ISSUES PAPER THREE

ELECTRICITY GENERATION FROM NUCLEAR FUELS

NUCLEAR FUEL CYCLE ROYAL COMMISSION

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ELECTRICITY GENERATION FROM NUCLEAR FUELS

THE NUCLEAR FUEL CYCLE ROYAL COMMISSION IS TASKED BY ITS TERMS OF REFERENCE WITH CONSIDERING THE FEASIBILITY OF ESTABLISHING AND OPERATING FACILITIES TO GENERATE ELECTRICITY FROM NUCLEAR FUELS IN SOUTH AUSTRALIA; THE CIRCUMSTANCES NECESSARY FOR THAT TO OCCUR AND TO BE VIABLE; THE RELATIVE ADVANTAGES AND DISADVANTAGES OF GENERATING ELECTRICITY FROM NUCLEAR FUELS AS OPPOSED TO OTHER SOURCES (INCLUDING GREENHOUSE GAS EMISSIONS); THE RISKS AND OPPORTUNITIES ASSOCIATED WITH THAT ACTIVITY (INCLUDING ITS IMPACT ON RENEWABLE SOURCES AND THE ELECTRICITY MARKET), AND THE MEASURES THAT MIGHT BE REQUIRED TO FACILITATE AND REGULATE THEIR ESTABLISHMENT AND OPERATION.

YOUR SUBMISSION

The Royal Commission is seeking submissions from interested members of the community, both within Australia and overseas, who have evidence, information or views which are relevant to its inquiry.

The purpose of this Issues Paper is to assist those proposing to make a submission to the Royal Commission.

It provides a factual background, from identified sources, relevant to understanding the questions on which the Commission seeks submissions. A submission should be in response to the questions posed in this Issues Paper. Your submission may address all, some or only one of the questions. Your submission is not limited by the factual background set out in this Issues Paper.

If you wish to make a submission on a topic that is not in response to a question in this Issues Paper you may do so, but it must be contained as an Appendix to your main submission which addresses the questions posed.

Before writing your submission you should read the Submissions Guideline (www.nuclearrc.sa.gov.au) issued by the Royal Commission. It may answer questions you have as to the form and content of your submission and how your submission will best assist the Commission.

A. NUCLEAR FUELS AND ELECTRICITY GENERATION

Power stations that use fossil fuels burn coal, oil or natural gas to generate heat and run turbines. Nuclear power relies on the heat energy created from the fission (splitting) of uranium atoms. From that point, current nuclear power plants typically use a steam power cycle (Rankine cycle) to generate electricity, under conditions similar to conventional coal (and some gas) power stations that are in commercial operation. Modern concentrated solar power and some geothermal systems also employ a similar steam cycle to generate electricity from thermal energy. In contrast, a wind turbine generates electricity directly from the motive force of the wind and solar photovoltaic panels generate electricity when light triggers the flow of electrons from a semiconductor in an electrical circuit.

Experimentation with nuclear reactors that could generate electricity to power cities commenced in the 1950s. Commercial operation of nuclear reactors became widespread in the 1960s, with most early deployment occurring in the US, UK, Europe, Russia and Japan. There are a number of types of reactor designs in commercial operation. Today, the most common types are the Pressurised Water Reactor (PWR), Boiling Water Reactor (BWR) (both termed Light Water Reactors – LWRs) and Pressurised Heavy Water Reactor (PHWR). The types of reactor are differentiated by their design, in particular by their technique for cooling the reactor core and for moderating (facilitating) the nuclear fission reaction, which in turn determines the extent to which the uranium needs to be enriched.

The power output of an electricity generating system is measured in megawatts electric (MWe) which quantifies the amount of electrical energy produced each second. Modern nuclear reactors are capable of producing more than 1000 MWe of power, with some designs producing between 1,600-1,800 MWe.[1] Plant size is in part a product of economies of scale that apply to the generation of electricity from nuclear fuels. Such an output compares to that of a very large coal or gas fired power station in Australia. For example, the Hazelwood brown coal power station in the Latrobe Valley in Victoria has a capacity of 1,600 MWe, and the combined Torrens Island gas-fired power station in Adelaide is 1,280 MWe. However, it is commonplace for coal or gas plants to have much smaller outputs in the range of 500 MWe.

Over the last decade, research has been undertaken into nuclear reactors of smaller size with corresponding smaller generating capacity of below 300 MWe. Renewed interest in smaller nuclear reactors has arisen as a result of the desire to reduce the financial burden of large capital expenditure, and provide the flexibility to supply into smaller electricity grids, for example within regional communities, or for large industrial users. Historically, smaller reactors have been used mostly in shipping, submarines and some remote military bases. At present, there are a number of small reactors in commercial operation, including in India (220 MWe) and Pakistan (300 MWe).[2]

Currently, there are a total of 395 nuclear power stations in operation around the world. In addition there are 43 reactors shut down in Japan, awaiting possible restart. According to the World Nuclear Association, a further 66 reactors are under construction, and some 165 reactors are planned.[3]

Further types of nuclear reactors are also under development which are referred to as "Generation IV" (to distinguish these technologies from the types of reactors discussed above collectively described as Generation II and III[4]). Many of these designs are Fast Neutron Reactors. The goals of Generation IV nuclear designs embody four core requirements: improved sustainability, economics, safety / reliability and proliferation resistance. Innovative advanced fission designs based on small modular reactors could, if commercialised, meet these goals, and mitigate hazards by incorporating passive safety with inherent self-protection. These reactor technologies use fuels more productively and generate less waste than conventional designs.

At present, Generation IV reactors are only in the research phase, with most development work being undertaken in US, UK, France and Russia. Currently, China also operates a test fast reactor, and India is soon to demonstrate a prototype sodium-cooled fast reactor (SFR). Some Generation IV reactors are designed to use thorium as a fuel. Unlike uranium, thorium does not require enrichment to be used in the fuel cycle; however thorium fuels may give smaller energy outputs depending on their composition. Prototype Thorium Molten Salt Reactor (MSR) technologies are proposed to be the subject of trials in India and China by 2017.[5]

NUCLEAR FUELS AND ELECTRICITY GENERATION CONTINUED

Delivery of electricity to consumers

Whether one or more nuclear reactors would be suitable to be developed in South Australia depends on how they might form part of the existing and future system for the supply and consumption of electricity in Australia.

Currently, almost all South Australians are supplied with electricity from generators connected to the National Electricity Market (NEM), transmitted through high voltage transmission lines (ElectraNet) and then distributed to businesses and households (SA Power Networks).

The NEM is the market in which electricity is traded between generators and retailers located in Australia's eastern and south-eastern states. It does not include the Northern Territory or Western Australia because there are no transmission interconnectors. It is managed by the Australian Energy Market Operator (AEMO).

The electricity supplied to the NEM is generated from a mixture of fuels and technologies. The total installed electricity generating capacity in Australia is around 50,000 MWe.[6] It is predominantly coal (74%) with the balance being met by gas (12%), and renewables such as wind, solar and hydro (14%). Figure 1 shows that the proportion generated from coal is falling.

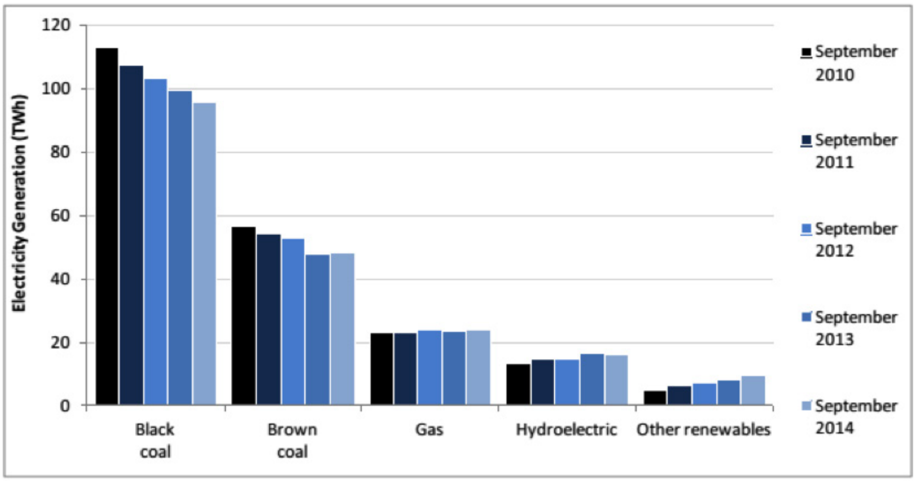

Figure 1: Contribution of various fuel types and technologies to electricity supply across Australia.[7]

In South Australia, AGL operates the Torrens Island Power Station in the Adelaide metropolitan region, which is the largest natural-gas-fired power station in Australia, having a capacity of 1280 MWe. The other major natural gas power station in Adelaide is at Pelican Point and has a capacity of 478 MWe. There are two coal-fired power stations operated by Alinta Energy in Pt Augusta, the Northern and Playford Power Stations, that have capacities of 546 MWe and 240 MWe respectively. The Northern Power Stations, which commenced operation in the mid-1980s, are forecast to cease operation in 2030.[8] The Playford Power Stations (coal-fired) are currently not in operation: Station A has been decommissioned, and Station B has not been in operation since 2012.

In addition, South Australia has 1203 MWe of installed wind generating capacity and 540 MWe of solar photovoltaic generation. This represents approximately 50% of the installed level of wind generating capacity across Australia and 17% of the photovoltaic generating capacity.[9] The location of all major electricity generating assets, and the transmission network, in the South Australian NEM is presented in Figure 2.

NUCLEAR FUELS AND ELECTRICITY GENERATION CONTINUED

Figure 2: Operating coal, natural gas, wind and diesel power stations across South Australia.[10]

NUCLEAR FUELS AND ELECTRICITY GENERATION CONTINUED

While in theory generators connected to the market are able to supply any customer connected through the interconnected transmission and distribution networks, there are physical constraints on the amount of electricity that can be supplied at any time. This means that any proposal to install a new generator within the NEM would need to consider the capacity of the network to effectively transmit the additional electricity. These constraints are monitored by the market operator within each 'region' of the market (each State broadly comprises a region). The South Australian regional NEM has an installed generating capacity of 5000 MWe. The presence of interconnectors between regions allows for the transmission of electricity between those regions. The Heywood interconnector (a transmission link between Mount Gambier in South Australia and Heywood in Victoria) allows for up to 460 MWe of surplus electricity to be exported to the Victorian regional NEM from South Australian generators (or imported, in times of deficit). By July 2016, the capacity of the Heywood interconnector is to be upgraded to 650 MWe.[11] The other interconnector (located between Berri in South Australia and Red Cliffs in Victoria) is the Murraylink direct-current interconnector, which allows for the transmission of up to 220 MWe of electricity from South Australia.

Customers who are not connected to the NEM are supplied via "off-grid" electricity generation and distribution systems. Off-grid consumers typically include industries such as agricultural processing facilities, mines, desalination plants and regional communities. Off-grid electricity demand is primarily supplied through natural gas and diesel fuel,[12] or solar photovoltaics and batteries for small operations and households.

In addition to issues of nuclear reactor technology and the market that any generator would supply, there are other feasibility considerations relevant to physical siting. These include the potential for earthquake activity and the availability of water for cooling of the steam generators.[13] Convenient access to relevant electricity transmission infrastructure to allow for delivery of electricity is likely to be required. If such infrastructure is not already in place, the feasibility of its construction will also need to be assessed. Access to other infrastructure such as roads, rail and ports is also likely to be required to deliver plant equipment to the site during construction, operation and maintenance, and to deliver nuclear fuel to, and waste from the site. A range of environmental assessments relevant to any particular site would include, but is not limited to, adequate evaluation of the impact on community amenities, noise, vibration and air quality; site contamination and waste management; and robust short and long-term management procedures for low, intermediate and high-level radioactive wastes.

The *Environment Protection and Biodiversity Conservation Act 1999* (Cth) prohibits approval being given under that Act for the construction or operation of a commercial nuclear reactor in Australia. The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) regulates the establishment and operation of nuclear installations by Commonwealth entities through the issuing of licences. Pursuant to the *Australian Radiation Protection and Nuclear Safety Act 1998* (Cth), ARPANSA is prohibited from authorising a Commonwealth entity to construct or operate such a facility.

In addressing the feasibility of establishing and operating facilities to generate electricity from nuclear fuels in South Australia:

3.1. **Are there suitable areas in South Australia for the establishment of a nuclear reactor for generating electricity? What is the basis for that assessment?**

While the Commission is not tasked with making a recommendation about the suitability of a specific site (or sites) in South Australia for a possible nuclear reactor facility, it will address the issue of site selection in a more general sense by identifying the factors relevant to that decision and best practice in that process.

3.2. **Are there commercial reactor technologies (or emerging technologies which may be commercially available in the next two decades) that can be installed and connected to the NEM? If so, what are those technologies, and what are the characteristics that make them technically suitable? What are the characteristics of the NEM that determine the suitability of a reactor for connection?**

3.3. **Are there commercial reactor technologies (or emerging technologies which may be commercially available in the next two decades) that can be installed and connected in an off-grid setting? If so, what are those technologies, and what are the characteristics that make them technically suitable? What are the characteristics of any particular off-grid setting that determine the suitability of a reactor for connection?**

PART A
FOOTNOTES / REFERENCES ON THE NEXT PAGE

[1] IAEA Reference Data Series No.2, Nuclear Power Reactors in the World 2014, available at http://bit.ly/1Du6Kra.

[2] A further three small nuclear power reactors are currently under construction in Argentina, Russia and China, along with others that range in capacity from 50 – 311 MWe in line for near-term deployment. World Nuclear Association Small Nuclear Power Reactors available at http://bit.ly/XnW2UL.

[3] IAEA Power Reactor Information System, last updated 24 April 2015, available at http://bit.ly/1Ghui3m.

[4] Most commercially operating nuclear reactors around the world today are based on Generation II designs. Generation III refers to variants of Generation II with additional safety features, including passive cooling.

[5] World Nuclear Association, Generation IV Nuclear Reactors Aug 2014 available at http://bit.ly/VdHbv9.

[6] AEMO, National Electricity Market Factsheet, available at http://www.aemo.com.au/About-the-Industry/Energy-Markets/National-Electricity-Market.

[7] Australian Government Dept. of Environment, Quarterly Update of Australia's National Greenhouse Gas Inventory: September 2014, Published Mar 2015, available at http://bit.ly/1K6ndpW.

[8] Alinta Energy, Port Augusta Solar Thermal Generation Feasibility Study Milestone 2 Summary Report, July 2014, available at http://bit.ly/1EPKVby.

[9] AEMO and ElectraNET, Renewable Energy Integration in South Australia, Oct 2014, available at http://www.aemo.com.au/Electricity/Planning/Integrating-Renewable-Energy.

[10] AEMO, South Australian Electricity Report – South Australian Advisory Functions Aug 2014 available at http://bit.ly/1aTBSs8.

[11] AEMO, The Heywood Interconnector: Overview of the Upgrade and Current Status, July 2014 available at http://bit.ly/1EtRTCM.

[12] Australian Govt. Australian Trade Commission, Australian Remote Renewables: Opportunities for Investment available at http://bit.ly/1PlsIEj.

[13] South Australia does experience infrequent earthquake activity in a zone of geological faults: see Issues Paper Four: Management, Storage and Disposal of Nuclear and Radioactive Waste.

NEXT
PART B
VIABILITY OF ELECTRICITY GENERATION IN SOUTH AUSTRALIA CONTINUED

B. VIABILITY OF ELECTRICITY GENERATION IN SOUTH AUSTRALIA

Assessing the viability of any new generating capacity requires consideration of the means by which electricity generators derive income from either the NEM or an off-grid setting, and whether sufficient demand for new electricity generation facilities exists now or in the future.

The electricity spot market

Electricity is traded in the NEM between generators and retailers of electricity in a spot market. A spot market involves a commodity, such as electricity, being traded between a buyer and seller for immediate delivery. Such a market is distinguished from the trade of a commodity at a pre-determined price over an extended period of time, such as under a long term contract, or at a price fixed by a regulator.

The market operator (AEMO) manages the NEM spot market by instantaneously matching power supply and demand in each region. Each generator bids to supply an amount of electricity into the market for a future five-minute interval. AEMO receives and accepts sufficient bids to meet demand for each 5 minute interval, starting with the lowest price bids first. When AEMO accepts a bid, the generator is 'dispatched' to supply the relevant amount of electricity at the relevant time, and the generator will be paid the 'spot price' for the electricity supplied by the last generator to be dispatched. Spot prices can be very volatile and vary between minus $1,000/MWh and $13,500/MWh. Retailers and generators have either vertically integrated or entered into long term financial contracts, known as hedging, to manage these risks. The difference between the spot price, their portfolio of managed contracts, and the cost to the generator of producing the electricity will determine the generator's profit or loss. By virtue of a system of subsequent reconciliations, AEMO pays generators the relevant spot prices for the electricity supplied to the NEM, and recovers those costs from electricity retailers. Electricity retailers in turn recover their costs from their retail customers (households and businesses, who generally do not participate directly in the NEM).

Current demand for electricity within the NEM is 193.6 terrawatt hours (TWh), which compares to the total demand in 2008-9 of 210.5 TWh see Figure 3. (1 TWh is equal to 1 billion kWh, with a kWh being the typical unit of electricity consumption which appears on most household and commercial electricity bills). Demand has been falling across the NEM regions since 2008-9 for a number of reasons, including the success of energy efficiency programs, reduced demand from large electricity users (including the closure of major industry), and the installation of rooftop solar photovoltaic systems.[15]

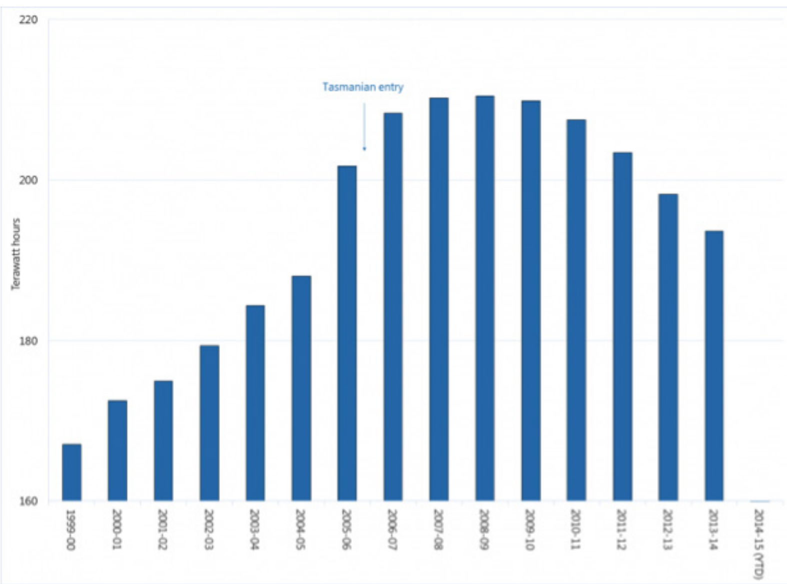

Figure 3: Total electricity consumption in the NEM from 1999 to 2014.[16]

VIABILITY OF ELECTRICITY GENERATION IN SOUTH AUSTRALIA CONTINUED

Daily demand for electricity in the NEM remains highly variable from region to region, and depends on population, climate, and industrial and commercial needs. The demand for electricity in South Australia exhibits a 'peaky' characteristic with the maximum demand for electricity being about double the average demand. The typical level of demand for electricity on a business day of average temperatures is 1400 MWe. However, on days of extreme temperature in January and February, demand for electricity within South Australia's regional NEM can increase to a peak of over 3200 MWe (see Figure 4).

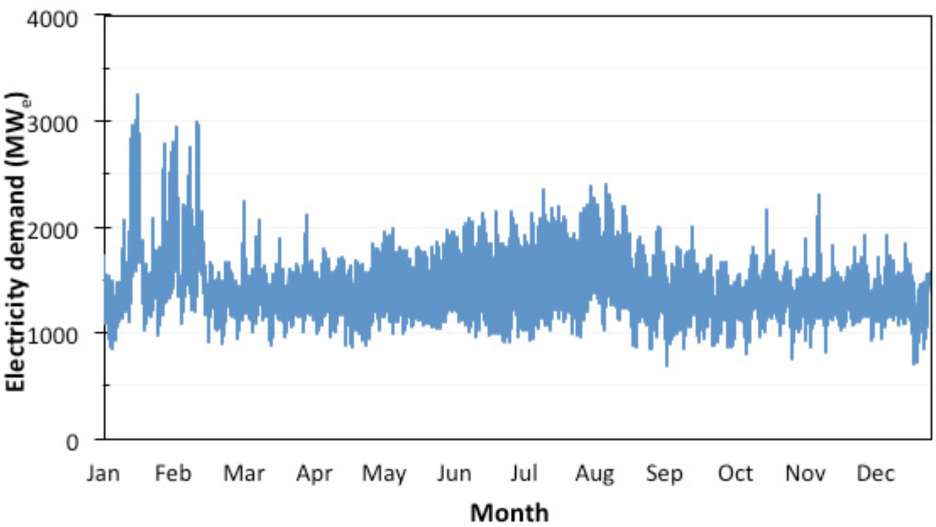

Figure 4: Time-series of half-hourly electricity demand in the South Australian regional NEM through 2014.[17]

AEMO has forecast (see Figure 5) that the NEM will continue to have surplus electricity generating capacity until at least 2023-24. The extent of surplus in South Australia and Tasmania is forecast to be less than that in the other NEM regions. The trend in surplus electricity generating capacity across the five NEM regions is shown in Figure 4. It shows that until 2023-24, South Australia will have an excess of approximately 600 MWe of installed capacity, meaning that this much capacity could notionally be withdrawn without affecting stable supply.

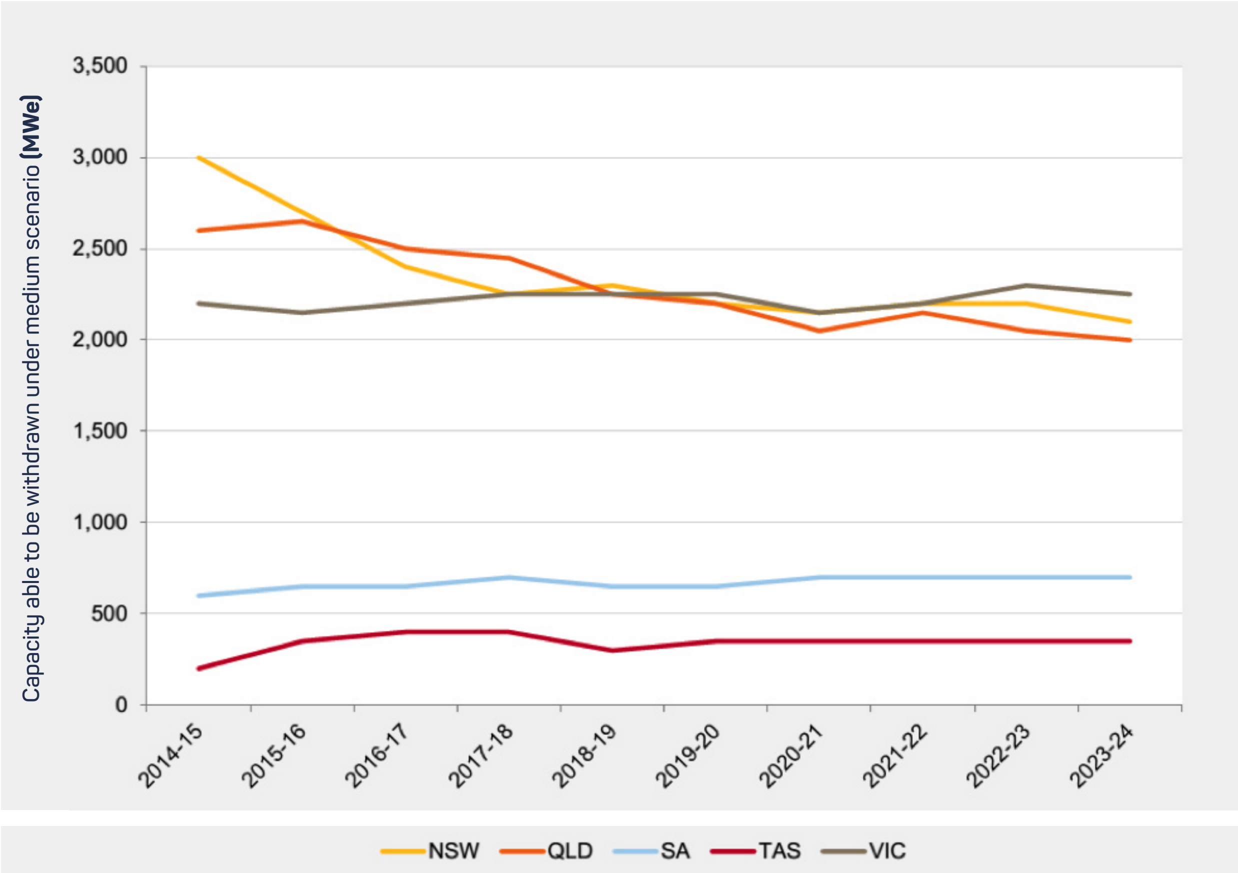

Figure 5: Forecast surplus electricity generating capacity (in MWe) across the five NEM states to 2023-24 in the medium electricity forecast growth scenario developed by AEMO.[18]

Off-grid arrangements

Supplying electricity to an off-grid industrial consumer or regional community may provide access to a captive consumer that has a stable and predictable demand profile. However, captive markets may also present a risk to a generator because demand for energy is directly related to the profitability or otherwise of a small group or a single captive consumer. This risk is evident in the demand for electricity from a desalination plant, for example, being subject to the presence or alleviation of drought conditions in a given region. In comparison, the risk of falling demand in the NEM is far smaller, given it is made up of a diverse mix of industrial, residential and commercial consumers. To mitigate the risk to a generator in an off-grid setting, "take or pay" contracts may be an option. Such contracts require the party to whom electricity is delivered to either consume it, or pay a penalty for not doing so.

Against that background:

3.4. What factors affect the assessment of viability for installing any facility to generate electricity in the NEM? How might those factors be quantified and assessed? What are the factors in an off-grid setting exclusively? How might they be quantified and assessed?

3.5. What are the conditions that would be necessary for new nuclear generation capacity to be viable in the NEM? Would there be a need, for example, for new infrastructure such as transmission lines to be constructed, or changes to how the generator is scheduled or paid? How do those conditions differ between the NEM and an off-grid setting, and why?

3.6. What are the specific models and case studies that demonstrate the best practice for the establishment and operation of new facilities for the generation of electricity from nuclear fuels? What are the less successful examples? Where have they been implemented in practice? What relevant lessons can be drawn from them if such facilities were established in South Australia?

3.7. What place is there in the generation market, if any, for electricity generated from nuclear fuels to play in the medium or long term? Why? What is the basis for that prediction including the relevant demand scenarios?

[14] The spot price of electricity is determined for each half hour period by averaging the six applicable 'dispatch prices' for that half hour. The 'dispatch price' is the bid made by the generator last dispatched to meet demand in the relevant 5 minute period.

[15] Climate Change Authority, Reducing Australia's Greenhouse Gas Emissions - Targets and Progress Review, Feb 2014.

[16] Australian Energy Regulator, National Electricity Market electricity consumption available at http://bit.ly/1E2awdV .

[17] AEMO, Aggregated Price and Demand 2011 - 2015, available at http://bit.ly/1bkmDJg.

[18] AEMO, Electricity Statement of Opportunities for the National Electricity Market, Aug 2014 available at http://bit.ly/1G9bK5i.

C. ADVANTAGES AND DISADVANTAGES OF DIFFERENT TECHNOLOGIES AND FUEL SOURCES; RISKS AND OPPORTUNITIES

As there are a number of fuels and technologies for the generation of electricity, any decision to establish and operate a nuclear facility for electricity generation in South Australia would need to consider the relative advantages and disadvantages of nuclear power compared to other sources and technologies, along with the risks and opportunities that nuclear power may present.

Many advantages and disadvantages of different kinds of technologies and fuels are relevant. These issues include matters such as differences in greenhouse gas emissions over the lifetime of the plant's operation, the cost of electricity generated, certainty of supply (intermittency), comparison of health and safety for the community and workers, local and wider environmental impacts, robustness of operating standards, security measures and management procedures to mitigate the risks presented by waste produced, and the cost of decommissioning, closing and relinquishing the site of a power plant. Some of these issues are discussed in further detail below.

After identifying all relevant advantages and disadvantages, a critical issue for the Commission will be to identify a reliable means by which those relevant advantages and disadvantages can be critically analysed. This will require consideration to be given to how those advantages and disadvantages might apply in South Australia at the relevant time in which a nuclear reactor for generating electricity might feasibly be established.

3.8. **What issues should be considered in a comparative analysis of the advantages and disadvantages of the generation of electricity from nuclear fuels as opposed to other sources? What are the most important issues? Why? How should they be analysed?**

Community and environment

Nuclear accident

A nuclear accident has the potential to cause significant and wide-ranging damage to people, property and the environment due to the harmful effects of exposure to radiation.

The meltdown at the Chernobyl reactor in Ukraine in 1986 demonstrated the potential for serious consequences from a nuclear reactor where there are inadequate safety precautions. The meltdown and destruction of Chernobyl reactor number 4 led to a large uncontrolled release of radioactive material into the environment. In the immediate aftermath, it resulted in the death of more than thirty operators and emergency services personnel from acute radiation sickness. A permanent exclusion zone of radius 30 km has been maintained around the facility since the meltdown. Despite initial estimates of radiation-related deaths being in the order of tens of thousands, the long-term health effects of the Chernobyl accident remain unclear but are now generally expected to be lower than originally anticipated.[19] It is relevant to note that the specific design of the Chernobyl plant has been criticised as inherently unstable and lacking sufficient containment structures, and would not have been able to be licensed for construction and operation outside of the former Soviet Union.

The serious consequences were further demonstrated on 11 March 2011 when an accident occurred in three of the six reactors at the Daiichi Nuclear Power Plant in Japan. The accident occurred as a result of a coolant loss following a tsunami triggered by the magnitude 9.0 Tōhoku earthquake. The reactors at this plant had a combined power generating capacity of 4,700 MWe, making it one of the fifteen largest nuclear power plants in the world. As a result of risks associated with radiation exposure, 154,000 people remain evacuated from the region and a 30 km exclusion zone around the reactor continues to be maintained.[20] Over 2011, a significant amount of radioactive material was released into the atmosphere, which will continue to present a remediation problem for decades. Further releases of radioactive water into the sea, groundwater and through surface water runoffs continue to present significant remediation problems.[21] These have had a deleterious impact on the feasibility of fisheries and agriculture in the Fukushima region.

ADVANTAGES AND DISADVANTAGES OF DIFFERENT TECHNOLOGIES AND FUEL SOURCES; RISKS AND OPPORTUNITIES CONTINUED

Investigations subsequent to the Fukushima Daiichi accident identified deficiencies in the siting of backup systems, operator and emergency response, disaster recovery planning, and communication of risks arising from the incident.[22] The official Independent Investigation Commission into the Fukushima Daiichi accident determined that all causes of the accident were foreseeable and could have been mitigated by the installation of basic safety and emergency planning measures. That Commission made a series of recommendations requiring more robust parliamentary scrutiny of the nuclear regulatory body and the plant operator (TEPCO), reform of crisis management systems, and regular monitoring and revision of laws to reflect global standards of operational safety, emergency response and attribution of roles. Internationally, the United Nations undertook a system-wide study of the implications of the accident which resulted in a number of recommendations.[23]

The design, safety and operational efficiency of modern nuclear facilities have improved significantly since the construction and operation of the reactors involved in the Fukushima Daiichi and Chernobyl accidents. This includes an emphasis on advanced safety systems. Nonetheless, the associated risks cannot be entirely eliminated.

Given that the construction or operation of a commercial nuclear power plant is effectively prohibited under Australian law, there is no existing State or Commonwealth regulatory regime in place to make the development and operation of such a facility in South Australia as safe as possible. Any such regulatory regime would need to be created so as to recognise and carefully manage the special risks associated with generating electricity from nuclear fuels potentially poses to the health and safety of people and the environment. Guidance would be available from overseas jurisdictions, including recent entrant nations, and international organisations such as the IAEA.

Australia is a party to a number of relevant international treaties and conventions in this area, including the Convention on Nuclear Safety. There is also a large body of technical standards and guidance documents, developed primarily through the IAEA, reflecting recognised international best practice in nuclear related activities. Any addition to or adaptation of existing regulatory frameworks for the purpose of sanctioning and regulating nuclear power generation in South Australia would need to identify and appropriately implement the relevant aspects of these applicable international instruments.

The construction or operation of a nuclear power plant in South Australia would also engage Commonwealth and State regulatory arrangements concerning environmental protection, land use and planning, and electricity generation and supply. The extent to which the construction or operation of a nuclear power plant would warrant separate or new regulation, or the adaptation of existing general regulatory arrangements, requires considered analysis.

It is also important to consider who bears the cost of an accident. Most jurisdictions with nuclear energy industries have developed and implemented specialised liability and insurance regimes. These regimes aim to ensure the availability of sufficient funds as compensation for damage that is sustained locally and beyond national borders, and also to provide sufficient financial certainty for industry participants. In general, under these regimes nuclear power station operators are strictly and exclusively liable for all damages resulting from a nuclear accident, irrespective of fault. Therefore, nuclear power station operators have to maintain a certain level of third party insurance. However these regimes often also cap the maximum amount of compensation payable by an operator, leaving the relevant government to meet any shortfall required for compensation and remediation.

Australia is currently a party to the Paris Convention on Third Party Liability in the Field of Nuclear Energy, but has not implemented a specialised domestic regime for civil liability for nuclear damage.

3.9. **What are the lessons to be learned from accidents, such as that at Fukushima, in relation to the possible establishment of any proposed nuclear facility to generate electricity in South Australia? Have those demonstrated risks and other known safety risks associated with the operation of nuclear plants been addressed? How and by what means? What are the processes that would need to be undertaken to build confidence in the community generally, or specific communities, in the design, establishment and operation of such facilities?**

3.10. **If a facility to generate electricity from nuclear fuels was established in South Australia, what regulatory regime to address safety would need to be established? What are the best examples of those regimes? What can be drawn from them?**

Greenhouse gas emissions and other waste products

Over the last 150 years, global average concentrations of carbon dioxide in the atmosphere have increased from pre-industrial levels of approximately 280 parts per million (ppm) to over 430 ppm. It is generally accepted that this has contributed to global warming: the global average temperature across the Earth's surface has increased by 0.85°C over the same period. The adverse impacts of global warming over the 21st century are predicted to include global sea level rise, longer and hotter heat waves, more frequent extreme precipitation events, and warming and acidification of the oceans.[24]

The 2009 UN Framework Convention on Climate Change in Copenhagen agreed on limiting warming to two degrees Celsius, relative to pre-industrial levels.[25] The most recent Intergovernmental Panel on Climate Change (IPCC) Report states that emissions reductions in the order of 40 - 70% of 2010 levels by the year 2050 have a reasonable prospect of achieving this objective.[26] The Commonwealth Government has committed to a policy that by 2020 it will reduce Australian greenhouse gas emissions to 5% below the emission levels in 2000.

The electricity sector in Australia contributes 33% of total national greenhouse gas emissions, and these emissions are largely attributable to the combustion of coal and natural gas.[27] Over the six years to September 2014, electricity sector emissions decreased by approximately 3% as a result of a number of factors, including falling electricity demand across the NEM, implementation of energy efficiency measures, and the increasing use of renewable fuels to generate electricity.

One technique for calculating the comparative advantages in terms of greenhouse gas emissions from different technologies or fuels used for generating electricity is to account for all of the carbon dioxide (and equivalent greenhouse pollutants) that are produced over the lifecycle of the fuel and infrastructure. This includes the emissions associated with recovering the fuel and those associated with the construction, operation and decommissioning of the infrastructure.

Lifecycle modelling is generally accepted as being a robust, first-order tool to quantify expenditure of generating electricity over the asset lifecycle, while also incorporating the impacts of waste management and decommissioning activities. Many lifecycle assessments have been undertaken over the last thirty years to compare and contrast the greenhouse gas emissions impact of renewable and non-renewable electricity generating technologies. The results from these analyses vary significantly depending on the technology and fuel mix that is considered and the underlying assumptions made with respect to operating characteristics and market interactions. It does not typically include systems effects such as emissions associated with grid management, and maintaining back-up reserves to ensure stable electricity supply.[28]

The results of lifecycle emissions assessments also depend on the region being analysed, and the current and anticipated rate of technology development. A recent series of lifecycle assessments carried out by the National Renewable Energy Laboratory in the United States sought to harmonise assumptions made across the large number of models published in the peer-reviewed literature.[29] While this has to a certain extent reduced the range of uncertainty arising from varying methods and assumptions, a case-by-case analysis is necessary to ensure the veracity of all modelling assumptions.

3.11. How might a comparison of the emission of greenhouse gases from generating electricity in South Australia from nuclear fuels as opposed to other sources be quantified, assessed or modelled? What information, including that drawn from relevant operational experience should be used in that comparative assessment? What general considerations are relevant in conducting those assessments or developing these models?

There are also other wastes and pollutants produced by the generation of electricity in addition to greenhouse gas emissions that have an effect on the community and the environment.

Current commercially operating nuclear reactors produce both nuclear and radioactive waste. The management, storage and disposal of these wastes requires particular facilities and techniques. These are addressed in detail in Issues Paper 4: Management, Storage and Disposal of Nuclear and Radioactive Waste.

Power stations that use coal as a fuel produce particulate air emissions (including soot and heavy metals), solid wastes (e.g. flyash) and liquid waste, both from mining processes and combustion during operation. The air emissions contain microscopic particles, including particulate matter with average diameter less than 2.5 microns. The generation of electricity using natural gas does not produce significant particulate emissions, but can contribute to the generation of photochemical smog in urban areas from the emission of oxides of nitrogen. In contrast, the process of generating electricity from wind or using solar photovoltaics produces very little waste. Wastes are however generated in the construction and decommissioning of any major industrial resource recovery and power generation facility.

3.12. **What are the wastes (other than greenhouse gases) produced in generating electricity from nuclear and other fuels and technologies? What is the evidence of the impacts of those wastes on the community and the environment? Is there any accepted means by which those impacts can be compared? Have such assessments making those comparisons been undertaken, and if so, what are the results? Can those results be adapted so as to be relevant to an analysis of the generation of electricity in South Australia?**

Operational health and safety

The operation of a nuclear reactor poses potential risks to workers at the plant due to radiation. While the potential risks of handling nuclear and radioactive waste are addressed in detail in *Issues Paper 4: Management, Storage and Disposal of Nuclear and Radioactive Waste*, the risks to workers at a nuclear power generation facility during its ordinary operation also need to be analysed comprehensively, bearing in mind the design and construction of the facility.

Activities involving the handling and storage of radioactive substances require a licence under the *Radiation Protection and Control Act 1982* (SA), the general objective of which is to ensure that exposure of persons to radiation is kept "as low as reasonably achievable". What is "reasonably achievable" depends on an analysis of the activity, risk, duration and the precautions that can be taken. Employers and contractors also owe a general statutory duty to ensure the health and safety of their workers and the community under the *Work Health and Safety Act 2012* (SA). The combined effect of those regulatory arrangements is that workers who deal with these substances must be provided with information about any potential hazards prior to commencing work and be provided with personal protective equipment which is specifically designed to protect against radiation exposure. In addition to limits being placed on the amount of radiation to which a worker may be exposed, other techniques such as monitoring and radiation tagging are required to be employed in specific circumstances. Limits and requirements for radiation protection of the community are developed in accordance with Australian and international standards.

3.13. **What risks for health and safety would be created by establishing facilities for the generation of electricity from nuclear fuels? What needs to be done to ensure that risks do not exceed safe levels?**

Safeguards

The operation of a nuclear reactor gives rise to non-proliferation policy issues given the potential for that technology to be applied for non-peaceful purposes.[30] Under existing law, permits to possess and operate that equipment must be obtained under the *Nuclear Non-Proliferation (Safeguards) Act 1987* (Cth). Furthermore, separate authorisation is required under Customs regulations in order to import reactor technology.

3.14. **What safeguards issues are created by the establishment of a facility for the generation of electricity from nuclear fuels? Can those implications be addressed adequately? If so, by what means?**

Economy

Impact on the market and other generation sources

A diverse mix of technologies and fuels offer different features to the electricity market in terms of their ability to match the transient nature of electricity demand, and in their ability to deliver stable supply to consumers.

Many generation technologies cannot be switched on (or off) at the request of power grid operators. They are known as non-dispatchable and are distinguished from peaking turbines that can be operated flexibly in response to short-term fluctuations in electricity demand. In Australia, open cycle gas turbines and hydro-electricity fulfil much of that role.

Other technologies are intermittent, often unpredictably so. Electricity generated from solar photovoltaics, wind and tidal energy systems are subject to changes in weather and other sources of natural variability. In the absence of commercial scale energy storage technology, back-up capacity must be available from other generators to ensure a stable, consistent supply of electricity. At present in Australia this back-up capacity is supplied predominantly by coal and gas generators. It is possible in the future that some mix of utility-scale thermal or distributed electric storage (batteries, including possible vehicle to grid systems) and smart grid management could address intermittency.

The financing of any new generation capacity (whether base load or intermittent) is likely to be affected by the price volatility in the NEM as a result of the large variations in demand. While generators manage price volatility by entering into futures contracts (a contract to sell a fixed amount of electricity in the future at a pre-determined price), the volatility still gives rise to long term revenue uncertainty. This is a characteristic of all deregulated (or liberalised) electricity markets.

In Australia, incentives to encourage investment in renewable sources has been provided through the Renewable Energy Target (RET). Under the arrangements established in the RET, renewable electricity generators are able to create renewable energy certificates for every MWh of electricity they produce and supply. Electricity retailers are required to purchase a certain amount of renewable energy certificates each year, which effectively creates demand for the production of electricity from renewable sources.

Recently in the UK, which also has had a deregulated electricity market like the NEM, a new nuclear power generation project for Hinkley Point was able to secure investment certainty by the development of a regulated "contract for difference" model for the purchase of the electricity supplied by the facility to retailers.[31] These arrangements are complex, but at a basic level require nuclear power generators to sell energy into the market as usual, and require a retailer to provide a top-up from the variable spot price to a pre-agreed 'strike price' (if the relevant spot price is less). At times when the spot price exceeds the strike price, the generator is required to pay back the difference, thus protecting consumers from over-payment.

3.15. **What impact might the establishment of a facility to generate electricity from nuclear fuels have on the electricity market and existing generation sources? What is the evidence from other existing markets internationally in which nuclear energy is generated? Would it complement other sources and in what circumstances? What sources might it be a substitute for, and in what circumstances?**

The unit cost of electricity generated

There are many competing claims about the cheapest source from which electricity may be generated.

To determine the relative cost of nuclear fuels for electricity generation as against other fuel sources, the costs of building and operating a nuclear reactor need to be quantified in a way that can be compared to the costs of building and operating any other electricity generating facility.

An approach that is typically employed to quantify and compare such costs is known as a levelised cost analysis. This analysis is intended to determine the unit cost of electricity generated. That analysis takes into account the initial infrastructure investment required, ongoing costs relating to operations and maintenance, fuel costs, financing costs, and costs relating to decommissioning and remediation.

Careful consideration must be given to the form of the analysis and the inputs to ensure the true comparability of the results for different fuel sources. For example, a levelised cost analysis may need to attach a "price" to environmental impacts which are not directly borne by the producer or consumer (an externality). It must also value future costs in present dollar terms – a determination of their net present value. The selection of a discount rate used in that calculation needs to be identified and justified. In calculating levelised costs it is also important to consider the operational life of the assets. For modern nuclear power installations, design lives are commonly 60 years. With likely life-extensions, such units could operate for 80 years or more. Costs need to be analysed over the entire period of the obligations created by, and consequences of, decisions to establish new facilities. For example, for a new nuclear installation in the UK, such costs include a very conservative estimate of treating and disposing of the waste, and of the ultimate decommissioning of the plant.

The two dominant inputs in the calculation of levelised cost are the capital cost of the nuclear power station and the cost of capital used to finance it. Many of the factors determining the cost of capital are driven by the policy context within which the nuclear power industry is developed and operates.

3.16. How might a comparison of the unit costs in generating electricity in South Australia from nuclear fuels as opposed to other sources be quantified, assessed or modelled? What information, including that drawn from relevant operational experience, should be used in that comparative assessment? What general considerations should be borne in mind in conducting those assessments or models?

Future economic impacts

There may be other benefits from the establishment of a nuclear reactor. An example is the ability of particular types of nuclear reactors to offer the capability to deliver stable high temperature (>850°C) process heat as well as electricity. This means that a nuclear reactor could potentially satisfy demand for industrial process heat and electricity from energy intensive industries including minerals processing, petrochemicals production and seawater desalination.

In addition, there may be opportunities for the development of related sectors. While establishment of facilities for the generation of electricity from nuclear fuels would require international expertise and co-operation – given that there are no domestic suppliers and operators of these plants – there will be a need for domestic specialist training by tertiary and technical providers. Skills required to operate and maintain these facilities would include expertise across all the major engineering services disciplines; environmental, physical and social sciences; and financial management. Australia has a well-established and mature market for the provision of all of these services for large infrastructure projects in the resources and power generation sectors, although the specialised skills required in the context of the construction, operation and maintenance of a nuclear reactor would require development.

There have been further positive and negative suggestions as to the wider impact of such a facility on the economy. A suggestion has been made that the establishment of nuclear facilities might encourage new investment by energy intensive industries seeking to take advantage of a reliable baseload power source or possible growth in advanced manufacturing. Conversely, it has been suggested that the establishment of nuclear facilities could have a negative impact on other sectors of the economy (for example tourism and agriculture) by reason of damage to reputation.

Against that background,

3.17. Would the establishment of such facilities give rise to impacts on other sectors of the economy? How should they be estimated and using what information? Have such impacts been demonstrated in other economies similar to Australia?

SECTION C
FOOTNOTES / REFERENCES ON THE NEXT PAGE

[19] UN Scientific Community on the Effects of Atomic Radiation, The Chernobyl Accident July 2012, available at http://bit.ly/1zd8TLy.

[20] Great East Japan Earthquake Reconstruction Agency, Government of Japan, The Status in Fukushima available at http://bit.ly/1A4l8oz.

[21] Kratchman J and Norton C, Fukushima Water Contamination – Impacts on the U.S. West Coast, US Nuclear Regulatory Commission Jan 2015 available at http://1.usa.gov/1FqvcP0.

[22] The National Diet of Japan, The official report of The Fukushima Nuclear Accident Independent Investigation Commission – Executive Summary, 2012 available at http://bit.ly/1uc9mlv.

[23] United Nations system-wide study on the implications of the accident and the Fukushima Daiichi nuclear power plant, Report of the Secretary General, available at http://www.un.org/ga/search/view_doc.asp?symbol=SG/HLM/2011/1.

[24] Inter-governmental Panel on Climate Change, Climate Change 2014 Synthesis Report.

[25] UN Framework Convention on Climate Change, Report of the Conference of the Parties on its fifteenth session, held in Copenhagen from 7 to 19 December 2009, Decision 2/CP.15, available at http://bit.ly/1kltvyE.

[26] Inter-governmental Panel on Climate Change, Climate Change 2014 Synthesis Report.

[27] Australian Government Dept. of Environment, Quarterly Update of Australia's National Greenhouse Gas Inventory: September 2014, Published Mar 2015, available at http://bit.ly/1K6ndpW.

[28] OECD, Nuclear Energy and Renewables: Systems Effects in Low-Carbon Electricity Systems, available at https://www.oecd-nea.org/ndd/reports/2012/system-effects-exec-sum.pdf.

[29] US Dept. of Energy National Renewable Energy Laboratory, Life cycle assessments of energy technologies, 2013 available at http://1.usa.gov/1A4DIwL.

[30] The safeguards issues associated with fuels to be used in those reactors and spent fuels following their use are addressed in other Issues Papers.

[31] UK Government, State aid approval for Hinkley Point C nuclear power plant, Dept. of Energy and Climate Change 2014, available at http://bit.ly/1vaiaAt.

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