 Mr Richard Pearce, *op. cit.*, p. 81.

259 OECD-NEA, *op. cit.*, p. 63.

> Inevitably, international pressure will continue for limits to be imposed. In the context of the Kyoto Protocol, a carbon cost of at least one US cent per kWh needs to be factored for coal generation, and at least half that for gas (on the basis of various proposals and European Union Emissions Trading Scheme transactions). This would effectively increase costs by 20 to 30%. By comparison, nuclear energy has zero cost for carbon emissions.[260]

4.221 ANSTO noted that studies of the effects of carbon emissions trading on electricity generating costs in Finland have rendered nuclear power far more competitive than gas and coal, with the costs of nuclear approximately €20 per MW compared to more than €40 per MW for coal. This calculation was said to be significant in Finland's decision to proceed with a nuclear power program.[261]

4.222 The UIC also cited a major study of the other external costs of various fuel cycles published by the European Commission in 2001. The study found that if other external costs were included, the price of electricity from coal would double and the price of electricity from gas would increase by 30 per cent.[262]

4.223 AMP CISFT argued that without imposing a substantial cost of carbon, nuclear power will remain uneconomic.[263] However, from the industry's perspective, the UIC and WNA argued that nuclear power is already economically competitive in many countries, even without factoring in a cost of carbon or considering nuclear's advantages of price stability and security of supply:

> In most industrialised countries today, new nuclear power plants offer the most economical way to generate base-load electricity—even without consideration of the geopolitical and environmental advantages that nuclear energy confers.[264]

4.224 The UIC argued that the cost of waste management (including eventual disposal) and decommissioning old reactors are internalised in power prices charged by nuclear utilities during the operational life of each plant. The back-end of the nuclear fuel cycle, including used fuel storage or disposal in a repository, contributes some 10 per cent of the overall cost of the electricity generated. Decommissioning plants is said to cost approximately 5 per cent of the total generating cost.[265]

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260 UIC, *op. cit.*, p. 14.

261 Dr Ron Cameron, *op. cit.*, p. 5.

262 UIC, *The Economics of Nuclear Power, loc. cit.*

263 Dr Ian Woods (AMP CISFT), *Transcript of Evidence*, 16 September 2005, p. 30.

264 WNA, *The New Economics of Nuclear Power*, *op. cit.*, p. 6; UIC, *loc. cit.*

265 UIC, *Submission no. 12*, p. 15.

4.225 As discussed further in the following chapter, the costs of nuclear waste disposal and decommissioning are funded by a levy on nuclear utilities which is set at 0.1 to 0.2 cents per kWh in the US and at similar levels in European countries. To date, more than US$28 billion has been committed to the US Nuclear Waste Fund by nuclear utilities.[266]

4.226 In contrast, the AMP CISFT argued that the operating costs of nuclear power plants do not include the costs for 'acceptable' waste disposal of the low and high level wastes produced. AMP CISFT claimed that the impact of waste disposal costs on the economics of nuclear power is illustrated in the UK where, it is asserted, British Energy (BE) is in financial difficulty due to the need to pay £300 million per year to British Nuclear Fuels (BNFL) for fuel reprocessing. Furthermore, it was argued that BE is unable to pay for plant decommissioning by internal sources, which is estimated to cost some £14 billion over future years. Similarly, AMP CISFT argued that the US Government is paying US$58 billion to develop the Yucca Mountain nuclear waste storage facility, but that 'it will take … 50 years before the nuclear power industry will collect enough to pay for the Yucca Mountain site.'[267]

Opportunity costs

4.227 Submitters that were critical of nuclear power cited studies which claimed that 'alternative energy sources [are] three to four times less costly as a means of reducing carbon dioxide than nuclear power.'[268] These submitters asserted that investment in nuclear power would reduce the amount of investment available for renewables and efficiency measures, and therefore worsen climate change because of the alleged opportunity cost this would involve.[269] For example, People for Nuclear Disarmament NSW argued that:

> In theory, nuclear expansion could proceed in tandem with concerted efforts in the areas of energy efficiency and renewable energy sources. In practice, nuclear expansion would most likely divert social and economic resources away from efficiency and renewables.[270]

266 *ibid*., pp. 15, 22, 40.

267 AMP CISFT, *Exhibit no. 65, op. cit*., pp. 18, 14.

268 Dr Gary Scott, *op. cit*., p. 4. See also: MAPW (Victorian Branch), *loc. cit*. The CFMEU also argued that: 'At best, nuclear power will be a modest but risky and expensive contributor to the problem of addressing climate change', *Submission no. 26*, p. 4.

269 See for example: NT Greens, *Submission no. 9*, p. 1; MAPW (WA Branch), *op. cit*., p. 5l; PHA, *loc. cit*; Mr Colin Mitchell, *Submission no. 67*, p. 1.

270 People for Nuclear Disarmament NSW Inc, *op. cit*., p. 6.

4.228 Research cited by Dr Helen Caldicott emphasised that use of nuclear power to address climate change would involve opportunity costs, asserting that nuclear power is the most costly option for prevention of climate change. It was argued that nuclear power has a higher cost per unit of CO_2 abated than its 'decentralised rivals', which 'means that every dollar invested in nuclear expansion will *worsen* climate change by buying less solution per dollar.'[271] That is, investment in nuclear power involves significant opportunity costs:

> Specifically, every $0.10 spent to buy a single new nuclear kilowatt-hour … could instead have bought 1.2 to 1.7 kWh of windpower … 0.9 to 1.7+ kWh of gas-fired industrial or ~2.2–6.5+ kWh of building-scale cogeneration …, an infinite number of kWh from waste-heat cogeneration …, or at least several, perhaps upwards of ten, kWh of electrical savings from more efficient use. In this sense of 'opportunity cost'—any investment foregoes other outcomes that could have been bought with the same money—nuclear power is far *more* carbon-intensive than a coal plant.[272]

4.229 AMP CISFT also argued that to address greenhouse gas emissions, on an opportunity cost basis, funds should be invested in alternative energy industries rather than nuclear power.[273]

4.230 In contrast, the studies cited above concluded that renewables, particularly wind, have consistently higher generation costs than nuclear plants. These costs are even higher if the necessity for standby generation is included (because of the intermittent nature of renewable electricity). The UIC stated that:

> Wind power, the main no-carbon alternative to nuclear, typically costs significantly more per kWh generated with its unpredictable availability requiring additional investment in back-up capacity.[274]

Subsidies

4.231 Critics of nuclear power argued that the industry is heavily subsidised. For example, the MAPW (Victorian Branch) argued that:

> Nuclear power is one of the most protected and heavily-subsidised industries in the world, and many cost estimates from proponents fail to take these into account. In the mid-1990s, governments

271 Dr Helen Caldicott, *Exhibit no. 68*, *loc. cit*. Emphasis in original.

272 *ibid*.

273 Dr Ian Woods, *op. cit*., p. 33.

274 UIC, *Submission no. 12*, p. 14. See also: Institute of Public Affairs, *Exhibit no. 46, The Economics of Nuclear Power*, p. 1.

> worldwide were subsidizing fossil fuels and nuclear power to the tune of US$250-300 billion per annum. While several transitional and developing country governments have since reduced energy subsidies substantially, global subsidies for conventional (fossil fuel and nuclear) energy remain many magnitudes higher than those for benign alternatives such as efficiency and renewables.[275]

4.232 Similarly, the AMP CISFT argued that the nuclear power industry is subsidised by government for its negative externalities, discussed above, of waste disposal and decommissioning. An example cited was the British Government's payments to BE, via an emergency loan, for waste disposal costs in the order of £184 million a year:

> If you do the calculation, you find that is equivalent to a subsidy of about £2.50 per megawatt hour produced, or about $A5. The industry—BNFL—in its publication say that the cost of waste disposal is only £0.80, so already there is an inconsistency between what is required for the government to subsidise waste disposal as opposed to what a proponent of the industry says is required.[276]

4.233 Research cited by Dr Helen Caldicott asserts that the US *Energy Policy Act 2005* is 'festooned with lavish subsidies and regulatory short cuts for favoured technologies that can't compete unaided.'[277] It is argued that the Act contains some US$13 billion in subsidies to support nuclear expansion, including loan guarantees, research and development support, licensing-cost subsidies, public insurance against regulatory delays, an increase in operating subsidies, tax breaks for decommissioning funds and a cap on liability payments in case of accidents.[278]

4.234 The ECNT alleged that during the first 15 years of development in the US, the nuclear power industry received subsidies amounting to $15.30 per kWh, while the wind industry received 46c per kWh in its first 15 years of operation. It was argued that 'these huge imbalances towards dangerous, polluting and greenhouse intensive fuels need to be urgently addressed.'[279]

4.235 However, the WNA has flatly rejected that the nuclear power industry requires subsidies to be viable:

> Nuclear power does not, as critics often allege, depend on subsidies to be economically sustainable. Fossil fuels benefit from

275 MAPW (Victorian Branch), *op. cit.*, p. 10. See also:

276 Dr Ian Woods, *op. cit.*, p. 29.

277 Dr Helen Caldicott, *Exhibit no. 68*, *op. cit.*, p. 16.

278 *ibid.*, pp. 16-17.

279 Dr Gary Scott, *op. cit.*, p. 4.

> direct subsidies in some countries (like coal in Germany) or from hidden subsidies in the form of pollution and other external costs not taken into account.[280]

4.236 As noted above, some submitters, including the ECNT and Uniting Church in Australia (Victoria and Tasmanian Synod) urged the Australian Government to significantly increase the provision of subsidies for research, development and implementation of renewables. However, the ANA and other submitters observed that renewables currently require large subsidies in order to increase adoption.[281] The AMP CISFT conceded that without subsidies, investments in renewables would not be attractive.[282]

4.237 The UIC noted that renewable capacity in Germany has risen to 17 GWe due to generous subsidies, with the actual cost of wind generation 7–9 Euro cents per kWh (double the cost of nuclear and coal) and requires a 6.2c per kWh average subsidy through a feed-in tariff.[283]

4.238 The UIC observed that if subsidies and other government incentives are provided to renewables in order to achieve lower carbon emissions, then these incentives:

> … should be applied to anything which achieves low carbon emissions and not … discriminating against nuclear power. In other words, if subsidies are available for wind in Australia, on the basis of carbon reduction, they should be equally available to nuclear.[284]

280 WNA, *The environment needs nuclear*, *loc. cit*.
281 Dr Clarence Hardy, *op. cit.*, p. 56.
282 Dr Ian Woods, *op. cit.*, p. 33.
283 UIC, *Exhibit no. 49, loc. cit*.
284 Mr Ian Hore-Lacy, *op. cit.*, p. 90.

Conclusions

Greenhouse gas mitigation

4.239 The Committee concludes that nuclear power unquestionably makes a significant contribution to the mitigation of GHG emissions—nuclear power plants currently save some 10 per cent of total CO_2 emissions from world energy use. This represents an immense saving of GHG emissions that would otherwise be contributing to global warming. If the world were not using nuclear power plants, emissions of CO_2 would be some 2.5 billion tonnes higher per year.

4.240 Australia's uranium exports displace some 395 million tonnes of CO_2 each year, relative to black coal generation, and this represents some 70 per cent of Australia's total GHG emissions for 2003. Evidence suggests that the cumulative carbon savings from nuclear power over the three decades to 2030 will exceed 25 billion tonnes.

4.241 In addition to its GHG mitigation benefits, nuclear power also offsets the vast emissions of sulphur dioxide, nitrous oxide and particulates which are produced by fossil fuelled plants.

4.242 The Committee notes the support shown for nuclear power by several foundational figures of the environment movement. These individuals now perceive that the risks of expanded use of nuclear power are insignificant in comparison to the threat posed by the enhanced greenhouse effect and global warming. The Committee notes calls by some in industry that, in view of the energy demands from heavily populated developing nations, Australia in fact has a moral responsibility to contribute to reducing global GHG emissions through the increased production and supply of uranium.

4.243 It was claimed that nuclear power will not solve climate change because it only reduces emissions from the electricity sector, which is only one source of anthropogenic GHG emissions. The Committee notes, however, that no representative of the uranium industry ever claimed that nuclear power alone could 'solve' climate change. In fact, it was repeatedly stated that nuclear power is one, albeit significant, part of the solution to global warming.

4.244 Although nuclear power has the potential to reduce emissions in the transport sector through the production of hydrogen, nuclear's greenhouse mitigation contribution is currently limited to the electricity sector. However, electricity generation, which is already the largest contributor of CO_2 emissions at 40 per cent of the global total, is also the fastest growing. It is imperative that emissions from this sector be reduced.

4.245 The Committee finds that over its whole fuel cycle nuclear power emits very small quantities of CO_2—orders of magnitude less than fossil fuels and quantities similar to, or less than, renewable such as wind.

4.246 Evidence suggests that renewables and energy efficiency measures alone have no prospect of meeting rapidly growing demands for energy and abating greenhouse emissions to the degree required. The weight of evidence points to the need for a mix of low-emission energy sources and technologies, in which nuclear power will continue to play a significant part.

4.247 In the context of rapidly growing energy demand, particularly from developing nations, nuclear power represents the only means of limiting increased emissions while meeting the world's voracious appetite for energy. While the Committee recognises that there is a role for renewables and certainly for greater use of efficiency measures, renewables are limited in their application by being intermittent, diffuse and pose significant energy storage problems. Renewables also require substantial backup generation, which needs to be provided by conventional baseload power sources. Promised baseload contributions from geothermal, which will be welcome, are yet to be developed on any scale.

4.248 The Committee believes that the nuclear versus renewables dichotomy, which is explicit in some submissions, is a false debate and misses the point: while renewables have a contribution to make, other than hydro and (potentially) geothermal, they are simply not capable of providing baseload power on a large scale. The relevant comparison, if one needs to be made, is between baseload alternatives. On this issue the evidence is clear—nuclear power is the only proven technology for baseload power supply which does not release substantial amounts of CO_2.

4.249 The Committee also recognises that given its comparative advantage in fossil fuels and the world's projected continued reliance on fossil fuels, Australia has a strong economic interest in supporting technologies that reduce the greenhouse intensity of these fuels. The Committee agrees that nuclear power should not be seen as competing with or substituting for clean coal technologies, and indeed renewables such as photovoltaics in which Australia has expertise.

Economics

4.250 A vital consideration in assessing nuclear power's viability as a GHG emission mitigation option relates to the economic competitiveness of nuclear power relative to other baseload alternatives. Evidence suggests that nuclear power plants have higher capital/construction costs than either coal or gas plants, which are characterised by mid-range and low capital costs respectively. However, nuclear plants have low fuel, operating and maintenance costs relative to the fossil fuel alternatives.

4.251 A range of recent studies have concluded that, in many industrialised countries, nuclear power is competitive with gas and coal-fired electricity generation, even without incorporating an additional cost for the carbon emissions from the fossil fuelled plants. Factors that influence the suitability of deploying nuclear plants in a particular situation include the projected prices of natural gas and coal, the discount rate employed, proximity and access to fuel sources such as low cost fossil fuels, and the quality of fuel sources.

4.252 Although nuclear plants generally have higher capital costs, the Committee notes there are developments which promise to reduce the construction costs and construction times for new plants, including possible regulatory reforms in the US and new plant designs. It seems clear that replicating several reactors of one design, or standardising reactors, reduces levelised generating costs considerably.

4.253 Although again the Committee does not wish to enter into a nuclear versus renewables debate, evidence suggests that renewables, particularly wind, have consistently higher generating costs than nuclear plants. These costs are even higher if the necessity for standby generation is included.

4.254 The Committee concludes that, in addition to security of energy supply and near-zero GHG emissions, nuclear power offers at least three economic advantages relative to other baseload energy sources:

- price stability, because the price of nuclear generated electricity is largely insensitive to variations in fuel prices;
- very low operating costs—consistently lower even than coal in the US; and
- internalisation of costs that are not incorporated in the cost of other sources of electricity, notably waste management.

4.255 Although the Committee is not in a position to assess the veracity of claims about subsidies received by the industry, claims by some submitters that the cost of decommissioning and waste disposal are not included in economic assessments of nuclear power or the price of its electricity are entirely mistaken. Unlike its fossil fuel alternatives, nuclear utilities are required to set aside funds to cover decommissioning and final waste disposal. While the adequacy of the funds set aside may be queried, there can be no question that these costs are internalised in the price of the electricity generated.

4.256 The Committee notes that if fossil fuel plants were required to internalise the environmental costs of their emissions (for example, if a cost of carbon were imposed), this would undoubtedly effect the cost of the electricity generated and could significantly improve the economic competitiveness of nuclear power, even in countries with plentiful supplies of low cost fossil fuels.

4.257 The issue of waste management is further addressed in the next chapter which, along with chapters six, seven and eight, discusses the three key objections to an expansion of uranium mining and use of nuclear power worldwide—waste, safety and proliferation of nuclear weapons.