12

Value adding — fuel cycle services industries, nuclear power, skills and training in Australia

For Australia – soon to displace Canada as the premier uranium exporter – to ignore the study of the uranium fuel cycle and its value-added technologies and industries indicates a pattern of intellectual and economic neglect possibly unparalleled in higher education policy and academic history.[1]

… Australia should seize the opportunity to maximise the financial return by not only selling more uranium but also adding value to the product by getting involved in other steps in the manufacture of nuclear fuel. Above all, we should sell uranium enriched to reactor fuel quality rather than simply selling uranium as yellowcake.[2]

In its own interests and as a contribution to the containment of greenhouse gas emissions globally, there is a strategic, economic and ethical case for Australia now, to include nuclear electricity generation in its energy infrastructure.[3]

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1 Professor Leslie Kemeny, *Exhibit no. 8*, *A power too good to refuse*, p. 1.

2 Mr James Brough (Australian Nuclear Forum), *Transcript of Evidence*, 16 September 2005, pp. 42–43.

3 Mr John O Reynolds, *Submission no. 5*, p. 4.

Key messages —

- **Currently, Australia simply mines and mills uranium ore, which is the lowest level of uranium beneficiation.**
- **Federal and state government decisions over the past 35 years have led to the abandonment of several opportunities to develop industries based on upgrading Australia's uranium resources for export. Perhaps the most significant of these missed opportunities involved a proposal to develop a commercial uranium enrichment industry in Australia by a consortium of Australian companies, the Uranium Enrichment Group of Australia—BHP, CSR, Peko-Wallsend and WMC—in the early 1980s. This proposal was terminated following a change of Federal Government.**
- **By the mid 1980s, the Australian Atomic Energy Commission (AAEC) had accrued twenty years of experience with uranium enrichment technology. The Commission had by then invested some $100 million on enrichment research alone. This knowledge and expertise was lost following the Federal Government's direction that the AAEC and its successor agency, the Australian Nuclear Science and Technology Organisation (ANSTO), abandon enrichment and other fuel cycle research.**
- **Australia possesses some 40 per cent of the world's uranium, perhaps more. By virtue of this immense resource endowment, Australia has a very strong economic interest in, and justification for, seeking to add value to its uranium resources prior to export. Such a development would allow Australia the opportunity to extract greater returns from its resource endowment, to develop sophisticated technologies and to expand its national skills base.**
- **The Committee supports the establishment in Australia of fuel cycle services industries which could, in accordance with International Atomic Energy Agency expert advisory group recommendations outlined in chapter seven, be established on a multinational or co-management basis, thereby increasing transparency and meeting non-proliferation objectives.**
- **By virtue of its highly suitable geology and political stability, Australia could also play an important role at the back-end of the fuel cycle, in waste storage and disposal. Again, such a development could be highly profitable, as well as possibly providing global security benefits. However, as noted in chapter five, the US Global Nuclear**

Energy Partnership initiative proposes to revolutionise spent fuel management (through the use of advanced burner reactors in the 'fuel supplier' nations), thereby generating waste that only requires short isolation periods. This could obviate the need for geologic repositories altogether.

- **The Committee has no in-principle objection to the use of nuclear power in Australia and believes that, subject to appropriate regulatory oversight, utilities that choose to construct nuclear power plants in Australia should be permitted to do so. There would be clear greenhouse gas emission and other technological and potential economic benefits from doing so.**
- **Nuclear power may not be immediately competitive in the Australian context, due to the quantity and quality of Australia's coal resources (and that carbon emissions are currently not priced). However, the Committee believes that if Federal and state governments continue to provide a range of incentives to achieve low carbon emissions, for example by subsidising renewables such as wind, then governments should not discriminate against nuclear power—which will achieve very low emissions but also generate baseload power, unlike the currently subsidised renewable alternatives.**
- **Even if deployment of nuclear power plants and other fuel cycle facilities in Australia is not imminent, steps should now be taken to develop a licensing and regulatory framework to support the possible eventual establishment of such facilities in Australia.**
- **The Committee is concerned that, with the closure in 1988 of Australia's sole university school of nuclear engineering, Australia no longer has an indigenous source of trained personnel in the nuclear field. The Committee concludes that the Australian Government should seek to progressively rebuild Australia's nuclear skills base. Among other initiatives, the Government should broaden ANSTO's research and development mandate, so that it is once again able to undertake physical laboratory studies of aspects of the nuclear fuel cycle that may be of future benefit to Australia and Australian industry. Consideration should also be given to re-establishing at least one university school of nuclear engineering.**

Introduction

12.1 The Committee's terms of reference and additional issues did not seek submissions relating to the possible domestic use of nuclear power or the question of establishing domestic fuel cycle services industries. However, a number of submitters volunteered opinions and information in relation to these matters. The Committee concludes its report with an overview of this evidence. The Committee also addresses itself to the skills base and research and development (R&D) activity to support Australia's current and possible future participation in the nuclear fuel cycle.

12.2 The chapter addresses the following issues in turn:

- Australia's history of 'missed opportunities' to add value to its uranium resources and to develop a domestic nuclear power industry;
- proposals to develop domestic fuel cycle services industries and specifically:
  - ⇒ uranium enrichment,
  - ⇒ nuclear waste treatment and disposal, and
  - ⇒ nuclear fuel leasing;
- the domestic use of nuclear power; and
- nuclear skills, training and R&D activity.

12.3 As the Committee's terms of reference concerned Australia's uranium resources, the evidence received in relation to these other matters is not exhaustive. The Committee also notes that these matters are being examined by the Prime Minister's Taskforce, appointed in June 2006, to review uranium mining, processing and nuclear energy in Australia. The terms of reference for the review include, inter alia, examination of the:

- potential for establishing other steps in the fuel cycle in Australia, such as enrichment, fuel fabrication and reprocessing;
- circumstances in which nuclear power could in the long term be economically competitive in Australia; and
- current state of nuclear energy research and development in Australia and the capacity for Australia to make a significantly greater contribution to international nuclear science.[4]

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4 Prime Minister of Australia, *Review of Uranium Mining, Processing and Nuclear Energy in Australia*, 6 June 2006, viewed 6 June 2006, <http://www.pm.gov.au/docs/Review%20of%20Uranium%20and%20Nuclear%20Energy%20in%20Australia.pdf>.

Australia's 'lost opportunities' to value add

12.4 The Committee was informed of the Australian Government's previously extensive involvement in nuclear R&D activity, principally through the former Australian Atomic Energy Commission (AAEC), which was established in 1953. For over 30 years, until its re-establishment as the Australian Nuclear Science and Technology Organisation (ANSTO) in 1987, the AAEC was engaged in R&D across the nuclear fuel cycle, including uranium enrichment, nuclear reactor designs, and radioactive waste disposal:

- The Commission's initial research program involved studies into two reactor designs—high temperature gas cooled reactors, operating on a thorium/uranium cycle, and liquid metal cooled reactors. This research continued until 1966.
- In 1966 research was refocused towards the design and operation of heavy water reactors and into a number of other fields, including spent fuel reprocessing and nuclear desalination.
- In 1965 the AAEC commenced uranium enrichment research, which grew to become the largest single research program within the Commission. In the 1970s and 1980s two methods of enrichment were investigated—gas centrifuge and laser enrichment, with the main focus being centrifuge enrichment.
- In 1969 a project was commenced to construct a 500 megawatt electrical nuclear power station at Jervis Bay in NSW, based on the then widely held view that nuclear power was likely to be introduced into Australia in the 1970s. Federal budgetary constraints caused the project to be deferred in 1971 and abandoned in 1972. [5]

12.5 In addition to its own enrichment R&D program, from the beginning of the 1970s the AAEC was heavily engaged in international enrichment studies, including the following:

- The 'Washington Talks' (November 1971), in which the US expressed interest in a multi-national plant in Australia using gaseous diffusion technology;
- France-Australia study (1971–72) on the use of French gaseous diffusion technology for a plant in Australia;

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5 The history of the AAEC and the research conducted by the Commission is described in Dr Clarence Hardy's *Atomic Rise and Fall: The Australian Atomic Energy Commission 1953–1987*, Glen Haven, Sydney, 1999.

- Association for Centrifuge Enrichment (ACE) Study (1973–74) with the European Tripartite countries (UK, Germany and the Netherlands); and
- Japan-Australia Study on Enrichment (1976–1978), for the possible establishment of a centrifuge enrichment plant in Australia for supply to Japan.[6]

12.6 In addition to these studies, the South Australian (SA) Government also conducted a Uranium Enrichment Study (1973–76), which also included the consideration of a possible conversion plant to manufacture uranium hexafluoride (UF_6), which is the interim stage between milling uranium and enrichment. In February 1976 the SA Uranium Enrichment Committee (UEC) recommended the establishment of a uranium processing centre at Redcliff, 30 km south of Port Augusta on the shores of the northern Spencer Gulf, incorporating a conversion plant and an enrichment plant (using centrifuge technology). The overall capacity of the plant was to convert 10 000 tonnes of uranium to UF_6 and then to 5 000 tonnes separative work units (SWU) of enriched uranium per year. The plant was to be established by the Commonwealth Government but with full State Government support.[7]

12.7 The UEC estimated that if uranium were enriched prior to export it would double the value of the initial mine product.[8] It was recommended that sales of uranium from Australian mines be made conditional on the refining and enrichment of such sales in the processing centre. The project was estimated to have provided permanent employment for 1 550 workers and further site development was proposed to include nuclear power generation and desalination of seawater. The UEC stated that:

> The project as a whole would be the largest development of its kind undertaken in Australia in recent years, comparable to the Snowy Mountains Scheme in money terms and impact on the Australian economy. The capital cost (including interest during construction) over an eight-and-a-half year period, is estimated at A$1400 million, and its potential earnings are set at nearly $426.5 million per annum.[9]

The project was finally abandoned by the SA Government in 1979.

12.8 In addition to the AAEC's own enrichment studies, in 1980 a private consortium, comprised of four companies (BHP, CSR, Peko-Wallsend and WMC) established the Uranium Enrichment Group of Australia (EUGA)

6 *ibid*., p.165.

7 SA Premier's Department, *Second Interim Report of the Uranium Enrichment Committee*, SA Government, Adelaide, February 1976, pp. 9.

8 *ibid*., p. 28.

9 *ibid*., p. 40.

as a joint-venture to carry out a pre-feasibility study to assess the commercial viability of establishing an enrichment industry in Australia. Following an interim and a final pre-feasibility report, which concluded, inter alia, that the establishment of a commercial enrichment industry would be feasible and likely to be profitable, EUGA proceeded to a feasibility study which was completed in 1982. It was proposed that gas centrifuge technology should be adopted, which would be obtained from the Tripartite CENTEC-URENCO companies, subject to necessary inter-governmental agreements on technology transfer.[10]

12.9 However, in 1983 the incoming Federal Labor Government indicated that it would not conduct the necessary technology transfer agreements with the Tripartite governments and the project was subsequently abandoned. The Labor Government also directed the AAEC to terminate its own enrichment program and to scale-down other nuclear fuel cycle work, with the exception of research into the 'Synroc' waste form for the management of high level radioactive waste.

12.10 Mr Keith Alder, who was appointed a Member of the Commission in 1968 and became the AAEC's General Manager from 1975 to 1982, presented his memoir, *Australia's Uranium Opportunities*, as evidence to the Committee. Mr Alder was overall director of the AAEC's research activities for 20 years and led the Commission's Jervis Bay Nuclear Power Station project.

12.11 Mr Alder argues that Australia had two real opportunities to embark on an enrichment industry—following the joint study with France in 1971–72 and the UEGA initiative, which was terminated in 1983. In both cases, the enrichment industry proposals were abandoned following changes in Federal Government. In relation to the termination of the EUGA proposal and, subsequently, the AAEC's enrichment research activities, Mr Alder argues:

> So, once again, a change in government in Australia stopped dead the prospects of establishing a worthwhile industry based on upgrading our natural resources for export.
>
> The companies involved in EUGA certainly believed in the commercial prospects of the industry. There can be no doubt Australia was in an excellent position to enter into very favourable arrangement for the technology transfer and future collaboration, and for growth of Australian industrial participation at a rate commensurate with market conditions …

10 Dr Clarence Hardy, *op. cit.*, p. 174

> Commercial and marketing studies and predictions carried out by EUGA and by the AAEC in support had shown potential annual export earnings from the enterprise to be in the range of $400–$800 million dollars by the turn of the century … A useful contribution to Australia's balance of payments problems, but we preferred to forgo it in favour of our misinformed political dogma …
>
> But worse was to come, for the same Government stopped all work in the AAEC on uranium fuel cycle topics, and closed down the AAEC research on enrichment, which had been in progress for nearly two decades, since 1965, at a cost approaching 100 million dollars.[11]

12.12 In his testimony before the Committee, Mr Alder reiterated that with the termination of the EUGA proposal: 'We lost an enormous opportunity then, which was a tragedy for Australia.'[12] The decision not to develop processing industries in the 1970s and 1980s was said to be 'disastrous in terms of lost opportunities for export earnings, jobs, and regional strategic influence.'[13] Mr Alder observed that, due to the decision to terminate the AAEC's enrichment research:

> As a result there is now … no work at all in Australia directed towards developing our uranium processing industry; this in a country holding well over 30 per cent of the world's economically recoverable uranium ores. We have thrown away successive opportunities …[14]

12.13 The Committee was also reminded that in the 1960s and 1970s virtually all the states were considering use of nuclear power, in addition to the Commonwealth Government:

> One of the main incentives for Jervis Bay … was to develop that whole framework for Australia before state generating bodies really were looking to go nuclear. When we did Jervis Bay in the 1960s everybody knew, including the electricity authorities of the states, that Australia was going to go nuclear in the 1970s. It was common knowledge. ETSA, the Electricity Trust of South Australia, had their own study group. They had done all their own estimates for a 250 megawatt plant on Kangaroo Island. The Victorian SEC had their own study group. New South Wales, of course, were our partners when we did the Jervis Bay [study]. Queensland had their own study group. ETSA from South

11 Mr Keith Alder, *Exhibit no. 2, Australia's Uranium Opportunities*, pp. 76–77, 78–79.

12 Mr Keith Alder, *Transcript of Evidence*, 16 September 2005, pp. 81–82.

13 Mr Keith Alder, *Submission no. 7*, p. 2.

14 Mr Keith Alder, *Exhibit no. 2, op. cit.*, p. 9.

> Australia had three engineers seconded to Harwell looking at nuclear power for South Australia when I was there in 1954.[15]

12.14 In May 1984, the Australian Science and Technology Council (ASTEC) completed a review of *Australia's Role in the Nuclear Fuel Cycle* ('the Slatyer Report', named after the ASTEC Chairman, Professor Ralph Slatyer). In conducting its review, Prime Minister Hawke directed ASTEC to examine, inter alia: Australia's safeguards arrangements; the opportunities for Australia, through its involvement in the fuel cycle, to further advance nuclear non-proliferation; and the adequacy of existing technology for the handling and disposal of waste products by consuming countries.[16]

12.15 Among its other findings, the Slatyer report concluded that Australia should participate in other stages of the nuclear fuel cycle, where such participation promotes and strengthens the non-proliferation regime. The Report suggested that the most suitable basis for developing an enrichment plant would be through the joint ownership and supervision of the appropriate facilities by Australia and other countries which share Australia's commitment to non-proliferation.[17]

12.16 However, the Hawke Government subsequently decided that it was not appropriate for Australia to become further involved in the nuclear fuel cycle—a policy which has been maintained by subsequent governments.[18]

12.17 In addition to state government legislative restrictions, Commonwealth legislation currently prohibits the establishment of uranium enrichment and other value adding industries and facilities in Australia:

- Section 140A of the *Environment Protection and Biodiversity Conservation Act 1999* prohibits the Minister for the Environment and Heritage from approving:

> … an action consisting of or involving the construction or operation of any of the following nuclear installations: a nuclear fuel fabrication plant; a nuclear power plant; an enrichment plant; or a reprocessing facility.[19]

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15 Mr Keith Alder, *Transcript of Evidence*, *op. cit.*, p. 90. See also: UIC, *Nuclear Energy Prospects in Australia*, Nuclear Issues Briefing Paper No. 44, viewed 24 August 2006, <http://www.uic.com.au/nip44.htm>. Victoria's State Electricity Commission undertook preliminary studies on building a large nuclear plant on French Island in Westernport in the late 1960s.

16 ASTEC, *Australia's Role in the Nuclear Fuel Cycle*, AGPS, Canberra, 1984, p. 1.

17 *ibid.*, p. 131.

18 See: UIC, *Uranium Enrichment*, Nuclear Issues Briefing paper No. 33, viewed 18 May 2006, <http://www.uic.com.au/nip33.htm>.

19 Mr Gerard Early (DEH), *Transcript of Evidence*, 10 October 2005, p. 11.

- Section 10 of the *Australian Radiation Protection and Nuclear Safety Act 1998* (ARPANS Act) prohibits the Australian Radiation Protection and Nuclear Safety Agency issuing a licence for the construction or operation of nuclear installations (fuel fabrication, enrichment, reprocessing or nuclear power plants) by any Commonwealth entity or on Commonwealth land.[20]

Value adding in Australia

12.18 The Association of Mining and Exploration Companies (AMEC) and others argued that 'as a general proposition, Australia has a history of producing the resources but we do not take it any further—we send our resources overseas.'[21] It was recommended that 'consideration and encouragement be given to developing and introducing various value-adding activities in Australia, particularly uranium enrichment'.[22]

12.19 Mr Robert Elliott submitted that:

> The emotion surrounding the nuclear fuel industry makes it tempting to remain with the current mine and export approach. I do not think that this serves the best interests of Australia or the world.[23]

12.20 Similarly, APChem Scientific Consultants questioned why it is that Australia, with such a significant share of world uranium resources, has failed to develop uranium processing industries:

> As the situation currently stands, Australia will continue to lag further behind in technological advances related to nuclear power and medicine … Continued expansion of uranium mining, without corresponding development of the nuclear industry within Australia will send this country down the well-worn path of selling its resources and assets and buying back the end products at exorbitant prices and a net loss to our economy.[24]

12.21 The ANF argued that Australia should value add across the fuel cycle and, in particular, enrich uranium for reactor fuel:

> Australia should seize the opportunity to maximise the financial return by not only selling more uranium but also adding value to

20 See: ARPANS Act, viewed 13 October 2006, <http://www.arpansa.gov.au/legframe.htm>.

21 Mr Alan Layton (AMEC), *Transcript of Evidence*, 23 September 2005, p. 20.

22 *ibid.*, p. 13.

23 Mr Robert Elliott, *Submission no. 1*, p. 1.

24 APChem Scientific Consultants, *Submission no. 38*, p. 4.

> the product by getting involved in other steps in the manufacture of nuclear fuel. Above all, we should sell enriched uranium to reactor fuel quality rather than simply selling uranium as yellowcake … We believe that Australia would be an ideal location for a fuel enrichment plant operating under multinational safeguards control such as recently suggested by the IAEA Director-General.[25]

12.22 Despite the 'lost opportunities' to establish industries to add value to Australia's uranium resources, Mr Alder remarked that Australia could still establish an enrichment industry:

> The opportunity to do that is still there, and the attraction of Australia as a place in which to do it is still there. In fact it is higher now than ever before because the demand for uranium is going up and Australian resources have increased. Australia is a very attractive place to overseas partners who want to go into the industry, just as they were attracted by our resources in 1982-83, when [the UEGA] enrichment study was done. It was not Australian science or Australian engineering that attracted the Americans, the French and the European Tripartite. They came to Australia in droves trying to sell us the idea that their technology would be used in Australia. The background for that has not changed, so we still have the opportunity.[26]

12.23 Furthermore, in his submission to the inquiry, Mr Alder argued that:

> There is still scope and opportunity for Australia to become a major fuel supplier to the nuclear power plants now operating and being built in many countries, and particularly in our Eastern neighbours e.g. Japan, China, Korea, Taiwan, India, Pakistan, and soon in Indonesia. We would need imported technology—we have lost what we had in the 1970's—but this has much to commend it, as it is likely that multinational plants for uranium enrichment and fuel manufacture will be favoured internationally because of their perceived advantages in preventing diversion of technology or fissile materials to weapons programs.
>
> There should be no difficulty in finding overseas partners for such enterprises—access to our uranium resources would provide the

25 Mr James Brough (ANF), *Transcript of Evidence*, 16 September 2005, p. 43.

26 Mr Keith Alder, *Transcript of Evidence*, *op. cit.*, p. 82.

> incentive, as it did for the international studies on uranium enrichment that we carried out in the 1970-80's.[27]

12.24 However, the Committee was cautioned that development of fuel cycle industries would require 'major shifts in Government thinking and policy making' from that of the past few decades.[28] Moreover, because Australian industry has had its 'fingers burnt badly … when it spent time and money on feasibility studies', Mr Alder argued that companies would need 'positive reassurance that the political climate would not change dramatically as it did in the past.'[29]

12.25 The ANF also argued that despite the missed opportunities to develop uranium enhancement industries:

> … it is better late than never, and it is the view of the ANF that the processes described for the production of finished reactor fuel elements should be re-examined to determine if such commercial enterprises can be established in this country. This will probably mean that partnerships with overseas companies or countries that have the commercially proven technologies will be required.[30]

12.26 In supporting the establishment of 'uranium enhancement industries' (conversion, enrichment and fuel fabrication) in Australia, the ANF noted that while uranium oxide exports in 2004 were valued at $410 million, if these other industries at the front-end of the fuel cycle were established in Australia the exported fuel could be worth in the order of $1.7 billion per year:

> This added value would not only mean greater income to this country but would be an important source of additional employment. Also, the production of reactor fuel here would facilitate the introduction of nuclear power if this were proven to be advantageous.
>
> Lastly, the operation of an enrichment plant will produce depleted uranium of an amount some seven times greater than the enriched uranium produced. This depleted uranium would constitute a tremendous energy asset for future use here and/or overseas [for use in breeder reactors].[31]

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27 Mr Keith Alder, *Submission no. 7*, p. 2. See also: Mr Keith Alder, *Transcript of Evidence*, 16 September 2005, p. 81.

28 *ibid*.

29 *ibid*.

30 ANF, *op. cit.*, p. 3.

31 ANF, *Exhibit no. 4, Australian Uranium Enhancement Industries*, p. 1.

12.27 It was noted, however, that because any enrichment technology developed by the AAEC has probably now been lost and the two technologies (gas centrifuge and laser enrichment) being studied by the AAEC were never developed to the stage of commercial application, Australia would have to employ imported technology. Similarly, with fuel fabrication, because fuel elements must be able to coexist in reactors with fuel elements manufactured by other vendors, this means that designs may have to be licensed from foreign vendors until Australia developed sufficient experience.[32]

12.28 Mr Alder argued that: 'Australia should get into the front-end of the nuclear fuel cycle as soon as possible. That is, instead of exporting yellowcake, we should get into conversion to UF_6 and enrichment.'[33]

12.29 Professor Leslie Kemeny also argued that enhancing uranium prior to export would be financially beneficial for Australia and that there would also be global non-proliferation advantages from Australia's involvement in the back-end of the fuel cycle:

> Exporting yellowcake without value adding is just plain dumb. And being involved in reprocessing and waste disposal strengthens Australia's ability to guarantee global non-proliferation.[34]

12.30 The Institute of Public Affairs (IPA) also noted that the added value through the stages of the nuclear fuel cycle shows that mining uranium represents only a modest part of total fuel costs and that the largest components are enrichment and reprocessing. The cost components for 1 kg of nuclear fuel (uranium dioxide, UO_2) are listed in table 12.1. The data shows that enrichment accounts for some 21 per cent of total fuel costs and reprocessing/back-end activities contributes some 47 per cent of total costs.

32 *ibid*., p. 2.

33 Mr Keith Alder, *Transcript of Evidence*, *op. cit.*, p. 89.

34 Professor Leslie Kemeny, 'Brace yourselves for a nuclear millennium', *The Australian*, 31 March 2006, p. 14.

Table 12.1 Costs to produce and reprocess 1 kg of UO_2 reactor fuel in US$, 2004

Process	Amount required	Cost (per kg or SWU)	Total cost	Percentage of total fuel cost
Front-end				
U_3O_8	8 kg	$45	$360	17%
conversion	7 kg U	$9	$60	3%
enrichment	4.3 SWU	$105	$450	21%
fuel fabrication			$240	11%
Total front-end			$1 110	53%
Back-end				
reprocessing			$1 000	47%
Total fuel cost			**$2 110**	**100%**

Source IPA, *Exhibit no. 48, Radioactive Waste Management in Australia*, p. 1.

12.31 The Submarine Institute of Australia (SIA) argued that by restricting industry's capacity to process uranium ore, governments not only restrict the economic return for the nation's resources, but also deny the nation the industry capability that would evolve from such activity. Moreover, as argued by the ANF and IPA above, the SIA stated that the breakdown of costs to fuel a typical light water reactor indicates that the additional three processing steps at the front-end of the fuel cycle (conversion, enrichment and fuel fabrication) represent almost half the costs to fuel the reactor—income which Australia chooses to forego:

> … by failing to take the sensible opportunity to value add, possibly by preparing fuel pellets ready for use in reactor, we deny Australia the income and the broader knowledge base of a more mature nuclear industry.[35]

12.32 Similarly, Professor Ralph Parsons, a former President of the Australian Institute of Nuclear Science and Engineering (AINSE), argued that:

> Uranium is currently mined in Australia and is exported as Yellowcake, Uranium Oxide. The nation would benefit if it were processed much further before being exported. The benefit would not only be financial but would also be in the stimulation of relatively high-technology industries.[36]

35 Rear Adm. Peter Briggs AO CSC (Retired) (SIA), *Transcript of Evidence*, 10 October 2005, p. 28; SIA, *Submission no. 21*, p. 5.

36 Professor Ralph Parsons, *Submission no. 24*, p. 1.

12.33 Professor Parsons also submitted that although much of Australia's fuel cycle expertise has been dissipated, a knowledge base to support value adding industries could once again be developed:

> Twenty five years ago there was expertise in this country in various stages of the nuclear fuel cycle, particularly in centrifuge enrichment and in the development of Synroc for waste disposal. That expertise has been dissipated but the nation now has sufficient depth of talent in Science, Engineering and Technology that the expertise could be redeveloped if there were the political will to do so.[37]

12.34 Should it be decided to establish industries along the uranium value chain in Australia, CSIRO expressed willingness to cooperate with ANSTO and industry in supporting value adding.[38]

12.35 In contrast, proposals to add value to Australia's uranium resources were rejected out of hand by individuals and groups opposed to nuclear power:

> Every time you dabble with nuclear, whether it is mining or making fuel rods or getting into enrichment—whatever it is—you are simply contributing to the global problem. There is no way around it. The only thing that you can do that is a complete safeguard is to not be involved and to do everything that you can internationally to close down the nuclear industry.[39]

12.36 The Committee now summarises three specific proposals suggested in evidence—that Australia should establish:

- a uranium enrichment industry;
- a waste disposal industry, including the operation of a geologic repository; and
- move to develop the full fuel cycle, including the 'leasing' of fuel assemblies to customer countries and the take-back of waste for final disposal.

37 *ibid*.

38 Dr Rod Hill (CSIRO), *Transcript of Evidence*, 19 August 2006, p. 10.

39 Mr Peter Robertson (ECNT), *Transcript of Evidence*, 24 October 2005, p. 12.

Proposals

Enrichment

12.37 The Committee was pleased to receive evidence from Silex Systems Ltd (Silex), an Australian company pioneering the development and commercialisation of a laser-based, isotopic separation enrichment technology known as SILEX—separation of isotopes by laser excitation.[40] Silex is a tenant at the Lucas Heights Science and Technology Centre in Sydney.[41]

12.38 Silex began laser isotope separation research in 1990 and proved the SILEX technology on a laboratory scale in 1994. In 1996 a Licence and Development Agreement for the application of SILEX technology to uranium enrichment was signed with the US Enrichment Corporation (USEC), the largest supplier of enrichment services in the world. To facilitate the joint Silex-USEC development of SILEX technology, an Australia-US Bilateral Treaty for Nuclear Cooperation was negotiated by the respective governments in 2000. The SILEX technology was officially classified by both US and Australian Governments in 2001. In 2002 full uranium enrichment was demonstrated via direct measurement.[42]

12.39 In October 2005 the US Government approved potential commercial partners of Silex accessing classified information, which enabled prospective partners to assess the potential of the company and its SILEX process with due diligence. Several companies expressed interest in partnering with Silex in developing and commercialising the technology.[43] In May 2006 the company announced that it had entered into a technology commercialisation and license agreement for SILEX technology with General Electric (GE).[44] A test loop, pilot plant, and a full-scale commercial enrichment facility will be constructed in the US.

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40 Dr Michael Goldsworthy (Silex Systems Ltd), *Transcript of Evidence*, 9 February 2006, p. 1. As at February 2006, Silex had a market capitalisation of some $400 million and 40 employees. See also: <http://www.silex.com.au/>. In addition to uranium enrichment to produce nuclear fuel, Silex is also conducting research and development in silicon enrichment, for advanced semiconductor materials, and carbon enrichment for medical diagnostic materials.

41 Silex Systems Ltd, *Exhibit no. 87, Response to Greenpeace claims,* ASX Release, 25 November 2004, p. 1. The alleged proliferation risks associated with the SILEX technology were addressed in chapter eight.

42 Silex Systems Ltd, *Exhibit no. 88, Presentation by Dr Michael Goldsworthy*, p. 19. A history of Silex Systems' development is available online at the company's web site, viewed 8 May 2006, <http://www.silex.com.au/>.

43 Silex Systems Ltd, *Uranium Project Update*, 1 May 2006, p. 1, viewed 5 May 2006, <http://www.silex.com.au/>.

44 Silex Systems Ltd, *Silex Signs Commercialisation and License Agreement with General Electric Company for the SILEX Uranium Enrichment Technology*, 22 May 2006, p. 1, viewed 23 May 2006,

12.40 As indicated in chapter two and elsewhere in the report, uranium enrichment is a key step in the front-end of the fuel cycle and is necessary to transform uranium into a form that is useable to fuel most reactors. Following mining and milling of uranium ore, uranium oxide is first converted into a gas, uranium hexafluoride (UF_6). The enrichment process follows, in which the concentration of the fissionable isotope U-235 is increased from its natural level (assay) of 0.7 per cent to between three to five per cent.

12.41 The enrichment process produces this higher concentration of U-235 by removing over 85 per cent of the U-238. This is done by separating the gaseous UF_6 into two streams, one being enriched to the required level and known as low-enriched uranium (LEU). The other stream is depleted in U-235 and is called 'tails'. Having been enriched, the gas is then reconverted to produce enriched uranium oxide, which is then fabricated into pellets and finally assembled into tubes, or fuel elements. Bundles of the tubes are inserted into a nuclear reactor core to produce the heat required to make steam and drive the turbines which generate electricity.

12.42 There are currently two enrichment technologies in large scale commercial use: gaseous diffusion, which is the oldest enrichment technology and referred to by Silex as 'first generation'; and gas centrifuge enrichment, a 'second generation' technology. It was explained that both of these technologies have significant drawbacks. Diffusion plants have very high operating costs, produce low enrichment levels, are very inefficient and consume large amounts of electricity. Centrifuge plants have very high capital costs, but consume less energy than diffusion plants. Both technologies are massive, requiring tens of acres each to deploy.[45]

12.43 The output of enrichment plants is referred to as separative work units (SWUs) and Silex stated that some 40 million SWUs are currently produced annually in the uranium enrichment market worldwide.[46] One SWU is currently valued at US$115. Enrichment costs are substantially related to electrical energy used. The gaseous diffusion process consumes

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<http://www.silex.com.au/public/uploads/announce/Silex-GE%20Agreement%20ASX%200506%20Final.pdf>. See also: General Electric, *GE Signs Agreement with Silex Systems of Australia to Develop Uranium Enrichment Technology; Move Would Expand GE's Presence Within Global Nuclear Sector*, Press Release, 22 May 2006, viewed 23 May 2006, <http://www.ge.com/en/company/news/index.htm>.

45 Dr Michael Goldsworthy, *op. cit.*, pp. 9–10.

46 *ibid.*, p. 6. See also World Nuclear Association (WNA), *The Global Nuclear Fuel Market*, WNA, London, 2005, pp. 151–158.

about 2 500 kWh per SWU, while gas centrifuge plants require about 50 kWh per SWU.[47]

12.44 In contrast to the existing enrichment technologies, SILEX is a laser based rather than mechanical process. While the precise numbers are classified, the SILEX enrichment efficiency is said to far exceed that of the existing technologies.[48] Key features of the technology are that it has very low energy requirements and much lower capital costs. Table 12.2 compares the existing technologies with the SILEX technology.

Table 12.2 SILEX v existing technologies

	SILEX	Gas Centrifuge	Gaseous diffusion
Developed	2000s	1940s	1940s
Process	Laser excitation	Mechanical ('centrifugal force')	Mechanical ('brute force')
Enrichment efficiency	2 to 20[1]	1.25	1.004
Estimated cost per unit (US$)	\$30~\$40[2]	\$60~\$80	~\$100
% of existing market[3]	0%	40%	45%
Status	Under development 3rd Generation	Proven 2nd Generation	Obsolete 1st Generation

Source Silex Systems Ltd, *Exhibit no. 88, Presentation by Dr Michael Goldsworthy*, p. 17.
1 Classified
2 Indicative estimate only—needs to be verified in Pilot Program
3 Approximately 15% of market currently supplied via Russian HEU material

12.45 As noted above, it was emphasised that enrichment is central to nuclear economics. Silex argued that nuclear fuel costs represent some 30 per cent of the total costs of nuclear power, with an approximate breakdown of the components of the fuel costs listed in table 12.3. While there is variation over time, uranium ore accounts for approximately 35 per cent of the costs of the fuel, while enrichment accounts for about 40 per cent and fuel fabrication some 20 per cent.[49] The ANF also noted that enrichment and fuel fabrication contribute some 41 per cent and 22 per cent of the total nuclear fuel cost respectively.[50]

47 WNA, *Uranium Enrichment*, WNA, London, March 2006, viewed 8 May 2006, <http://world-nuclear.org/info/inf28.htm>.

48 Dr Michael Goldsworthy, *op. cit.*, p. 10.

49 *ibid.*, p. 6.

50 ANF, *Exhibit no. 4, loc. cit.*

Table 12.3 Nuclear fuel costs—percentage of total

Stage of front end of cycle	Percentage of total
Uranium ore	~35%
Conversion (to UF_6)	~5%
Enrichment	~40%
Fuel fabrication	~20%

Source Silex Systems Ltd, *Exhibit no. 88, Presentation by Dr Michael Goldsworthy*, p. 13.

12.46 As the price of uranium rises, demand for enrichment services increases. As Silex explained:

> By increasing the level of enrichment to produce lower tails assay, this also decreases the amount of ore consumed. So you can extract more from the same kilogram of uranium by increasing the enrichment and throw away less. This has an impact on increasing uranium prices and an increase in enrichment services.[51]

12.47 Silex suggested that its technology is so efficient that it may even be possible to take the waste stream from previously enriched uranium (i.e. the tails) and re-enrich it:

> … our process is looking so efficient that we might be able to re-enrich a lot of the stockpiled tails from the last 30 or 40 years of enrichment that are still sitting there. These have only been stripped from 0.7 per cent to 0.4 per cent or 0.35 per cent. They have had only half of the good stuff taken out because uranium was so cheap. Now that uranium is becoming more expensive and our technology means it is half the cost to enrich, you might have a secondary source of uranium. We could go and re-enrich the tails back up to natural uranium or continue. So there is a real dynamic between enrichment and uranium.[52]

12.48 The outlook for enrichment services published recently by the World Nuclear Association (WNA) predicts growth in its reference case. Based on the WNAs uranium enrichment market outlook, Silex has estimated the value of the market in the years ahead. In 2006 the enrichment market was estimated to be worth US$5 billion and is projected to be worth $17 billion by 2025, assuming growth corresponding to the WNA's reference case for world enrichment requirements.[53]

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51 Dr Michael Goldsworthy, *op. cit.*, p. 6.

52 *ibid.*, p. 11.

53 Silex System Ltd, *Exhibit no. 88, Presentation by Dr Michael Goldsworthy*, p. 15; WNA, *The Global Nuclear Fuel Market: Supply and Demand 2005–2030*, WNA, London, 2005, p. 93.

12.49 Silex described what Australia could potentially earn if the nation were to enrich about the same proportion of uranium that it currently exports as uranium oxide:

> If we translate that to the Australian situation, where we do not enrich uranium—we let everyone else make this money at our expense—in 2015, if we assume we are providing about one-third of the world's uranium, the value of enrichment that we could achieve by enriching here in Australia is about $US3 billion a year. By 2025, if we enriched that one-third share here in Australia instead of sending it overseas, that number increases to about $US6 billion or $A8 billion. That is the lost opportunity to Australia from not enriching here in Australia.[54]

12.50 In short, the value added by enriching uranium in Australia could potentially be approximately A$8 billion per year by 2025. However, with the restrictions on enrichment in Australia, Silex explained that its intention is to take the technology to the US and have a royalty stream coming back to Australia:

> Our preference would be to do it here and make all the money, but I do not think that is going to happen in my lifetime. So we are going to have a relationship with an American company or two … and have a royalty stream coming back to Australia on our technology.[55]

12.51 In terms of the supply and demand balance, Silex emphasised that there is no overcapacity in the enrichment services industry and demand exists for new entrants over the next 10 to 20 years. It was argued that with the continued operation of two older gaseous diffusion enrichment plants (one in France owned by Areva and another in the US, owned by USEC) a balance exists between supply and demand for enrichment services at present. However, the two diffusion plants, constructed in the 1950s and 1960s, are scheduled to be closed.

12.52 By 2010, even allowing for the planned construction of three of the newer centrifuge plants, one in France (by Areva) and two in the US (by USEC and the US National Enrichment Facility (NEF)), Silex argued that there will be a supply deficit of up to 13 million SWU. If there is no other source of supply, Areva and USEC will be forced to keep their older gaseous diffusion plants in operation beyond 2010. However, it is estimated that by 2015 the supply deficit will have grown to 27 per cent of demand, or 15

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54 *Dr Michael Goldsworthy, op. cit.*, p. 7.

55 *ibid.*, p. 8.

million SWU. The implication of these forecasts, which are listed in table 12.4, is that there *is* a place in the market for the SILEX technology:

> It takes 10 years to build any of these plants, and it will take us 10 years to get to a commercial position. So we need to look this far out. Already you can see a very big supply deficit emerging over the next 10 years. This is the industry. People who say there is an overcapacity are kidding themselves.[56]

Table 12.4 Uranium enrichment market outlook—supply and demand forecasts

Supplier	2005		2010		2015	
	MSWU	%	MSWU	%	MSWU	%
AREVA (GD)	9	20	?	-	0	-
USEC (GD)	7	16	?	-	0	-
USEC (HEU)	6	13*	6	12	0	-
URENCO (C)	7.5	17	9	18	10	18
TENEX (C)	12	26	12	24	12	12
AREVA (C)	0	-	2	4	7.5	13
USEC (C)	0	-	2	4	3.5	6
NEF (C)	0	-	2	4	3	5
OTHER (C)	3.5	8	4	8	5	9
SUPPLY	45	100	37	74	41	73
DEMAND	45		50		56	
DEFICIT	***0***	***0***	***13***	***26%***	***15***	***27%***

Source Silex System Ltd, *Exhibit no. 88, Presentation by Dr Michael Goldsworthy*, p. 16.
Notes:
MSWU = Million separative work units
GD = Gaseous diffusion
HEU = Highly enriched uranium
C = Gas centrifuge
* Russian HEU material provided to the US

12.53 The Committee notes, however, that in its forecast of supply and demand in the nuclear fuel market over the period to 2030, the WNA concludes that:

> Given the modular expansion capability of gaseous centrifuge designs and the required timelines for building new nuclear plants, capacity in the enrichment sector of the fuel cycle should be able to meet the requirements of the worldwide commercial nuclear fleet under any current projection of demand.[57]

56 *ibid.*, p. 9.
57 WNA, *op. cit.*, p. 157.

12.54 Appendix H lists the world's uranium enrichment plants, their status (operable, under construction or decommissioned), the technology employed, operator, nameplate capacity, annual production, year of start up of commercial operation/proposed date, and date of shutdown.

12.55 It was noted that the SILEX technology is the sole surviving laser enrichment technology in the world. A range of Governments, including the US, Japan, Britain, France and Germany, have previously attempted to build laser enrichment technologies and all have failed. However, Silex expressed confidence in its prospects of commercial success, arguing that its approach is quite different to those attempted by these governments. In particular, Silex claims to have viable engineering concepts and its technology can be industrialised.[58]

12.56 The company has also commenced preliminary activities in the next phase of its Technology Development Program—the Test Loop Program. The objective of the Test Loop Program is to demonstrate efficient enrichment in plant-scale prototype facilities, and to accurately measure process efficiency and evaluate economics. This program is expected to take up to two and a half years to complete.[59]

12.57 Silex advised that it will take the company some six or seven years to produce commercial material at a pilot level and another three to four years before industrial level production could occur. A commercial plant could be operational in 2013, with a small scale plant costing in the order of A$500 million to construct.[60] However, the company expressed confidence about the potential for the technology's commercial development:

> … Silex is well positioned to capitalise on the impending increase in the demand for new enrichment capacity, and the need to replace the aging gaseous diffusion capacity still in use today. If the economics of the SILEX process prove to be as attractive as we anticipate, our technology will become a major player in the uranium enrichment industry.[61]

12.58 The ANF and others also argued that, consistent with International Atomic Energy Agency (IAEA) proposals (described in chapter seven) for the establishment of any future fuel cycle facilities under multinational

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58 Dr Michael Goldsworthy, *op. cit.*, p. 10.

59 Silex Systems Ltd, *Project and Operational Update*, ASX Announcement, 15 March 2006, p. 2, viewed 5 May 2006, <http://www.silex.com.au/>.

60 Dr Michael Goldsworthy, *op. cit.*, p. 14. The same capacity centrifuge plant would cost in the order of three times this amount.

61 Silex Systems Ltd, *Project and Operational Update*, ASX Announcement, 15 March 2006, p. 1, viewed 5 May 2006, <http://www.silex.com.au/>.

control, 'Australia might be an ideal location for at least a fuel enrichment plant under multinational safeguards control.'[62]

Nuclear waste disposal

12.59 Nova Energy argued that Australian industry and Government should develop a position on the storage and disposal of nuclear waste in Australia:

> I think there is a responsibility as part of the overall debate about uranium mining to have a clear position, as an industry and as a government, as to whether it is acceptable in the community to ultimately store [nuclear waste] material, but I think we are obligated to have resolved those issues before mining occurs, whether storage is ultimately in Australia or elsewhere.[63]

12.60 Similarly, Arafura Resources and the CSIRO argued that Australia should develop a policy that outlines the stewardship issues and conditions of product ownership associated with uranium supply, usage, and disposal.[64]

12.61 A number of submitters expressed support for establishing a nuclear waste disposal industry in Australia and constructing a high-level waste repository. It was emphasised that Australia has suitable geology to host a repository and a waste disposal industry would be highly profitable. For example:

- Silex submitted that:

> … it would be fantastic to see Australia playing a role in every step of the fuel cycle. Not only that, there is a waste industry out there waiting to happen, of nuclear waste being stored around the world, which amounts to hundreds of billions of dollars. It is waiting for someone to come along and do it. The waste industry itself is a huge economic resource.[65]

- Southern Gold stated that it:

> … firmly believes that suitable repository sites exist within stable geological environments within Australia and that Australia must

62 ANF, *Submission no. 11, loc. cit.*

63 Mr Richard Pearce (Nova Energy Ltd), *Transcript of Evidence*, 23 September 2005, p. 80.

64 Arafura Resources NL, *Submission no. 22*, p. 10; CSIRO, *Submission no. 37*, pp. 8–9. See also: Minerals Council of Australia, *Submission no. 36*, pp. 19–20.

65 Dr Michael Goldsworthy, *op. cit.*, p. 20.

> take advantage of the economic benefits of storing small quantities of high-level nuclear waste.[66]

- AINSE submitted that:

> Because of the stable geological nature of the Australian mainland there may be good business opportunities associated with the storage and handling of nuclear waste.[67]

12.62 As mentioned in chapter five, Dr Ian Smith, Executive Director of ANSTO, argued that 'Australia has some of the best geology in the world' for a repository and that 'there are hundreds of sites in Australia which would be suitable for that purpose.'[68]

12.63 Arafura Resources emphasised Australia's geological suitability and the global security benefits of Australia conducting waste disposal:

> Australia … has ideal waste storage locations given the geological stability of many areas, large areas of ideal host rocks, and the remoteness of many locations from large populations. Deep burial in dry stable rock is the ideal location for radioactive storage as the product can naturally decay without causing any harmful effects on the environment. With a product as sensitive as radioactive waste, Australia could be the best place for waste storage given our ideal geological locations, political stability and responsible attitudes. It will be safe from illegitimate use if it is stored in Australia. The community has a right to know that nuclear waste can be safely disposed of.[69]

12.64 Arafura also argued that Australia 'could become a leader in safe secure disposal' of nuclear waste and that the nation should now identify strategic waste disposal locations.[70]

12.65 The Institute of Public Affairs (IPA) likewise submitted that:

> Australia may be in a unique position to offer safe long term burial of waste. This will not only make a substantial contribution to world security but also offer a very large business opportunity.[71]

12.66 The IPA argued that Australia, along with Namibia/South Africa, the Terim Basin in China and southern Argentina have potential disposal sites whose geological properties would intrinsically provide reliable long-term containment for nuclear waste. These sites would meet the geological

66 Southern Gold Ltd, *Submission no. 54*, p. 10.

67 AINSE, *Submission no. 77*, p. 2.

68 Dr Ian Smith (ANSTO), *Transcript of Evidence*, 13 October 2005, p. 15.

69 Arafura Resources NL, *Submission no. 22*, p. 6.

70 *ibid.*, p. 10.

71 IPA, *Exhibit no. 48, Radioactive Waste Management in Australia*, p. 1.

characteristics required of a so-called 'high-isolation site' such as minimal groundwater flow, maximum time for any waste to reach the biosphere, minimal possibility of human exposure, and long-term stability in climate and geology.[72]

12.67 It was noted that in addition to the geological requirements, there are a number of non-geological criteria that limit even further the number of possible locations for a repository. These criteria include suitable transportation corridors, political stability, and national institutions and technology capable of overseeing the repository's safe development and operation. The IPA argued that after considering all such criteria, truly ideal high-isolation sites are in fact very rare.[73]

12.68 The IPA argued that Australia should offer to dispose of the wastes generated from the uranium supplied from Australian mines in the first instance, and then consider the disposal of wastes from the Asian region where countries are unlikely to find secure high-isolation sites. Based on an industry price estimate of $1 million per tonne of spent fuel (which corresponds to a cost of approximately 0.4 cents/kWh for a light water reactor), it was argued that even restricting storage to Australian-sourced uranium would make for a substantial market of 1 000 to 2 000 tonnes of spent fuel annually—that is, revenues of $1–2 billion annually for disposal of Australian-sourced uranium alone.[74] As noted in chapter five, 12 000 tonnes of spent fuel is discharged annually worldwide, and there is currently a global inventory of some 270 000 tonnes of spent fuel and its derivatives in interim storage.[75]

12.69 In summary, the IPA argued that:

> The disposal of spent fuel and high-level waste in Australia is a major opportunity. It would not only be a significant business opportunity, but also a major enabling step for the use of nuclear power, an important contribution to nuclear safety, and a major contribution to our region.[76]

12.70 Areva and Arafura Resources also suggested that Australia should take back the waste produced in nuclear reactors using Australian uranium.[77]

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72 *ibid.*, pp. 6, 8.

73 IPA, *Exhibit no. 47, The Safe Disposal of Nuclear Waste*, p. 3.

74 *ibid.*

75 IPA, *Exhibit no. 48, op. cit.*, p. 10.

76 IPA, *Exhibit no. 47, loc. cit.*

77 Mr Stephen Mann (Areva), *Transcript of Evidence*, 23 September 2005, p. 11; Mr Alistair Stephens (Arafura Resources NL), *Transcript of Evidence*, 23 September 2005, p. 52.

12.71 Mr John Reynolds, formerly the Chairman of the Uranium Information Centre, submitted that, given the vast area of remote and geologically stable terrain in Australia, it would be readily achievable to site a repository in Australia from a technical and safety view point. However, it was argued that:

> The problems lie in the politics of location as already shown in the unfortunate failure to determine a location for a national repository for low level medical … wastes, whose risk to public safety … was in reality virtually non-existent.
>
> Our failure is essentially because subjective political action has frustrated real understanding of the risks and benefits of establishing an engineered repository.[78]

12.72 While accepting that 'this is politically the most difficult area', Professor Leslie Kemeny argued that Australia should accept nuclear waste from other countries:

> I believe Australia, as a potential major supplier of uranium to an energy hungry world should take on this responsibility as financially lucrative, as a sunshine industry and as a place which is geologically and in every way suitable for acceptance of so-called nuclear waste.[79]

12.73 Other submitters, particularly those critical of nuclear power, argued that if Australia permits uranium mining, then Australia should also be responsible for the nuclear waste which results from its use.[80]

12.74 While AMEC doubted whether Australia had a 'moral' obligation to dispose of nuclear waste generated from the use of Australian uranium, it also argued that 'there is a wonderful opportunity for Australia to capture the ability to dispose of radioactive waste in this country and to do it safely.'[81]

12.75 The Northern Territory Minerals Council (NTMC) also questioned whether Australia has an obligation to accept nuclear waste and suggested that such considerations should be conducted on economic grounds alone:

> In terms of the proposition of taking back nuclear waste, that should be viewed as an economic rather than a moral decision. I do not think that it follows, as some have said, that because we produce uranium we have a moral obligation to take back spent fuel rods and the like. The vast quantity of economic benefit is

78 Mr John O Reynolds, *Submission no. 5*, p. 6.

79 Professor Leslie Kemeny, *Transcript of Evidence*, 16 September 2005, pp. 93–94.

80 See for example: Ms Janet Marsh, *Submission no. 2*, p. 3.

81 Dr David Blight (AMEC), *Transcript of Evidence*, 23 September 2005, p. 17.

> derived by those producing power and selling it down the track. The percentage we derive from selling the product is minuscule. If it makes economic sense, by all means look at it on that economic and scientific basis, but I do not think there is a moral obligation to do it.[82]

12.76 In relation to the commercial prospects for the Australian synthetic rock (Synroc) waste technology, described in chapter five, ANSTO commented that 'synroc has been identified internationally … as being the disposal route of choice for plutonium-contaminated material.'[83] ANSTO is currently building a pilot plant with the British Nuclear Group to process waste material contaminated with plutonium, as part of the clean-up of the Sellafield site in England. ANSTO is also pursuing the opportunity of having Synroc used for three sites in the US which have similarly large clean-up programs.

12.77 The ANF and Arafura Resources argued that ANSTO certainly has expertise in waste disposal and that Synroc is the best technology available, but noted that it may be more expensive than the glass alternative. In terms of its capabilities, it was observed that Synroc 'is much more than is really required.'[84] Other countries are said to have made considerable investments in other waste forms that they are unlikely to abandon in favour of Synroc:

> Although it will find a place in the future for special applications, Australia should remember that both Britain and France have the equivalent of about a £5 billion investment in their present way of doing things, and they are certainly not going to just shut that down so they can embrace synroc. There will come a time when the plant becomes obsolete, and that will be the time when these people will be making decisions about synroc. However, if we were to use one of the processes in Australia, synroc is probably the one we would choose.[85]

Synroc is being considered for use in the UK to immobilise five tonnes of intractable plutonium waste that cannot be reprocessed economically.[86]

12.78 AINSE argued that there is accelerator/reactor-driven waste destruction research underway in several countries, notably in Japan (at J-PARC), the US and France. As described in chapter five, some of this research is aimed

82 Mr Ian Henwood (NTMC), *Transcript of Evidence*, 24 October 2005, p. 39.
83 Dr Ian Smith (ANSTO), *Transcript of Evidence*, 13 October 2005, p. 17.
84 Dr Philip Moore (ANF), *Transcript of Evidence*, 16 September 2005, p. 48.
85 *ibid*.
86 *ibid*.

at reducing the activity of highly radioactive isotopes by a factor of 100, thereby reducing the required storage time of waste from thousands to a few hundred years. AINSE argued that if the Australian Government decides to become involved in the beneficiation of nuclear waste through the development of waste storage solutions, then it should offer to participate in these transmutation research programs. If storage solutions were developed in conjunction with J-PARC technology, the industry could also involve strategic alliances for Australia.[87]

12.79 The CSIRO submitted that it also has expertise in the area of radioactive waste management and could contribute in areas complementary to ANSTO's existing technology capabilities, such as:

- material development to increase the lifetime and performance of materials of construction and containment used in the nuclear industry;
- chemical processing to reduce the escape of certain waste forms into the environment;
- the customisation of the properties of zeolite materials used for the capture and retention of radioactive organic species that may not have high levels of sorption onto clay and rock surfaces used traditionally for containment materials;
- more efficient and effective handling systems to promote the ability of disposing of radioactive wastes;
- integrated modelling of fluid flow and solute transport to allow development of more effective management systems and better understanding of geotechnical impacts and two phase gas migration;
- linking physical models of groundwater flow and radionuclide transport to biosphere models of plant uptake and human ingestion; and
- linking process models to risk models.[88]

12.80 In the context of the issue of siting a Commonwealth radioactive waste repository in the Northern Territory, the Northern Land Council submitted that there is potential for Australia to develop world's best practice in nuclear waste management:

> In terms of world's best practice, we believe that the Northern Territory Department of Minerals and Energy could actually deal

87 AINSE, *loc. cit.*

88 CSIRO, *Submission no. 37*, p. 9.

> itself into a sphere of excellence in mining and in nuclear waste repositories that would set Australia apart.[89]

A 'Nuclear Fuel Cycle Complex' and fuel leasing

12.81 The Australian Nuclear Association (ANA) proposed the eventual development of a 'cradle to grave' concept for Australia's uranium, which would involve the construction of an 'Integrated Nuclear Fuel Cycle Complex' (NFC Complex) in Australia. The concept would:

> … take Australia's uranium through the front end of the nuclear fuel cycle to the production of fuel elements which would be leased to overseas nuclear power programs. The spent fuel would be returned to Australia, stored, reprocessed and the unused uranium and plutonium recycled into MOX fuel for lease to overseas nuclear plants. The high level waste would be converted into Synroc and placed in a deep repository in the most suitable part of Australia.[90]

12.82 The ANA argued that this approach, which would involve the gradual establishment of facilities on a stage by stage basis, would 'place Australia at the leading edge of the nuclear industry, earn enormous export revenue and contribute significantly to the world's non-proliferation needs.'[91] Moreover, the project would involve a huge investment of capital, technology and a skilled workforce. In short, it would be 'the 21st Century equivalent of the Snowy Mountains Scheme.'[92]

12.83 The benefits of an integrated NFC Complex were said to include:

- less transport distance and time between fuel cycle stages with lower cost;
- less risk of loss of valuable material by accident and access by terrorists;
- easier control by regulatory agencies responsible for non-proliferation;
- multi-national or international involvement with greater transparency;
- less or no need for small countries to invest in their own expensive and politically sensitive facilities provided they are guaranteed supply.[93]

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89 Mr Norman Fry (NLC), *Transcript of Evidence*, 24 October 2005, p. 22. See also: NLC, *Submission no. 78*, p. 6.

90 Mr Robert Gishubl, *Exhibit no. 90*, *A Cradle to Grave Concept for Australian Uranium*, by Dr Clarence J Hardy, p. i.

91 *ibid*.

92 *ibid*.

93 *ibid*., p. 2.

12.84 Based on WNA projections for demand and supply of fuel cycle services, and reinforcing the claims made by Silex, the ANA concluded that current conversion and enrichment capacity is sufficient to meet current demand, but there will be insufficient capacity in these industries by 2010 due to the risk of new capacity not coming online, especially in the US. It was argued that:

> … this presents a window of opportunity for an Australian NFC Complex, starting with conversion and enrichment and then adding fuel fabrication and finally reprocessing and waste management.[94]

12.85 Even if the WNA's 'business as usual' scenario eventuates, in which nuclear capacity increases only modestly over the period to 2030, the ANA argued that:

> … there will be a substantial increase in requirements for uranium and fuel cycle services including conversion, enrichment, fuel fabrication, reprocessing, recycle of recovered uranium and plutonium, and waste management facilities. There is a very good opportunity to design and construct multi-national or international fuel cycle centres. These offer technical, economic and non-proliferation advantages.[95]

12.86 Nova Energy also expressed support for the eventual development of advanced nuclear industries in Australia, which would commence with uranium enrichment and eventually involve the fabrication and return of used fuel rods:

> The idea of producing U_3O_8 concentrates … and having a high-tech, high-value industry that enriches uranium in Australia, exports fuel rods and then brings back those fuel rods to Australia for re-treatment and/or storage strikes me as ultimately a very advanced, high-tech, high-value and responsible industry for Australia to head towards.[96]

12.87 Similarly, Professor Leslie Kemeny submitted that:

> A dominant supplier of uranium—such as Australia—should capitalise on both the front and the rear end of the global fuel cycle by enriching the mined product, fabricating the fuel, leasing it to trading parties and disposing in suitable waste repositories. The return on the front and rear end processing costs of around $1500

94 *ibid.*, p. 6.

95 *ibid.*, p. 11.

96 Dr Timothy Sugden (Nova Energy Ltd), *Transcript of Evidence*, 23 September 2005, p. 73.

> (Aus) per kilo each can thereby be optimised and the proliferation and safeguards risks minimised.[97]

12.88 Although personally opposed to the concept of fuel leasing because of alleged weaknesses in the international safeguards regime, Professor Richard Broinowski argued that the concept of fuel leasing has merit:

> We are selling yellowcake. Yellowcake is the lowest form of beneficiation of uranium. Enormous value could be added to it if we had even a uranium hexafluoride [conversion] plant, if we could fabricate it into fuel rods and if we could lease the rods, not sell them—this was put twice to the Fraser government as something we should seriously do, and they turned it back … if we had the whole cycle and we bought back, as a morally conscientious people should, the spent fuel that we have so happily sold to the world—we could have developed a very important and powerful industry here in Australia. That would give us a greater say in the international community about nuclear matters …[98]

12.89 Southern Gold also supported the concept of developing other fuel cycle industries so that Australia can both manufacture nuclear fuel and then receive back the waste products for storage and final disposal. The benefits were said to include the substantial profits that could be earned and greater control over the fuel cycle, thereby reducing proliferation risks.[99]

12.90 However, the Committee notes that the Australian Safeguards and Non-Proliferation Office (ASNO) is critical of the fuel leasing proposal. ASNO's submission to the Prime Minister's Nuclear Energy Review sets out the following objections:

- the fuel leasing proposal implies, incorrectly, that Australia's current safeguards are deficient and fails to address the real proliferation risk, which is said to be the detection of clandestine and undeclared nuclear activities (e.g. Iraq, DPRK, Libya and Iran), particularly undeclared centrifuge enrichment;
- the proposal is unrealistic (e.g. it would not be practicable for Australia to manufacture fuel assemblies for all Australia's uranium customers—some 60 different reactor models in total) and would involve other

97 Professor Leslie Kemeny, *Submission no. 64*, p. 5.

98 Professor Richard Broinowski, *Transcript of Evidence*, 16 September 2005, pp. 19–20.

99 Mr Ric Horn (Southern Gold Ltd), *Transcript of Evidence*, 19 August 2005, p. 15.

major practical issues such as cost, infrastructure, availability of experienced workforce, and substantial lead-times; and

- it fails to recognise major changes taking place on spent fuel management, notably the move away from currently established PUREX technology to the concept proposed for the US GNEP initiative, in which plutonium will be recycled without first separating this material from uranium, minor actinides and some fission products (thereby reducing the proliferation and terrorism risks).[100]

12.91 The Committee concludes that as a country possessing some 40 per cent—and potentially more—of the world's uranium resources, Australia has always had an extremely strong economic interest in, and justification for, seeking to add value to its uranium resources prior to export. By repeatedly preventing the establishment of such facilities, such as uranium conversion and enrichment, Australia has foregone considerable additional export revenues, the development of sophisticated technologies and expanded national skills and expertise.

12.92 The Committee has no in-principle objection to Australia developing domestic fuel cycle services industries. Indeed, as argued by some submitters, fuel cycle facilities could well be established in Australia on a joint ownership, co-management or drawing rights basis, in accordance with the IAEA's expert advisory group recommendations outlined in chapter seven, thereby providing a high level of transparency for regional neighbours and the international community generally. Such a development would have clear global non-proliferation benefits, while also allowing Australia the opportunity to extract greater returns from its immense uranium resource endowment, to develop sophisticated technologies and to expand its national skills base.

12.93 The Committee also notes evidence that Australia possesses ideal locations for a geologic repository to dispose of nuclear waste and that, again, a waste management industry could be of immense economic value to the nation. Such a development could also involve the development of sophisticated technologies and skills. Operation of such a facility in Australia could also have global non-proliferation benefits. Australia already holds considerable expertise in the immobilisation of high level waste through the Synroc technology.

12.94 The Committee recognises that prior to such facilities being established in Australia, governments would first need to develop an appropriate

100 Mr John Carlson, Director General, ASNO, submission to the *Uranium Mining, Processing and Nuclear Energy Review*, p. 30, viewed 16 October 2006, <http://www.pmc.gov.au/umpner/submissions/77_sub_umpner.pdf>.

licensing and regulatory framework, and remove legislative prohibitions on the establishment of such facilities.

Recommendation 12

The Committee recommends that the Australian and state governments, through the Council of Australian Governments:

- **examine how Australia might seek greater beneficiation of its uranium resources prior to export and encourage such a development, while meeting non-proliferation objectives proposed in initiatives such as the US Global Nuclear Energy Partnership (GNEP) and the International Atomic Energy Agency's (IAEA) proposed multilateral approaches to the nuclear fuel cycle;**
- **examine the possible establishment of fuel cycle facilities (for example, uranium conversion and enrichment plants) which, in accordance with the IAEA's recommendation for such facilities to be operated on a multilateral basis, could be operated on a joint ownership, co-management or drawing rights basis with countries in the region intending to use nuclear energy in the future;**
- **examine whether, in light of the advances in spent fuel management proposed in the GNEP initiative, there is in fact a potential role for Australia in the back-end of the fuel cycle;**
- **in the event these proposals are adopted, develop a licensing and regulatory framework, that meets world's best practice, to provide for the possible establishment of fuel cycle services industries and facilities in Australia; and**
- **having established an appropriate regulatory regime, remove legislative impediments to the establishment of nuclear fuel cycle facilities in Australia and, specifically, repeal or amend:**
  - ⇒ **Section 140A of the *Environment Protection and Biodiversity Conservation Act 1999*, and**
  - ⇒ **Section 10 of the *Australian Radiation Protection and Nuclear Safety Act 1998.***

The Committee further recommends that such examination take account of full life cycle costs and benefits of the proposed facilities.

Domestic use of nuclear power

12.95 Several submitters called either for the introduction of nuclear power in Australia or for the issue to at least be thoroughly examined. AMEC argued that 'the future adoption of nuclear energy will allow Australia to effectively contribute to the consistent global reduction of greenhouse gas emissions' and recommended that 'the question of nuclear energy being used as an electricity supply option in Australia be constantly reviewed.'[101]

12.96 Mr John Reynolds submitted that:

> In its own interests and as a contribution to the containment of greenhouse gas emissions globally, there is a strategic, economic and ethical case for Australia now, to include nuclear electricity generation in its energy infrastructure.[102]

12.97 Mr Barry Morgan was direct in his submission to the Committee:

> For heavens sake stop messing around with enquiries etc and get on with not only opening up more mines but actually building our own reactors and developing clean pollution free electricity generation.[103]

12.98 However, Mr Keith Alder argued that even if there were bipartisan support it could take 12 to 15 years before a nuclear power station would be operating in Australia. The reason given for this was that a first reactor in a new country would take longer because of the regulation and licensing procedures that would first need to be established. It was estimated that construction time would be not less than six years.[104]

12.99 Mr Reynolds argued that there would be a number of advantages to the nation from the use of nuclear power, beyond its environmental merits, its contribution to global greenhouse gas mission abatement and the security of fuel supply from domestic resources that it offers:

- it would enhance Australia's credibility in the global uranium trade and help secure a long term and beneficial participation in the nuclear fuel market;

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101 Mr Alan Layton (AMEC), *Transcript of Evidence*, 23 September 2005, p. 13. See for example: Mr Robert Elliott, *Submission no. 1*, p. 1.

102 Mr John O Reynolds, *op. cit.*, p. 4.

103 Mr Barry Morgan, *Submission no. 68*, p. 1.

104 Mr Keith Alder, *Transcript of Evidence*, *op. cit.*, p. 91.

- it would provide a new dimension of technology in Australia, in which education and technical institutions would participate with great benefit;
- it would provide new and challenging opportunities to the manufacturing and service industries;
- new skilled and professional employment opportunities and career paths would be generated;
- it would stimulate possible adoption of down-stream industries such as uranium conversion (to UF_6), enrichment to fuel grade, and possibly fuel manufacture; and
- it could offer an opportunity for Australia to become a world nuclear fuel provider in the longer term with the further possibility of offering fuel reprocessing and storage services. These would be most valuable industries and would strengthen Australia's already respected efforts in supporting the international instruments against proliferation of nuclear weapons.[105]

12.100 In addition, Mr Reynolds argued that in the longer term it can be expected that hydrogen will be used a substitute for present transport fuels. It was claimed that research suggests that nuclear energy may well become a basis for the production of hydrogen using high temperature reactor technologies, thereby reducing greenhouse gas emissions from the transport sector.[106]

12.101 Professor Leslie Kemeny also argued that 'we should accept nuclear power as a mature technology, legitimate for Australia's use.'[107] Professor Kemeny also argued that Australia has not necessarily lost time in delaying adopting nuclear power because of the evolution of reactor designs. For example, it was noted that Generation IV reactor designs will be suitable for electricity generation, producing potable water by desalination and, as noted by Mr Reynolds, for the production of hydrogen for transportation.[108]

12.102 Several submitters, including AMEC, the Australian Academy of Technological Sciences and Engineering (AATSE), Mr Keith Alder and others, called for an examination of the use of nuclear power in the

105 Mr John O Reynolds, *op. cit.*, p. 7.
106 *ibid.*
107 Professor Leslie Kemeny, *Transcript of Evidence*, *op. cit.*, p. 93.
108 *ibid.*, p. 97.

Australian context, and particularly for a thorough investigation of the economic viability of a domestic nuclear power industry.[109]

12.103 Other submitters, including the IPA and AMP CISFT submitted that nuclear power will not be competitive in the domestic context due to Australia's vast endowment of low-cost, high-quality coal resources.[110]

12.104 The IPA argued that estimates for the generation costs of nuclear power plants in Australia vary from the low $50s to the upper $60s per MWh, while coal in Eastern Australia costs under $40/MWh and natural gas is $44/MWh. These estimates exclude taxes, subsidies and other regulations designed to alter the choice of power generation technologies. Thus, it was concluded that:

> As it is 30–60 per cent more expensive than coal-generation, and somewhat more costly than gas, in the absence of government intervention, nuclear does not have a future in Australia in the medium-to-long term. Nuclear is, on the other hand, significantly more cost effective than wind and all other exotic alternatives.[111]

12.105 However, the IPA noted that if an EU-type Greenhouse Gas Emission Trading Scheme were established in Australia (thereby increasing the costs of carbon emissions) this would significantly alter the cost ranking of the various power generation technologies in Australia. It was argued that if the current EU carbon price (presently trading at around €16 per tonne CO_2) were to emerge from a carbon trading scheme in Australia, nuclear power would be the lowest cost source of future energy in Australia.[112]

12.106 It was submitted that if Australian governments were to require a 60 per cent reduction in the country's greenhouse gas emissions, nuclear power would need to play a major role:

> Indeed, it is difficult to envisage how a 60 per cent reduction target can be achieved other than by all, future, large base-load power stations being nuclear.
>
> Such a policy would need to effected by a carbon tax or a system of vesting tradeable rights to carbon dioxide emissions.[113]

12.107 The IPA emphasised, however, that it strongly opposes the establishment of a carbon trading scheme, arguing that it would increase electricity and

109 See: AATSE, *Submission no.3*, p. 1; Mr Keith Alder, *Submission no. 7*, p. 4; Mr John O Reynolds, *op. cit.*, p. 6; AMEC, *op. cit.*, p. 6.

110 See: IPA, *Exhibit no. 46, The Economics of Nuclear Power*, p. 1; AMP CISFT, *Submission no. 60*, p. 7.

111 IPA, *ibid.*

112 *ibid.*, p. 2.

113 *ibid.*, p. 3.

gas prices by at least 50 per cent and would be accompanied by a considerable loss of wealth through 'writing off the value' of Australia's brown and black coal resources. A secondary implication could be the nation's loss of comparative advantage in raw materials processing, which would mean the migration from Australia of the aluminium, iron and steel, and chemical industries.[114]

12.108 Southern Gold supported the examination of domestic use of nuclear power and also noted that if carbon taxes or some regulatory restriction on carbon emissions were imposed on coal fired plants this would make nuclear power more economic in the Australian context.[115]

12.109 As noted in the discussion of greenhouse gas emissions and nuclear power in chapter four, the Uranium Information Centre (UIC) observed that if subsidies and other government incentives are provided 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.[116]

12.110 Other submitters observed that while nuclear power may not be economically competitive, nevertheless 'the market should be allowed to determine the competitiveness of nuclear generation' in the Australian context.[117]

12.111 It was emphasised that if Australia were to embrace nuclear power, or to develop other fuel cycle services industries, then it would first need to establish a licensing and regulatory framework to support an expanded nuclear industry, which the nation currently lacks.[118] The issue of the domestic skills base to support such developments is considered further below.

12.112 The Committee also notes that the CSIRO is conducting an Energy Futures Forum, as part of the work of the Energy Transformed National Research Flagship Program, which has been set up to bring together a broad range of industry and community groups in a scenario planning exercise exploring potential futures of the Australian stationary energy and

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114 *ibid*.

115 Mr Ric Horn, *op. cit*., p. 16.

116 Mr Ian Hore-Lac (UIC), *Transcript of Evidence,* 19 August 2005, p. 90.

117 Mr Andrew Crooks, *Submission no. 84*, p. 8.

118 See: Mr John O Reynolds, *op. cit.*, p. 8. This point is emphasised in ASNO's submission to the Prime Minister's Nuclear Energy Review, *op. cit*., p. 34.

transport industries. Running over an 18-month period, the Forum intends to:

> … develop key energy scenarios that will be modelled by purpose-built world-class techno-economic models to determine potential energy industry and technology pathways and highlight possible impacts to society, environment and the economy. The range of energy scenarios considered will include those addressing the potential for nuclear power in the mix.[119]

12.113 Scenarios will be developed by industry and community forum participants only (assisted by a professional facilitator), and CSIRO and ABARE will provide the modelling tools and analysis.

12.114 In contrast to the support for the establishment, or at least the examination, of a nuclear energy industry in Australia, some 27 submitters to the inquiry expressed opposition to the use of nuclear power in Australia for the reasons addressed at length in chapters five, six, seven and eight (i.e. waste, safety and proliferation).[120]

Defence implications — nuclear propulsion for warships

12.115 The SIA argued that the Australian Government's energy white paper, *Securing Australia's Energy Future*, which was published in June 2004, 'was seriously flawed in not considering nuclear power as a source of energy' in the Australian context.[121] The SIA argued that given the long lead times for the construction of nuclear power plants, 'this makes the priority to revisit this policy all the more urgent.'[122] It was acknowledged that although the domestic use of nuclear power was outside the Committee's terms of reference, the SIA argued that 'your inquiry has sparked serious debate on the matter and I urge you to take any opportunity to cause a review of our policy to occur.'[123]

12.116 The SIA submitted that if Australia were to adopt nuclear power this would then present the nation with an option to consider the acquisition of a nuclear powered submarine capability in the period 2020 to 2050. SIA

119 CSIRO, *Submission no.37*, p. 10.

120 See for example: Mrs Janet Marsh, *Submission no. 2*; MAPW (WA Branch), *Submission no. 8*; The Greens (NT), *Submission no. 9*; Mr John Schindler, *Submission no. 10*; Darwin No War Committee, *Submission no. 13*; The Uniting Church in Australia (Tasmanian and Victorian Synod), *Submission no. 40*; Australian Conservation Foundation, *Submission no. 48*; Public Health Association of Australia, *Submission no. 53*; Mr R Hinkson, *Submission no. 61*; Ms K Winter, *Submission no. 62*; Mr W Lewis, Submission no. 65; Ms J Catalano, *Submission no. 70*; Ms A Macintosh and others, *Submission no. 82*.

121 Rear Adm. Peter Briggs AO CSC (Retired) (SIA), *Transcript of Evidence*, 10 October 2005, p. 28.

122 *ibid*.

123 *ibid*.

argued that trends in the regional security environment make consideration of nuclear propulsion essential as the Collins Class submarine nears the end of its life in 2020–2025.[124]

12.117 Nuclear propulsion in submarines was said to confer several important advantages, including: the capacity to proceed at high speed without endurance constraints and the need to expose the submarine to recharge batteries; and impressive mobility that allows quick response and reduced risk of counter detection.[125]

12.118 It was argued that to operate nuclear powered submarines would almost certainly require a domestic nuclear power industry:

> There is no doubt that nuclear propulsion for submarines offers significant operational advantages in the regional security environment likely to prevail in the medium term—15 to 20 years and beyond. Nevertheless, the introduction of a nuclear powered submarine would be difficult to achieve without commensurate expansion of the nuclear support industry beyond that established for the replacement nuclear research reactor at the Australian Nuclear Science and Technology Organisation. Such an expansion would require a whole-of-government commitment to a nuclear energy program … a nuclear industry base is an essential starting point to create the opportunity to consider such a capability.[126]

12.119 In particular, SIA argued that such a capability would need to be backed up by a 'power generation industry which produces the bulk of graduates and provides the engineering experience that you need in through-life support for the submarine.'[127] It was submitted that without the capability provided by a domestic nuclear power industry, service support and maintenance for the submarines would become extremely expensive and highly dependent on an overseas supplier.[128]

124 SIA, *Submission no. 21*, pp. 8-11.
125 *ibid*., p. 10.
126 Rear Adm. Peter Briggs AO CSC (Retired), *loc. cit*.
127 *ibid*., p. 33.
128 SIA, *op. cit*., p. 11.

The thorium fuel cycle — an alternative for Australia to consider

12.120 Professor Igor Bray, a physicist at Murdoch University and Deputy Director of the ARC Centre of Excellence in Antimatter Studies, argued that, in the Australian context, power derived from the thorium fuel cycle should also be considered. The reasons advanced for this were that: as with uranium, Australia possesses the largest reserves of thorium in the world (as described in chapter three); Australia has not thus far invested to 'go down purely the uranium route'; and thorium promises a number of important potential benefits over the uranium fuel cycle, described below.[129]

12.121 Although the isotope thorium-232 (Th-232) is not itself fissionable, it was explained that, having been initiated with some other fissile material (e.g. U-235 or Pu-239), a breeding cycle similar to but more efficient than that with U-238 and plutonium can be set up. Thorium-232 will readily absorb a neutron to become Th-233 which normally decays to protactinium-233 and then U-233, which is fissile. The irradiated fuel can then be unloaded, separated and then fed back into another reactor as part of a closed fuel cycle.[130] Hence, Th-232 is 'fertile', as is U-238.[131]

12.122 The use of thorium offers potential benefits, including that it produces much less plutonium and other transuranic waste.[132] Thus, the thorium fuel cycle is said to hold non-proliferation and waste advantages over conventional uranium fuel cycles:

> … the thorium fuel cycle has potential for breeding fuel without the need for fast neutron reactors. It is inherently going to be safe. It should lead to considerably less weapons grade material. Waste will be much more manageable, with a shorter half-life. So there is considerable potential. I believe it could be a key factor in the sustainability of nuclear energy.[133]

12.123 In addition, almost all of the mined thorium is potentially usable in a reactor, compared with only 0.7 per cent of natural uranium (the

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129 Professor Igor Bray, *Transcript of Evidence*, 2 March 2006, p 7.

130 Professor Igor Bray, *Exhibit no. 90*, *Thorium based fission*, p. 7.

131 World Nuclear Association (WNA), *Thorium*, Information and Issues Briefs, WNA, London, 2005, viewed 8 May 2006, <http://www.world-nuclear.org/info/inf62.htm>. WNA, *Thorium, loc. cit*.

132 Professor Igor Bray, *Transcript of Evidence*, *op. cit*., p. 3. See also: WNA, *Thorium, loc. cit*. Transuranic elements are very heavy elements formed artificially by neutron capture and possibly subsequent beta decay(s). These elements have a higher atomic number than uranium (92). All are radioactive. Neptunium, plutonium, americium and curium are the best-known.

133 *ibid*., p. 4.

fissionable isotope 235 of uranium): 'So you have about 40 times more energy per unit mass available.'[134]

12.124 It was noted, however, that there are problems associated with use of thorium, including 'a high cost of fuel fabrication, and there are technical problems in reprocessing.'[135]

12.125 The use of thorium based fuel cycles has been studied for some 30 years, but on a far smaller scale than uranium and plutonium. Research has been conducted in Germany, India, Japan, Russia, the UK and the US. While there are several reactor concepts based on thorium fuel cycles under consideration and use of thorium-based fuel is planned for two reactors currently under construction in India, the thorium fuel cycle is yet to be commercialised.[136]

12.126 Friends of the Earth–Australia (FOE) opposed use of Th-232 as a reactor fuel on the grounds that while use of the thorium might reduce proliferation risks, it would not eliminate these risks altogether. For example, FOE stated that the use of HEU or plutonium to initiate a Th-232/U-233 reaction is a proliferation concern and U-233 is a fissile material requiring safeguards protections.[137]

Nuclear skills, training and R&D activity

12.127 A key question which follows proposals to develop domestic value adding industries and possible use of nuclear power is the issue of whether Australia has sufficient skills and expertise to support greater involvement in the nuclear fuel cycle. As noted at the beginning of the chapter, this issue is currently being examined by the Prime Minister's Nuclear Energy Review.

12.128 The CSIRO expressed confidence that Australia does possess the necessary skills to support value adding:

> In short, if Australia wishes to extend its technological operations significantly along the uranium fuel value chain, there are the

134 *ibid.*

135 Professor Igor Bray, *Transcript of Evidence, loc. cit.*

136 *ibid.*, p. 3. See for example information on the Energy Amplifier concept, viewed 8 May 2006, <http://press.web.cern.ch/Public/Content/Chapters/AboutCERN/ResearchUseful/Future/Future-en.html>.

137 FOE et. al., *Exhibit no. 71, Nuclear Power: No Solution to Climate Change*, section 3.7.

> necessary research skills within CSIRO and ANSTO to support such developments.[138]

12.129 However, most submitters expressed the contrary view that, in general, Australia lacks the relevant skills and knowledge to support greater involvement in the nuclear fuel cycle. It was also argued that the scope of nuclear research activity undertaken in Australia is now distinctly limited.

12.130 Several submitters argued that most of Australia's expertise relating to nuclear reactors and the fuel cycle, which was developed over several decades by the AAEC, was lost as a result of changes in Government policy in the 1990s and the re-establishment of the Atomic Energy Commission as ANSTO.[139] For example, Mr John Reynolds observed that:

> … Australia does not have as strong a nuclear science and engineering establishment as it did in the early years of the Australian Atomic Energy Commission.[140]

12.131 Likewise, Professor Leslie Kemeny argued that, as the AAEC's successor agency, ANSTO has been:

> … ordered to abandon research and development in most aspects of nuclear power technology and the uranium fuel cycle. Its brief was redirected to the operation of the HIFAR research reactor, environmental research and the production of radioisotopes for hospitals and industry.[141]

12.132 The ANF also submitted that most of the technology and expertise developed by the AAEC throughout the 1960s and 1970s, in conversion, enrichment and fuel fabrication, was subsequently lost:

> … the experience that the AAEC once had in these areas—and we are thinking particularly of nuclear power—has really disappeared with the retirement of people like us. Certainly ANSTO is engaged in various areas of nuclear technology, but there are very few people there these days who understand much about reactors … they are just not allowed to do any further work on that at the present time.[142]

12.133 In terms of the expertise to operate an enrichment industry specifically, Mr Keith Alder argued that while Australia 'had all the know-how to do it

138 CSIRO, *Submission no. 37*, p. 8. See also: Dr Rod Hill (CSIRO), *Transcript of Evidence*, 19 August 2005, p. 2.

139 Mr Keith Alder, *Submission no. 7*, p. 2.

140 Mr John O Reynolds, *Submission no. 5*, p. 8.

141 Professor Leslie Kemeny, *Exhibit no. 9, Power to the people*, p. 1.

142 Dr Philip Moore (ANF), *Transcript of Evidence*, 16 September 2005, p. 47; ANF, *Submission no. 11*, p. 3.

20 years ago', the current situation is markedly different: 'We have lost our own expertise'.[143]

12.134 In terms of the scope of nuclear research undertaken in Australia, Dr Ron Cameron, ANSTO's Chief of Operations, confirmed that under the ANSTO Act the organisation is only permitted to conduct research into nuclear science and technology and it applications, rather than into nuclear energy itself. While the ANSTO Act permits the organisation to 'maintain an understanding of and expertise in the nuclear fuel cycle generally', the organisation has not had an active program in any area of nuclear energy research since it was formed in 1987.[144]

12.135 However, Mr James Brough, President of the ANF, also asked whether Australia has the skills to pursue uranium enrichment:

> Do we have the expertise? Australia ran a successful enrichment project which was cancelled in the early 1980s. The Silex enrichment project, or process, is being developed and it is looking good. So, given time, we could develop the domestic commercial system or we could work with an overseas producer to establish a plant here.[145]

12.136 Professor Ralph Parsons, a former President of AINSE, was also somewhat more optimistic about the potential for Australia's skills:

> Twenty five years ago there was expertise in this country in various stages of the nuclear fuel cycle, particularly in centrifuge enrichment and in the development of Synroc for waste disposal. That expertise has been dissipated but the nation now has sufficient depth of talent in Science, Engineering and Technology that the expertise could be redeveloped if there were the political will to do so.[146]

12.137 CSIRO noted that Australia maintains expertise in reactor operations and radiopharmaceutical manufacture at Lucas Heights, while CSIRO itself conducts research in the area of radionuclide removal from minerals sands and the treatment of rare earth deposits. However, other than CSIRO and ANSTO, it was noted there is now no nuclear science and engineering expertise in any of Australia's universities.

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143 Mr Keith Alder, *Transcript of Evidence*, 16 September 2005, p. 90. Mr Keith Alder, *Submission no. 7*, p. 1.

144 Dr Ron Cameron (ANSTO), *Transcript of Evidence*, 13 October 2005, p. 18. See also: Section 5(1)(a) of the *Australian Nuclear Science and Technology Organisation Act 1987*, viewed 20 April 2006, <http://www.austlii.edu.au/au/legis/cth/consol_act/ansatoa1987505/>.

145 Mr Jim Brough (ANF), *Transcript of Evidence*, 16 September 2005, p. 43.

146 Professor Ralph Parsons, *Submission no. 24*, p. 1.

12.138 It was also argued that if Australia were to value add prior to exporting uranium, technical capabilities would need to be enhanced and coordination of skills would need to be improved:

> Coordination of existing skills around Australia would be necessary to establish a critical mass in support of the industry. At the moment it is quite fragmented. Indeed, no university in Australia has a school of nuclear science and engineering. There would need to be a significant enhancement of those capabilities into the future if we did desire to increase our involvement in the value chain.[147]

12.139 CSIRO argued that key impediments to the establishment of an enrichment industry in Australia are 'the lack of an integrated nuclear science and technology group of researchers in this country' and the role of public perceptions of the acceptability of value adding.[148]

12.140 Professor Kemeny also pointed out that since the closure of the School of Nuclear Engineering at the University of NSW in 1988, Australia has not had a single tertiary level school of nuclear engineering. Nuclear research in Australia is now said to occur solely 'behind the razor wire' of Lucas Heights in Sydney, almost entirely removed from the community:

> … in 1988, the School of Nuclear Engineering at the University of NSW, the only one of its type in Australia was closed after a distinguished 24-year record of operation. In that time it had trained many of the senior staff of the AAEC, the Australian Safeguards Office and the Australian Radiation Protection and Nuclear-Safety Agency. Its Australian and overseas graduates and its staff have produced an impressive list of internationally refereed publications and occupy many important positions in the nuclear energy field around the world. At the same time the Australian School of Nuclear Technology at Lucas Heights, run jointly by the University of NSW and the AAEC, was closed.[149]

12.141 It was argued that Australia's history in nuclear research differs markedly from the situation in the US, where some 30 universities operate their own research reactors, many staffed by trained students.

12.142 Professor Kemeny also expressed the view that public discussion of nuclear-related issues in Australia, such as uranium mining in the Kakadu National Park, the management of radioactive waste, research reactor operations at Lucas Heights and the possible domestic use of nuclear

147 Dr Rod Hill (CSIRO), *Transcript of Evidence*, 19 August 2005, p. 2.

148 *ibid*.

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

power are 'still largely being debated at the level of talkback radio'. It was argued that 'decision-making in such areas deserves the disciplines of appropriate tertiary education.'[150] Moreover:

> The Australian community has a right to know the relative risks and the environmental impacts of various fuel cycles, as well as the technical limitations, true costs and energy audits of the alternative technologies. Yet Australia is without a single school of nuclear engineering at university level, a situation viewed with incredulity by the academic, diplomatic and political communities of the developing countries of East Asia and the Pacific.
>
> Many of these have a big investment in the growth of peaceful nuclear energy and nuclear science and technology within their borders. For Australia, which is about to displace Canada as the premier uranium exporter, to ignore the study of the uranium fuel cycle and its value-added technologies and industries indicates a pattern of intellectual and economic neglect possibly unparalleled in higher education policy and academic history. Canada has a fully fledged nuclear industry and many schools of nuclear science and engineering.[151]

12.143 Mr Damien Ewington, the Regional Manager Uranium for Areva, confirmed from his own experience that nuclear education is indeed deficient in Australia:

> At least for a generation now the education of young people in this country has, at best, been lacking. At worst, it has been quite negative towards the nuclear industry. I am a geologist by training. The only university education that I had with regard to uranium or the nuclear industry was, quite literally, exposure to what pitchblende or uraninite looks like in year 1 mineralogy class. That was it. Everything I have learned about the nuclear energy industry and uranium exploration in general has been learned on the job since I became a geologist …
>
> You also need to look at nuclear engineers and nuclear physicists and the level of training that goes on in tertiary institutions in Australia. You need to train people … and to educate them in the philosophies of the nuclear energy industry. We could take a step back through to primary and secondary education as well. This is the place where the government could be intimately involved …[152]

150 *ibid*.

151 *ibid*.

152 Mr Damien Ewington (Areva), *Transcript of Evidence*, 23 September 2005, p. 11.

12.144 Professor Kemeny also described the contents of a typical tertiary-level nuclear syllabus and what he contends are some of the potential benefits from improved nuclear education:

> Nuclear engineering … [is] at the leading edge of modern science and technology. Apart from important contributions to the field of energy supply and research, nuclear engineers have made fundamental contributions to society in medicine, agriculture, food technology, metallurgy, industrial control technology and non-destructive testing. They have also contributed to many basic research fields, including fluid flow, heat transfer, material science, neural network theory, radiation health and safety, and artificial intelligence …
>
> Features of the syllabus include every aspect of the uranium fuel cycle from mining to fuel enrichment and fabrication, use in reactors, and reprocessing and waste disposal … The basic principles of Earth's background radiation [and] health and safety issues—so misunderstood by Australian society—are taught in theory and demonstrated by experimental measurement.
>
> At postgraduate level, students learn to design advanced nuclear power plants for electricity generation, desalination, hydrogen production, nuclear marine propulsion, energy systems in space and other industrial application. They can also study radioisotope production for use in medicine, archaeology, agriculture, coastal engineering and non-destructive testing. The design and engineering of fusion systems is also an option.[153]

12.145 The SIA argued that if Australia was to value add or to develop a domestic nuclear power industry, it would need to rebuild its nuclear engineering skills base:

> Australia has lost the capacity it did have, with the nuclear engineering school having closed … There is no doubt that part of the process that would have to be undertaken if you were to contemplate a nuclear power generation industry would be to re-establish the engineering capacity that once was there but which has been, as a matter of policy, closed down.[154]

12.146 SIA noted that the closure of the School of Nuclear Engineering at UNSW has now prompted concerns about a shortage of nuclear engineers and scientists for the next generation:

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153 Professor Leslie Kemeny, *Exhibit no. 43, Pseudo-Science and Lost Opportunities*, pp. 3–4.

154 Rear Adm. Peter Briggs AO CSC (Retired) (SIA), *Transcript of Evidence*, 10 October 2005, p. 32.

> Whilst ANSTO provides a national capability to advise on matters nuclear today, one wonders where the next generation of engineers and scientists will come from?[155]

12.147 It was also argued that it is important for Australia to move beyond the research reactor stage 'to understanding the scale of the kind of engineering that is required in civil reactors in the nuclear power generation business.'[156]

12.148 Similarly, the CSIRO confirmed that the existing skills base in Australia could not be easily coordinated to ensure the optimal development of the uranium industry, and suggested that consideration should be given to

> … the training and development of the next generation of researchers since there is no longer a tertiary institution offering nuclear engineering within Australia and because there is a critical shortage of graduates entering the exploration and mining industry in general.[157]

12.149 However, Professor Igor Bray of Murdoch University argued that, at least in the area of nuclear physics, Australia does have a number of internationally renowned scientists.[158]

12.150 Proposals in evidence to assist in rebuilding Australia's nuclear skills base included:

- re-establishing at least one Australian university school of nuclear engineering;
- broadening ANSTO's R&D mandate, so that it is once again able to undertake physical laboratory studies of aspects of the fuel cycle and nuclear power that may be of benefit to Australia and Australian industry;
- encouraging greater university research into aspects of the nuclear industry and fuel cycle through the research grants awarded by AINSE; and
- actively developing a 'cadre of experts', in a way similar to the original establishment and staffing of the AAEC, including through the use of secondments to countries and companies with operations which Australia may be interested to pursue.[159]

155 SIA, *Submission no. 21*, p. 5. See also: Mr John O Reynolds, *Submission no. 5*, p. 8.
156 Mr John Thornton (SIA), *Transcript of Evidence*, 10 October 2005, p. 32
157 CSIRO, *Submission no. 37*, p. 12.
158 Professor Igor Bray, *Transcript of Evidence*, 2 March 2006, p. 11.
159 Mr Keith Alder, *Exhibit no. 2, op. cit.*, pp. 16–17.

12.151 Professor Kemeny emphasised the importance of improving tertiary education in nuclear engineering in Australia, and particularly noted its importance for Australia's future:

> In the new millennium there will be increasing use of nuclear science and technology in every field of human endeavour … The global community would be wise to make a significant educational investment in this area and encourage young people to grasp the many professional challenges of a nuclear future.[160]

12.152 Declaring his support for the re-establishment of at least one Australian university school of nuclear engineering, Professor Kemeny argued that:

> The pubic does not relate well to centralised monolithic research laboratories surrounded by barbed-wire. Both fission and fusion physics were born in universities and every effort should now be made to repay this initiative through strong facilities and well equipped laboratories in one or more of Australia's universities.[161]

12.153 As to how such a school might be funded, Professor Kemeny expressed the hope that 'those who benefit from uranium sales might help … start up schools of nuclear engineering'.[162] It was also stated that:

> … Australia's uranium miners should start showing interest in all areas of value-adding technology in the production of commercial grade nuclear fuel and the reprocessing and disposal of nuclear waste.[163]

12.154 Mr Keith Alder argued that one initiative should be an expansion of ANSTO's mandate to conduct laboratory research into aspects of the fuel cycle:

> I would certainly suggest that one of the [initiatives] should be a broadening of the program of ANSTO so that it is involved not only in paper study but also in physical laboratory research, even if it is a long way off, on the treatment of uranium and uranium fuels … I think if you are going to rebuild scientific confidence, you have to put back into the scientific program research and development on the things you want to know about. That is a good start.[164]

160 Professor Leslie Kemeny, *Exhibit no. 9, op. cit.*, p. 3.

161 Professor Leslie Kemeny, *Exhibit no. 43, loc. cit.*

162 Professor Leslie Kemeny, *Transcript of Evidence*, 16 September 2005, p. 95.

163 Professor Leslie Kemeny, *Exhibit no. 9, loc. cit.*

164 Mr Keith Alder, *Transcript of Evidence*, *op. cit.*, pp. 91–92.

12.155 Mr Alder also argued that AINSE, which consists of representatives of the universities and ANSTO, could also be used to encourage greater research into aspects of the fuel cycle:

> AINSE is a very good body for cooperation between the government research institutions and the universities … When research contracts, research sums and research grants are handed out by AINSE, perhaps they could be slanted more towards the nuclear industry and not just to neutron diffraction and the other things. Then, if you can get university staff interested in and working on matters associated with the nuclear fuel cycle and reactor theory and so on and teaching them, perhaps you are away.[165]

12.156 AINSE provides a focus for cooperation in the nuclear scientific and engineering fields. It has a specific mandate to arrange for the training of scientific research workers and the award of scientific research studentships in matters associated with nuclear science and engineering. AINSE explained that it provides competitive funding by which university researchers and research students gain access to the facilities and expertise at ANSTO. AINSE awards some 200 nuclear-related research grants each year under a National Competitive Research Grants Scheme, and supports over 100 PhD students who are working on projects requiring access to nuclear science facilities.[166]

12.157 AINSE itself submitted that it could play a role as a facilitator for university-based strategic research on the nuclear fuel cycle, particularly in the following areas: (i) underlying nuclear and materials science though national and international collaboration; (ii) the beneficiation of nuclear waste through accelerator-driven transmutation treatment; and (iii) nuclear fusion research, which is discussed further below.[167]

12.158 In terms of the nuclear skills base in Australia, Dr Ian Smith, Executive Director of ANSTO, stated that there is currently a worldwide shortage of people with skill sets for the nuclear industry. This situation was said to exacerbate the Australian problem, 'because we do not have an indigenous source of people coming out with training.'[168] ANSTO explained that it has responded to this situation by instituting its own

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165 *ibid*., p. 92.

166 AINSE, *op. cit*., p. 1. See also: AINSE, *About AINSE*, viewed 20 October 2006, <http://www.ainse.edu.au/ainse2.html>.

167 *ibid*.

168 Dr Ian Smith (ANSTO), *Transcript of Evidence*, 13 October 2005, p. 18.

training program and sending its graduate recruits to international destinations.[169]

12.159 Dr Smith observed that while ANSTO does currently interact with universities and the construction of the replacement reactor has refreshed skills and allowed some technology transfer, 'to maintain that I think it would be sensible to have a program with some universities and an overseas company or university to work with.'[170]

12.160 The Committee regrets that Australia has lost the expertise it once held in nuclear energy and the fuel cycle. The Committee notes with concern that, since 1988, Australia has not had a tertiary-level school of nuclear engineering. Consequently, Australia has no indigenous source of trained personnel in the nuclear field. It is also a concern that successive Australian Governments have prohibited ANSTO from conducting any nuclear energy and fuel cycle R&D.

12.161 In order to facilitate the possible eventual development of fuel cycle services industries in Australia and to allow for the possible eventual use of nuclear energy, as well as to provide appropriately qualified staff for Australian regulatory agencies, the Committee concludes that the Australian Government should seek to progressively rebuild Australia's nuclear skills base. The Committee is concerned that Australia is already experiencing a shortage of suitably qualified people with skill sets for the nuclear and associated industries. This is a matter that merits Government attention, regardless of whether Australia expands its involvement in the nuclear fuel cycle.

12.162 Among its other proposals, the Committee recommends that the Government examine re-establishing a University School of Nuclear Engineering and an Australian Research Council Research Network or Centre(s) of Excellence in the relevant fields. One of the benefits of this approach would be to take the study of the nuclear fuel cycle out from 'behind the fence' of Lucas Heights, thereby encouraging greater public understanding, awareness and acceptance of this important field of study and research.

12.163 The Committee supports broadening ANSTO's R&D mandate to undertake studies of the fuel cycle and nuclear energy. The Committee is enthused at the possibilities presented by the new Open Pool Australian Light-water (OPAL) reactor as a platform for attracting graduate students interested in the opportunities that R&D of this kind may present. The Committee also calls upon the private sector, notably the uranium

169 *ibid.*, p. 19.

170 *ibid.*

industry, to support such developments, for example by funding relevant university scholarships and working more closely with ANSTO.

12.164 The Committee further recommends that Australian nuclear scientists and engineers be assisted to study at overseas universities and with companies where relevant skills could be obtained. A program of secondments should also be developed with technical departments of the IAEA for suitably qualified Australian nuclear scientists and engineers.

Recommendation 13

The Committee recommends that the Australian Government take steps to rebuild Australia's nuclear skills base and expertise by:

- **broadening the Australian Nuclear Science and Technology Organisation's (ANSTO) research and development mandate, so that it is able to undertake physical laboratory studies of aspects of the nuclear fuel cycle and nuclear energy that may be of future benefit to Australia and Australian industry;**
- **developing a program whereby Australian nuclear scientists and engineers are assisted to study at overseas universities and/or to be placed with companies where relevant expertise resides, in order to expand Australia's knowledge base;**
- **increasing engagement by Australian nuclear scientists and engineers at a technical level with the International Atomic Energy Agency, for example through a program of secondments and placements;**
- **examining the possibility of re-establishing at least one Australian University School of Nuclear Engineering and an Australian Research Council Research Network or Centre(s) of Excellence in the relevant fields;**
- **encouraging industry to increase its collaborations with and support of ANSTO's proposed expanded research activities and any school of nuclear engineering that may be established; and**
- **encouraging greater university research into aspects of nuclear energy and the nuclear fuel cycle through the allocation of research grants awarded by the Australian Institute of Nuclear Science and Engineering.**

Fusion energy research

12.165 The Committee was informed of the potential merits of fusion power and the status of technological development for this energy source by representatives of the Australian International Thermonuclear Experimental Reactor (ITER) Forum (the Forum). The Forum comprises over one hundred Australian scientists and engineers engaged in aspects of fusion energy science, with the scientists drawn from five Australian universities and ANSTO. The goal of the Forum is controlled fusion as an energy source.[171]

12.166 Whereas power from nuclear reactors is generated by the process of fission, which is the splitting of a heavy atomic nucleus (uranium-235) with a consequent release of energy, fusion is the combination of two light nuclei to form more massive nuclei with the consequent release of energy. In essence, the fusion process is the opposite to fission.[172] Fusion occurs continuously in the universe. In the core of the sun, at temperatures of 10–15 million degrees celsius (°C), hydrogen is converted to helium, providing the energy that sustains life on earth.

12.167 The most straightforward fusion reaction to initiate is the combination of two isotopes of hydrogen (deuterium and tritium) to form helium and a neutron, releasing energy in the process. Along with fission, the energy output of fusion is 'millions of times greater than that of coal', as indicated in table 12.5.[173] In theory, a fusion reaction involving ten grams of deuterium (which can be extracted from 500 litres of water) and 15 grams of tritium (produced from 30 grams of lithium), would produce enough energy to supply the lifetime electricity needs of an average person in an industrialised country.[174]

12.168 In the sun, gravity is sufficiently strong to overcome the repulsive force between the similarly charged atoms. On earth, gravity is too weak and the material must be heated to over 100 million °C. In order to constrain the material at such high temperatures strong magnetic fields are used, with the most advanced being the 'tokamak', a doughnut-shaped vessel in which the plasma resides.

171 Dr Matthew Hole (Australian ITER Forum), *Transcript of Evidence*, 8 December 2005, p. 1.

172 *ibid.*, pp. 1–2.

173 *ibid.*, p. 2.

174 M Hole and J Howard, *Australia cannot afford to miss the fusion train*, Canberra Times, 29 June 2005, p. 17.

Table 12.5 Comparison of energy release per reaction

Fission ($U^{235} + n \rightarrow Xe^{134} + Sr^{100} + n$)	200 000 000 units*
Fusion ($D^2 + T^3 \rightarrow He^4 + n$)	17 600 000 units
Coal ($C_6H_2 + 6.5\ O_2 \rightarrow 6\ CO_2 + H_2O$)	30 units

Source Australian ITER Forum, *Exhibit no. 83, Presentation by Dr Matthew Hole*, p. 3.
* Units are electron volts per reaction

12.169 The possibility of producing energy for commercial use by fusion has been researched for several decades. A growing consortium of countries (with seven full partners to date including China, Korea, EU, Japan, Russia, India and the US) are cooperating to construct the next-generation fusion test reactor—the International Thermonuclear Experimental Reactor (ITER, which also means 'the way' in Latin)—under the auspices of the IAEA. In June 2005 it was announced that the reactor will be built at Cadarache in southern France, for an estimated A$10 billion. The ten-year operation costs will amount to an additional $6 billion.

12.170 The Forum noted that, aside from the international space station, ITER is world's largest science project and fusion R&D is ranked as the highest funding priority by the US Department of Energy.[175]

12.171 The ITER will be a 500 megawatt experimental reactor (equivalent in size to a medium-sized coal-fired plant) with three principal objectives: to demonstrate fusion energy for peaceful purposes ('ITER is a pre-prototype power plant and the last large-scale fusion energy experiment en route to power production'); to explore the 'burning plasma regime'; and to demonstrate the integration of technologies and address materials issues.[176] It is intended that following the ITER experiment, a demonstration reactor will be constructed in 2025, enabling the construction of the first commercial fusion power plant by around 2050.

12.172 It was claimed that if commercial fusion reactors become practicable, they will offer a number of important advantages, particularly in comparison to fission technology:

- fusion is inherently safe as there can be no chain reactions, explosions or meltdowns;
- fusion will be unable to produce fissile materials that can be used for weapons;

175 Dr Matthew Hole, *op. cit.*, p. 3.
176 *ibid.*

- there is a virtually unlimited supply of fuel:

> Even using the most extravagant world energy use predictions, there is sufficient D-T [deuterium-tritium] to power the earth for tens of thousands of years. This is beyond civilisation time scales. Using a next generation fusion reaction—a deuterium-deuterium reaction—there is sufficient fuel to power the earth for millions of years.[177]

- fusion produces only small amounts of radioactive waste and almost all is short lived:

> Even employing present-day ferritic technology in the vessel structure, a fusion power plant is 3,000 times less radioactive than its fission equivalent 100 years after shutdown. Indeed, within one human lifetime the entire fusion power plant could be completely recycled. Using future vanadium alloy structures, fusion is a staggering one million times less radioactive after 30 years than fission.[178]

12.173 In terms of the costs of generating electricity, the Forum argued that the internal costs of fusion, which includes construction, fuelling, operating the plant and decommissioning, are comparable to those of fission (and less costly than gas). As to the external costs, which include estimates of environmental damage and impacts on public and worker health, fusion is very attractive and was said to be comparable to wind.[179]

12.174 Other evidence also suggested that fusion has good prospects for making an economically attractive contribution to the future energy mix. Initially, the internal costs of fusion electricity would be some 50 per cent more expensive than electricity from fossil fuels and roughly comparable to renewables. The use of advanced materials will lead to an internal cost of fusion electricity approaching that of fission or fossils fuels. Fusion has small external costs and is about an order of magnitude lower than fossil fuel electricity.[180]

12.175 The Committee was informed that Australia has a history of fusion energy research and it was claimed that an Australian, Sir Mark Oliphant, actually discovered the fusion process in 1934. In 1946 a graduate of the University of Sydney, Dr Peter Thonemann, pioneered early fusion research in the UK and in 1958 Sir Mark Oliphant commenced plasma

177 *ibid.*, p. 2.
178 *ibid.*
179 *ibid.*, pp. 10–11.
180 Australian ITER Forum, *Exhibit no. 85, Prospects for economic fusion electricity*, p. 25.

physics research at the ANU. It was argued that Australian fusion research continues to make valuable contributions.[181]

12.176 The Australian ITER Forum argued that a range of potential benefits and opportunities would follow if Australia were to increase its engagement in ITER and fusion energy research. These include:

- an abundant supply of future base-load energy to replace fossil fuels;
- combined with the translation to electric transportation, fusion offers Australia and the world energy independence from oil and an end to the geopolitical instability brought by the regional concentrations of oil—that is, energy security;
- near-term economic and political benefits, with some 80 per cent of the A$10 billion construction cost of ITER returned to industry through contracts;
- science and technology benefits, which will also impact on other forms of energy production and industries, such as aerospace;
- training and retention of skills;
- responding to climate change;
- fostering international research links;
- scientific credibility; and
- enhance Australia's position in the IAEA.[182]

12.177 In summary, it was argued that fusion energy 'offers the world a near zero greenhouse gas emission base-load power supply, capable of sustaining civilisation for millions, if not billions of years.'[183] It was argued that a low CO_2 emission strategy requires investment in a range of nuclear and renewable technologies, and that fusion offers clear benefits:

> Fusion provides not only an endless source of energy for our civilisation but an endless range of opportunities for Australian science and industry, if we embrace its opportunities early enough to remain competitive. The ITER project offers a path forward to access these opportunities. The window of opportunity to maximise Australia's competitive advantage is, however, closing as I speak. For this reason alone, involvement in the ITER project needs to be urgently addressed by the Commonwealth.[184]

181 Australian ITER Forum, *Exhibit no. 83, Presentation by Dr Matthew Hole,* p. 12.
182 *ibid.*, p. 13.
183 Dr Matthew Hole, *op. cit.*, p. 1.
184 *ibid.*, p. 5.

12.178 The Forum argued that, perhaps most importantly, Australia possesses many of the advanced materials which will be in demand for the construction of fusion reactors, such as vanadium, tantalum, titanium, zirconium and niobium. Australia's share of these resources is listed in table 12.6. Australia also has some four per cent of the world's lithium, which is used to produce tritium for fusion reactions. One mine in Western Australia currently produces 60 per cent of the world's lithium minerals in concentrate form.[185] The Forum argued that this represents an opportunity for Australia to value add by processing and manufacturing the elements required, rather than sell them in their raw state.

Table 12.6 Australia's share of fusion related materials

Aspect of fusion process / reactor	Mineral	Australian EDR[3] in kilotonnes (% of world)	Australian total[1] in kilotonnes
Fuel	Lithium	170 (4.1%)	257
Structural	Vanadium	2 586 (19.9%)	5 061
	Tantalum	53 (94.6%)	154.2
	Titanium[2]	80.7 (21.5%)	158.7
	Zirconium[2]	14.9 (40.5%)	40.9
Superconductor	Niobium	194 (4.3%)	2 147

Source Australian ITER Forum, *Exhibit no. 83*, *Presentation by Dr Matthew Hole*, p. 17.
[1] Demonstrated plus inferred resources
[2] Inferred from mineral sand deposits
[3] Economic Demonstrated Resources

12.179 Professor Kemeny also expressed support for further fusion energy research, noting that fusion 'offers the prospect of an almost inexhaustible supply of energy for future generations'.[186]

12.180 AINSE submitted that it has maintained an interest in fusion research and that greater participation in this experimentation will have a number of benefits, including the opportunity for Australia to develop and share in intellectual property which will, in the future, be of considerable value. It was also argued that ITER presents an opportunity for Australian industry to participate in materials research and eventually the production of the specialised materials required for the containment of the plasma. Australian expertise could also be involved in the design and development of software needed to control the fusion reaction.[187]

185 This is the Greenbushes mine, owned by Sons of Gwalia Ltd, *Greenbushes Mine Fact Sheet*, viewed 4 May 2006, <http://www.sog.com.au/pages/amd_greenbushes.asp>. Dr Matthew Hole (Australian ITER Forum), *Transcript of Evidence*, 8 December 2005, p. 8.

186 Professor Leslie Kemeny, *Exhibit no. 42, Emerging Nuclear Energy Systems – A One Hundred Year Perspective*, p.6.

187 AINSE, *op. cit.*, p. 2.

12.181 In other evidence, Professor Igor Bray commented that Australian scientists will be consultants to ITER and provide data for aspects of the project.[188]

12.182 The Australian ITER Forum argued that in order to preserve and grow Australia's fusion research program it was necessary that fusion science become a national research priority. It was also recommended that:

- Australia should negotiate a subscription to ITER as a matter of urgency, as the 'window of opportunity is quickly closing'; and
- a national or international research centre be established to consolidate Australia's efforts in fusion related research.[189]

12.183 While the cost of being a full partner in the ITER project is 10 per cent of the total, the Australian ITER Forum stressed that engagement is possible with subscriptions of a significantly lower fraction than this, perhaps even less than one per cent. Countries can also make contributions in kind by offering materials. However, the Forum stated that this would require engagement by the Australian Government with the ITER negotiators:

> We certainly could, but that would require negotiation between government and the ITER negotiators. It is something we would like to bring to the attention of government, but we feel that that level of interaction really needs to come clearly from government.[190]

12.184 It was argued that if Australia were to subscribe to ITER, 'that money would flow back to Australia. So the demand would be there for the lithium or titanium or whatever they want and that money would come back'.[191]

12.185 A complexity in achieving Government engagement was argued to be the diverse nature of fusion research. Fusion research does not fall under any one portfolio, with elements of the research come under some four government portfolios.

12.186 In relation to a domestic research centre, the Forum argued that 'Australian graduates are highly sought after by the world's large fusion laboratories' and therefore a domestic fusion research centre was essential to 'to preserve and grow existing competence.'[192]

188 Professor Igor Bray, *Transcript of Evidence*, *op. cit.*, pp. 2, 6.

189 Dr Matthew Hole, *op. cit.*, pp. 3, 5.

190 *ibid.*, p. 8.

191 Professor John O'Connor (Australian ITER Forum), *Transcript of Evidence*, 8 December 2005, p. 8.

192 Dr Matthew Hole, *op. cit.*, p. 4.

12.187 Subsequent to their attendance at a public hearing, the Australian ITER Forum advised the Committee that in December 2005 the Australian Government agreed to fund the visit to Australia of ITER partners to discuss the project with Australian Government officials.

12.188 FOE argued that fusion poses a number of weapons proliferation risks, including: the production or supply of tritium, which can be diverted for use in boosted nuclear weapons; and plasma physics research can be used as a cover for development of nuclear weapons technologies.[193]

12.189 The Committee is persuaded of the immense potential benefit that fusion energy represents for the world and, specifically, the potential benefits for Australian science and industry from involvement in the ITER project. The Committee believes that involvement in this experimentation is simply too important for the nation to miss, even if the introduction of fusion power is indeed many decades off. Accordingly, the Committee recommends that Australia secure formal involvement in the ITER project and seek to better coordinate its research for fusion energy across the various fields and disciplines in Australia.

Recommendation 14

The Committee recommends that the Australian Government:

- **negotiate an appropriate subscription for Australia to the International Thermonuclear Experimental Reactor project on a whole-of-Government basis;**
- **support the establishment of a national research centre to consolidate and coordinate Australia's efforts in fusion related research; and**
- **examine the merits of establishing fusion science as a national research priority.**

Conclusions

12.190 The Committee agrees that for Australia to possess such a large proportion of the world's uranium resources—approximately 40 per cent of the global total—and *not* to have taken up opportunities over the past 35 years to develop uranium enhancement industries is highly regrettable. In addition to the foregone export earnings and the missed opportunities

193 FOE et. al, *loc. cit.*

to develop sophisticated technologies and an associated domestic knowledge base, the failure to press ahead with the development of fuel cycle services industries in Australia has wasted a significant public R&D investment. This had amounted to some $100 million by the time of the termination of the AAEC's enrichment research in the mid 1980s. The nation has also lost a generation of nuclear research and engineering expertise.

12.191 In addition to domestic economic and technological benefits, increased involvement by Australia in the fuel cycle could have non-proliferation and security advantages. Indeed, as argued by some submitters, fuel cycle facilities could well be established in Australia on a multination basis, in accordance with the IAEA's expert advisory group recommendations outlined in chapter seven, thereby providing a high level of transparency for regional neighbours and the international community generally. Such a development would have clear global non-proliferation benefits, while also allowing Australia the opportunity to extract greater returns from its immense uranium resource endowment, to develop sophisticated technologies and to expand its national skills base.

12.192 The Committee urges that state governments re-evaluate the merits of the eventual establishment of such industries within their jurisdictions, particularly in the uranium rich jurisdictions of South Australia, the Northern Territory and Western Australia. Furthermore, the Committee wishes to encourage Australian companies, such as those that participated in the UEGA enrichment industry proposals of the early 1980s, to actively consider the opportunities such developments might present in the future.

12.193 Although the Committee is naturally pleased that Silex has succeeded in partnering with GE to develop its laser enrichment technology in the important nuclear fuel market of North America, again the Committee regrets that this technology could not be commercialised in Australia. The Committee notes the significant returns that could be earned from the establishment of an Australian enrichment industry using SILEX technology.

12.194 The Committee concludes that, by virtue of its highly suitable geology and political stability, Australia could also play an important role at the back-end of the fuel cycle in waste storage and disposal. Again, such a development could be highly profitable, as well as possibly providing global security benefits. However, as noted in chapter five, the US GNEP initiative proposes to revolutionise spent fuel management (through the use of advanced burner reactors in the 'fuel supplier' nations), generating waste requiring short isolation periods. This could obviate the need for geologic repositories altogether. However, even if Australia were to receive back the waste generated from use of Australian-sourced uranium alone, this could still generate annual revenues in the billions of dollars, as well as developing highly sophisticated technologies. The Committee also notes that the IAEA has suggested the eventual establishment of back-end facilities on a multinational basis. Given the prospect that some nations currently using nuclear power will not be able to establish domestic repositories (e.g. due to unsuitable geology), this is a service that Australia could be uniquely positioned to provide for the world.

12.195 The Committee has no in-principle objection to the use of nuclear power in Australia and believes that, subject to appropriate regulatory oversight, utilities that choose to construct nuclear power plants in Australia should be permitted to do so. There would be clear greenhouse gas emission and other technological and potential economic benefits from doing so.

12.196 Nuclear power may not be immediately competitive in the Australian context, due to the quantity and quality of Australia's coal resources (and that carbon emissions are currently not priced). However, the Committee believes that if Federal and state governments continue to provide a range of incentives to achieve low carbon emissions, for example by subsidising renewables such as wind, then governments should not discriminate against nuclear power—which will also achieve very low emissions and generate base load power, unlike the currently subsidised renewable alternatives.

12.197 Even if the domestic use of nuclear energy and uranium enhancement industries in Australia are not established in the near future, the Committee recommends that the Australian and state governments commence examining best practice licensing and regulatory frameworks that could be put in place to facilitate the eventual establishment of such facilities.

12.198 Should the nation ever wish to develop uranium enhancement industries or to use nuclear energy, it seems likely that the relevant skills base would need to be rebuilt (a possible exception being nuclear waste treatment, given ANSTO's Synroc technology and expertise).

12.199 The Committee notes that Australia no longer has a domestic source for the training of nuclear scientists and engineers. Relevant training is undertaken 'in house' by ANSTO and its personnel are sent to overseas destinations. While the Committee is pleased that this occurs, it believes that the Australian Government should now take steps to rebuild Australia's nuclear expertise and skills base. Initiatives the Committee recommends include examining the re-establishment of a university school of nuclear engineering. The Committee calls upon the uranium industry to support such developments, for example by funding relevant university scholarships. The Committee also proposes that ANSTO's research mandate once again be broadened to undertake actual R&D into aspects of the fuel cycle and the use of nuclear energy.

Supplementary remarks

12.200 The three Labor members of the Committee offer qualified support for the recommendations and conclusions of Chapter 12 as follows:

- The Labor members of the Committee note that whilst there is conflicting evidence about the demand for new enrichment facilities, the lack of governance for enrichment facilities under the NPT and IAEA safeguards regime should preclude the development of new enrichment facilities anywhere in the world. Under the current regime, there is nothing illegal about any country having enrichment technology. Yet the acquisition of highly-enriched uranium or separated plutonium is one of the most technically difficult but important steps towards making a nuclear weapon. If a country with a full nuclear fuel cycle decided to break away from its non-proliferation commitments, a nuclear weapon capability could be within reach in a short time. This is the dilemma now confronted in Iran. As the UN struggles to hold it to account under the NPT and the IAEA safeguards regime, it has never been clearer that the NPT should be reviewed to address the ambiguity about the alleged right of nations to acquire proliferation-sensitive technologies, such as enrichment facilities. The Committee urged that the NPT be reviewed to address this question in chapter seven. The Labor members support such a review and Dr Mohamed ElBaradei's (Director General of the IAEA) May 2005 proposal for a five-year moratorium on the establishment of new enrichment and reprocessing facilities to allow such a review to be completed. The Labor members further note that Australia lacks the skills-base necessary to support a domestic enrichment industry. The Labor members are therefore opposed to an enrichment industry in Australia.
- The Labor members of the Committee note that, whilst there is considerable evidence that Australia's geology is highly suitable for the disposal of nuclear waste and that, theoretically, Australia has the technological and skills capacity to develop a nuclear waste industry, the reality is that Australia has not yet been able to leverage this capacity to manage its own low and intermediate level waste. The Labor members are of the view that this is related to a history of

dishonest political campaigns and a failure of national leadership on this issue. Without first developing and proving Australia's capacity to manage domestic low and intermediate level waste, Labor members believe it would be imprudent to consider any further development of a nuclear waste industry in Australia. The Labor members also note that Australia's technology and skills capacity is being exported to manage nuclear waste in other countries, providing a value-adding opportunity to Australian entities. Further, Labor members note that, according to the Australian Strategic Policy Institute in its August report on uranium exports and security, provided nuclear waste facilities are subject to the IAEA safeguards regime wherever they are located in the world, there is no security imperative to import nuclear waste to Australia for management. The Labor members are therefore opposed to the importation of nuclear waste to Australia.

- The Labor members of the Committee note that the overwhelming evidence is that, now and for the foreseeable future, nuclear power in Australia is not economic and Australia lacks the skills-base necessary to support a domestic nuclear power industry. The Labor members are of the view that Australia has two current options for securing reliable, competitive baseload power in the long term—clean coal and nuclear. The Labor members believe that Australia's low electricity prices as a result of coal-fired power generation are a key source of competitive advantage for the nation's industries and Australia's priority should therefore be to clean up coal-fired power generation, increase the uptake of gas and renewable technologies for peaking and niche markets, and support the research and development of renewable technologies for future baseload. The Labor members are therefore opposed to a nuclear power industry in Australia.

The Hon Geoff Prosser MP

Chairman

November 2006