Transforming our economy.
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Sustaining our future.

Submission to the
South Australian
Nuclear Fuel Cycle Royal Commission

SENATOR SEAN EDWARDS
LIBERAL SENATOR FOR SOUTH AUSTRALIA

ABSTRACT

A large and growing market exists in Asia to provide management services for used nuclear fuel. South Australia is ideally placed to take a prominent global position in servicing that market. This submission proposes an ambitious model of services predicated on providing custody of used fuel, rather than disposal, paired with the committed commercialization of the infrastructure required to undertake complete recycling of the material while generating zero-carbon electricity. This submission finds that such an integrated project delivers net-present value exceeding $28 billion to South Australia. This provides scope for far-reaching economic benefits, including the provision of free wholesale power to the state, the reduction or elimination of some state-based taxation, direct and indirect creation of many thousands of jobs, and sustained funding for leading renewable energy initiatives.

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Foreword

This document is my submission to the South Australian Nuclear Fuel Cycle Royal Commission. It details an ambitious, visionary and achievable proposal to leverage advanced nuclear technologies in the service of transforming the South Australian economy while providing plentiful supplies of clean energy.

The opportunities available to South Australia from this exciting new direction cannot be overstated. South Australia can transform its fortunes while solving some of the world's biggest challenges: recycling nuclear fuel and providing reliable clean energy on a large scale. As the analysis undertaken for this submission demonstrates, an integrated proposal for storing and recycling used nuclear fuel is estimated to deliver $28.1 billion in value to the South Australian economy in today's money.

That is the modest projection from modelling undertaken. It could in fact be much higher under different scenarios. Significantly, $28 billion is close to South Australia's current state debt. Under a number of the modelling scenarios canvassed here it is clear South Australia would be positioned to end its status as a "mendicant" state within the Federation.

Perhaps most amazingly of all is that the real benefits are not even to be found in that $28.1 billion figure.

I believe South Australians will embrace an ambitious proposal if benefits are both clear and equitably shared. So I asked a question: could the project give the power away to South Australians? The analysis suggests this this plausible. The project outlined in this submission could be scaled-up to a level that provides 25% more electricity every year than South Australia currently uses, displacing 5 million tons of carbon dioxide in the process and give the power away. With electricity given to the market at zero dollars per megawatt hour wholesale, the project still makes $17 billion in today's money.

My submission details a plausible and profoundly transformative industrial outcome for South Australia. With wholesale prices making up around a third of typical household electricity bills, every South Australian household would directly benefit from this project for the next one hundred years. This will help our elderly run their heaters and air conditioners whenever they need to and help every family make ends meet with less worry about the quarterly bill.

A long list of stalled projects in mining, industry and commerce will be greenlighted thanks to the massive boost in the competitiveness of South Australia. Companies will be able to operate here with the assurance of a reliable supply of low-cost energy that is free of greenhouse gas emissions. This would reinvigorate our capital city, towns and regions and bring life and growth to our communities.

The power will be available nearly every hour and every day of every year and that opens up opportunities. Our desalination plant could be operated not only for managing crisis drought conditions but also for the benefits of enhanced water supply. South Australia could boost agricultural output. Instead of talking about a food revolution, South Australia could have one. We could meet the burgeoning demand for quality produce in Asian markets, feeding people in need as they transition into modern, industrialised nations.

The project developments themselves would be a magnet for the world. In commercialising the most advanced recycling and reactor technology, South Australia would become firmly established as a centre of excellence in advanced nuclear technologies. Our scientific, industrial and tertiary sectors would operate in a thriving environment of research and learning. Our students of all ages could aspire to and prepare for exciting careers in science and technology right here in South Australia.

Nothing in this submission is new or unproven technology but some of it is yet to commercialise. Some parties view that as risk. I see the flipside of opportunity. Our clean slate in nuclear energy development is a prize asset if we wish to target the advanced nuclear market. We can fund the creation of a robust licensing process tailored for advanced, passively safe recycling reactors. South Australia can aim to be first to license such technology and issue a contract to build.

From there South Australia would forge a path of accelerated development in advanced manufacturing of a new generation of energy technologies. Instead of buying finished product from overseas as with wind turbines and solar panels, highly skilled South Australians in secure jobs would be making passively safe reactors in factory environments. Those reactors, built, demonstrated and operating in South Australia, would then be exported to the world to perform the vital environmental job of displacing coal.

The economic outcomes of this proposal are lucrative enough to stimulate many economic multipliers across the local and national economies. Notably, South Australia could reduce burdensome levels of taxation. Given the projected revenue streams we could entertain a host of major infrastructure projects to underpin the attractiveness of our state for new industrial production and associated service sector opportunities. Better, cleaner transportation, world's best health care, local Universities rising up the ranks and forging the nation's best primary and secondary school systems might be within reach. Reversing the decades' long net migration from South Australia becomes a likely prospect. Successive state governments would have the capacity to support vibrant communities, address poverty and familial dysfunction and support the preservation of nature. Our parks and wild places could receive greater protection, restoration, enhancement and scientific research for the benefit of us, our children and their children. This is to mention but a few of the prospects that open up as choices South Australians can make together, creating the best place to raise a family, bar none.

Such options are closed to South Australia today. They could open in the space of a generation, and start as soon as consensus for action is achieved. When investigating these opportunities I aimed to assess the need for near-term positive impacts in the South Australia economy. With the prospect of local political bipartisanship, it became clear from our modelling that significant employment would be created within three years and large revenues would begin flowing within six years. South Australia would be on a pathway of transformation: from an economic laggard to the powerhouse of the south. No longer an economy of the boutique and the niche, South Australia would be a global centre for excellence in one of the most important industries of the 21st century: reliable, scalable clean energy. With fortunes transformed, South Australia's beautiful environment, wonderful food and unmatched lifestyle would finally rest securely on a foundation of global economic relevance.

There is no taxpayer subsidy behind this proposal, nor calls for government subsidy or protection. This project is based on the truest form of economic development: meeting a demand with products and services your customers want. Realising this outcome needs the people of South Australia to call for the right to determine our own future, on the basis of evidence and free from interference.

Such economic and industrial transformation is a lot to claim. That's why this proposal is so detailed.

While the Nuclear Fuel Cycle Royal Commission was announced in February this year, the research behind this submission commenced over 18 months ago. It represents longstanding consultation and interaction with Australian experts, academics and business people. This commenced out of a conviction that South Australia needed to seek large, innovative opportunities for development to transform our state into a place our children will want to stay in to forge careers and raise families. Extensive discussions were held to seek understanding of where and how South Australia could profit from further engagement in the nuclear fuel cycle in a way that brought near-term and transformative economic change, and also in a way that was likely to earn broad public support.

A profoundly challenging and exciting framework emerged based on recycling used nuclear fuel. That prompted our investigation in consultation with independent Australian and international stakeholders. The critical point to convey is that these stakeholders verified the opportunities as fundamentally sound, and my engagement with potential customers verified the scale of the economic benefits outlined in the submission.

The advent of the Nuclear Fuel Cycle Royal Commission was an unexpected development for which I commend the state government. It provides the ideal forum to present a comprehensively researched technical and business case for consideration. To achieve this, services of researchers were retained to prepare this submission in close consultation with my office.

We need a robust conversation and that comes from transparency. Every effort has been made to bring the best information to the table in this submission, albeit within the budgetary constraints of my office. Every figure we have used is disclosed and sourced. Every source is fully referenced. Where original work was required, it was professionally delivered. When faced with a range for a cost, the analysis chose high end figures, and when faced with a range for a benefit, the analysis tested a credible range. We recruited external reviewers to test the proposition against their knowledge and experience. If a solid argument is made to change an assumption, it can be changed and the outcome can be tested. I openly invite and encourage discussion and debate over the proposal.

When those conversations have concluded, when the outcomes have been tested and when the transformative opportunity for South Australia remains before us, then the real question must be asked: do we have the courage to go for it?

That is a question South Australians must answer together. I commend this document to both the Nuclear Fuel Cycle Royal Commission and the people of South Australia for consideration. I commit to continuing to use the powers of my office to secure the benefits this proposal will deliver the state of South Australia and the nation.

I invite you to join me.

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September 2015

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Executive Summary

Overview

This submission to the South Australian Nuclear Fuel Cycle Royal Commission details an ambitious, visionary and achievable proposal to leverage advanced nuclear technologies in the service of transforming the South Australian economy while providing plentiful supplies of clean energy.

Globally, there is an under-serviced market for the management of used nuclear fuel. Several nations are holding quarantined budgets in the tens of billions of dollars with no satisfactory pathway to discharge responsibility for this material.

Plans and facilities for geological disposal for such material are at various stages of advancement, worldwide. However no such facility is licensed and operational, and no such facility is intended to service a multinational market. Geological repositories are costly with long lead times to construct and large challenges in social acceptance.

This submission argues that technological advances are rendering the model of geological disposal unnecessary, in light of the proven capabilities to recycle this material for plentiful further energy, and dispose of long-lived material in the process. This submission instead proposes South Australia embraces an innovative model of service provision based on the novel combination of the following established approaches and revolutionary fuel recycling technologies on the cusp of commercialisation:

1. A multinational Independent Spent Fuel Storage Installation (ISFSI)
2. An industrial-pilot scale fuel recycling and fabrication facility based on pyroprocessing
3. Inherently safe fast-breeder nuclear reactors
4. Deep borehole disposal of short-lived waste products

Modelling indicates that, in a mid-range scenario, the above, integrated project would deliver a net-present value of $28 billion to South Australia.

Independent Spent Fuel Storage Installation

An independent spent fuel storage installation (ISFSI) refers to a stand-alone facility for the storage of used nuclear fuel in dry casks. They have been established in many nations to provide storage of used nuclear fuel for a period of decades. These facilities are demonstrably safe, based on a large body of evidence and knowledge. Above-ground, interim management is a technically mature and certain process.

ISFSIs ranging in capacity from 40,000 tonnes of heavy metal (tHM) to 100,000 tHM represent a plausible range of sizes. The establishment of an ISFSI in South Australia to serve the Asian market would rapidly follow emerging domestic policy in the United States.

Fuel recycling and fabrication facility

The ISFSI, while profitable in isolation, does not ensure long-term job creation, establishment of new industry and provision of low-cost clean energy. This project therefore includes a pathway of committed investment in the necessary infrastructure to fully recycle this material for clean energy.

All constituent elements of used nuclear fuel, other than about 3-5% constituting fission products, can be recycled as fuel for a fast-neutron reactor, with the generation of zero-carbon electricity occurring as a consequence. This firstly requires electrolytic reduction and electrorefining to cleanse the fuel of fission products and then segregate the main metals for the fabrication of new fuel rods. A recently completed project at Argonne National Laboratories (USA) has provided detailed design and costing of a facility for the processing and refabricating of nuclear fuel at a rate of 100 t year^{-1}; a pilot-industrial scale.

Consistent with the proposal to establish a multi-national ISFSI, South Australia would be ideally placed to demonstrate this recycling process at industrial-throughput scale. This enables the separation of useable fuel material for clean energy generation.

A commitment to the early development of such a facility forms part of this integrated proposal for South Australia. As well as recycling used fuel, this facility is also a fuel fabrication plant. South Australia could be among the first locations in the world to establish fabrication processes for the closed recycling fuel cycle.

Integral Fast Reactors / PRISM

This proposal recommends South Australia embraces the commercialisation of the Generation IV integral fast reactor (IFR) technology from the outset. This offers crucial potential benefits:

- » The IFR is able to consume all fissile plutonium and all the higher actinides while transmuting all U-238 into fissile material.
- » The IFR runs on used nuclear fuel and breeds its own new fissile material within the reactor containment, thus being a 'breeder reactor'.
- » A conversion ratio of fissile to fertile material of greater than one (i.e. breeding as much or more fuel than is consumed) means a fast reactor is a sustainable large-scale energy source, in principle for tens of thousands of years.

The IFR is now ready for commercialisation as the Power Reactive Innovative Small Module (PRISM) from GE-Hitachi. As a small reactor (311 megawatts electric (MWe) unit) there will be minimal technical limitation to the connection of this generator.

PRISM is an inherently safe design thanks to characteristics of both the fuel and coolant. These characteristics mean the reactor operates at atmospheric pressure and is "walkaway safe". These inherent safety features are not merely theoretical, but have been demonstrated in simulated major accident conditions, where the reactor behaved as expected, passively shut itself down and reached stable equilibrium conditions for the removal of heat.

This submission asserts that a commitment to a leading role in the commercialisation process of the PRISM, tied to and funded by the establishment of used fuel storage, is precisely the level of calculated ambition South Australia must embrace to rejuvenate our economy and establish new, highly skilled industry for the 21st century.

This proposal delivers an outstanding outcome in terms of waste reduction for electricity generation, particularly when viewed through the lens of substitution for existing fossil fuel generation in the National Electricity Market.

The basic principles of the PRISM reactor and associated recycling facility mean that the normal operation of this system extends the energy value of existing used nuclear fuel by a factor of approximately 20 or more, by deriving energy from the 95-97% of material that is either fissile or fertile. In the process the system decreases the radioactive longevity of the material by over two orders of magnitude. No upstream mining is required. Basic operations therefore lead to a net reduction of existing inventories of unused material and displacement of extractive mining.

The waste fission products are radioactive but with only a medium-term collective half-life of 30 years and are small in quantity (approximately 1 kg MWyear^{-1}). This means that within approximately 300 years, the radioactivity has returned to the levels of natural uranium ore. This fission product material would likely be immobilised in zeolite or vitrified (turned into glass) for final disposal. In the event of 622 MWe PRISM generation operating in South Australia, approximately 622 kg of fission product waste would be produced, annually, for the production of nearly 5 million megawatt hours (MWh) of electricity.

The electricity generated from 622 MWe of PRISM generation would displace approximately 5 million tonnes of carbon dioxide equivalent (tCO$_2$-e year^{-1}) from the National Electricity Market based on grid-average emissions intensity.

Deep borehole disposal

The fission product material will eventually require safe disposal. An ideal option may be deep-borehole disposal. Such disposal can be developed incrementally to match the rate of waste production. Investigations to date indicate borehole disposal will deliver reliably good outcomes. Prima facie, it is highly likely that the deep borehole approach would be successful in South Australian conditions for disposal of this small, short-lived, incrementally produced waste-stream.

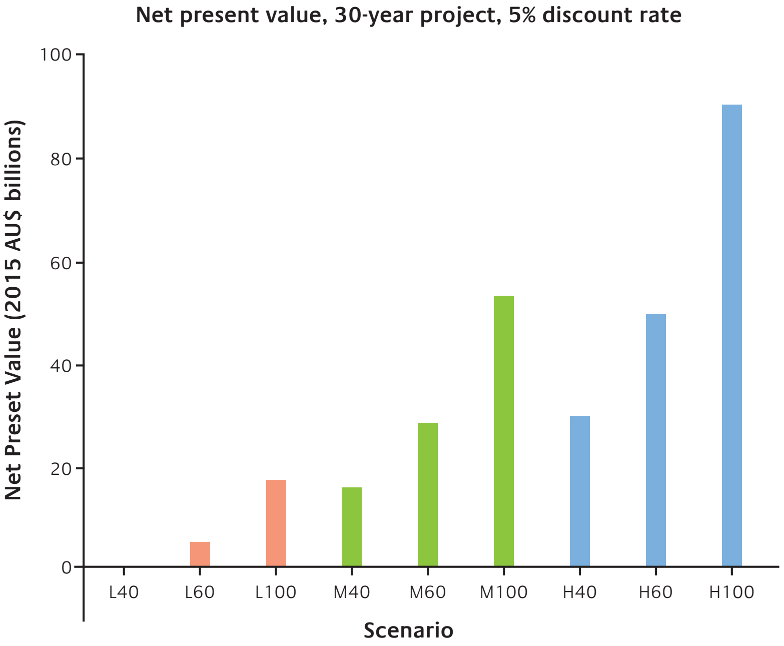
Business Case

This submission has assessed the business case for the proposal using a net-present value assessment, applying a project life of 30 years consistent with South Australian government treasury guidelines. All figures have been inflated and converted (where necessary) to 2015 $AU. A real discount rate of 5% has been applied, representing medium market risk. Under these conditions and based on the timelines provided above, net present value of the proposal for three illustrative scenarios is shown in the table below. Net present value for all nine modelled scenarios is shown in the figure below. All figures are 2015 Australian dollars.

Net present value and benefit:cost for all illustrative scenarios, 5% discounting

	NPV 5%	Benefit:cost 5%
Low	-0.3	0.9
Mid	28.1	2.5
High	90.3	5.7

Net present value calculations, all scenarios

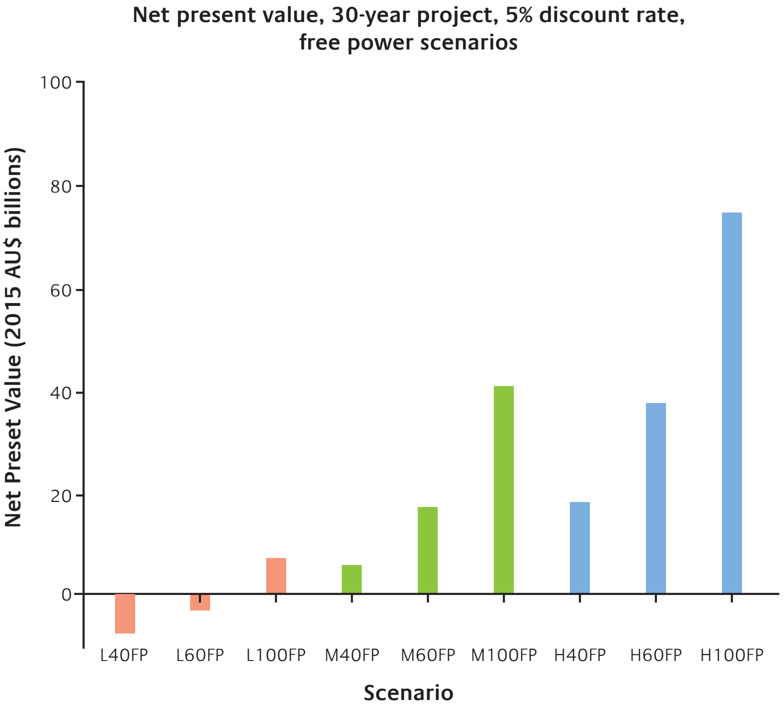


The business case finds multi-billion dollar NPV in all scenarios excluding the illustrative low scenario, where net loss of $0.3 billion is incurred. The illustrative mid-range scenario delivers NPV of $28.1 billion and a benefit:cost of 2.5 at 5% discounting.

This proposal postulates the possible provision of all PRISM-generated electricity, less self-use, to South Australians at the notional wholesale price of $0 MWh^{-1}. This analysis modelled the staged development of six PRISM reactors, deployed in pairs, totalling 1,866 MWe, financed through this integrated project.

Our findings suggest that the "free power" outcome is plausible. Offering the electricity at no charge to South Australian citizens, businesses and industries sends a clear message in recognition that the state of South Australia has come together to capitalise on this opportunity, and should be rewarded.

Net present value, free power scenarios



Job creation

The implementation of this proposal would create direct and indirect employment in South Australia. Direct employment in the construction and operation of the proposed facilities will number in the thousands. However the greatest employment impacts likely to occur in response to the availability of low-cost clean energy and the reinvestment of revenues into new industries.

The employment impacts of this proposal could be transformative. It is founded on accessing existing, well-established international budgets, cumulatively worth over $100 billion and growing, providing a world's-best service to meet this market, and reinvesting proceeds in ongoing development for South Australia.

Transport considerations

The development of this integrated project would demand the transportation of used nuclear fuel into South Australia. These processes and practices are mature, with a large body of data.

Since 1971 approximately 300 sea voyages have been made carrying used nuclear fuel or separated high-level waste over a distance of more than 8 million kilometres. This transportation has occurred with no property damage or personal injury and no breach of containment. The Australian Nuclear Science and Technology Organisation makes a similar finding, stating "there has never been an in-transit accident that has caused serious human health, economic or environmental consequences attributable to the radioactive nature of the goods". Transportation of used nuclear fuel is, therefore, a mature, well-established process.

Location considerations

The facilities discussed in this submission are suitable for deployment broadly across South Australia. South Australia offers the (putative) advantage of availability of remote locations with world-leading geological stability. While valuable, nothing about the facilities proposed in this submission demands the use of remote locations. An early, reflexive focus on remote locations may lead to unhelpful and counterproductive discourse.

The evidence from international practice demonstrates that nuclear facilities co-exist with dozens of communities in close proximity, and within a few hundred kilometres of major world cities including Helsinki, Madrid, Shanghai and New York. It is demonstrably not the case that extreme remote locations are a requirement.

This proposal recommends a consent-based process illustrated by established and emerging practice around the world. There are many encouraging examples that should be understood and applied to progressing development of nuclear facilities in South Australia.

Conclusion

The South Australian Nuclear Fuel Cycle Royal Commission provides an opportunity for evidence-based examination of the opportunities for South Australia in the nuclear fuel cycle. This comprehensively researched submission asserts that a transformative opportunity is to be found in pairing established, mature practices with cusp-of-commercialisation technologies to provide an innovative model of service to the global community. The commitment to commercialisation of full recycling of nuclear fuel holds the potential to access significant revenues from customer nations, while justifiably earning the support of the South Australian community through the creation and sharing of benefits including:

» The potential for wholesale electricity priced at $0 MWh^{-1}

» Direct job creation in the thousands

» Establishing genuine new industry in advanced manufacturing

» Locking in a clean, reliable electricity supply

» Demonstrating the commercialisation of recycling and clean energy technologies and processes that will be of major global significance in this century

» Profits that can be reinvested for further economic development

South Australia brings to the table a suite of advantages. A clean slate in nuclear energy means there is much work to do, but provides the opportunity to create the world's most innovative research and commercialisation environment for advanced nuclear technologies. Our well-known stability in governance, finance and physical environment, along with our outstanding global reputation, remain logical signposts for undertaking such innovation in this part of the world. Our location and trading relationships with Asia, including trade in mined uranium, provide access to the greatest levels of demand for service in used fuel management. Our highly regarded institutions including our science organisation (ANSTO), regulator (ARPANSA) and safeguards office (ASNO) provide a firm foundation for expansion.

Perhaps most importantly though, South Australia has demonstrated a willingness to explore these opportunities. The importance of this cannot be overstated.

Benefits of the scale outlined in this submission are not available via well-trodden paths. The business model is novel. Commercialisation is required. Partnerships will be needed. Innovation and courage will be demanded. However it represents approximately $28 billion in value for South Australia that can be seized. With sufficient governmental and institutional backing, the benefits of this proposal could be realised in South Australia. Economically, socially and environmentally, our state would be transformed for the better.

Contents

Preamble

This submission to the South Australian Nuclear Fuel Cycle Royal Commission proposes an innovative, integrated project for the storage and recycling of used nuclear fuel. The proposal is of global significance in scale and ambition.

This submission outlines a proposal to develop and integrate three facilities of leading-edge nuclear technologies plus an innovative waste disposal method, to form an ambitious, multi-national nuclear project.

The economic outcomes of this proposal are premised on heavily front-loading revenue generation for South Australia via the provision of fuel custody services and promptly reinvesting in a committed program of developing advanced nuclear recycling and power generating infrastructure.

Key definitions

There is commonly conflation of the terms "spent nuclear fuel", "used nuclear fuel", "nuclear waste" and "radioactive waste". Definitional clarity is of utmost significance to this submission.

The relevant Australian Code of Practice[1] defines radioactive waste as follows:

> *"Means waste materials which contain radioactive substances for* ***which no further use is envisaged****"* (emphasis added)

This Australian definition is similar to the relevant international Joint Convention[2] which states:

> *"radioactive waste" means radioactive material in gaseous, liquid or solid form* ***for which no further use is foreseen*** *by the Contracting Party or by a natural or legal person whose decision is accepted by the Contracting Party, and which is controlled as radioactive waste by a regulatory body under the legislative and regulatory framework of the Contracting Party;"* (emphasis added)

Note both definitions expressly state that material is waste only when no further use is envisaged or foreseen. The Joint Convention separately defines "spent fuel" as:

> *"nuclear fuel that has been irradiated in and permanently removed from a reactor core"*

Australia's Environmental Protection and Biodiversity Conservation Act (1999) (Sect. 22) provides similar definitions:

> *"radioactive waste" means radioactive material for which no further use is foreseen.*
>
> *"spent nuclear fuel" means nuclear fuel that has been irradiated in a nuclear reactor core and permanently removed from the core.*[3]

This submission is premised on maintaining the definitional clarity between waste and spent nuclear fuel. This submission proposes novel approaches for managing and recycling spent nuclear fuel (more accurately, "used nuclear fuel"). Under this proposal, further use is foreseen for the material.

This submission is not, therefore, proposing the simple establishment of waste management or disposal services or the importation of radioactive wastes in any sense. To the contrary this proposal is predicated on actively and profitably centralising and then recycling inventories of what others might consider nuclear waste. This submission will henceforth refer to "used nuclear fuel", and will refer to "waste" only for material for which no further use is foreseen.

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[1] National Health and Medical Research Council (1993)

[2] International Atomic Energy Agency (1997)

[3] Australian Government ComLaw (1999)

1| Introduction: Addressing a Need

Currently there are about 270,000 tonnes of heavy metal (tHM) of used nuclear fuel in storage worldwide[4]. Approximately 12,000 tHM of used nuclear fuel are produced each year[5]. This will increase in line with future growth in nuclear energy worldwide. In 2040 there will likely be 705,000 tHM in storage globally[6].

No country has indefinite plans to keep used fuel at above ground reactor sites. Nor does any country have a licenced, operating facility for deep geological disposal of used fuel from the civilian nuclear sector[7]. Construction for the Finnish disposal facility is advanced and in Sweden construction has commenced. The deep disposal facility in the USA is advanced but is now politically stalled[8]. While progress varies globally, management of used fuel remains one of the major challenges facing the nuclear industry.

Concepts for multinational disposal or management of used nuclear fuel have been the subject of discussion for decades, including proposals relating to Australia[9]. No national government has yet come forward with a proposal for a multi-national spent fuel repository that has solid political and social support[10]. The IAEA states that a disposal service for used fuel would “certainly be an attractive proposition”[11] for smaller nuclear nations and new market entrants. Fourteen of the thirty current nuclear nations have fewer than five nuclear reactors.

There are growing quarantined used fuel management budgets with no outlet. Japan has accumulated $35 billion for the construction and operation of a nuclear repository[12]. The unspent nuclear waste fund of the United States is approximately $25 billion, and was receiving revenues of $750 million per year[13]. South Korea faces impending shortages of licensed storage space for used nuclear fuel[14] and expresses an urgent need for more storage[15].

Taiwan appears to be similarly motivated by the compelling need to discharge responsibility for its accumulated used nuclear fuel for which it has no acceptable long-term provisions in place[16]. On February 17 2015, Taiwan Power Co. sought public bids worth US$356 million for offshore spent nuclear fuel reprocessing services. On the basis of this tender, the willingness to pay for an inclusive used nuclear fuel reprocessing service is nearly US$1,500 $kgHM^{-1}$ and the potential market in just existing material from Taiwan alone is approximately $US5 billion. This approximately accords with Taiwan’s existing Nuclear Back-End fund of $US7.6 billion[17].

This submission quantifies the potential market for this service via original modelling of current and future used fuel inventories for key potential partner nations in Asia.

Used fuel inventories were modelled for the Republic of Korea, Taiwan, Japan and China[18] to provide representative regional estimates. The modelling scenarios were based on a range of potential policy settings for each country. For more detail on the fuel inventory modelling please refer to Appendix 1.

This analysis finds that in base case settings of existing policy, the used fuel inventories for these four nations, in 2040, will be as follows:

» Republic of South Korea: 48,000 tHM

» Taiwan: 9,000 tHM

» Japan: 38,000 tHM

» China: 100,000 tHM

In each of these cases, there is scope for larger inventories on the basis of farther-reaching policies relating to nuclear deployment. The modelling excluded India, a nation experiencing rapid growth in the nuclear sector. Modelling also excluded potential future nuclear nations in Asia including Malaysia, Indonesia, Thailand and Vietnam.

In summary, the demand for service in the management of used nuclear fuel is real. It is growing, the rate of growth in increasing, the growth is increasing most strongly in Asia and the most urgent need for service lies in Asia.

South Australia is ideally placed geographically, politically, institutionally and reputationally to capitalise on this pent-up regional demand for service. Tapping this market can drive revitalisation of the South Australian economy. However this submission proposes an innovative model of service for this demand.

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[4] World Nuclear Association (2015c)

[5] World Nuclear Association (2015c)

[6] Cronshaw (2014)

[7] Feiveson et al. (2011)

[8] World Nuclear Association (2015c)

[9] World Nuclear Association (2015b)

[10] Feiveson et al. (2011)

[11] International Atomic Energy Agency (2013)

[12] World Nuclear Association (2014)

[13] Feiveson et al. (2011)

[14] (Cho (2014); Dalnoki-Veress et al. 2013)

[15] Kook (2013)

[16] Rosner and Goldberg (2013)

[17] Platts (2015)

[18] Work by Dr San Hong, University of Adelaide

2| Rethinking the Solution

Existing nuclear nations have been forming and revising policy and practices relating to used fuel management for over 50 years, reflecting evolving knowledge, evidence and understanding as well as prevailing political and geopolitical considerations. This has resulted in heterogeneity of policies and plans around the world[19].

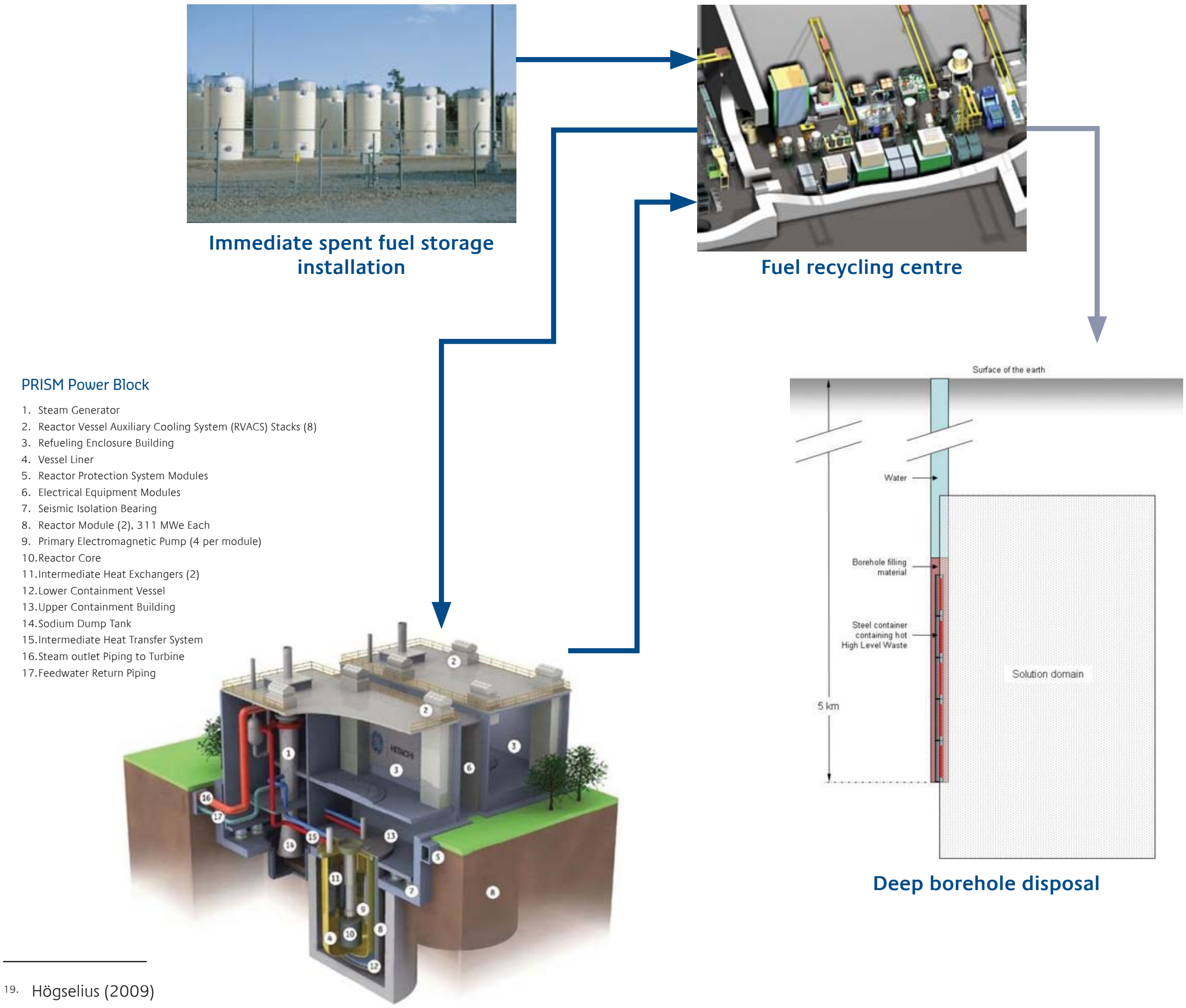
This submission argues that none of the current approaches to used fuel management are optimal economically, environmentally, socially or in relation to concerns about proliferation. This submission proposes a new, evidence-based approach: establishing an above ground, dry cask storage facility to be synergistically developed with modern, full fuel recycling fast nuclear reactors and low-cost, high-certainty disposal techniques for eventual waste streams.

In this synergy lies a pathway to large, near-term investment, jobs and profits for South Australia and medium-term development of globally-leading new industry.

This is achieved through deploying, in combination, the following facilities and approaches:

1. Independent spent fuel storage installation
2. Fuel recycling and refabricating facility
3. Fast breeder reactor integrated with the fuel recycling facility
4. Deep borehole disposal of short-lived waste

Figure 1: Integrated technologies for a new approach to used fuel management



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[19] Högselius (2009)

2.1| Independent Spent Fuel Storage Installation

Profitably and rapidly meeting the demand for service in used-fuel management requires South Australia to consciously reject established notions of underground geologic disposal. South Australia must instead create an equivalent service in permanent custody. This can be rapidly implemented. From the point of view of the customer, the result is the same: responsibility for the material will be discharged to South Australia.

An independent spent fuel storage installation (ISFSI) refers to a stand-alone facility for the storage of used nuclear fuel in dry casks. They have been established in many nations to provide storage of used nuclear fuel for a period of decades,[20] typically as a necessary response in the absence of accessible long-term used fuel repositories[21]. Evidence of the performance and safety of these facilities has been accumulating for more than 25 years in the US alone[22]. The US Nuclear Regulatory Commission (NRC) recently ruled used nuclear fuel may be safely stored for up to 60 years in dry cask storage post the closure of the reactor[23]. Assuming expected reactor life of 40 years, used nuclear fuel may be legally stored in an ISFSI for around 100 years.

Storage times in such locations may be increased or decreased based on “policy considerations”[24]. South Australia might therefore institute policy, at the outset, that recognises the capability of such facilities for the purposes of storage for up to a century or more. A recently announced facility in New Mexico for interim storage of used fuel in the United States would hold 75,000 tHM on just 13 hectares[25]. A facility is also proposed in Texas for interim storage of used fuel for up to 100 years[26]. The establishment of a similar facility in South Australia to serve the Asian market would rapidly follow emerging practice in the United States.

Above-ground, interim management of used nuclear fuel is a technically mature and certain process. Cumulative international experience provides a “vast technical record, as well as an appropriate understanding of the operational practices that are beneficial for spent fuel storage”[27]. The multi-faceted advantages of such an approach have been well documented[28] along with operational and maintenance requirements[29], the physical resilience of the containment[30] and the end-of-life considerations[31].

Regarding the safety and reliability of dry cask storage the NRC[32] states:

> *Since the first casks were loaded in 1986, dry storage has released no radiation that affected the public or contaminated the environment. There have been no known or suspected attempts to sabotage cask storage facilities. Tests on spent fuel and cask components after years in dry storage confirm that the systems are providing safe and secure storage. NRC also analyzed the risks from loading and storing spent fuel in dry casks. That study found the potential health risks are very small.*

These facilities are demonstrably safe, based on a large body of evidence and knowledge. No aspect of this storage proposal represents new technologies or approaches. The development of a centralised, multi-national facility to be based in South Australia represents an ambitious project with important governmental, regulatory and social considerations. This submission subsequently demonstrates that such ambition is worthwhile.

On the basis of the representative modelling described in the previous section, the full subscription and loading of a 40,000 tHM facility in the 20 years to 2040 represents a conservative, low-end investment in this market. A 60,000 tHM facility presents a credible mid-range scenario. A 100,000 tHM presents an entirely plausible upper-end scenario.

However this submission unequivocally is not focussed on the simple establishment of used-fuel storage with an indefinite, open ended management strategy. While profitable in isolation, this does not meet important goals of transformative economic change, long-term job creation, establishment of new industry and provision of low-cost clean energy. Such open-ended proposals could fail the vital test of social licence.

This submission recommends pairing the ISFSI with the up-front commitment to, and most rapid possible establishment of, infrastructure for the full recycling and re-use of this used fuel for the provision of reliable, clean electricity.

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[20] Casey Durst (2012)

[21] Casey Durst (2012)

[22] Werner (2012)

[23] Werner (2012)

[24] Kazimi, Moniz and Fosberg (2011)

[25] Nuclear Energy Institute (2015)

[26] Grant (2015)

[27] International Atomic Energy Agency (2007)

[28] (Bunn et al. (2001); Hamal, Carey and Ring (2011); Rosner and Goldberg (2013))

[29] International Atomic Energy Agency (2007)

[30] Lee et al. (2014)

[31] Howard and van den Akker (2014)

[32] United States Nuclear Regulatory Commission Office of Public Affairs (2014)

Figure 2 Basic site plan for ISFSI[33]

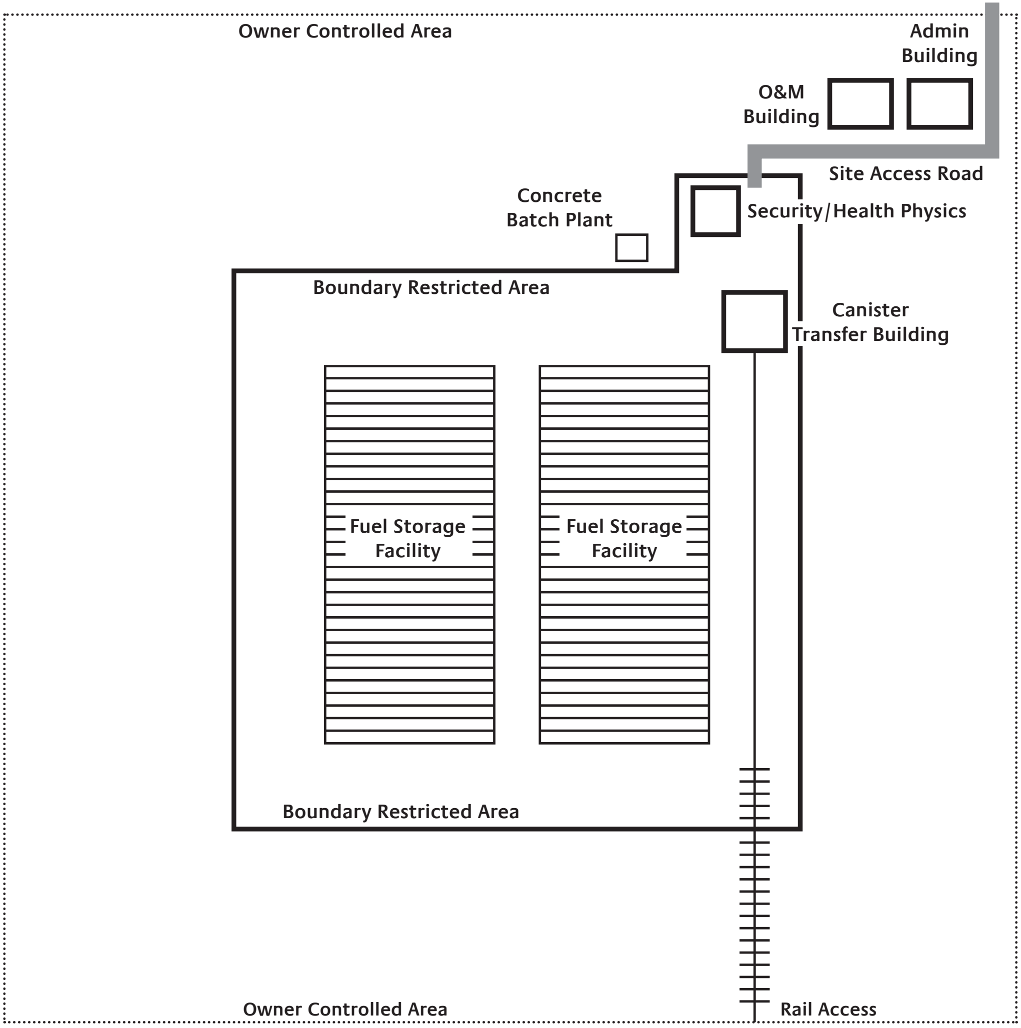
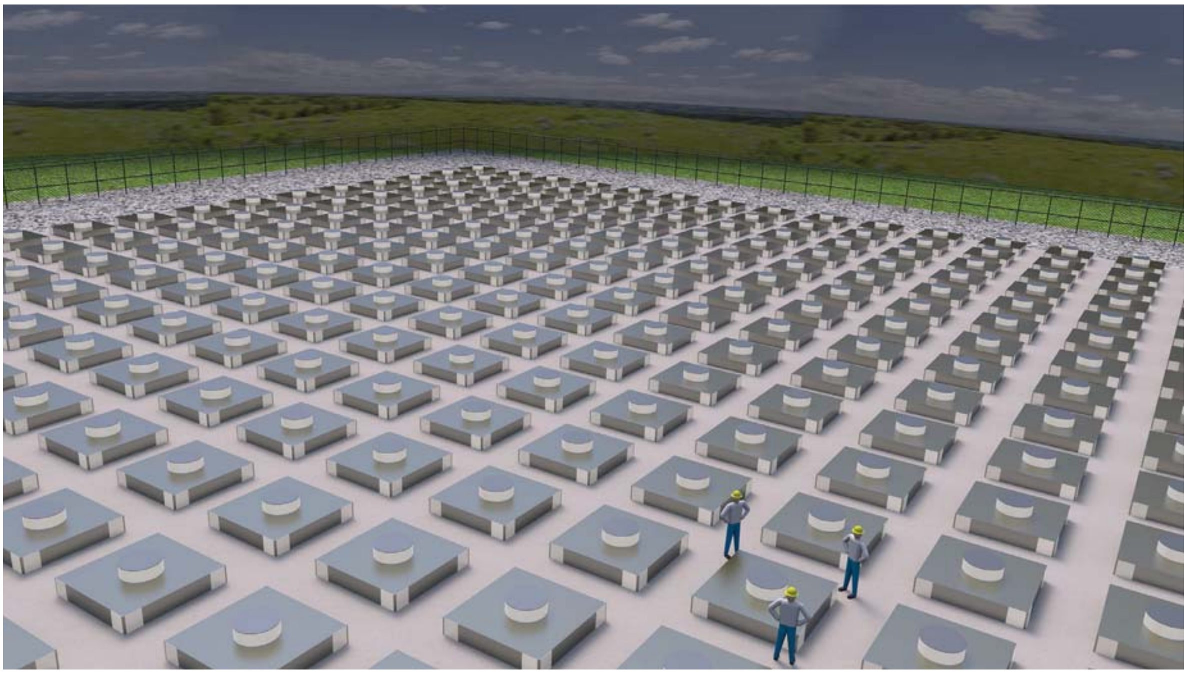


Figure 3 Conceptual representation of an ISFSI[34]



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[33] Electric Power Research Institute (EPRI) (2009)

[34] Holtec http://www.holtecinternational.com/2015/04/holtec-partners-with-elea-llc-in-new-mexico-to-build-consolidated-interim-storage-facility/

2.2| Fuel Recycling

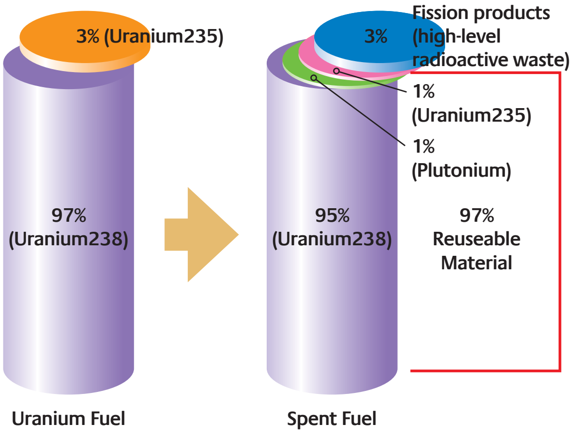
This submission posits that best practice management of used nuclear fuel will, in future, be based upon:

- Recognition of the residual energy value of the material, being around 20 times the energy that was accessed by light-water reactor technology. Thus, used fuel from the world's nuclear fleet is a remarkable, already refined, primary energy resource of extraordinary residual generation potential. Such a resource could deliver enormous benefit to South Australia.
- Extraction and fissioning of all long-lived actinides, to decrease the radioactive half-life of remaining stored material.
- Planned conversion of stockpiled fertile material into fissile fuel, providing a near-inexhaustible supply of electricity and heat.

All constituent elements of used nuclear fuel, other than about 3-5% constituting fission products, can be recycled as fuel for a fast-neutron reactor, with the generation of zero-carbon electricity occurring as a consequence. This firstly requires electrolytic reduction for converting oxide fuel to metal and removing most of the fission product gases, followed by electrorefining to further cleanse the fuel of fission products and then segregating the main metals for the fabrication of new fuel rods[35]. The viability of this electro-reduction process chemistry, known as pyroprocessing, was established many years ago at the level of high-capacity testing[36]. As part of the treatment of used fuel from the Experimental Breeder Reactor II, which ceased operations in 1994, research and investigations into pyroprocessing has continued to the present day at Idaho National Laboratories[37]. This ongoing research process has permitted refinement of the process towards commercialisation.

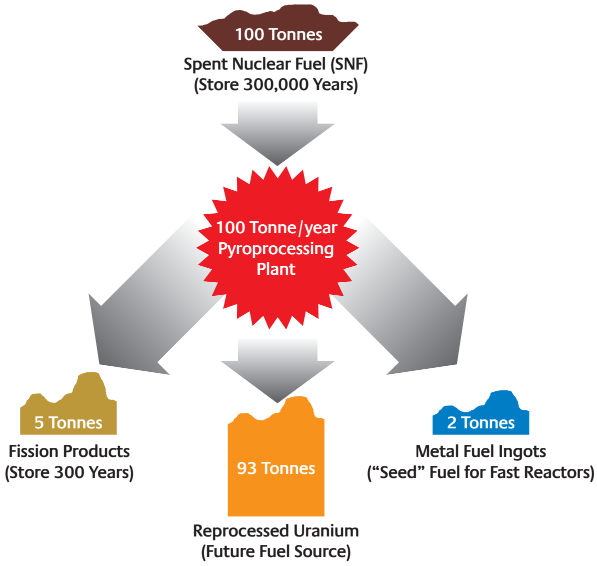
Consistent with the proposal to establish a multi-national ISFSI, South Australia would be ideally-placed to develop this recycling process at industrial-throughput scale. This would speed the recycling of the stored material and more quickly enable the separation of useable fuel material for clean energy generation.

Figure 4: Change in composition from unused to used nuclear fuel



A recently completed project at Argonne National Laboratories (USA) provides detailed design and costing of a facility for the processing and refabricating of nuclear fuel at a rate of 100 t year^{-1} [38]. An advance copy of the public report has been provided by the lead researcher[39] for use in this submission. Committing to the early development of such a facility forms part of our integrated proposal for South Australia. The recycling process is summarised in Figure 5 and illustrated in a flowchart in Figure 6.

Figure 5 Summary of pyroprocessing outcomes



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[35] Argonne National Laboratories/ Merrick and Company (2015)

[36] Argonne National Laboratories/ US Department of Energy (Undated)

[37] Simpson (2012)

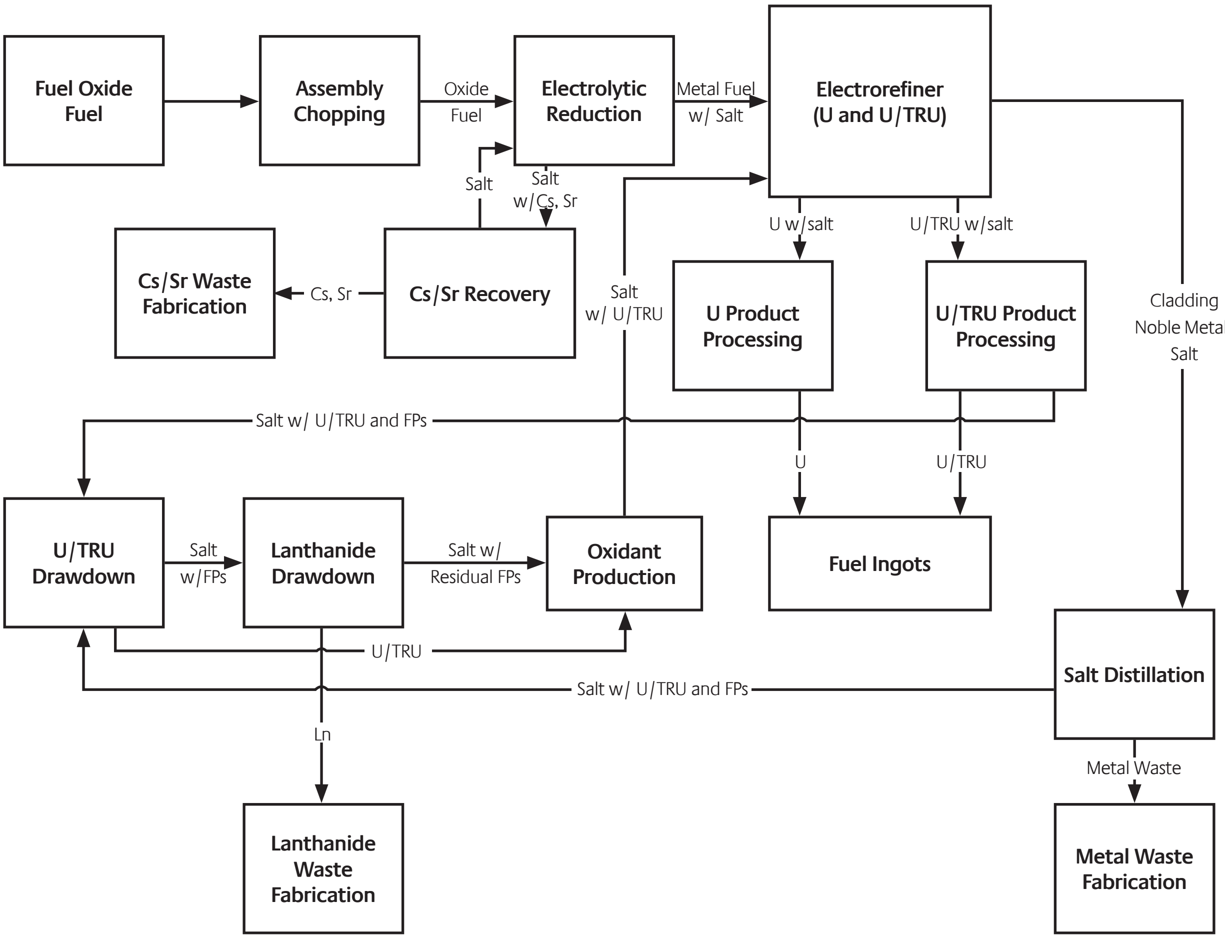
[38] Argonne National Laboratories/ Merrick and Company (2015)

[39] Dr Yoon Il Chang

An opportunity therefore exists for South Australia to become one of the first locations for deployment of a commercial-scale oxide-to-metal fuel conversion and re-fabrication facility, demonstrating the closed recycling fuel cycle.

A conversion and fabrication facility of 100 t year^{-1} would be well in excess of South Australian-only fuel requirements, or indeed all Australia's advanced nuclear fuel requirements. South Australia would fabricate and accumulate a new standard of nuclear fuel that requires no mining, conversion or enrichment of raw uranium, suitable for the emerging range of Generation IV fast neutron reactors. This could be sold in future both nationally and internationally. Based on current prices for fabricated light water reactor fuel[40], the facility may produce $300 million worth of export product per year. As the market is currently nascent for fuel of this type this future benefit has been excluded from our economic analysis, but should be taken into account in subsequent, more searching economic studies.

Figure 6: Conceptual flowsheet for the treatment of used light water reactor fuel[41]



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[40] World Nuclear Association (2015a)

[41] Argonne National Laboratories/ Merrick and Company (2015)

Figure 7 Partial interior layouts for 100 t $year^{-1}$ fuel recycling facility[42]

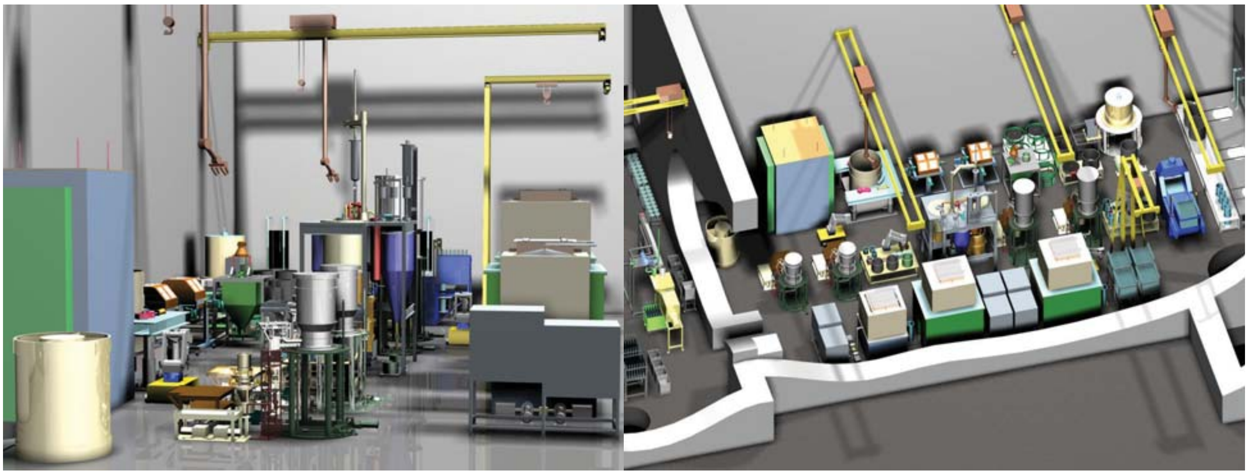
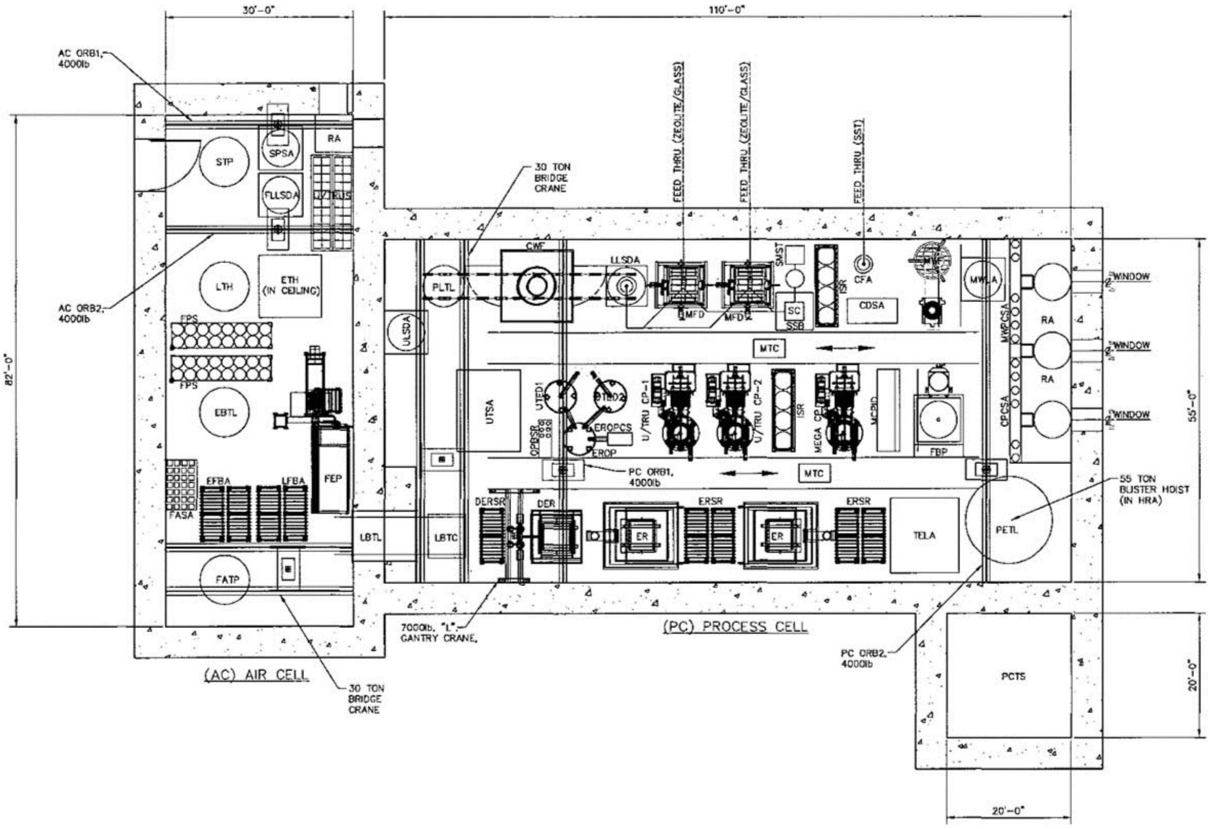


Figure 8 Facility layout for 100 t $year^{-1}$ fuel recycling facility[43]



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[42] Till and Chang (2011)

[43] Till and Chang (2011)

2.2.1 | Non-proliferation

Safeguarding is and will remain an essential part of any nuclear industry. Australia already has the advantage of highly respected nuclear regulatory bodies in the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA)[44] and the Australian Safeguards and Non-Proliferation Office (ASNO)[45]. These bodies have overseen Australia's successful engagement with nuclear technologies and resources, including our mining and export of uranium, and the operation of two nuclear reactors including the recently commissioned, world-class OPAL reactor at Lucas Heights, outside of Sydney. Thus, Australia possesses an underlying regulatory infrastructure that can expand, with the necessary government support, along with any further involvement in the nuclear fuel cycle. This can serve to retain the justified confidence of the Australian and international community.

Nonetheless, safeguarding nuclear actions is rendered far more effective by technologies with intrinsic technical barriers to nefarious use.

The fuel recycling technologies discussed in this submission were purpose-designed to avoid the production of pure, separated plutonium. Materials directly usable for weapons cannot be produced. The plutonium product is "inherently co-mingled with minor actinides, uranium and fission products"[46] due to the separation being electrolytic and not chemical. Pyroprocessing is, thus far, more proliferation resistant than existing plutonium-uranium extraction processes (known as PUREX, which has been used since the 1940s). Recycling processes will take place via remote handling in hot cells, presenting physical barriers that increase the ease of monitoring and the difficulty of access and diversion[47].

Pairing this recycling technology, integrated on the same site, with a fast reactor (see following section) is an effective, direct means to net-consume and eliminate existing plutonium. The reactor operations can be tailored to increase the net rate of plutonium disposal[48]. This is, of course, a profound non-proliferation advantage. The non-proliferation advantages and safeguard considerations of this technology are discussed at length in relevant literature[49].

Deployment of this technology would, by necessity, raise Australia's level of involvement and engagement with safeguard and non-proliferation processes. This increased involvement would deliver a strong net-benefit, globally, to the desired outcomes of safe and peaceful uses of nuclear technology and non-proliferation, and the progressive safe disposal of existing inventories of used nuclear fuel. As noted above, appropriately supported expansion of Australia's existing, highly regarded regulatory institutions will enable the appropriate regime to be put in place by the Australian Government to provide absolute confidence on this matter. The Australian public will expect and demand no less.

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[44] http://www.arpansa.gov.au/

[45] http://dfat.gov.au/international-relations/security/asno/Pages/australian-safeguards-and-non-proliferation-office-asno.aspx

[46] Hannum et al. (1996)

[47] Till and Chang (2011)

[48] (Hannum et al. 1996; Triplett, Loewen & Dooies 2010)

[49] (Argonne National Laboratories/ Merrick and Company 2015; Hannum & Wade 1997; Hannum et al. 1996; Till & Chang 2011; Wade & Hill 1997)

2.3| Integral Fast Reactors (IFR)

Many Generation III (and so called III+) passively safe reactor designs, several already proven in international markets, would be technologically acceptable for NEM connection in the appropriate grid location. This would possibly be within South Australia but, due to the larger size of these reactors (600-1,000 MWe), this is more likely suitable in the more populous eastern states with much higher load concentrations. Such technologies should not be ruled out of a role in South Australia's generating mix, or that of Australia more broadly.

In order to capitalise on the commercial potential offered by the IFSFI, and to demonstrate a pathway for beneficial use and permanent disposal of used fuel, this proposal recommends South Australia embraces the commercialisation of the Generation IV integral fast reactor (IFR) technology from the outset.

Generation IV fast neutron reactors are at the cusp of commercialisation. This pathway thus entails first of a kind (FOAK) technological and commercial risk[50], however it is not a pathway of fundamental research and development uncertainty. This submission argues that this juncture represents an optimal opportunity for ambitious investment by South Australia in leading new technology. The perceived FOAK risk can be minimised by the partnering or joint venturing between government, commercially and technologically strong Australian interests and international organisations. This includes the technology vendor that has directly expressed interest in public-private partnerships.[51]

The IFR is now ready for commercialisation as the Power Reactive Innovative Small Module (PRISM) from GE-Hitachi[52]. Many reactor designs with advanced fuel cycles have been proposed and are under development at various stages of completion. This submission focusses on the integral fast reactor/PRISM because:

1. All aspects of the technology have been comprehensively proven in laboratory conditions with a prototype reactor[54] and various aspects have been documented in detail in scientific literature.
2. The technology is now commercially available from a major supplier (GE-Hitachi).
3. The design was based on principles including full conversion of uranium into energy, not merely the small fissile portion of it. This represents an ideal partner to a multinational, above-ground storage facility and an industrial-scale recycling facility.
4. This technology requires no upstream mining, related infrastructure and potential land use degradation or pollution to obtain its primary energy. It simply re-uses an existing, currently stockpiled resource.
5. A conversion ratio of fissile to fertile material of greater than one (i.e. breeding as much or more fuel than is consumed) means a fast reactor is a sustainable large-scale energy source, in principle for tens of thousands of years.[55]

As a small reactor (311 MWe unit) there will be minimal technical limitation to the connection of this generator. The existing South Australian network could lose up to 450 MW of generation from a single contingency event[56]. The PRISM falls comfortably within that range, just larger than the existing largest single generating unit in South Australia (270 MW at Port Augusta). Each PRISM development (an installation of twin, compact power modules) would add 622 MWe of dispatchable, zero-carbon generation.

A PRISM reactor, running with the suitable configuration of the fuel core, achieves a conversion ratio of 1.2[57], rendering existing used fuel a vast source of further energy. However this is an operational decision. The PRISM is versatile, with different core configurations prioritising different outcomes, such as Used-Nuclear Fuel Recycle (conversion ratio 0.72), Breakeven (conversion ratio 1.06), or Weapons Pu Consumption (conversion ratio 1.00)[58].

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[50] Discussed at length in Gittus (2006)

[51] 'Prepared testimony, Kelly Fletcher, Sustainable Advanced Technologies Leader, General Electric Company' (2006)

[52] GE Hitachi (2014)

[53] Nordhaus, Lovering and Shellenberger (2013)

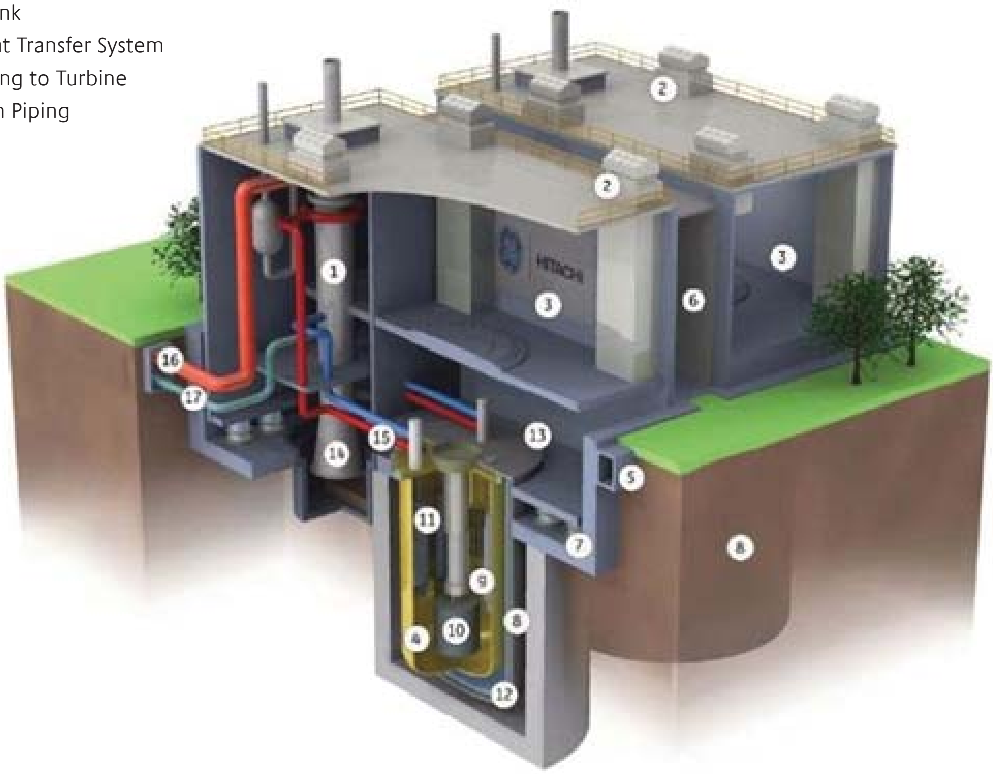
[54] Till and Chang (2011)

Following a fuel cycle the electrochemical recycling facility (described in the previous section) removes impurities, enabling the metal fuel to be re-cast into new fuel slugs with the addition of make-up material from the used-fuel stockpile[59]. The physical integration of the reactor and fuel recycling leads to the term Integral Fast Reactor. The removed impurities, known as fission products, are small in mass and short-lived, rendering management and disposal well within institutional capabilities. This is discussed in detail in section 2.4.

Figure 9: Schematic of the PRISM Power Block

PRISM Power Block

1. Steam Generator
2. Reactor Vessel Auxiliary Cooling System (RVACS) Stacks (8)
3. Refueling Enclosure Building
4. Vessel Liner
5. Reactor Protection System Modules
6. Electrical Equipment Modules
7. Seismic Isolation Bearing
8. Reactor Module (2), 311 MWe Each
9. Primary Electromagnetic Pump (4 per module)
10. Reactor Core
11. Intermediate Heat Exchangers (2)
12. Lower Containment Vessel
13. Upper Containment Building
14. Sodium Dump Tank
15. Intermediate Heat Transfer System
16. Steam outlet Piping to Turbine
17. Feedwater Return Piping



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[55] Kazimi, Moniz and Fosberg (2011)

[56] Electranet (2012)

[57] Triplett, Loewen and Dooies (2010)

[58] Triplett, Loewen and Dooies (2010)

[59] Argonne National Laboratories/ US Department of Energy (Undated)

PRISM is an inherently safe design thanks to characteristics of both the fuel and coolant. The all-metal coolant enables operations at ambient pressure. The metal fuel ensures overpower events are halted by simple physics (expansion of metal fuel with increased heat, leading to neutron leakage and loss of chain reaction). Residual decay heat is removed, passively, for an indefinite period[60] thanks to the thermal conductivity of the liquid metal coolant (68.8 W mK^{-1})[61] being approximately 100 times greater than that of water.

These inherent safety features are not merely theoretical. In 1986, the researchers operating the Experimental Breeder Reactor II (the research prototype precursor to the PRISM reactor) simulated two major accident conditions: unprotected loss of flow and unprotected loss of heatsink.

The first test (unprotected loss of flow) simulated total station blackout while the reactor was running at full power, where all shutdown mechanisms, including direct operator intervention, have failed. The reactor was "on its own". Exactly as modelled, an initial rapid rise in outlet coolant temperature was followed by a sharp loss of reactivity and reactor shutdown with no operator intervention, with the reactor reaching stable equilibrium conditions for the removal of heat.

In the second test (unprotected loss of heat sink) the reactor was isolated from the heat exchanger. Exactly as in the first test, the (more gradual) rise of temperature led to a loss of reactivity and completely passive shutdown of the reactor[62].

It has been erroneously claimed that a sodium-cooled fast reactor can explode in the manner of a nuclear weapon[63]. In the extremely low probability event that the inherent safety features of the reactor, described above, are overcome, the low melting point of the metal fuel "provides a passive mechanism for dispersing the fuel so that it cannot resemble a prompt critical configuration"[64]. This "low temperature dispersal" of the fuel "provides a massive negative reactivity injection, overwhelming all other reactivity effects" and as a result "there is no prompt criticality"[65]. The metal IFR fuel was tested in the Transient Reactor Test Facility, an experimental reactor that subjects reactor fuel to massive overpower events that are well-outside of normal operating conditions. The fuel was taken from zero power to greater than four times the nominal peak power in just five seconds. The result was as described above but better than expected: the behaviour of the fuel serves to "terminate over-power transients no matter what their cause"[66].

Concerns are often raised about the reactive nature of sodium. The sodium coolant is held in a reactor vessel with access only from the top of the reactor, and this access is covered with inert gas[67]. The 20 cm gap between the reactor wall and containment vessel is also filled with gently pressurised inert gas. As the reactor operates at atmospheric pressure, in the unlikely event of any failure of the reactor vessel there will be no energetic voiding of the coolant. Any leaks will be small, slow and readily detected. This space is also sized so that, in the unlikely event of a leak, it will retain all of the primary sodium while keeping the core, stored spent fuel, and heat exchanger inlets covered with sodium[68]. The small reactor unit size means the cores can be located below grade, with rammed earth providing an additional containment.

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[60] (Brook et al. 2014; Till & Chang 2011; Triplett, Loewen & Dooies 2010; Wade, Wigeland & Hill 1997)

[61] International Atomic Energy Agency (2012)

[62] Till and Chang (2011)

[63] See Heard (2015)

[64] Till and Chang (2011)

[65] Till and Chang (2011)

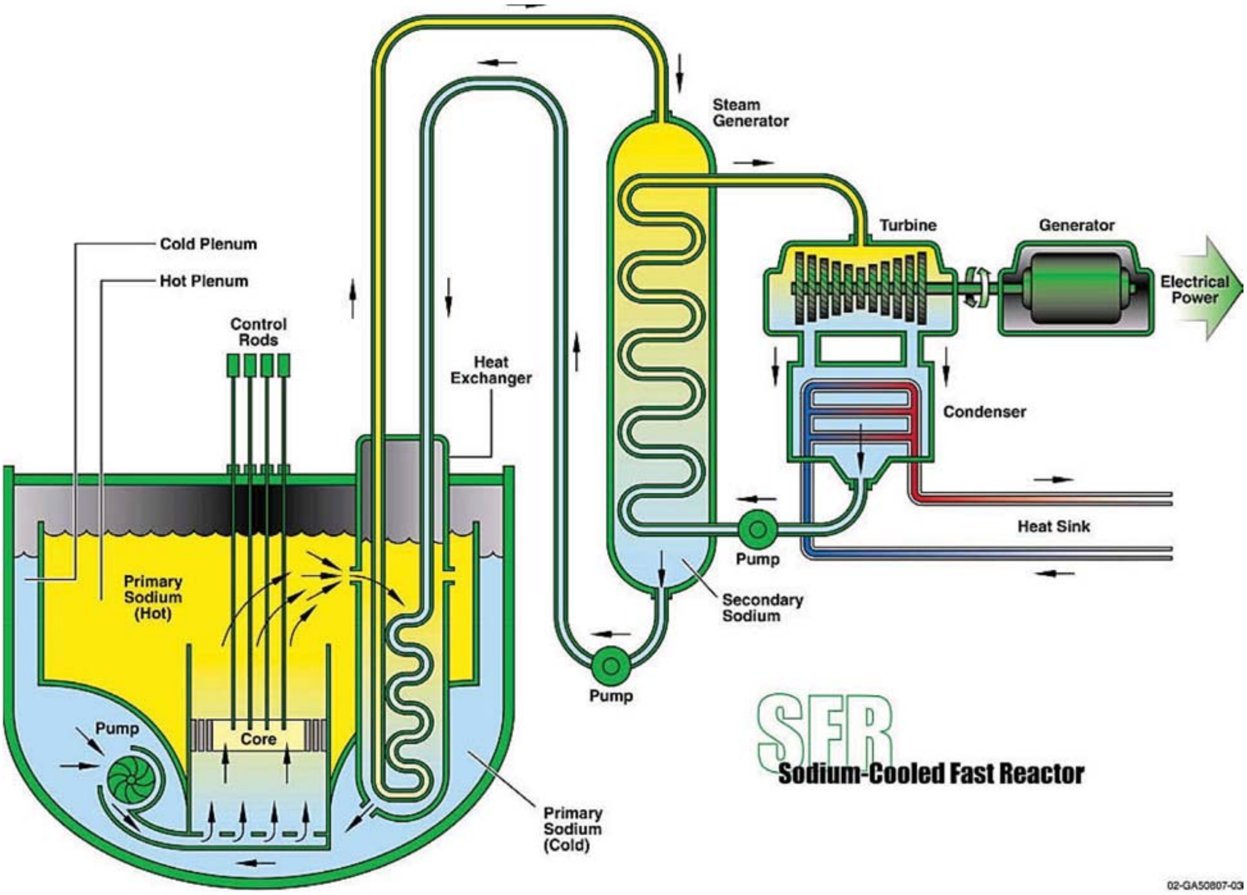
[66] Till and Chang (2011)

[67] Triplett, Loewen and Dooies (2010)

[68] Triplett, Loewen and Dooies (2010)

The coolant is highly compatible with the metal reactor walls, the metal fuel and the metal pipes, resulting in no corrosion and minimal deposition of material on fuel, even in prolonged irradiation[69]. A secondary, non-radioactive sodium-loop removes heat from the reactor core to the heat exchanger via double-walled steel pipes. At no time does irradiated sodium leave the reactor core.

Figure 10: Heat transfer from sodium cooled fast reactor showing secondary, non-activated sodium loop



A version of the PRISM reactor is under consideration in the UK for the purpose of downgrade and disposal of unwanted plutonium stockpiles[70]. PRISM carries "the necessary design attributes of a successful sustainable nuclear energy system- one that could be feasibly deployed within this decade"[71].

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[69] Till and Chang (2011)

[70] Nuclear Decommissioning Authority (2014)

[71] Brook et al. (2014)

In testimony to a US Senate subcommittee[72], General Electric made the following remarks

> *"At this point, the key issues in the deployment of this new technology are related to design, codes and standards. If the Government chooses to deploy a PRISM reactor…the work that remains is really about nuts and bolts project engineering and management- the technology is ready to be deployed."*

This submission asserts that commitment to a leading role in the commercialisation process of the PRISM, tied to and funded by the establishment of used fuel storage, is precisely the level of calculated ambition South Australia must embrace to rejuvenate our economy and establish a new, highly skilled industry for the 21st century.

Box 1: Strategic infrastructure investment assists all players.

This self-funded proposal provides a foundation of critical infrastructure development that supports South Australia as a logical destination for other advances in nuclear technology.

Under certain policy settings, mature generation III+ reactor designs could be deployed in Australia as a source of reliable, greenhouse free energy. These reactors offer evolutionary improvements to the existing fleet. Other innovative reactor designs may use existing, light water reactor fuel cycles, but achieve step-change improvements in manufacturing and deployment costs. These reactors would be supported by access to approved storage space for used nuclear fuel.

Liquid-fuelled reactor designs with replaceable cores may ultimately provide lower-cost reactors (than, for example, solid-fuel PRISM reactors) that can more rapidly integrate and dispose of plutonium and other actinides that are segregated in the fuel recycling facility. The fuel recycling facility thus enhances the utility of such a reactor design and vice versa. However such reactors lack the breeding capability to make complete use of existing uranium stockpiles and provide feedstock to new reactors. Therefore they do not supplant the importance and utility of an IFR/PRISM reactor. Access to pyroprocessing and PRISM reactor facilities would also enable complete disposition of the transuranics from the used liquid fuels, reducing the radioactive half-life of the waste stream.

The potential progression to the development of a "fuel leasing" model for Australian mined uranium would be supported by both approved multinational storage space and the development of recycling infrastructure and knowledge in fuel fabrication.

This proposal is supportive and mutually reinforcing of other developments in advanced nuclear technology. It provides a solid foundation for development of an all-encompassing push for excellence in advanced nuclear technologies to be based in South Australia, with deep ties to our scientific, education, industrial and manufacturing sectors.

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[72] 'Prepared testimony, Kelly Fletcher, Sustainable Advanced Technologies Leader, General Electric Company' (2006)

2.4| Deep Borehole Disposal

The basic principles of the PRISM reactor and associated recycling facility mean that the normal operation of this system extends the energy value of existing used nuclear fuel by a factor of 20 or more, by deriving energy from the 95%-97% of material that is either fissile or fertile. In the process the system decreases the radioactive longevity of the material by over two orders of magnitude.

After a cycle of fission, fissile material is transmuted to fission products. The fission products are radioactive but with only a medium-term collective half-life of 30 years and are small in quantity (approximately 1 kg $MWyear^{-1}$). Within approximately 300 years, the radioactivity has returned to the levels of natural uranium ore. Longer-lived actinides and fission products can be expected to remain in trace amounts[73]. This fission product material would likely be immobilised in zeolite or vitrified (turned into glass) for final disposal[74]. In the event of 622 MWe PRISM generation operating in South Australia, approximately 622 kg of fission product waste would be produced, annually, for the production of nearly 5 million MWh of electricity.

Therefore, the technologies described above would both reduce and defer the need for final disposal of radioactive material. However, fission product material will eventually require safe disposal. An ideal option may be deep-borehole disposal. This consists of drilling a borehole, or array of boreholes, into deep rock (up to 5,000 m), emplacing waste in the lower 2,000 m and sealing the upper 3,000 m with a carefully engineered borehole seal system[75]. These boreholes are a mere 0.91 m diameter at surface, telescoping to 0.43 m at 5,000m depth[76]. For fission product disposal the material could be placed in smaller diameter and potentially shallower boreholes that will be simpler and less costly to drill[77]. A single deep borehole might accommodate over 250 tonnes of used fuel material for disposal[78]. In principle, one borehole might provide disposal space for fission products from 622 MWe of PRISM generation for the life of the reactor.

There are numerous advantages to this approach over traditional mined repository approaches:

» The disposal can be developed incrementally to match the rate of waste production.

» The required rock formations are common at the depth in question. Suitable sites are numerous.

» It is low-cost per unit disposed material, with current estimates of US$158 $kgHM^{-1}$. These costs could be reduced further with centralised repacking of material for final disposal[79].

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[73] Todd (2015)

[74] Brook et al. (2014)

[75] Brady et al. (2012)

[76] Brady et al. (2012)

[77] United States Department of Energy (2014a)

[78] Brady et al. (2012)

[79] Brady et al. (2012)

[80] Brady et al. (2012)

The deep-borehole repository concept is not field-tested and a full-scale demonstration of feasibility is required[80]. However it is also “expected to be reliably achievable in crystalline rocks with currently available commercial drilling technology, and there are no known technical issues that present unreasonable barriers to drilling to this diameter at depth”[81].

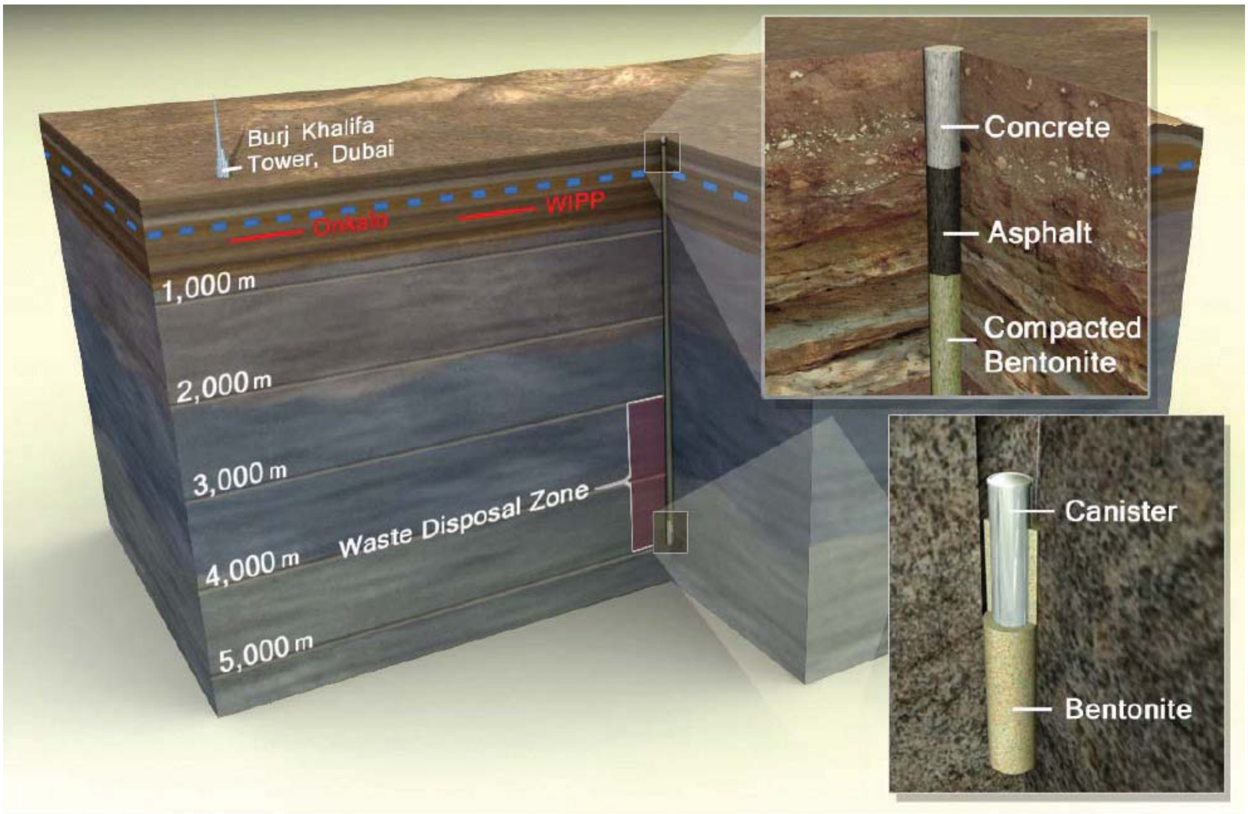
The United States Department of Energy is proposing a multi-year deep-borehole field test to “confirm the safety and feasibility of the concept before proceeding further with implementation”[82]. They are expressly proposing to seek “international collaboration with other nations that have expressed interest in deep borehole disposal concept”[83].

The United States Department of Energy confirms this solution is likely to be more quickly implemented than mined repository disposal pathways, stating:

“Preliminary evaluations of deep borehole disposal indicate a high potential for robust isolation of the waste, and the concept could offer a pathway for earlier disposal of some wastes than might be possible in a mined repository.”[84]

Previous studies have identified South Australia as possessing among the best locations, globally, for stable disposal of long-lived radioactive material[85]. Prima facie, it is highly likely that the deep borehole approach to disposal would be successful in South Australian conditions.

Figure 11: General concept for deep borehole disposal of high-level radioactive waste



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[81] United States Department of Energy (2014a, p. 26)

[82] United States Nuclear Regulatory Commission (2014, p. 14)

[83] United States Department of Energy (2014a, p. 26)

[84] United States Department of Energy (2014a)

[85] Arius Association (2015)

2.4.1 | Broader Waste Considerations

It is vital to consider not simply what waste is created by nuclear electricity, but also what waste is avoided by nuclear electricity. The PRISM solution would ensure the displacement of fossil generation from the market. According to Australia's National Pollution Inventory, the electricity generation and coal mining sectors are among the largest sources for several toxic pollutants as shown in Table 1. None of these pollutants will be emitted from a PRISM reactor (or indeed any nuclear fission).

Table 1: Quantity of selected pollutants and ranking of electricity generation and mining sectors[86]

Pollutant	Electricity generation sector, quantity, ranking	Coal mining sector, quantity, ranking
PM 10	25,000,000 kg, 6th largest	320,000,000, 2nd largest
PM 2.5	12,000,000 kg, overall largest	7,100,000, 2nd largest
Sulphur dioxide	580,000,000 kg, equal largest	N/A
Oxides of nitrogen	410,000,000 kg, overall largest	82,000,000 kg, 5th largest

The original fuel stock for the PRISM reactor is existing used fuel. There is no upstream mining impact and hence no associated wastes as occur in the mining of coal, oil, gas or uranium or the growth of biomass.

South Australia is a net-importer of electricity from Victoria[87]. Selected annual emissions of solid and gaseous waste from the 2,210 MWe brown coal facility at Loy Yang[88] have been normalised to 622 MWe. In Table 2 this is compared to pollution and the key waste stream from the proposed PRISM reactor.

Table 2: Comparison of solid and gaseous waste, brown coal and PRISM

Pollutant/waste	Loy Yang (brown coal)	PRISM (fast nuclear reactor)
EMISSIONS TO AIR (KG)		
Carbon monoxide	1,700,000	0
Sulphur dioxide	60,000,000	0
Oxides of nitrogen	23,000,000	0
PM 10	3,000,000	0
PM 2.5	14,000,000	0
Volatile organic compounds	390,000	0
Chlorine and compounds	3,000	0
TRANSFERS TO DISPOSAL (KG)		
Zinc and compounds	18,000	0
Lead and compounds	6,900	0
Fission product, short-lived	0	622

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[86] http://www.npi.gov.au/npidata/action/load/browse-search/criteria/year/2014/browse-type/Industry , searched by industry and subsets

[87] Discussed in Heard, Bradshaw and Brook (2015)

[88] Sourced from 2013/2014 reporting to the National Pollution Inventory http://www.npi.gov.au/npidata/action/load/emission-by-individual-facility-result/criteria/state/VIC/year/2014/jurisdiction-facility/00004339

2.4.2| Geenhouse Gas Emissions

From the point of view of greenhouse gas emissions, the electricity generated from 622 MWe of PRISM generation would displace approximately 5 million tCO_2-e year^{-1} from the National Electricity Market based on grid-average emissions intensity.

The calculation of lifecycle emissions from different energy sources is a mature area of academic enquiry with consistent conclusions that are accepted at the highest levels[89]. In a 2011 study via the Intergovernmental Panel on Climate Change, over 125 estimates drawn from 32 separate references (screened from an original 249 references) were reviewed for the lifecycle greenhouse gas emissions of nuclear energy. This review indicated that, across the full lifecycle, nuclear energy is among the lowest greenhouse-gas forms of electricity production, as shown in Table 3. Studies have been prepared specifically for Australian conditions and meta-review of the relevant literature has been undertaken by a leading Australian university[90], delivering results close to international studies.

Table 3: Results of literature review of lifecycle assessments of greenhouse gas emissions from electricity generation technologies[91]

Technology	Lifecycle greenhouse gas emissions, 50th percentile, gCO_2e kwh^{-1}
Biopower	18
Solar PV	46
Solar CSP	22
Geothermal Energy	45
Hydropower	4
Ocean Energy	8
Wind Energy	12
Nuclear Energy	16
Natural Gas	469
Oil	840
Coal	1,001

These outcomes support the inclusion of nuclear generation in a clean energy mix. The PRISM reactor will deliver even better performance in this regard than conventional nuclear thanks to:

- Avoidance of mining-related emissions. There is no fuel mining
- Avoidance of milling of uranium
- Avoidance of enrichment of uranium
- Elimination of several stages of transportation of mined material and fuel material
- Operations at atmospheric pressure, demanding lesser inputs of steel and other reinforcing materials in construction of the reactor

There will be other small, short lived waste streams associated with the fuel recycling facility[92] (e.g. old zirconium cladding from recycled fuel) that would require disposal in a suitable facility. Such waste streams are likely to be either low-level waste or intermediate-level waste. These materials are already in circulation. The PRISM/fuel recycling solution proposed in this submission does not create these wastes. It will, however, take proper responsibility for their safe disposal.

Exclusive focus on novel wastes generated from nuclear electricity runs the risk of delivering narrow findings deprived of vital context for good decision-making. This proposal delivers an outstanding outcome in terms of waste reduction for electricity generation, particularly when viewed through the lens of substitution for existing fossil fuel generation in the National Electricity Market.

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[89] Moomaw et al. (2011)

[90] Lenzen (2008)

[91] Adapted from Moomaw et al. (2011)

[92] Argonne National Laboratories/ Merrick and Company (2015)

3| Business Case

This section presents the business case for the development of this proposal (being an ISFSI, plus a fuel recycling and fabrication facility, plus PRISM reactors, plus eventual waste disposal) using a net-present value assessment, applying a project life of 30 years consistent with South Australian government treasury guidelines.

All costs referenced below have been inflated to 2015 dollars, and all $US values have been converted to $AU based on the exchange rate at July 2015 (AU$1.37 per US$1), and are thus to be read as 2015 $AU.

3.1| Scenario Development

In order to capture a full range of potential outcomes, the business case presents nine possible scenarios based on a range of assumptions for key variables. Three illustrative scenarios are chosen from these nine scenarios: low, mid and high. These scenarios are defined in Table 4.

Table 4: Business case scenarios

Scenario	ISFSI size (tHM)	Fuel custody price ($ tHM^{-1})	Electricity price ($ MWh^{-1})
L40 (Low scenario)	40,000	685,000	20
L60	60,000		
L100	100,000		
M40	40,000	1,370,000	50
M60 (Mid scenario)	60,000		
M100	100,000		
H40	40,000	2,055,000	80
H60	60,000		
H100 (High scenario)	100,000		

Key assumptions and inputs for developing and assessing scenarios are discussed below.

3.2| Size of the Storage Facility

Based on the work discussed in section 1, an ISFSI of 60,000 tHM storage capacity is selected for the mid scenario.

A 40,000 tHM capacity is a conservative low estimate for developing the range of illustrative scenarios and an input to the low scenario.

In the event of heavy demand from several regional partners including China, full subscription and loading of a 100,000 tHM ISFSI is regarded as a plausible upper estimate to bound the illustrative scenarios. This size is selected for the high scenario.

3.3| Revenue Assumptions

Fuel custody price

The mid scenario applies a spent-fuel price of \$1,370,000 (US\$1,000,000) tHM^{-1}. This figure is commonly quoted for the disposal of spent nuclear fuel[93]. This is below the US\$1,500,000 tHM^{-1} currently offered for reprocessing services from Taiwan, and below quoted ranges[94] of US\$1,200,000- US\$2,000,000 tHM^{-1}. Conversely, consultation suggested a price of US\$400,000 tHM^{-1} was approximately accurate based on current rates of saving in the US nuclear power industry.

A low-price of \$685,000 tHM^{-1} (US\$500,000) and a high price of \$2,055,000 tHM^{-1} (\$US1,500,000) is applied as upper and lower bounds in the development of the illustrative scenarios, and applied in the high and low scenarios respectively.

Electricity price

The mid scenario applies a wholesale electricity price of \$50 MWh^{-1}, which is below the average wholesale price of \$74 MWh^{-1} for 2012/13 in South Australia[95]. NEM-wide, a wholesale electricity price of \$50 MWh^{-1} is representative of recent pricing[96].

The low scenario and high scenario apply wholesale electricity prices of \$20 and \$80 MWh^{-1} respectively.

All scenarios assume operation of the 622 MWe PRISM reactor units at a capacity factor of 90%. This provides just under 5 million MWh $year^{-1}$ and assumes export when necessary from South Australia via the National Electricity Market interconnectors to Victoria and New South Wales.

Residual asset values

The PRISM reactors have an assumed rated life of 60 years. The analysis assumes linear depreciation of asset value and quantified residual asset value as a benefit to the project arising in project year 30.

The fuel recycling facility has an assumed rated life of 40 years. The analysis assumes linear depreciation of asset value and quantified residual asset value as a benefit to the project arising in project year 30.

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[93] Arius Association (2015)

[94] Bunn et al. (2001)

[95] Australian Energy Regulator (2013)

[96] See Figure 5 Australian Energy Regulator (2013, p. 9)

3.4| Cost Assumptions

Capital costs

Capital costs for the ISFSI are based on inclusive, detailed figures cited in a 2009 report[97] and set at $912 million for a 40,000 tHM facility. The source report also provided disaggregated scaling of capital costs for a 60,000 tHM facility, being $1,026 million. These cost scaling assumptions cost a 100,000 tHM facility at $1,256 million.

Capital cost for the development of a 100 t year^{-1} fuel recycling and fabrication plant is set at $617 million, a high-end figure which incorporates a 20% contingency loading[98].

Our modelling has assumed global first-of-a-kind (FOAK) capital costs for the PRISM reactors[99] of $8,302 million for two reactor units of 311 MWe each (622 MWe total) with shared balance of plant.

Table 5: Summary of capital costs

Capital Item	Cost			Source
ISFSI size (tHM)	**40,000**	**60,000**	**100,000**	
ISFSI	912	1,026	1,245	Electric Power Research Institute (EPRI) (2009)
Fuel recycling and fabrication plant	617			Argonne National Laboratories/ Merrick and Company (2015)
PRISM 622 MWe	8,302			United States Department of Energy (2014b)

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[97] Electric Power Research Institute (EPRI) (2009)

[98] Argonne National Laboratories/ Merrick and Company (2015)

[99] United States Department of Energy (2014b)

Operational costs

Operational costs for the loading period of the ISFSI are based on inclusive, detailed figures and are set at \$620 million year^{-1} [100] and \$698 million year^{-1} for the 40,000 and 60,000 tHM facilities respectively. This includes provision of dual-purpose canisters for transport and storage of all material. Cost-scaling assumptions[101] have been applied to cost the operations and loading of a 100,000 tHM facility at \$853 million year^{-1}. A total loading period of 20 years has been assumed irrespective of facility size to determine total operational costs for the loading period.

Annual operational costs for the post-loading, caretaker period for a 40,000 tHM and 60,000 tHM ISFSIs are set at \$6.1 million and \$6.8 million year^{-1} respectively[102]. Cost-scaling assumptions have been applied to scale-up these costs for the 100,000 tHM facility to \$8.4 million year $^{-1}$.

Operational costs for the 100 t year^{-1} fuel recycling and fabrication plant are set at \$70 million year^{-1} [103].

Annual operational costs for the PRISM twin pack are \$208 million year^{-1} [104].

A disposal cost of \$138 kg^{-1} is assumed for conditioned fission products. This is lower than published estimates[105] of \$216 kg^{-1}, accounting for the shorter half-life of the material, permitting shallower drilling in a wider range of conditions to achieve the required disposal outcomes. Fission products are produced at a rate of approximately 1 kg MWyear^{-1} [106] resulting in annual cost of approximately \$86,000 year^{-1}.

Table 6: Summary of operational costs

Operational item	Cost			Source
ISFSI size (tHM)	**40,000**	**60,000**	**100,000**	-
ISFSI loading	620	698	853	Electric Power Research Institute (EPRI) (2009)
ISFSI caretaker	6	7	8	Electric Power Research Institute (EPRI) (2009)
Fuel recycling and fabrication plant	70			Argonne National Laboratories/ Merrick and Company (2015)
PRISM 622 MWe	208			United States Department of Energy (2014a)
Deep borehole disposal	0.086			Adapted from Brady et al. (2012)

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[100] Electric Power Research Institute (EPRI) (2009)

[101] Electric Power Research Institute (EPRI) (2009)

[102] Electric Power Research Institute (EPRI) (2009)

[103] Argonne National Laboratories/ Merrick and Company (2015)

[104] United States Department of Energy (2014b)

[105] Brady et al. (2012)

[106] based on figure from Carmack et al. (2009)

3.5| Project Timelines

This analysis assumes the commencement of a committed project in project-year 0 and assumes firm bipartisan political support at both state and federal government level. The proposed timeframes reflect the relevant literature.

For the ISFSI 3-year planning is assumed followed by 3-year construction, with revenues commencing in project year 6[107]. A linear, staggered increase in loading is assumed over the first four years, steady loading rates for twelve years followed by linear decrease in loading rates for the final four years to the 20th year of loading.

A concurrent planning, designing and site preparation program is assumed for the fuel recycling facility over project years 0-2, with construction and commissioning in project-years 3-6 and operations commencing in project year 7[108]. Operational costs are assumed to be uniform for the remainder of the project period.

For the PRISM reactors planning and approvals are assumed underway from project years 0-4, with construction and commissioning from years 5-9 and operations commencing in project-year 10. This has been selected to represent an ambitious mid-point estimate between literature suggesting timeframes of as little as six years[109] and up to approximately fifteen years[110].

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[107] Consistent with indicative timeframe in Electric Power Research Institute (EPRI) (2009)

[108] Consistent with schedule shown in Argonne National Laboratories/ Merrick and Company (2015)

[109] Brook et al. (2014)

[110] Nuclear Decommissioning Authority (2014)

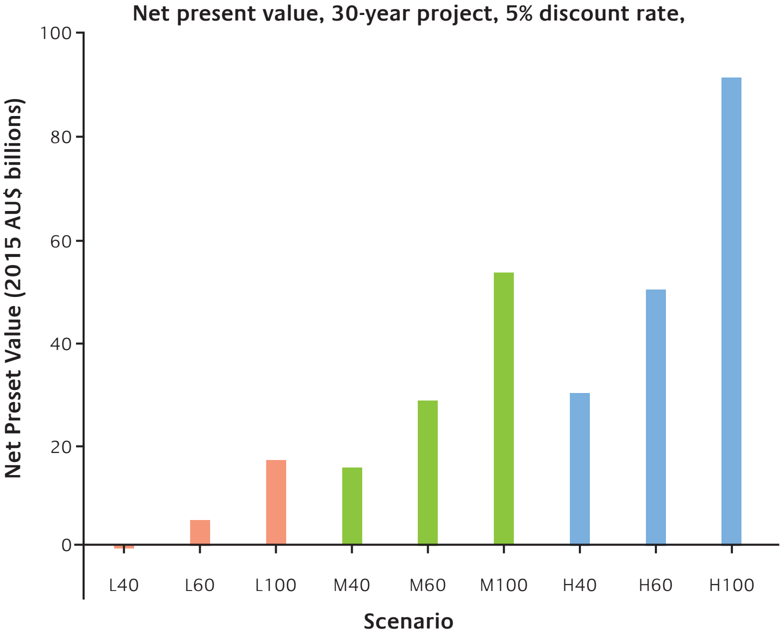
4| Economic Findings

The *Guidelines for the evaluation of public sector initiatives*[111] applies a 30-year project life for major construction proposals and a real discount rate of 5%, representing medium market risk. Under these conditions and based on the timelines determined, net present value (NPV) of the illustrative scenarios is shown below in Table 7. Figure 12 shows the NPV for all scenarios, as defined in Table 4 (page 29).

Table 7: Net present value and benefit:cost for low, mid and high scenarios, 5% discounting

	NPV 5%	Benefit:cost 5%
Low (L40)	-0.3	0.9
Mid (M60)	28.1	2.5
High (H100)	90.3	5.7

Figure 12: NPV, all scenarios as defined in Table 4



4.1| Discussion of Findings

The business case finds multi-billion dollar NPV in all scenarios excluding the illustrative low scenario. Given the efforts to be inclusive and conservative in all assumptions of costs (including fully incorporating cask purchase, loading and transportation, FOAK PRISM reactor costs, waste disposal), this is an outcome that suggests further more detailed project evaluation is warranted.

It is evident that a larger storage facility is indicated; such a project is profitable at the lowest price settings for fuel storage and electricity sales. The marginal cost of increased storage is small compared to total project costs.

The illustrative mid-range scenario delivers NPV of $28.1 billion and a benefit:cost of 2.5 at 5% discounting, a credible outcome based on the underlying assumptions.

Revenues from reactor fuel sales potentially worth $300 million per year were excluded. Cascading benefits from infrastructure development including ports and railways were not considered. These flow-on benefits to the South Australian economy would be appreciable both financially and in terms of job creation. A full economic impact assessment process would identify and quantify these benefits.

Given the attraction of the project further engagement is warranted with the reactor vendor to boost certainty in capital and operational costs for the PRISM reactor. This step will demand committed government support. Delays, while a potential political setback, are likely to improve NPV outcomes, as the total project will be further front-loaded with growing revenues from the fuel storage.

Overall, the business case outcomes are insensitive to most other cost components. The challenge in establishing this project is certainly not an economic one. Indeed project failure could be viewed as $28.1 billion foregone by South Australia, potentially taken up by less well-placed competitors.

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[111] Department of Treasury and Finance (2014)

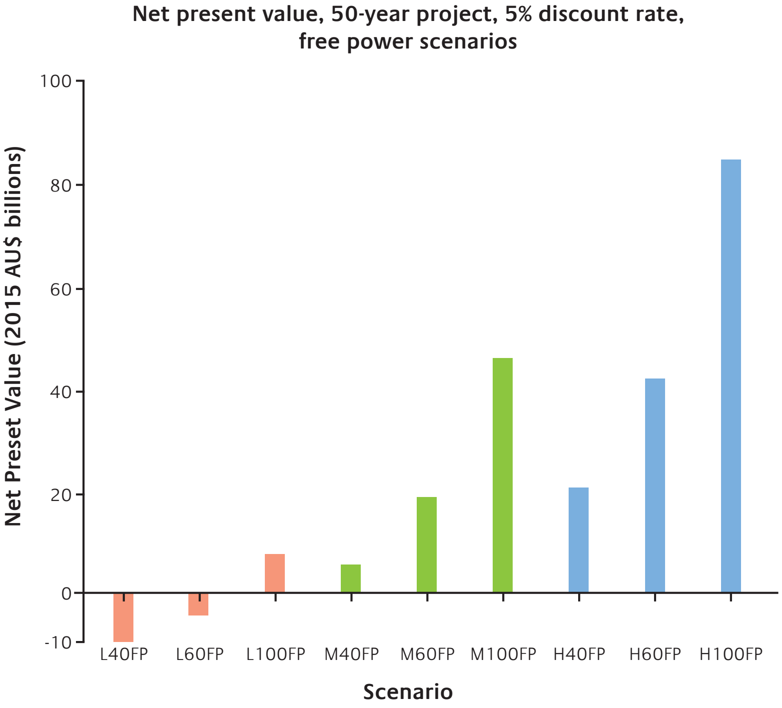
4.2| Free Power for South Australia?

As a means of simultaneously encouraging acceptance of this proposal, equitably sharing benefits and spurring further economic recovery, this proposal postulates the possible provision of all PRISM generated electricity, less self-use, to South Australians at the notional wholesale price of \$0 MWh^{-1}.

This analysis modelled the staged development of six PRISM reactors, deployed in pairs, totalling 1,866 MWe, financed through this integrated project. At an assumed 90% capacity factor, these reactors could provide approximately 16 TWh $year^{-1}$, against current state-wide demand of 12 TWh $year^{-1}$ [112].

Additional PRISM units were assigned a capital cost of \$2.1 billion based on an extrapolation of expected price declines[113], representing an assumed nth-of-a-kind (NOAK) cost of \$3,400 kW^{-1}. This assumption is approximately 25% higher than quoted NOAK costs for PRISM reactors[114] and hence is regarded as a conservative overestimate. Marginal operational cost for each additional PRISM unit was assumed at \$69 million $year^{-1}$ [115]. Construction of PRISM units 3-4 and 5-6 is assumed in project years 9-13, with commissioning in project year 14. This additional reactor construction and operation was included in all scenarios to test net present value results with the price of sold electricity set to \$0 MWh^{-1} and project life extended to fifty years. Findings are shown in Figure 13. All scenarios are as defined in Table 4 (page 29) with “free power” denoted “FP”.

Figure 13: Net present value, free power scenarios



Our findings suggest that the “free power” outcome is deliverable while maintaining overall net-profitability in nearly all scenarios.

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[112] Note instantaneous demand in South Australia can be as high as 3500 MW. Other generators would be required to meet peak demand. This process has not sought to model the provision of every unit of electricity to South Australia in real time.

[113] As shown in Appendix B, United States Department of Energy (2014b)

[114] ‘Prepared testimony, Kelly Fletcher, Sustainable Advanced Technologies Leader, General Electric Company’ 2006)

[115] United States Department of Energy (2014b)

4.3 | Job Creation

The implementation of this proposal would create direct and indirect employment in South Australia.

The ISFSI (60,000 tHM) would provide 106 operational jobs during the 20-year loading and 40 operational jobs during the caretaker period[116].

The fuel recycling and fabrication facility would generate over 1,000 construction jobs during peak construction and 380 ongoing operational jobs[117] based on analysis of disaggregated staffing cost estimates[118].

Each 622 MWe PRISM twin pack will generate approximately 500 operational jobs[119], with peak construction employment ranging from 1,000 to 1,400 workers[120].

The flow-on employment impacts are likely many times larger than the direct job creation. The influx of zero-price wholesale electricity with high reliability would enhance the competitiveness of existing industry, and provide a strong pull for development of new mining, industrial and commercial developments in South Australia.

Low-cost energy could be directly converted to the increased availability of water via South Australia's desalination plant. Enhanced water availability could drive sustained increases in agricultural output to meet growing demand for food in Asia.

The development of PRISM units would build expertise and infrastructure for advanced manufacturing capability in small modular fast reactors. Such employment cannot be readily moved to, or substituted for, in other jurisdictions.

The overall profitability provides scopes for other economically stimulating actions, for example removal of payroll tax. Further investment could be funded by this project such as sustained research and development in high-efficiency solar photovoltaics. South Australia could build a strong foundation from which to service multiple emerging domestic and global energy markets.

The foundation infrastructure developed under this proposal, combined with a world's best regulatory and commercial environment for nuclear, would attract continued investment from many stakeholders in the development of advanced nuclear technologies and manufacturing (refer Box 1).

Overall the employment impacts of this proposal could be transformative. Critically this is not predicated on ongoing domestic subsidisation of manufacturing. Rather, it is firmly founded on accessing existing, well-established international budgets, cumulatively worth over $100 billion, providing a world's-best service to meet this market and reinvesting proceeds in ongoing development for South Australia.

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[116] Electric Power Research Institute (EPRI) (2009)

[117] Brown (2015)

[118] Argonne National Laboratories/ Merrick and Company (2015)

[119] Based on Staff MWe^{-1} of 0.8 for new small modular reactors cited in International Atomic Energy Agency (2001)

[120] Brown (2015)

5| Transport Considerations

The development of this integrated project would demand the transportation of used nuclear fuel from international customers into South Australia. Fortunately such transportation is safe and mature. These conclusions are supported by a large body of data.

Since 1971 approximately 7,000 shipments of used fuel (over 80,000 tonnes) have been moved using both land and sea transportation modes. Approximately 300 sea voyages have been made carrying used nuclear fuel or separated high-level waste over more than 8 million kilometres[121]. Major shipment routes have included:

- 40,000 tonnes of used fuel shipped to Areva's La Hague reprocessing plant (including Australian material from the HIFAR reactor[122]).
- 30,000 tonnes of mostly UK used fuel shipped to UK's Sellafield reprocessing plant.
- 7,140 tonnes of used fuel in 160 shipments from Japan to Europe by sea.
- 4,500 tonnes of used fuel shipped around the Swedish coast.

Other major domestic transportation of material occurs in USA and Sweden every year.

The World Nuclear Association reports no related property damage or personal injury, no breach of containment, and very low dose rate to the personnel involved (e.g. 0.33 mSv yr^{-1} per operator at La Hague). The Australian Nuclear Science and Technology Organisation echoes this finding, stating "there has never been an in-transit accident that has caused serious human health, economic or environmental consequences attributable to the radioactive nature of the goods"[123]. By contrast over 2,000 people were killed in incidents involving the transportation of LPG in the 30 years to 2001 in OECD nations alone[124].

Transportation of this used nuclear fuel is undertaken using Type B casks, which are heavily shielded and can weigh up to 110 tonnes empty. These casks are subjected to the following regulated tests[125]:

- A free-drop test in which the cask is dropped through a distance of 9 metres onto a flat, essentially unyielding horizontal surface with the package striking the surface in the position expected to produce maximum damage. A package dropped from this height strikes the ground at a speed of about 13 metres second^{-1} (48 km hour^{-1})
- A puncture test in which the cask used in the free-drop test is dropped through a distance of 1 metre onto the upper end of a 15.2 centimetre diameter solid, vertical, cylindrical mild steel bar mounted on an essentially unyielding horizontal surface. The package is dropped onto the bar in a position that is expected to produce maximum damage.
- A thermal test in which the same cask is fully engulfed in a hydrocarbon-fuel fire with an average flame temperature of at least 800°C for a period of 30 minutes.
- An immersion test in which an undamaged specimen is subjected to a pressure head equivalent to immersion in 15 metres of water.

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[121] World Nuclear Association (2015d)

[122] Route and process described here http://www.areva.com/EN/operations-1379/nuclear-used-fuel-shipment-from-australia-to-europe.html

[123] Australian Nuclear Science and Technology Organisation (Undated)

[124] Figures cited in House of Representatives Standing Committee on Industry and Resources (2006)

[125] Committee on Transportation of Radioactive Waste (2006)

The full extent and results of accident and impact testing of transport casks for used nuclear fuel has been comprehensively documented[126]. This includes the extreme, full scale test scenarios undertaken by Sandia National Laboratory. Videos of these tests are available[127]. These tests involved:

1. Impacts of tractor-trailer rigs carrying spent fuel transport packages into a concrete barrier at nominal speeds of 100 km hour^{-1} and 130 km hour^{-1}.
2. Impact of a locomotive into a spent fuel transport package mounted on a truck trailer at a simulated grade crossing at a nominal speed of 130 km hour^{-1}.
3. Impact of a spent fuel transport package mounted on a railcar into a concrete barrier at a nominal speed of 130 km hour^{-1}, followed by exposure to a fire.

In the first two full-scale tests, the containment packages displayed only superficial damage and slight deformation. In the third test, exterior damage was greater however aside from slight bowing of the fuel rods "the assembly was otherwise undamaged"[128]. More recently, aircraft crash testing was simulated using a non-explosive missile moving at nearly 1,000 km h^{-1}, with the cask surviving this impact intact[129].

Transportation of used nuclear fuel is, therefore, a mature, well-established process. A summary of the international experience reached the following conclusion[130]:

> *"The transportation of used nuclear fuel has been and continues to be conducted safely in Canada and internationally. In over 45 years of used nuclear fuel transport, not a single incident or accident has resulted in significant radiological damage to people or the environment. In all, over 80,000 tonnes of used nuclear fuel have been transported around the world to date. The industry's excellent safety record is a direct result of robust international standards which have been adopted and implemented by national regulatory programs."*

Within Australia, transportation of radioactive materials is governed by the recently updated Australian Code[131], which reflects the most recent recommendations from the International Atomic Energy Agency. ANSTO transports around 2,000 radioactive packages every month both within Australia and overseas. This has occurred without incident. There has been over 11,000 container movements from Australia's uranium mining industry, with no transport incidents recorded that have posed any risk to public health or the environment. In 2013 there were 201 incidents reported to the Australian Radiation Incident Register, of which three were transport related, all minor, with no risk to workers or the public[132]. Relative to the accepted practice of transporting petrol on roads in tankers without public concern, no nuclear fuel or waste transports would pose comparable risks, with solid materials robustly enclosed.

The establishment of a multi-national ISFSI in South Australia will rely on mature and proven technologies and practices with exemplary safety records. While there will be governmental, regulatory and societal hurdles relating to the establishment of this facility, there exists no compelling, evidence-based argument in health, safety or environmental impacts against the transportation of the used nuclear fuel to South Australia.

Concerns exist regarding the transportation of radioactive material in the Australian community[133] and this must be addressed proactively. The public tends to estimate risks perhaps many thousands of times higher than expert assessment. Increasing the amount of available information does little, in isolation, to decrease the risk perception but rather tends to increase uncertainty[134]. This reinforces the lessons of risk communication that the "deficit model" of communication has limited utility if applied bluntly. Nonetheless the development of knowledge remains influential in the formation of attitudes, though the relationship is likely more complex than generally appreciated[135].

Evidence suggests that the maintenance and expansion of the application of existing policies, practices and technologies by Australia will ensure the excellent Australian and international track-record in transport of radioactive materials is maintained. While Australia will undoubtedly need to boost capacity in these areas, this poses no insurmountable hurdle. However, further public discussion will be needed using this evidence, guided by the best available risk communication expertise.

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[126] Committee on Transportation of Radioactive Waste (2006)

[127] www.ocrwm.doe.gov/newsroom/videos.shtml

[128] Committee on Transportation of Radioactive Waste (2006)

[129] Video footage of this test is available here http://www.holtecinternational.com/news/videos/

[130] Stahmer (2009)

[131] Australian Radiation Protection and Nuclear Safety Agency (2014)

[132] Australian Radiation Protection and Nuclear Safety Agency (2015)

[133] For example the group Nuclear Operations Watch Port Adelaide

[134] Riddel (2009)

[135] Sturgis and Allum (2004)

6| Location

The facilities discussed in this submission are suitable for deployment across South Australia. Co-location of the fuel storage, recycling facility and fast reactors would be optimal in terms of cost, safety, and minimisation of movement of material.

Relating to the reactor facilities, the PRISM features small reactor units (311 MWe) that may be deployed in series to create larger power stations. This is analogous to the coal-fired facilities of Port Augusta where three generating units are co-located. Total installed capacity at the location is 760 MWe, but no single generating unit exceeds 270 MWe. Therefore there will be minimal additional requirements for connection. As a water-cooled thermal generator, like existing facilities at Port Augusta or Torrens Island, proximity to sea water for cooling is advantageous. The existing transmission network in South Australia offers many potentially suitable locations for siting such a facility.

An above ground fuel storage facility requires a suitable area of land, preferably with proximity to existing or potential port and rail facilities. Many locations in South Australia are likely to offer these conditions. The fuel recycling facility is logically co-located with both the fuel storage facility and the fast reactors. On the basis of international experience and South Australia’s existing electricity and industrial infrastructure, no technical impediment is foreseen to locating these facilities in South Australia, with a wealth of suitable locations for doing so. Health and environmental impacts of these facilities would be expected to be much lower than equivalent fossil fuel infrastructure, with no emissions of airborne pollution and minimal, fully contained waste streams, as discussed in section 2.4.

Remote Locations

South Australia offers the (putative) advantage of availability of remote locations with world-leading geological stability. While valuable, nothing about the facilities proposed in this submission demands the use of remote locations. An early, reflexive focus on remote locations may lead to unhelpful and counterproductive discourse.

This analysis presents an audit of a representative selection of 24 dry cask storage sites and fuel disposal sites maintained within nuclear power-equipped countries, and the communities that share the general areas. For each site the closest community was identified, and the communities within the radii out to 100 kilometres and 200 kilometres, and the distance to the largest notable city outside this area. The methodology applied to this process is described in Appendix 2: Review of fuel storage locations and proximity of communities and major settlements, along with a complete table of findings. A sample is shown in Table 8 below.

The evidence from international practice demonstrates that nuclear facilities co-exist with dozens of communities in close proximity, and within a few hundred kilometres of major world cities including, Helsinki, Madrid, Shanghai and New York.

It is demonstrably the case that extreme remote locations are not a requirement. Any reflexive focus on remote locations, from the outset, circumvents good process and sends a message that the facilities are hazardous. Evidence from global practice shows this is not the case. A focus on remote locations also raises the probabilities that facilities will interact with areas of strong sensitivity to Australia's indigenous communities. Indigenous communities should be welcomed into any siting process, however on the basis of international practice there need be no imposition, whatsoever, of these facilities into remote South Australian land.

This proposal centres on the temporary storage of used fuel to be followed by recycling for energy. As such, South Australia's acknowledged geological stability is an advantageous quality, relevant for the future disposal of lesser quantities of much shorter-lived material. Given the short half-life and very small quantities, technically suitable options for borehole disposal will likely abound in South Australia.

In discussing the location of the facilities outlined in this proposal this submission advocates a consent-based process whereby:

- All technically suitable locations in South Australia are available for consideration, with no arbitrary exclusions.
- Evidence of technical suitability and international practice remains prominent in discussions at all times.
- Local stakeholders are engaged in a free and voluntary process.
- Community support, equity, and creation and sharing of benefits are prominent principles upon which the process is to be based.

Such bottom-up practices have been deployed with success in Finland and Sweden[136]. These processes have been adopted in-part by the Australian Federal Government for the most recent siting attempt for a facility to centralise Australia's low and intermediate level radioactive waste, with early indications of positive outcomes[137]. Consent-based processes are proposed and underway for fuel storage facilities in the United States[138]. These are encouraging examples that should be understood and applied to progressing development of nuclear facilities in South Australia.

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[136] Nuclear Energy Institute (2014)

[137] Department of Industry and Science (2015)

[138] (Moniz (2014); Nuclear Energy Insittute (2015))

Table 8: Selection of nuclear facilities and proximity to communities and major settlements

COUNTRY	INSTALLATION	CLOSEST COMMUNITY	COMMUNITIES WITHIN 100	COMMUNITIES WITHIN 200	OTHER NEARBY MAJOR SETTLEMENTS
US	Diablo Canyon	San Luis Obispo 19km	Santa Maria, Atascadero, Cambria, Paso Robles, San Miguel, Gorda, Pismo Beach, Lompoc, Solvang	Bakersfield, Hanford, Lost Hills, Delano, Porterville, Tulare, Visalia, Fresno, King City, Salinas, Monterey, Goleta, Oxnard, Ventura	Los Angeles 270km, San Francisco 320km
UK	Sellafield	Seascale 2km	Egremont, Cleator Moor, Whitehaven, Workington, Maryport, Aspatria, Silloth, Wigton, Dalston, Carlisle, Gretna Green, Brampton, Haltwhistle, Alston, Keswick, Penrith, Pooley Bridge, Howtown, Wasdale Head, Boot, Shap, Stanhope, Appleby-in-Westmorland, Kirkby Stephen, Ravenstonedale, Bowness-on-Windermere, Kendal, Sedbergh, Millom, Dalton-in-Furness, Barrow-in-Furness, Grange-over-Sands, Carnforth, Morecambe, Lancaster, Ingleton, Bentham, Fleetwood, Blackpool, Preston, Douglas	Ballymena, Bangor, Belfast, Dunmurry, Lisburn, Newry, Dundalk, Warrenpoint, Portpatrick, Stranraer, Campbeltown, Girvan, Ayr, Troon, Irvine, Greenrock, Paisley, Glasgow, Stirling, Falkirk, Livingston, Edinburgh, Musselburgh, North Berwick, Dunbar, Eyemouth, Berwick-upon-Tweed, Melrose, Kelso, Harwick, Bamburgh, Seahouses, Alnwick, Newcaslt-upon-Tyne, Sunderland, Durham, Hartlepool, Stockton-on-Tees, Middlesbbrough, Whitby, Richmond, Malton, Ripon, Harrogate, York, Leeds, Bradford, Halifax, Bolton, Manchester, Liverpool, Warrington, Sheffield, Chesterfield, Stoke-on-Trent, Chester, Wrexham, Rhyl, Llandudno, Conwy, Bangor, Caenarfon, Holyhead, Porthamdog, Harlech, Shrewsbury,	Cardiff 327km
China	Gansu	Xigu 11km	Baiyin, Lanzhou, Linxia	Huangnan, Haidong, Xining, Gannan, Dingxi,	Xi'an 530km
Canada	Darlington	Bowmanville 5km	Oshawa, Ajax, Clarington, Port Perry, Uxbridge, Newmarket, Aurora, Vaughan, Toronto, Mississauga, Brampton, Caledon, Oakville, Georgina, Innisfil, Barrie, Cannington, Beaverton, Lindsay, Snug Harbour, Kawartha Lakes, Orillia, Peterborough, Bridgenorth, Curve Lake, Buckhorn, McCrackens Landing, Norwood, Havelock, Campbellford, Gores Landing, Cobourg, Colborne, Brighton, Baltimore, Brockport, Medina, Niagara Falls	BellevillePrince Edward, Deseronto, Greater Napanee, Kingston, Marmora, Kaladar, Sharbot Lake, Cloyne, Bancroft, Barry's Bay, Haliburton, Minden, Gravenhurst, Bracebridge, Huntsville, Kearney, Rosseau, Parry Sound, McDougall, Midland, Collingwood, Meaford, Owen Sound, Hanover, Walkerton, Guelph, Waterloo, Kitchener, Startford, Hamilton,Ingersoll, Simcoe, Buffalo, West Seneca, Fredonia, Houghton, Salamanca, Allegany, Olean, Alfred, Hornell, Geneseo, Rochester, Canandaigua, Newark	Detroit 390km, Ottawa 294km
Finland	Onkalo**	Kaaro 8km	Eurajoki, Kiukainen, Harjavalta, Nakkila, Luvia, Ulvila, Leineperi, Pori, Kullaa, Palus, Ruosniemi, Viasvesi, Makholma, Kaanaa, Lyttyla, Noormarkku, Lamppi, Tahkoluoto, Saarikoski, Pooskeri, Merikarvia, Lankoski, Siikainen, Pormakku, Honkakoski, Kankaanpää, Niinisalo, Honkajoki, Jamijarvi, Honkilahti, Koylio, Säkylä, Rutava, Vampula, Virttaa, Oripää, Kalikka, Yläne, Uusikartano, Raasi, Laitila, Uusikaupunki, Loimaa, Meillilä, Riihikoski, Mynämäki, Mietoinen, Askainen, Masku, Vahto, Paatinen, Lieto, Aura, Tarvasjoki, Turku, Naantali, Velkua,	Koski, Salo, Halikko,Pernio, Kisakallio, Lohja, Inga, Fiskars, Raseborg, Bromarf, Dalsbruk, Nagu, Korpo, Houtskär, Brändö, Sottunga, Utö, Kökar, Föglö, Lemland, Marjehamn, Godby, Hasvidden, Eckerö, Hyvinkää, Riihimäki, Forssa, Jokioinen, Janakkala, Hämeenlinna, Parola, Urjala, Akaa, Valkeakoski, Lempäälä, Kangasala, Pikonlinna, Tampere, Orivesi, Ikaalinen, Ruovesi, Vippula, Mänttä, Haapamäki, Virrat, Kotala, Parkano, Karvia, Isojoki, Lalby, Kaskinen, Närpes, Jurva, Kurikka, Seinäjoki, Ylistaro, Alavus, Laihia, Solf, Molpe, Korsnäs, Pörtom	Helsinki 222km, Vaasa 207km

7| Conclusion

The South Australian Nuclear Fuel Cycle Royal Commission has provided a once-in-a-generation opportunity for an evidence-based appraisal of the opportunities for South Australia in further engagement with the nuclear fuel cycle.

The greatest opportunities for South Australia will be found where our potential competitive advantages converge with market demand.

While opportunities may abound across the nuclear fuel cycle, such particular convergence is unlikely to be found in the globally mature, established nuclear industry.

This submission argues that just such a convergence is found in the custody and management of used nuclear fuel, with a focus on Asia.

However South Australia must go further. Open ended management strategies for used nuclear fuel may not win public acceptance and do not, in isolation, sufficiently stimulate the creation of new and exciting industries to provide high-value jobs of the future.

This proposal identifies the opportunity to move early in the commercialisation of new technologies for the complete recycling of used nuclear fuel with the production of clean electricity as a result, and to do so as an integrated financial project with the storage of used fuel.

In this synergy there may be found widespread community support for a project that is highly innovative, deploys leading technologies, supports the foundation of new industries, demonstrates world-leading practices in recycling, and delivers low-cost electricity.

Modelling indicates that this project is likely worth $28 billion to South Australia in present value.

This is a challenging pathway to deliver an ambitious project. However Australia possesses the necessary institutional infrastructure to achieve this project with adequate governmental funding and support. The first stage, the establishment of multinational above-ground fuel storage, can be commenced immediately upon securing the necessary political and legislative conditions at state and federal government level.

On an evidence-base, the safety of all aspects of this proposal is established beyond question. The deployment of these technologies will beneficially impact the Australian environment with the substitution of clean fission from recycled material for combustion of fossils fuels. The proposal does not call for the use of remote lands, but rather acknowledges the suitability of these facilities for location across South Australia, based on overwhelming international evidence.

This is a transformative opportunity for South Australia. For it to be realised, change is required.

RECOMMENDATIONS

- Repeal arbitrary legislative barriers to expansion in the nuclear fuel cycle at both state and federal government level.
- Commit to high quality communication and engagement with the South Australian community, governmental sectors and business communities regarding the potential project.
- Undertake comprehensive state-wide economic analysis of the identified project, in consultation with key international vendors and stakeholders. If the findings of this submission are confirmed to the satisfaction of government, the project should proceed.
- Engage directly with probable customers for storage of used fuel in the Asian region to build the necessary commercial and political relationships and frameworks for this trade to proceed.
- Undertake comprehensive legal review of state, federal and international legislations and treaties for relevant interactions with the project proposed in this submission.
- Establish processes with Australia’s critical regulatory and scientific institutions in preparation for the implementation of this proposal.
- Work with key Australian and international stakeholders to establish a framework world’s best regulatory environment for the commercialisation of advanced nuclear technologies.

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Appendix 1

Fuel Inventory Modelling

Method

Due to the different current conditions of the selected countries (China, Japan, South Korea and Taiwan), different approaches and scenarios are applied.

China

Currently China operates about 23.1 GW of nuclear power capacity[139], and plans to add about 217 GW by 2050. The plan scenario of this analysis follows the nuclear plan. The nuclear capacity for the plan scenario will reach 58 GW by 2020, 150 GW in 2030 and 250 GW in 2050. The low scenario assumes that there is no additional nuclear power excluding currently operating, constructing and planned capacity. The total capacity for the low scenario will reach 91 GW by 2050. The high scenario follows the assumption by Hu[140]. About 70 GW of nuclear power plants will be installed by 2020, 200 GW by 2040 and 500 GW by 2050. This is the pre-Fukushima nuclear plan in China. The capacity of breeder reactors are excluded from the calculation.

Due to the large gap between the currently operating capacity and the future expectation, technological development and short experience of China, the calculation method is applied[141].

$$M = \frac{P_e \cdot CF \cdot 365}{\eta_{th} \cdot B_d}$$

M is mass of fuel loaded per year (MTHM/year), B_d is discharge burnup which is between 8 GWd/MTHM (PHWR) and 65 depended on the type of reactors, Pe is installed electric capacity (GWe); CF is capacity factor (85%), η_{th} is thermal efficiency (33%).

Japan

Currently Japan has about 44.6 GW of nuclear power capacity currently stopped operating since the Fukushima-Daiichi nuclear accident[142]. The plan scenario is assumed that the nuclear power in Japan will generate around 22% ~ 24% of the total electricity consumption[143]. It is assumed that currently closed nuclear power plants (including Fukushima power plants) will be remained as is, the other nuclear power plants will be restarted to operate from 2016, and will continue by 2050. The low scenario is assumed that all nuclear power plants will be decommissioned when they reach the expected life span, and all new power plants under construction or plan will be cancelled. The high scenario is based on the plan scenario; however, assumed that aged power plant (the expected life span < 2040) will be replaced to advanced reactors with larger capacity.

The calculation approach similar to China is applied to Japan due to the lack of data. The capacity factor of nuclear power in Japan is noticeably low (<70%) compared with other countries like South Korea and China. Discharge burnup is 40 GWd/tU, and thermal efficiency is 33%. The conversion factor of 0.95 is multiplied to convert the amount of uranium input to spent fuel (heavy metal) output.

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South Korea

Currently nuclear power with the capacity of 20.7 GW is being operated in South Korea[144]. The plan scenario follows the current electricity generation plan until 2035[145]. Between 2015 and 2023, South Korea is planning to build 1.4 GW of nuclear power plants every year. The total capacity of nuclear power will be 32.9 GW by 2023, and the capacity will be maintained thereafter. Aged reactors will be renewed. The high scenario is assumed that nuclear power plants will be constructed with the reduced trend (1.4 GW bi-annually) between 2024 and 2050). Additionally aged nuclear reactors will be replaced with generation III reactors with higher capacity (1.4 GW). The total nuclear capacity will be 54.3 GW by 2050. The phase-out scenario is assumed that all nuclear power plants will be phased out in South Korea when reaching the planned operational life span of each nuclear power plant, and all the nuclear power plant plans will be cancelled.

The annual nuclear fuel data by power plants in a year between 2000 and 2014 is obtained from Korea Hydro and Nuclear Power (KHNP)[146]. The conversion factor of 0.95 is multiplied to convert the amount of uranium input to spent fuel (heavy metal) output. For the generation III reactors (APR1400) that do not have historical data, the average value of generation II reactors (OPR1000) which use the same type of nuclear fuel (PLUS 7) is applied. The capacity difference is compensated by multiplying 1.4.

Taiwan

Currently nuclear power with the capacity of 7.6 GW is being operated in Taiwan[147]. The plan scenario follows the new energy policy of Taiwan (8.3 GW by 2050)[148]. Since the energy policy of Taiwan has the “Move towards a nuclear-free homeland” position, it is difficult to expect increasing nuclear power capacity in Taiwan. Therefore the high nuclear scenario assumes only that aged nuclear power plants will be replaced with advanced nuclear power reactors with higher capacity after the expected life span year (11.2 GW by 2050). The low nuclear power scenario is assumed that Taiwan will cancel all nuclear power programs currently planned and decommission currently operating power plants when they reach the expected life span. For the low scenario, maximum capacity is 4.3 GW in 2025 and it will maintain by 2050.

The empirical approach that uses the historical data of Taiwan is applied to calculate the amount of spent fuels[149]. Here the quantity of spent fuel is assumed to follow the historical trend of each power plant.

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Spent Fuel Inventory

South Korea

	2015	2020	2025	2030	2035	2040	2045	2050
High	13808	19000	24500	29727	35380	41291	47628	54224
Plan	13808	18854	23797	28570	33344	38117	42890	47663
Low	13808	18071	21478	23343	24398	25189	25695	26009

China

	2015	2020	2025	2030	2035	2040	2045	2050
High	4254	8720	17934	32199	51565	75457	104168	137774
Plan	4254	8720	16765	27878	43016	60049	78599	98739
Low	4254	8720	16205	24426	32646	40867	49087	57308

Taiwan

	2015	2020	2025	2030	2035	2040	2045	2050
High	3595	4314	5344	6511	7678	8845	10012	11180
Plan	3595	4226	4905	5584	6263	6943	7622	8301
Low	3595	4080	4322	4322	4322	4322	4322	4322

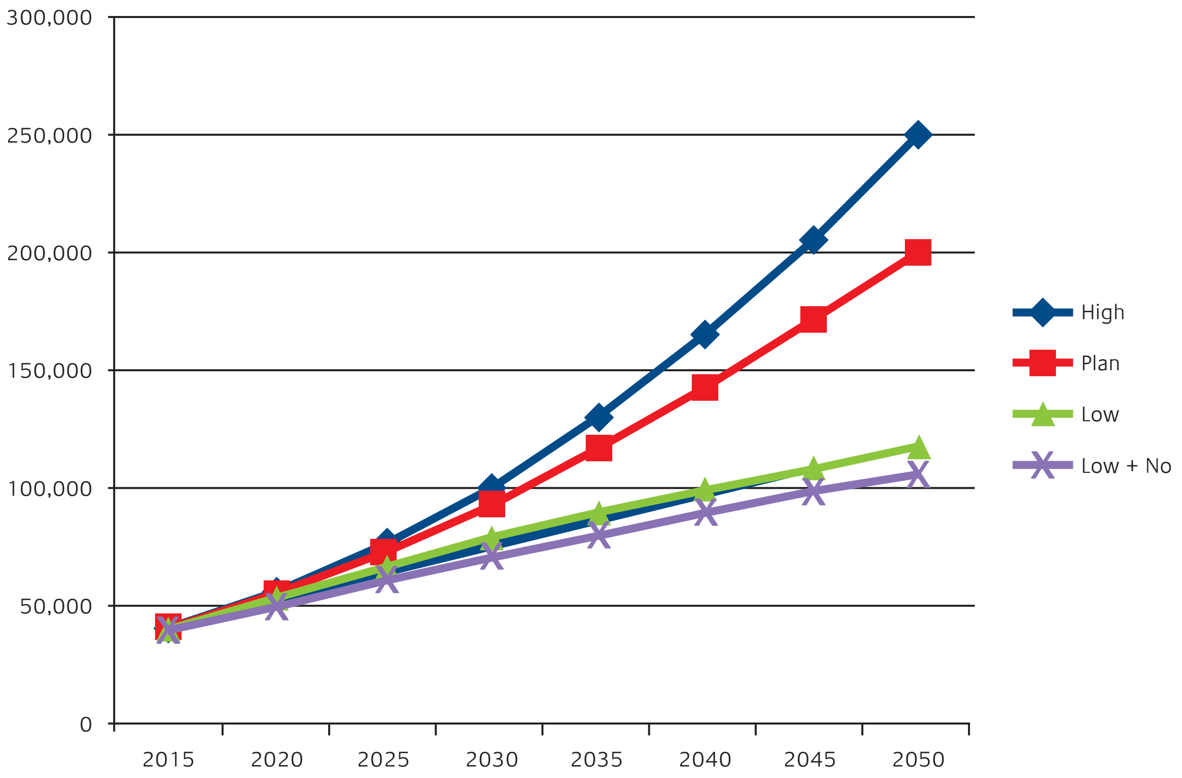
Japan

	2015	2020	2025	2030	2035	2040	2045	2050
High	19000	22676	26520	30365	34209	38158	42194	46229
Plan	19000	22676	26520	30365	34209	38053	41898	45742
Low	19000	22280	25117	27063	28283	28738	29041	29110
No	19000	19000	19000	19000	19000	19000	19000	19000

150.

Total

	2015	2020	2025	2030	2035	2040	2045	2050
High	40657	54710	74298	98802	128832	163751	204002	249407
Plan	40657	54476	71987	92397	116832	143162	171009	200445
Low	40657	53151	67122	79154	89649	99116	108145	116749
Low + No Japan	40657	49871	61005	71091	80366	89378	98104	106639



Appendix 2

Review of fuel storage locations and proximity of communities and major settlements

A representative selection of dry cask storage sites maintained within nuclear power-equipped countries, and the communities that share the general areas.

Methodology

Representative countries were selected for American, European and Asian locations. Locations of dry casks were determined by consulting official records or the World Nuclear Association databases, and coordinates found on Google maps. Where possible, actual dry casks or associated storage bunkers were visually identified. For each site, the Google maps "measure distance" tool was used to determine the closest community, the radii out to 100 kilometres and 200 kilometres, and the distance to the largest notable city outside this area, were applicable. A visual survey of all visible cities, towns and villages was undertaken within these boundaries; each list is presented as representative of settlements co-existing with relatively close-by, safely stored used nuclear fuel material, but should not be considered exhaustive. Communities are listed in no particular order of size, population or proximity to storage facilities.

Dry cask storage

The technology for encapsulation of used and thoroughly cooled fuel assemblies was first used at Surry nuclear power plant in Virginia, USA, in 1986 as a solution to inadequate spent fuel pool capacity. Generally, dry, radioactive used fuel assemblies are packed and sealed under helium atmosphere within thick shells of steel and concrete which feature natural ventilation for residual cooling. Each fully loaded cask masses in excess of 150 metric tonnes and is engineered to withstand forces equivalent to airplane or missile impacts without loss of integrity. In nearly thirty years this approach has demonstrated unequivocal, robust safety and suitability as an interim solution to used fuel storage issues. Recently, the US Nuclear Regulatory Commission expressed confidence that used fuel can be safely stored for over a century. The private industry for used fuel management is growing.

There are various dry cask-type designs used globally, though models from Holtec and Areva Transnuclear are the most recognisable. Other models are utilised in Europe, and CANDU bundles (which are very different geometry to LWR fuel assemblies) are mostly contained in much larger, rectangular containers. Some designs are intended to be placed horizontally within impregnable concrete bunkers, such as Areva NUHOMS and MACSTOR.

Of particular note are the examples of Humboldt Bay and Pickering nuclear sites. Humboldt Bay was an early model boiling water reactor of very small generating capacity on the Californian coast, rendered uneconomical by increasingly strict US regulations following the Three Mile Island accident. Its used fuel was transferred to six dry casks during decommissioning and they sit safely on a secure concrete pad, closely surrounded by several small coastal communities. In contrast, the Ontarian nuclear plant of Pickering sits on the coast of Lake Ontario 30 kilometres from the central business district of Toronto. All of its used fuel is stored on site in dry storage containers.

While many commercial nuclear power plants make use of dry cask storage they also invariably store new or used fuel material in fuel pools within the facility buildings. There are more conceivable eventualities involved in this form of storage than with dry storage, but within the bounds of strictly-enforced reporting procedures there have been no injuries or deaths associated with either method of used fuel management. The CLAB interim storage facility has been included in the list as an example of designed-for-purpose fuel pool storage.

The HABOG facility managed by COVRA in the Netherlands (51.440641, 3.711324) is an example of above-ground interim storage of true nuclear waste received back from reprocessing at La Hague. It is 9 kilometres from the community of Middleburg and 53 kilometres from Antwerp.

Useful references

NRC

http://www.nrc.gov/waste/spent-fuel-storage/dry-cask-storage.html

http://public-blog.nrc-gateway.gov/2015/03/12/dry-cask-storage-the-basics/

http://www.nrc.gov/waste/spent-fuel-storage/wcd.html

http://pbadupws.nrc.gov/docs/ML1232/ML12320A697.pdf

Brands of dry storage

http://us.areva.com/EN/home-3138/areva-inc-areva-tn--nuhoms-used-fuel-storage-system.html

http://www.holtecinternational.com/productsandservices/wasteandfuelmanagement/hi-storm/

http://www.nacintl.com/drytransfer

http://www.wcstexas.com/

IAEA INPRO

https://www.iaea.org/newscenter/news/enhancing-cooperation-spent-fuel-and-high-level-waste-management

China

http://nautilus.org/napsnet/napsnet-special-reports/spent-nuclear-fuel-management-in-china/

Canada

http://www.opg.com/generating-power/nuclear/nuclear-waste-management/Documents/PWMFbrochure.pdf

Zwilag

http://www.zwilag.ch/en/cask-storage-hall-_content---1--1054.html

Clab

http://www.skb.se/upload/publications/pdf/clabeng.8.3.pdf

https://www.iaea.org/newscenter/news/action-sea-transport-security-exercise-conducted-coast-sweden

COUNTRY	INSTALLATION	COORDINATES	CLOSEST COMMUNITY	COMMUNITIES WITHIN 100	COMMUNITIES WITHIN 200	OTHER NEARBY MAJOR SETTLEMENTS
US	Surry	37.165556,-76.697778	San Luis Obispo 19km	Richmond, Norfolk, Chesapeake, Virginia Beach, Hampton, Newport News, Petersburg,	Charlottesville, Rocky Mount, Greenville, Ocean City, Washington DC	
	Diablo Canyon	35.210833,-120.856111	West Richland 18km	Santa Maria, Atascadero, Cambria, Paso Robles, San Miguel, Gorda, Pismo Beach, Lompoc, Solvang	Bakersfield, Hanford, Lost Hills, Delano, Porterville, Tulare, Visalia, Fresno, King City, Salinas, Monterey, Goleta, Oxnard, Ventura	Los Angeles 270km, San Francisco 320km
	Columbia	46.471111,-119.333889	Monticello 5km	Richland, Kennewick, Prosser, Grandview, Sunnyside, Toppenish, Union Gap, Yakima, Desert Aire, Royal City, George, Quincy, Moses Lake, Warden, Othello, Connell, Walla Walla, Milton-Freewater, Pendleton, Stanfield, Hermiston, Boardman		Seatle 260km
	Monticello	45.331811, -93.850412	Port St Lucie 14km	St Cloud, Sauk Rapids, St Joseph, Santiago, Becker, Cold Spring, Annadale, Litchfield, Dassal, Cokato, Albertville, Princeton, Elk River, Cambridge, Minneapolis, Minnetonka, St Paul, Edina, Bloomington, Hutchinson	Eau Claire, Mankato, Alexandria, Brainerd, Rochester	
	St Lucie	27.348611,-80.246389	St Leonard 7km	Melbourne, Palm Bay, Sebastian, Vero Beach, South Beach, Fort Pierce, Yeehaw Junction, Basinger, Okeechobee, Lakeport, Buckheaqd Ridge, Port Mayaca, Indiantown, Moore Haven, Belle Glade, Pahokee, Delray Beach, Boynton Beach, Palm Gardens Beach, Jupiter, Stuart	Roca Raton, Fort Lauterdale, Hollywood, Miami, Freeport, Cape Coral, Fort Myers, Port Charlotte, Sebring, Winter Haven, Lakeland, Kissimmee, Orlando, Sanford, Cocoa Beach, Cape Canaveral	Tampa 228km
	Calvert Cliffs	38.431944,-76.442222	Lycoming 3km	California, Hollywood, St Marys City, Prince Frederick, Huntingtown, Chesapeake Beach, Waldorf, La Plata, Dahlgren, Colonial Beach, King George, Port Royal, Montross, Cambridge, Oxford, St Michaels, Easton, Alexadria, Fairfax, Annapolis, Bethesda, Bowie, Chantilly, Salisbury, Fredericksburg, Washington DC	Charlottesville, Baltimore, Richmond, Williamsburg, Norfolk, Newport News, Virginia Beach, Ocean City	Philadelphia 201km, New York 328km

COUNTRY	INSTALLATION	COORDINATES	CLOSEST COMMUNITY	COMMUNITIES WITHIN 100	COMMUNITIES WITHIN 200	OTHER NEARBY MAJOR SETTLEMENTS
	Fitzpatrick	43.523333,-76.398333	King Salmon 600m	Novelis, Scriba, Demster, New Haven,Oswego, Fruit Valley, Southwest Oswego, Furniss, Hannibal, North Hannibal, Fairdale, Minetto, Granby Center, Fulton, Volney, Palermo, Mallory, Hastings, Mexico, Colosse, Maple View, Parish, Fernwood, Port Ontario, Pulaski, Lacona, Altmar, Williamstown, Camden, Central Square, Rome, Oneida, Clinton, Syracuse, Liverpool, Baldwinsville, Auburn, Weedsport, Sodus, Sodus Point, Watertown, Fort Drum, Prince Edward, Kingston	Rochester, Brockport, Medina, Geneseo, Houghton, Alfred, Hornell, Watkins Glen, Elmira, Ithaca, Cortland, Binghamton, Norwich, Oneonta, Cooperstown, Potsdam, Canton, Smiths Falls, Perth, Marmora, Kaladar, Peterborough, Cobourg, Brighton, Quinte West, Belleville	Buffalo 213km, Toronto 240km
	Humboldt Bay	40.741713, -124.212138	Seabrook 1km	Capetown, Port Kenyon, Ferndale, Loleta, Fortuna, Hydesville, Rio Dell, Scotia, Pepperwood, Bridgeville, Redcrest, Dinsmore, Hyampom, Cutten, Eureka, Samoa, Kneeland, Maple Creek, Dinsmores, Fernwood, Blue Lake, Willow Creek, Salyer, Burnt Ranch, Patrick's Point, Trinidad, McKinleyville, Arcata, Weitchpec, Hoopa, Big Bar, Helena, Hayfork, Peanut, Ruth, Alderpoint, Miranda, Myers Flat, Burlington, Petrolia	Garberville, Leggett, Covelo, Red Bluff, Anderson, Redding, Millville, Shasta Lake, Dansmuir, Mt Shasta, McCloud, Yreka, Fort Jones, Etna, Klamath	Sacramento 335km
	Seabrook	42.898889,-70.850833	Sizewell 700m	Saco, Waterboro, Sanford, Wells, Ogunquit, Lebanon, Rochester, Somersworth, Dover, York, Portsmouth, Durham, Laconia, Tilton, Concord, Bow, Hooksett, Manchester, Bedford, Amherst, Londonderry, Nashua, Salem, Lawrence, Newburyport, Lowell, Westford, Rockport, Gloucester, Beverly, Boston, Newton, Fitchburg, Leominster	Portland, Brunswick, Jackson, Littleton, Franconia, Berlin, Lebanon, Hanover, Woodstock, Killington, Rutland, Keene, Brattleboro, Pittsfield, Springfield, Providence, Plymouth	New York 335km, Montreal 355km

COUNTRY	INSTALLATION	COORDINATES	CLOSEST COMMUNITY	COMMUNITIES WITHIN 100	COMMUNITIES WITHIN 200	OTHER NEARBY MAJOR SETTLEMENTS
UK	Sizewell B	52.214182, 1.617882	Seascale 2km	Southwold, Lowestoft, Great Yarmouth, Caister-on-Sea, Hemsby, Mundesley, North Walsham, Wroxham, Norwich,Wymondham, Dereham, Swaffham, Watton, Attleborough, Barnham, Diss, Eye, Thetford, Lakenheath, Ely, Milton, Newmarket, Cambridge, Bury St Edmunds, Stowmarket, Saffron Walden, Halstead, Braintree, Colchester, Clacton-on-Sea, Harwich, Felixstowe, Dedham, Sudbury, Haverhill, Ipswich, Aldeburgh	Chelmsford, Southend-on-Sea, London, Croydon, Margate, Cantebury, Maidstone, Guildford, Reading, Luton, Bicester, Milton Keynes, Bedford, Northampton, Kettering, Corby, Peterborough, Leicester, Grantham, Spalding, King's Lynn, Boston, Skegness, Cromer	The Hague 183km
	Sellafield	54.421120, -3.500463	Shimen 2km	Egremont, Cleator Moor, Whitehaven, Workington, Maryport, Aspatria, Silloth, Wigton, Dalston, Carlisle, Gretna Green, Brampton, Haltwhistle, Alston, Keswick, Penrith, Pooley Bridge, Howtown, Wasdale Head, Boot, Shap, Stanhope, Appleby-in-Westmorland, Kirkby Stephen, Ravenstonedale, Bowness-on-Windermere, Kendal, Sedbergh, Millom, Dalton-in-Furness, Barrow-in-Furness, Grange-over-Sands, Carnforth, Morecambe, Lancaster, Ingleton, Bentham, Fleetwood, Blackpool, Preston, Douglas	Ballymena, Bangor, Belfast, Dunmurry, Lisburn, Newry, Dundalk, Warrenpoint, Portpatrick, Stranraer, Campbeltown, Girvan, Ayr, Troon, Irvine, Greenrock, Paisley, Glasgow, Stirling, Falkirk, Livingston, Edinburgh, Musselburgh, North Berwick, Dunbar, Eyemouth, Berwick-upon-Tweed, Melrose, Kelso, Harwick, Bamburgh, Seahouses, Alnwick, Newcaslt-upon-Tyne, Sunderland, Durham, Hartlepool, Stockton-on-Tees, Middlesbbrough, Whitby, Richmond, Malton, Ripon, Harrogate, York, Leeds, Bradford, Halifax, Bolton, Manchester, Liverpool, Warrington, Sheffield, Chesterfield, Stoke-on-Trent, Chester, Wrexham, Rhyl, Llandudno, Conwy, Bangor, Caenarfon, Holyhead, Porthamdog, Harlech, Shrewsbury,	Cardiff 327km
Taiwan	Chinshan	25.285833,121.586111	Jinshan 3km	Sanzhi, Tamsui, Beitou, Wanli, Jinshan, Qidu, Keelung City, Zhongzheng, Bali, Wugu, Luzhou, Shilin, Songshan, Neihu, Xizhi, Pingxi, Shuangxi, Luzhu, Taishan, Sanchong, Taipei, New Taipei City, Taoyuan City, Guishan, Tucheng, Xindian, Pinglin, Yilan City, Hsinchu City, Miaoli City	Taichung City, Hualien City, Xincheng,	

COUNTRY	INSTALLATION	COORDINATES	CLOSEST COMMUNITY	COMMUNITIES WITHIN 100	COMMUNITIES WITHIN 200	OTHER NEARBY MAJOR SETTLEMENTS
	Kuosheng	25.202778,121.6625	Xigu 11km	Approximately as above – the sites are 12km apart.		
China	Gansu	36.150700, 103.518400	Zhongjia Bridge 2km	Baiyin, Lanzhou, Linxia	Huangnan, Haidong, Xining, Gannan, Dingxi,	Xi'an 530km
	Qinshan Phase III	30.433056,120.95	Würenlingen 2km	Jiaxing, Tongxiang, Hangzhou, Xiaoshan, Pinghu, Jinshan, Shangyu, Yuyao, Cixi, Ningbo, Fengchua	Zhoushan, Jinhua, Changzhou, Wuxi, Suzhou, Shanghai, Nantong	
Switzerland	Zwilag	47.541111, 8.231667	Bowmanville 5km	Baden, Waldshut-Tiengen, Schaffhausen, Bonndorf, Todtnau, Feldberg, Titisee-Neustadt, Donaueschingen, Villingen-Schwenningen, Tuttlingen, Singen, Konstanz, Kreuzlingen, Fraufeld, Winterthur, Kloten, St Gallen, Zurich, Liechtenstein, Lucerne, Zug, Arth, Schwyz, Altdorf, Glarus, Stans, Interlaken, Thun,Bern, Lyss, Biel, Solothurn, Langenthal, Aarau, Olten, Delemont, Porrentruy, Basel, Altkirch, Mulhouse, Thann, Bad Krozingden, Freiburg, Emmendingen, Colmar, Eguisheim, Lahr,Gengenbach	Besancon, Lausanne, Davos, Oberstdorf, Ulm, Stuttgart, Karlsruhe, Strasbourg	Geneva 217km, Munich 261km
Canada	Darlington	43.872778,-78.719722	Fairport 1km	Oshawa, Ajax, Clarington, Port Perry, Uxbridge, Newmarket, Aurora, Vaughan, Toronto, Mississauga, Brampton, Caledon, Oakville, Georgina, Innisfil, Barrie, Cannington, Beaverton, Lindsay, Snug Harbour, Kawartha Lakes, Orillia, Peterborough, Bridgenorth, Curve Lake, Buckhorn, McCrackens Landing, Norwood, Havelock, Campbellford, Gores Landing, Cobourg, Colborne, Brighton, Baltimore, Brockport, Medina, Niagara Falls	BellevillePrince Edward, Deseronto, Greater Napanee, Kingston, Marmora, Kaladar, Sharbot Lake, Cloyne, Bancroft, Barry's Bay, Haliburton, Minden, Gravenhurst, Bracebridge, Huntsville, Kearney, Rosseau, Parry Sound, McDougall, Midland, Collingwood, Meaford, Owen Sound, Hanover, Walkerton, Guelph, Waterloo, Kitchener, Startford, Hamilton,Ingersoll, Simcoe, Buffalo, West Seneca, Fredonia, Houghton, Salamanca, Allegany, Olean, Alfred, Hornell, Geneseo, Rochester, Canandaigua, Newark	Detroit 390km, Ottawa 294km

COUNTRY	INSTALLATION	COORDINATES	CLOSEST COMMUNITY	COMMUNITIES WITHIN 100	COMMUNITIES WITHIN 200	OTHER NEARBY MAJOR SETTLEMENTS
	Pickering	43.811667,-79.065833	Asco 2km	Approximately as above – the sites are 28km apart.		
Spain	Asco	41.2,0.569444	Trillo 2km	Falset, L'Ametlla de Mar, Miravet, Gandesa, Tortosa, Horta de San Joan, Maella, Calaceite, La Fresneda, Valderrobres, Beceite, Alcaniz, Calanda,Hijar, Albalate del Arzobispo, Andorra, Alcorisa, Molinos, L'Ampolla, Amposta, Sant Carles de la Rapita, Mequinenza, Sastago, Quinto, Bujaraloz, Castejon de Monegros, Sena, Fraga, Alcarras, Lleida, Torrefarrera, Mollerussa, Les Borges Blanques, Granyena de les Garriges, Balaguer, Artesa de Segre, Argamunt, Ponts, Guissona, Tarrega, Montblanc, Calaf, Igualada, Valls, Calafel, Tarragona, Salou	Sabadell, Barcelona, L'Hopitalet de Llobregat, Lloret de Mar, Tossa de Mar, Vic, Manresa, Berga, Cardona, Andorra la Vella, Sort, Vielha, Germ,Monzon, Barbastro, Huesca, Ejea de loas Caballeros, Zaragoza, Cuarte de Huerva, Tudela, Tarazona, Borja, Calatayud, Daroca, Calamocha, Escucha, Albarracin, Teruel, Mora de Rubielos, Culla, Castellon de la Plana, Vila-real	Madrid 368km
	Trillo	40.701111,-2.621944	Uthammar 5km	Cifuentes, El Sotillo, Alaminos, Mirabueno, Algora, Abanades, Luzaga, La Hortezuela do Ocen, Riba de Saelices, Esplegares, Sacecorbo, Ocentejo, Valtablado del Rio, Arbeteta, Armollones, Zaorejas, Villanueva de Alcoron, Olmeda de Cobeta, Selas, Herreria, Corduente, Ventosa, Taravilla, Poveda de al Sierra, Valsalobre, Carrascosa, Beteta, Puente de Vadillos, Santa Maria del Val, Fuetescusa, Canamares, Priego, Albendea, Alcantud, Vindel, Arbeteta, Escamilla, Millana, Alcocer, Sacedon, Aunon, Alocen, El Olivar, Budia, Yelamos de Arriba, Atanzon, Valfermoso de Tajuna, Tendilla, Hueva, Pastrana, Horche, Guadalajara, Marchamalo, Santos Humosa, Yunquera de Henares, Torija, Brihuega, Civica, Utande, Hita, Alarilla, Alovera, Alcala de Henares, Buendia, Albalate de Zorita, Priego, Siguenza, Jadraque,Madrid, Tarancon, Cuenca	Toledo, Las Rozas, Segovia, Avila, Sepulveda, Coca,Aranda de Duero, El Burgo de Osma, Soria, Tarazona, Zaragoza, Requena, Albacete, La Roda, Villarrobledo, Tomelloso, Manzanares, Campo de Criptana, Alcazar de San Juan	

COUNTRY	INSTALLATION	COORDINATES	CLOSEST COMMUNITY	COMMUNITIES WITHIN 100	COMMUNITIES WITHIN 200	OTHER NEARBY MAJOR SETTLEMENTS
Sweden	Clab*	57.411374, 16.654922		Ävro, Grönö, Vinö, Alö, Hamnö, Flivik, Blankaholm, Misterhult, Blomsterhult, Figeholm, Virbo, Farbo, Stensjö, Virbo, Boda, Gissebo, Getterum, Ishult, Dalsebo, Falla, Tuna, Alsarp, Vena, Flatebo, Hultsfred, Lönneberga, Bänarp, Målilla, Rosenfors, Mörlunda, Höganäs, Bockara, Oskarshamn, Klämna, Paskallavik, Fliseryd, Ruda, Högsby, Fågelfors, Fagerhult, Uranäs, Virserum, Åseda, Norrhult, Korsberga, Nye, Skirö, Vetlanda, Vimmerby, Ankarsrum, Gunnebo, Västervik, Blackstad, Gullringen, Katthult, Ingatorp, Mönsterås, Högsby	Växjö, Vislanda, Moheda, Lammhult, Värnamo, Ljungby, Gislaved, Sävsjö, Vaggeryd, Hestra, Tranemo, Jönköping, Nässjö, Eksjö, Österbymo, Tranås, Gränna, Bankeryd, Ulricehamn, Norrköping, Linköping, Vadstena, Motala, Katrineholm, Skövde, Kalmar, Karlskrona	Gothenburg 281km, Copenhagen 315km
			Kaaro 8km			
Finland	Onkalo**	61.23513,21.4821	San Luis Obispo 19km	Eurajoki, Kiukainen, Harjavalta, Nakkila, Luvia, Ulvila, Leineperi, Pori, Kullaa, Palus, Ruosniemi, Viasvesi, Makholma, Kaanaa, Lyttyla, Noormarkku, Lamppi, Tahkoluoto, Saarikoski, Pooskeri, Merikarvia, Lankoski, Siikainen, Pormakku, Honkakoski, Kankaanpää, Niinisalo, Honkajoki, Jamijarvi, Ojala, Kairila, Vihtejärvi, Savi, Lavia, Osara, Suodenniemi, Kiikoinen, Putaja, Häijää, Hämeenkyrö, Kauvatsa, Kiika, Aetsä, Sastamala, Kärppää, Unto, Kokemäki, Sammaljoki, Illo, Reikoski, Huittinen, Eura, Lappi, Kolla, Rauma, Reila, Kodisjoki, Ihode, Hinnerjoki, Pyhäranta, Laaja, Raulio, Laitila, Honkilahti, Koylio, Säkylä, Rutava, Vampula, Virttaa, Oripää, Kalikka, Yläne, Uusikartano, Raasi, Laitila, Uusikaupunki, Loimaa, Meillilä, Riihikoski, Mynämäki, Mietoinen, Askainen, Masku, Vahto, Paatinen, Lieto, Aura, Tarvasjoki, Turku, Naantali, Velkua, Taivassalo, Kustavi	Koski, Salo, Halikko,Pernio, Kisakallio, Lohja, Inga, Fiskars, Raseborg, Bromarf, Dalsbruk, Nagu, Korpo, Houtskär, Brändö, Sottunga, Utö, Kökar, Föglö, Lemland, Marjehamn, Godby, Hasvidden, Eckerö, Hyvinkää, Riihimäki, Forssa, Jokioinen, Janakkala, Hämeenlinna, Parola, Urjala, Akaa, Valkeakoski, Lempäälä, Kangasala, Pikonlinna, Tampere, Orivesi, Ikaalinen, Ruovesi, Vippula, Mänttä, Haapamäki, Virrat, Kotala, Parkano, Karvia, Isojoki, Lalby, Kaskinen, Närpes, Jurva, Kurikka, Seinäjoki, Ylistaro, Alavus, Laihia, Solf, Molpe, Korsnäs, Förtom	Helsinki 222km, Vaasa 207km

Appendix 3

Contingency Modelling

Capital cost estimates for the construction of the PRISM reactors have been sourced from a report by the United States Department of Energy. Senate testimony from General Electric suggests NOAK costs of the PRISM reactor may be approximately $2000 kW^{-1} installed.

Nonetheless, the cost figure applied in this analysis is in reference to the construction of a first-of-a-kind reactor. Incidents of early construction costs exceeding estimates are sufficiently common in nuclear construction. It is therefore prudent to test the economic outcomes of this proposal against potential cost overruns in capital cost of the reactors.

Modelling of this contingency was undertaken by adding 40% to the quoted capital costs of the PRISM reactor. Outcomes are shown on the right.

Figure 14 Net present value outcomes with contingency costing of reactors

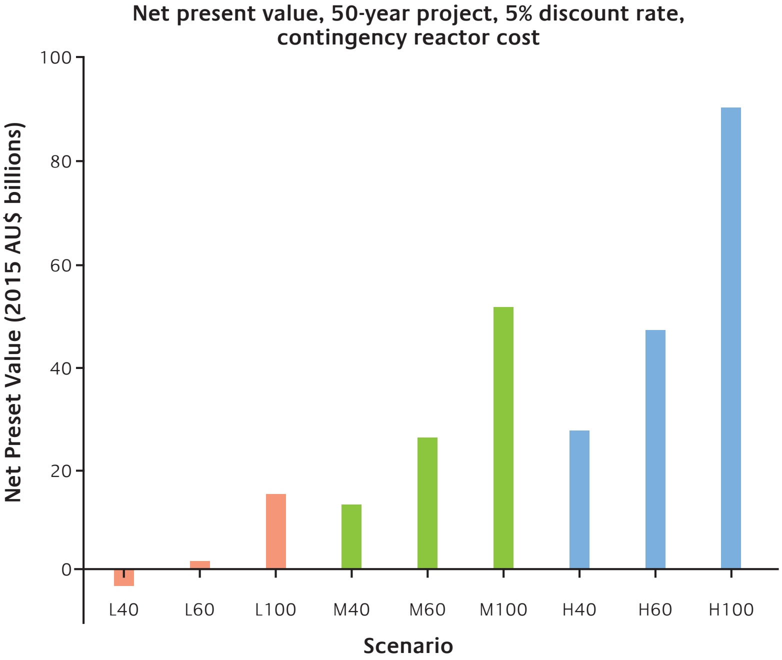
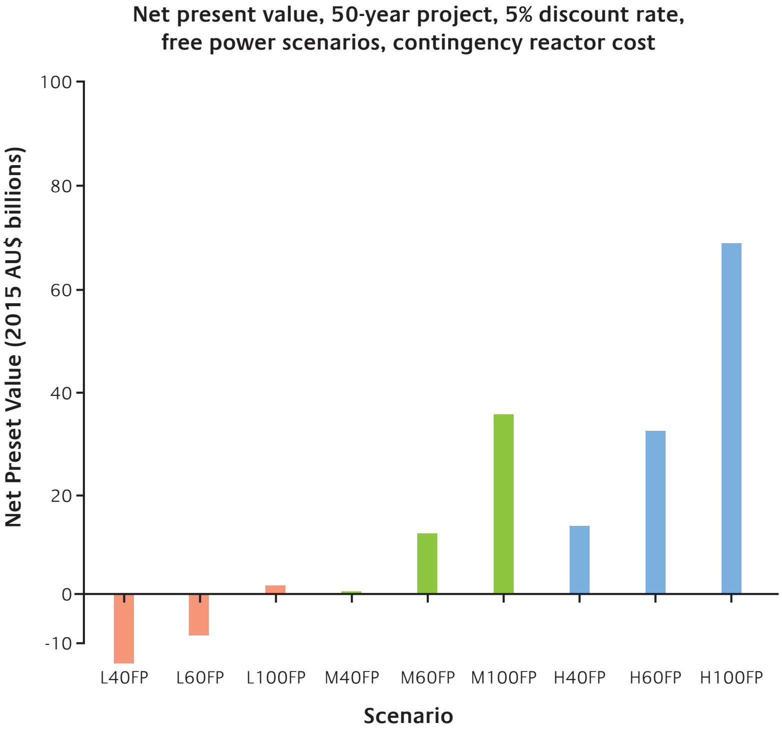


Figure 15 Net present value outcomes in free power scenarios with contingency costing of reactors



Adding the 40% contingency factor to all PRISM capital costs delivers a material difference to the outcomes. However overall, the proposal remains very attractive. Under the basic project, it is still only the Low illustrative scenario that delivers a loss to South Australia.

Under the “free power” scenario, positive economic outcomes become more dependent on larger storage facility size and higher price paid for material. Nonetheless the scope remains for positive economic outcomes across most scenarios.

While greater confidence must be sought regarding capital cost of the PRISM reactors, the overall project is economically robust even under reasonable cost-overrun assumptions.

Appendix 4

Suggested Further Reading

The Integral Fast Reactor (IFR): An Optimized Source for Global Energy Needs

Available from https://ams.confex.com/ams/91Annual/webprogram/Handout/Paper179693/179693_replacement.pdf

Prescription for the Planet: The painless remedy for our energy and environmental crises

Available from http://www.thesciencecouncil.com/index.php/prescription-for-the-planet

The case for a near-term commercial demonstration of the Integral Fast Reactor

Available from http://bravenewclimate.com/2012/10/23/the-case-for-near-term-commercial-demonstration-of-the-integral-fast-reactor/

Beyond wind: furthering development of clean energy in South Australia

Available from: http://www.tandfonline.com/doi/full/10.1080/03721426.2015.1035217#.VcQTifmqpBc

PRISM: A competitive small modular sodium-cooled reactor

Availble from http://gehitachiprism.com/wp-content/themes/geh_prism/resources/PRISM_Triplett_Loewen_Dooies.pdf

Plentiful Energy: The Story of the Integral Fast Reactor,

Available from http://www.thesciencecouncil.com/pdfs/PlentifulEnergy.pdf