Responses to questions posed in the Nuclear Fuel Cycle Royal Commission Issues Paper 3: Electricity Generation from Nuclear Fuels

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Question 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?

Commercially available technologies (Generation II & III) and emerging technologies (Generation IV) are addressed separately.

Generations II, III & III+

There are no commercially available reactor technologies that are suitable for installation and connection to the NEM grid in South Australia. Generating capacity of commercially available reactors, which have rated power of 600 megawatt (MW) upwards, is too large for both the transmission system and for back-up requirements when the nuclear power reactor experiences forced outages.

While it would be technically possible to install a commercially available nuclear reactor in one of the eastern mainland states of the NEM if a suitable site could be found, that option is difficult to justify on the grounds of safety, economics, life-cycle CO_2 emissions (see response to Question 3.11) and inflexibility of operation.

Generation IV reactors

No Generation IV reactor is commercially available and all types are more complex than existing commercially available technologies (Generations II, III & III+). Therefore Generation IV reactors are likely to be even more expensive in terms of levelised cost of energy (LCOE) than Generations II and III. However, it is impossible to cost them credibly.

It would be a huge financial risk for a country like Australia, with no prior experience with nuclear power stations, to install a Generation IV nuclear reactor. Even France, with many reactor-years of experience in nuclear power, made a very expensive error in installing its large demonstration fast breeder reactor, Superphénix, 1200 MW. It was launched in 1974, connected to the grid in 1986 and was closed in 1998 after many technical problems. It cost €12 billion (2010 currency) excluding decommissioning and operated for only 10 months (Cours des Comptes 2012). Fast neutron reactors at the demonstration level of maturity are operating in Russia and India. The Russian 800 megawatt (MW) BN-800 demonstration fast neutron reactor commenced operation in 2014 after nearly 30 years of on-off construction. The pro-nuclear MIT study of 2003 did not expect that the breeder cycle would come into commercial operation during the following three decades and the 2010 report did not change that (MIT 2003, 2010).

Small modular reactors (SMRs), that could be mass-produced, have been the dream of the nuclear industry for decades. They may (or may not) become commercially available in the next two decades. They are also impossible to cost. However, if SMRs do eventually reach the market, they are likely to be initially more expensive in terms of LCOE than existing commercially available reactor that have economies of scale. In order to obtain the benefits of mass production, SMRs would need a large market, yet there is little or no evidence of demand for such a reactor.

Thorium reactors are more complex than uranium reactors because they need at least one additional step: the conversion of non-fissile thorium to fissile uranium-233 by bombarding the former with neutrons. India is attempting to develop them.

The integral fast reactor has only limited research development to the pilot stage. Other proposed ‘advanced’ reactors need much R&D too.

Question 3.4 (part): What factors affect the assessment of viability for installing any facility to generate electricity in the NEM? How might those factors be quantified[a] and assessed?

Factor	Quantified or assessed
Contribution to risk of nuclear war[b]	A scientific treatment of risk must recognize that Risk = Probability x Impact. The impacts of even a limited nuclear war could kill billions of people, as a result of the devastation of agriculture by nuclear winter from the dispersion of soot around the planet (Robock & Toon 2010). Although the probability of nuclear war cannot be quantified, this is not a scientific reason for ignoring the contribution of nuclear power to the proliferation of nuclear weapons. The argument by nuclear proponents, that the risk of nuclear war depends on other variables (e.g. research reactors; international disputes) in addition to having nuclear power, is logically irrelevant to the point that nuclear power is increasing the risk of nuclear war. Already nuclear energy has assisted several countries to develop in secret nuclear weapons for the first time (India, Pakistan, North Korea, South Africa) and several other countries to commence (Argentina, Australia, Brazil, Iran, Libya, South Korea, Taiwan) (references for each country cited in Diesendorf 2014 Chapter 6). If we wish to reduce the risk of nuclear war, then transitioning away from nuclear energy is one way of doing that.
Risk of major accident	Risk = Probability x Impact. Impacts are huge, but there is insufficient data to calculate probability.
Life-cycle CO_2 emissions	g CO_2/kWh – as in Lenzen (2008) and Sovacool (2008)
Air and water pollution	Standard, taking into account toxicity as well as quantity. Assessments must integrate impacts over future generations
Other toxic or radioactive wastes	Standard, taking into account toxicity as well as quantity. Assessments must integrate impacts over future generations
Land degradation	Land area per kWh actually occupied, heavily polluted or made unsuitable for agriculture (on agricultural land) or biodiversity. Flawed calculations by opponents of renewable energy, who calculate the land spanned by wind farms instead of the land actually occupied, should be firmly

	rejected. Exclusion zones (for people and agriculture) of at least 20 km radius should be set around nuclear power stations and reprocessing plants and counted as degraded land.
Total economic cost, including subsidies	LCOE (including external costs) in $/MWh or c/kWh + unquantifiable costs. Most proponents of nuclear energy willfully ignore its huge subsidies, which must be included. Subsidies include investment tax credits, loan guarantees, research and development, uranium enrichment, nuclear waste management, decommissioning of nuclear power stations, caps on liability for reactor accidents and stranded assets paid for by electricity consumers and taxpayers (WISE 2005; Koplow 2007, 2011; Schneider et al. 2009, pp.70–88; Meyer et al. 2009). Meanwhile, subsidies to renewable energy, for example, in the form of feed-in tariffs and certificate schemes, are being rapidly reduced in Europe, Australia, and North and South America. The whole life-cycle must be costed. Cost estimates of technologies that are not commercially available, such as Generation IV nuclear reactors, must be given low credibility.
Variable cost (fuel, operation and maintenance)	$/MWh or c/kWh. Although this is part of total economic cost, it must be considered separately too, because merit order (ranked order for dispatching power stations) is determined by bids based mostly on variable cost. Since the variable costs of nuclear are greater than those of wind and solar farms, they are displaced from base-load operation by these renewable energy power stations under existing market rules. This is known as the Merit Order Effect (Agora EnergieWende 2013). To change the rules would give yet another subsidy to nuclear.
Ability to be integrated into the grid	Multiple factors, including location and size of generating unit; variable cost; flexibility in operation if partnered with a large contribution from variable renewable energy power stations; operating cost (including fuel cost) which is the principal determinant of merit order.
Time period from planning, building infrastructure, construction, to generation	Days, months or years, depending upon the technology.
Reliability of the whole generating system[c]	Loss-of-load probability (used widely in USA & Europe); annual energy shortfall (used in Australian NEM); frequency & duration of loss-of-load (used in parts of Europe)

Notes to Question 3.4

a. Not all factors can be quantified: e.g. contribution to the risk of nuclear war. This is not ground for ignoring them, since they could override all factors for which quantitative data are available.

b. See response to Question 3.13.

c. Dispatchability of individual power stations has been proposed incorrectly by some critics of renewable energy. This is not a valid factor in power system planning, because it is the reliability of the whole generating mix that is far more important than the reliability of individual power stations. Power system engineers measure reliability of the whole system by such indicators as Loss-of-Load-Probability (LOLP), or (in the case of the National Electricity Market) annual energy shortfall (Čepin 2011; Mai et al. 2012; Elliston et al. 2012). A mix of variable (wind and solar PV) and flexible, dispatchable renewable energy sources can be just as reliable as a conventional generating system (Elliston et al. 2012, 2013,2014; Mai et al. 2012; Rasmussen et al. 2012; Henning & Palzer 2014; Palzer & Henning 2014).

Question 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?

There is no need for any additional base-load power station in the NEM, whether it be nuclear or coal. Renewable energy is ready to replace fossil fuels. Demand on the grid has decreased each year for the past five years. The factors responsible are:

- the growth of rooftop solar PV which is now cheaper than retail electricity from the grid in most of Australia;
- increasing efficiency of electricity use encouraged by high retail electricity prices; and
- the continuing decline of Australia's manufacturing industries.

Ageing coal-fired power stations are starting to be retired or closed for part of the year, partly as a result of the Merit Order Effect. Nuclear power stations, with higher variable costs than wind and solar, would also be displaced by the Merit Order Effect (Agora Energiewende 2013).

To summarise the Merit Order Effect, at each time-step, the spot price of electricity is determined by the highest successful bid. The market operator accepts bids to operate from various power stations in ranked order from the lowest to the highest required to meet demand at that time-step. Wind and solar PV power stations, with lower operating costs than fossil fuel or nuclear power stations, can bid the lowest prices (based on their short-run marginal costs). So they displace some fossil- or nuclear-fuelled power stations that have to bid higher prices, thus reducing the spot price. This reduction is increased in markets, such as the NEM in 2015, with an excess of generating capacity.

Renewable energy, together with energy efficiency, is ready to take the place of base-load power stations. On-shore wind energy is now much cheaper than nuclear energy. At suitable sites in South and North America, large solar PV power stations are contracting to sell electricity at unsubsidized prices less than those of subsidized nuclear. The costs of wind and solar are still declining – details in the following two paragraphs.

Wind

The multinational financial analysts Lazard (2014) estimated unsubsidized costs of $37–81/MWh for on-shore wind averaged across the USA. An independent empirical study by US Department of Energy reported in 2013 levelised power purchase agreement (PPA) prices for wind power in different regions of the USA: for the interior (the region with the highest wind speeds generally) were about $25/MWh, and in the west (the region with the lowest wind speeds generally) about $60/MW (US DoE 2014, Fig.46). The US government subsidises wind with a Production Tax Credit of $23/MWh over 10 years, so the actual cost average in the interior was about $47/MWh plus any state subsidies, and in the west about $87/MWh plus any state subsidies. These are approximately consistent with the ranges estimated by Lazard (2014), which include federal subsidies. Wind energy prices are even lower in Brazil: in 2014 contracts were awarded at a reverse auction for an average unsubsidised clearing price of 129.3 real/MWh (US $41/MWh) (GWEC 2014, p.32).

Solar PV

Lazard (2014) estimated unsubsidized costs of $72–86/MWh for large-scale solar PV in the USA. In New Mexico, USA, a Power Purchase Agreement for $57.9/MWh has been signed for electricity from the Macho Springs 50 MW solar PV power station; federal and state subsidies bring the actual cost to around $80–90/MWh depending on location (Kroh 2014). In Chile a contract for electricity from a large-scale solar PV power station to be built in 2016 has been signed for US$89/MWh without subsidy; in addition, for generation in 2017, a contract has been signed for US$85/MWh (Roselund 2014). In Brazil in 2014 contracts for solar power were awarded at a reverse auction for an unsubsidised clearing price of US$87/MWh and previously in Uruguay for an unsubsidised price of US$91/MWh (Bloomberg New Energy Finance 2014). While not all contracts will be fulfilled, the global trend of declining prices is clear.

Nuclear

Lazard (2014) estimates nuclear costs in the USA at $124–132/MWh. This range includes quantifiable direct government subsidies, which are not counted in private costs. Direct government subsidies included in this estimate are presumably investment tax credits, loan guarantees, research and development grants. Subsidies not included in Lazard's estimate are for uranium enrichment, nuclear waste management (for which nuclear power station operators pay only a nominal amount of 0.1 c/kWh), decommissioning of nuclear power stations, caps on liability for reactor accidents and stranded assets paid for by electricity consumers and taxpayers (WISE 2005; Koplow 2007, 2011; Schneider et al. 2009, pp.70–88; Meyer et al. 2009).

The Australian head of Bloomberg New Energy Finance was recently quoted as providing the following LCOEs for new electricity generating technologies in Australia (in AUD): wind $74/MWh, large-scale solar PV $119/MWh, coal $92/MWh (Seccombe 2015).

Question 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?

- Human error, together with deliberate disregard of public safety in order to reduce costs, cannot be eliminated entirely, even in a country with advanced technologies and social systems such as Japan. Error and disregard for human safety include design, siting, operation and management of nuclear facilities.

- It is better to avoid such an unforgiving technology as nuclear energy.

- If any new nuclear power stations are ever built anywhere, they should be located underground in places where they cannot pollute the groundwater if they experience an accident. This has never been done for commercial nuclear power reactors, presumably because of the cost.

Question 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?

The Royal Commission should be guided by the meta-analyses of life-cycle assessments by Sovacool (2008) and Lenzen (2008). The latter is one of the few pro-nuclear authors who recognises that life-cycle emissions from conventional nuclear energy facilities will increase greatly as uranium ore-grade declines, as occurs with mining in general (Norgate & Jahanshahi 2010). Most uranium mining is in remote locations and is done with diesel fuel. The increase life-cycle emission from mining (and milling) is likely to happen over the lifetimes of new Generation II, III and III+ nuclear power stations, making them significant greenhouse gas emitters. Fast breeder reactors would have much lower life-cycle emissions, but these are not close to being commercially available.

The table below, which is Table 9 of Mudd & Diesendorf (2010), shows life-cycle CO_2 emissions from nuclear energy under various assumptions. It compares the results of Lenzen (2008) with those Storm van Leeuwen & Smith (2005) modified by Mudd & Diesendorf (2010). Although they differ in absolute values, both sets of estimates show a substantial increase in life-cycle CO_2 emissions when high-grade uranium ore is replaced with low-grade.

TABLE 9

Total CO_2 emissions (g CO_2/kWh) from nuclear fuel chain according to Lenzen or SvLS for high-grade and low-grade uranium ore, including wind and natural gas for comparison.

U ore grade	(Excluding mine rehabilitation)		(With mine rehabilitation)	Wind[c]	Natural
(% U_3O_8)	Lenzen[a]	SvLS[b]	SvLS[b]		Gas[d]
0.15	60	107	117	10 - 20	491 - 577
0.01	131	220	437	10 - 20	491 - 577

a Lenzen (2008) excludes significant emissions from the clean-up of mine waste
b We have modified SvLS's results as presented in column three to incorporate Lenzen's corrections for emissions from construction and decommissioning, while keeping SvLS's own results for high-level nuclear waste management. SvLS's results are reproduced unchanged in column 4
c Data from Lenzen (2008)
d Data from ISA (2006)

Question 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?

The risks with the biggest impacts are:

(1) Nuclear war

An increase in the risk of nuclear war resulting from nuclear weapons proliferation cloaked by the development of nuclear energy.

India, Pakistan, North Korea and South Africa used civil nuclear energy in varying degrees as a cloak to build in secret their nuclear weapons programs. Furthermore, Australia, Argentina, Brazil, Iran, Libya, South Korea and Taiwan all used civil nuclear energy to cloak their commencement of nuclear weapons programs, but discontinued them en route. In addition, nuclear expertise resulting from a nuclear energy program provides a civilian-military connection. For references see Institute for Science and International Security <http://www.isis-online.org> ; Nuclear Weapons Archive <http://nuclearweaponarchive.org>; and the list by country in Diesendorf (2014, Chapter 6).

2. Nuclear accident and terrorism

A major nuclear accident resulting in widespread dissemination of high-level radioactive fallout.

Terrorism at a nuclear reactor or high-level waste dump or during transportation of radioactive materials, resulting in public exposure to high-level radioactive materials.

3. Long-term emission of low-level radiation

If we ignore future generations, the exposure to low-level radiation from uncovered uranium mining waste mountains is a minor risk. But, if we consider impacts on future generations and integrate impacts (e.g. a few cancers per year) over 100,000 years, this would be a major hazard.

Solutions

Apart from global nuclear disarmament, the best solution for reducing the risk of nuclear war would be to phase out nuclear power, as Germany is doing. Although this would not address the purely military development of nuclear weapons, it would reduce the number of countries with potential to make nuclear weapons and hence would reduce the probability of nuclear war.

The second best solutions have been obvious for 50 years but never implemented:

- IAEA Safeguards have failed to stop the proliferation of nuclear weapons from ‘peaceful’ nuclear facilities. Therefore nuclear power stations, uranium enrichment plants and reprocessing plants should be placed under strict international control, not just occasional inspection, backed up with UN military guard units.

- Any new nuclear power stations should be located underground in locations where they cannot pollute groundwater.

- Uranium mining waste dumps should be covered at the expense of the owners of the uranium mines.

Question 3.15 (part): …Would [the establishment of a facility to generate electricity from nuclear fuels] complement other sources and in what circumstances?... What sources might it be a substitute for, and in what circumstances?

We must distinguish South Australia, which already has much renewable energy, from the rest of the NEM. Nuclear energy would be the worst possible partner for South Australia's large and growing wind and solar generation, due to the inflexibility in operation of nuclear power stations. The best partners for large penetrations of wind and solar PV are flexible peak-load power stations, such as hydro with dams, open-cycle gas turbines (which can be biofuelled) and concentrated solar thermal with thermal storage. Unlike base-load power stations, these peak-load stations can follow and smooth the fluctuations in output from the variable renewable energy power stations. As batteries become cheaper over the next decade, they too will be able to help smooth these fluctuations.

Since coal power is likely to disappear from SA's generation mix long before a nuclear reactor could be installed, a heavily subsidised nuclear power station could displace wind, any large solar power stations and any remaining base-load gas power. However, nuclear couldn't compete economically with renewables if it were unsubsidised and had to operate under existing market rules, where it would be lower on the merit order (i.e. lower priority for dispatching) than wind or solar power.

A nuclear power station could only substitute for a coal-fired power station in the NEM if the decision ignored the much higher costs and physical risks of nuclear compared with renewable energy.

The notion that base-load demand must be supplied by base-load power has been demonstrated to be a false myth by both practical experience and computer simulation modelling.

(i) Practical experience

SA is one of several states or countries around the world with high penetrations of RE that demonstrate that base-load power stations are unnecessary. SA has two base-load coal-fired and several gas-fired power stations. In 2014 wind power supplied one-third and residential solar PV 6% of annual electricity generation, making a total of 39% annual electricity coming from variable RE. Partly as a result of the growth of wind and solar power, one coal station (Playford B) was shut down for the whole year and the other (Northern) for half the year. Torrens Island A, originally operated as a base-load gas-fired power station, is scheduled to be closed by its owner AGL in 2017.

At noon on 26 December 2014 wind and solar PV together supplied 60% of electricity demand and for the whole of that day (midnight to midnight) supplied 52% of demand (Parkinson 2015a). On 5 May 2015, at midnight and at 9:00 am, wind power alone supplied two-thirds of demand on the grid (Parkinson 2015b). The system has operated reliably and stably, even though, over a year, there has been no increase in gas-fired generating capacity or in the operation of existing gas-fired power plants. There has been a small increase in imports of electricity from Victoria, however the net import in 2014 was still much less than that in 2004–05 and 2005–06 when there was much less wind power capacity in the SA grid (AEMO 2014, Fig.11).

(ii) Computer simulations

Hourly computer simulations spanning 1–8 years from many countries and regions, confirm and extend the growing practical experience with high penetrations of RE (Diesendorf 2014, Chapter 3). They include studies from the USA (Mai et al. 2012), Europe (e.g. Heide et al. 2011; Rasmussen et al. 2012; Henning & Palzer 2014; Palzer & Henning 2014) and Australia (Elliston et al. 2012, 2013, 2014; AEMO 2013). Each hour the simulations strive to balance wind and solar supply from actual weather data against actual demand. They find that 80–100% annual electricity generation from RE, with most of this supplied by variable RE sources, is technically feasible and reliable, without any base-load power stations. Many of these simulations are based entirely on commercially available RE technologies that are scaled up in the computer models.

For 75–100% renewable electricity, reliability is achieved by:

- a mix of variable RE and flexible (fast response) dispatchable RE sources such as gas turbines (either biofuelled or fossil fuelled), concentrated solar thermal (CST) with thermal storage and hydro with dam, as illustrated in Figure 1;
- geographic dispersion of RE power stations together with a few new major transmission links;
- in some cases, demand modification by means of 'smart' meters and switches in a 'smart' grid.

The best use of CST is not as base-load (which it cannot do anyway in winter), but rather as a valuable, flexible, dispatchable source of RE.

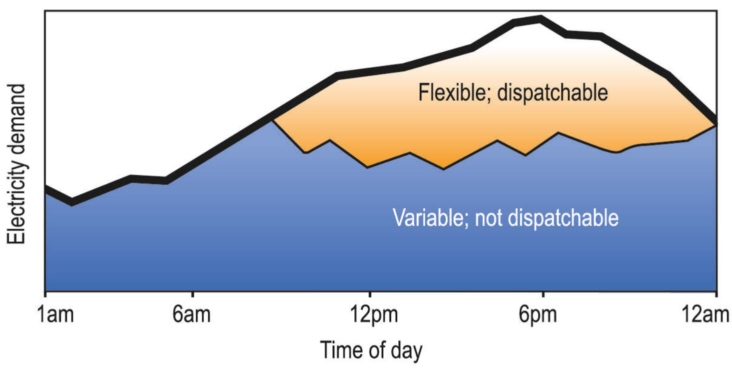

Figure 1: Reliably meeting daily demand with a combination of variable and flexible power stations.

Notes: Figure 1 shows demand and supply on a typical summer day. In the UNSW hourly computer simulation models of the NEM (Elliston et al. 2012, 2013, 2014), variable sources are wind and solar PV; flexible, dispatchable sources are hydro with dams, biofuelled gas turbines and CST with thermal storage. Variations in wind and solar PV are relatively small as a result of geographic dispersion.

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100% Renewable Electricity for South Australia

Appendix to Submission to the Nuclear Fuel Cycle Royal Commission

Term of Reference 3: Electricity Generation

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11 June 2015

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Executive Summary

South Australia (SA) is the leading Australian state in terms of the proportion of renewable energy supplying the state's annual electricity consumption. With its excellent wind and solar resources and its already high penetrations of wind energy into the grid and solar photovoltaics (PV) onto its residential rooftops, SA has a realistic opportunity to become the first Australian state to reach 100% renewable electricity.

This study examines scenarios where the future electricity mix of South Australia (SA) be predominantly or entirely based on renewable energy (RE) by 2030. Two particular scenarios are:

1. 100% renewable electricity by 2030.
2. A mix of 75% renewable electricity and 25% gas by 2030, with the option to continue to 100% renewable electricity by 2040.

The study considers renewable energy (RE) resources, benefits, reliability, costs and risks of the scenarios and the policies needed from the SA government to drive the transition to the renewable energy scenarios. In doing so, it refutes 11 common myths about RE disseminated by its opponents. It also discusses whether nuclear energy could play a role in a predominantly RE future and refutes 12 common myths about nuclear energy disseminated by its proponents.

Benefits

The benefits of transitioning to an electricity future that is predominantly or entirely based on RE are both environmental and economic. It would reduce SA's greenhouse gas emissions substantially. It would also reduce air pollution and associated respiratory diseases. It could export renewable electricity to the eastern states and possibly, in the long term, overseas. To undertake this transition SA could create a wide range of new jobs for manufacturing components of wind turbines, concentrated solar thermal (CST) power stations and electric vehicles; engineering jobs for installation and grid connection of RE power stations; and technical and sales jobs for the installation of rooftop solar PV. Large-scale RE reduces the price of wholesale grid electricity. Consumers who install rooftop solar PV reduce their electricity bills.

Reliability

Practical experience from several countries and states with high penetrations of variable types of RE sources (e.g. wind and solar PV), including SA, gives confidence that the electricity supply system can be operated reliably with penetrations of *at least* 40% annual average generation from variable RE sources and, with appropriate transmission connections to neighbouring countries or states, penetrations of 100%. SA itself has already demonstrated that it can operate reliably and stably for hours when the contribution of variable RE reaches two-thirds of demand.

Hourly computer simulations spanning 1–8 years from many countries and regions, including the Australian National Electricity Market (NEM), confirm and extend the growing practical experience. They show that 80–100% annual electricity generation from RE, with at least two-thirds of annual generation supplied by variable RE, is technically feasible and reliable. Each hour the simulations aim to balance supply from actual weather data against actual demand. Many of these simulations are based entirely on commercially available RE technologies that are scaled up in the models.

For 80–100% renewable electricity, reliability is achieved by:

- a mix of variable RE (e.g. wind and solar PV) and flexible, dispatchable[1] RE sources (e.g. CST with thermal storage, biofuelled gas turbines and hydro with dams);
- geographic dispersion of RE power stations assisted by one or two new major transmission links;
- demand management assisted by 'smart' meters and 'smart' switches in a 'smart' grid.

In Australia, the USA and similar climatic regions there is no need for innovative storage technologies nor large amounts of any type of storage. Combinations of CST with thermal storage and infrequently operated gas turbines with fuel storage are sufficient for maintaining the reliability of large-scale RE generation. Hydro with dams (including pumped hydro) is an optional extra for further strengthening reliability of supply. In Europe, where there is less solar resource and very little potential for CST, storage will play a more important role.

There is no need for any base-load power stations, such as coal or nuclear. Indeed, the lack of operational flexibility of coal and nuclear makes them poor partners for high penetrations of variable RE. This is one of several reasons why France is planning to decrease is its nuclear contribution to total annual electricity generation.

Although nuclear power generally has a much higher capacity factor (annual average power output divided by rated power) than wind and solar PV, it too has reliability challenges, in this case resulting from extreme weather and severe accidents.

Economics

The capital costs and the levelised cost of energy (LCOE) from solar PV have declined dramatically over the past decade and continue to decline as the result of market growth, technological improvements and experience in installation. Rooftop solar PV is now economically competitive with retail prices of grid electricity in most of Australia. Only a few medium-scale solar power stations have recently been installed on the ground in Australia and so costs are still quite high here, although declining. Recently contracts have been signed for electricity from proposed large-scale solar PV power stations in three countries of South America for around US 9 c/kWh (USD 90/MWh) without subsidy. In New Mexico, USA, a Power Purchase Agreement for US 5.79 c/kWh has been signed for electricity from a 50 MW solar PV power station, however this plant will receive federal and state subsidies. Once investor confidence is restored in Australia, unsubsidised prices below USD 9 c/kWh will inevitably spread to Australia and other high insolation regions of the world.

On world markets the capital costs and the costs of energy from wind farms have been declining steadily since 2008. At excellent sites in the USA wind power is now generating electricity at power purchase prices of US 2–4/kWh (to which the Production Tax Credit of US 2.3c/kWh over 10 years should be added); prices are still declining. In Australia the levelised cost of wind energy is about AU 8–10c/kWh. Once investor confidence is restored in Australia, the Australian prices will continue to decline too.

[1] A 'dispatchable' power station is one that can generate electricity on demand.

CST is still expensive, due to the current small size of the world market. However, over the next decade its cost is likely to be halved. With low-cost thermal storage, CST will play a valuable complementary role to solar PV and wind, especially for meeting evening peaks in demand.

Subsidies to RE, although initially high in Europe and Australia, are being reduced to low levels as the technologies mature and markets grow. On the other hand, despite a history of over half a century, it is difficult to find evidence of a single nuclear power station that has been built without huge subsidies. Nuclear subsidies around the world include research and development, subsidies to fossil fuels used in uranium mining, uranium enrichment, nuclear waste management, decommissioning of nuclear power stations and other facilities, limitation of insurance liability for accidents, no liability for the proliferation of nuclear weapons, loan guarantees and stranded assets paid for by electricity consumers and taxpayers.

Even without allowing for the value of subsidies, the price range of nuclear energy is about double the price range of on-shore wind energy and is greater than the cost of solar energy from large-scale solar PV power stations in high-insolation regions of the USA and South America. Furthermore, a standard-sized nuclear power station would be too big to fit into the SA grid and small reactors are not commercially available.

Based on conservative projections of technology costs to 2030 by the Australian Bureau of Resources and Energy Economics, peer-reviewed, published computer simulations by a UNSW research group (Elliston et al. 2012; 2013; 2014) finds that 100% RE would be economically competitive with:

- a new 'efficient' fossil fuelled supply system if either a carbon price of at least \$50/tonne CO_2 were introduced or, in the absence of a carbon price, if current subsidies to the production and use of all fossil fuels were transferred temporarily to RE;
- a new all-gas scenario if wholesale gas prices in the NEM region are equal or close to current prices in Queensland (which have been dragged up by high export prices);
- new coal or gas with carbon capture and storage almost everywhere, except possibly in southern Victoria.

With less conservative cost projections, 100% RE may already be competitive with new fossil fuel mixes.

Large penetrations of RE into the grid are reducing the wholesale price of electricity, with both benefits and challenges for RE.

Policies recommended

State government policies recommended for achieving the benefits of a RE future include strong targets for greenhouse gas reductions for 2020, 2025 and 2030 and for large-scale renewable electricity for the same years. Since the federal government has reduced the national large-scale renewable energy target (LRET) for 2020 and is still encouraging uncertainty about its future, SA could possibly introduce its own tradable certificate scheme associated with its own RET. In this case it would be preferable to create separate large-scale targets for wind, solar PV and CST with thermal storage, because a mix of these sources will be needed for achieving a reliable, stable supply of 75–100% renewable electricity. Then one option is to create RE certificates for each of these technologies. However, this option may require supporting legislation from the federal government.

Alternatively, and independently of the federal government, SA could have LRETs without tradable certificates and instead follow the ACT's precedent of having *well-designed* reverse auctions (del Rio & Linares 2014) for each RE technology together with feed-in tariffs or contracts for difference (McConnell & Kallies 2015) for the winning bids. The success of the ACT scheme, in terms of speed of implementation and low feed-in tariff prices achieved, while providing investor income certainty, is a strong recommendation of this policy (Buckman et al. 2014).

The SA government should mandate that rooftop solar PV should be paid fair feed-in tariffs based on the value of the RE fed into the grid. At present electricity retailers charge typically 25–35 c/kWh for grid electricity, but pay only 0–8 c/kWh for electricity fed into the grid from small-scale RE. As in Minnesota USA, where US 14 c/kWh is the preliminary recommended feed-in tariff (Farrell 2014), the value calculation should take into account that distributed local RE generation usually makes use of only a small part of the distribution system and avoids environmental and health damage from fossil fuels. Feed-in tariffs could be varied in time according to the balance between supply and demand, thus giving incentives to rooftop and other small-scale RE owners to install some battery storage to meet the evening peak in demand. A 'smart' grid, with a roll-out of very smart meters and switches, is a prerequisite for this. Feed-in tariffs and contracts for difference can be funded either by a small increase in electricity prices paid by all consumers and/or by a SA carbon price.

The SA government should ensure fair prices for retail electricity, which should also vary in time according to the balance between supply and demand. To facilitate fair pricing of grid electricity and fair feed-in tariffs, the SA government should speed up the inevitable transition to a 'smart' grid, where customers have 'smart' meters and switches that permit both customers and electricity retailers to switch off particular circuits for short periods, depending on supply and demand in the grid, governed by the contract between supplier and consumer.

As the contributions from wind and solar PV grow, policies will also needed to encourage investment in flexible, fast-response, peak-load power plant that is operated intermittently for short periods of time when there is insufficient wind and sun. This could be done with a capacity payment, available to this kind of plant but not to inflexible, slow-response base-load coal and nuclear power stations.

An important piece of new infrastructure for 100% RE in SA would be a high-voltage, high-capacity, transmission line linking Port Augusta via Broken Hill to the eastern electricity grid in NSW. This would feed the principal load centres in NSW with excess wind power from SA, solar and wind power from western NSW and possibly in the long term hot rock geothermal power from central Australia. The transmission line could be funded jointly by the SA, NSW and federal governments.

Conclusion

The transition to a reliable electricity supply-demand system with 100% RE in SA is technically feasible and affordable.

As the contribution of RE increases, it reduces the wholesale price of electricity and increases the requirement for flexible, dispatchable technologies to complement wind and solar PV, removing base-load power stations, that is, coal or nuclear, as options in SA's electricity mix.

The policies required to support the transition involve targets, new price structures for both grid electricity and feed-in tariffs, and either tradable certificates associated with a LRET or preferably reverse auctions together with feed-in tariffs or contracts for difference, as in the ACT. The transition could be facilitated by introducing a 'smart' grid to foster improved demand management and by building a new high-capacity transmission line between SA and NSW to foster geographic diversity of RE supply to the NEM.

Compared with scenarios involving nuclear power, the RE scenarios are reliable, much less dangerous, less expensive, emit less life-cycle CO_2, offer a wider range of environmental, health and employment benefits, and can be implemented much more rapidly. For a system with a high and increasing contribution from RE, nuclear energy would be the worst possible partner, on account of its inflexibility in operation. Furthermore, a nuclear power station (600 MW or more) would be too big for the SA grid system and would need a huge amount of back-up. Yet small modular reactors are not commercially mature.

Considering all its shortcomings, nuclear is too expensive, too inflexible, too dangerous, too CO_2-intensive, too slow a technology to introduce and too big for South Australia.

Abbreviations

ACT	Australian Capital Territory
AEMO	Australian Energy Market Operator
CST	concentrated solar thermal
GW	gigawatt
GWh	gigawatt-hour
kWh	kilowatt-hour
LCOE	levelised cost of energy
LRET	Large-scale Renewable Energy Target
MW	megawatt
MWh	megawatt-hour
NEM	National Electricity Market
NSW	New South Wales
PV	photovoltaic
RE	renewable energy
REC	Renewable Energy Certificate
SA	South Australia
STC	Small-scale Renewable Energy Certificate
UNSW	University of New South Wales aka UNSW Australia

Conversion factor

$10/MWh = 1 c/kWh

1. Introduction

South Australia (SA) is the leading Australian state in terms of its contribution from renewable energy (RE) to annual electricity generation. Its performance in this regard is comparable with that of Denmark, the country with the highest percentage of annual electricity generation from non-hydro RE, as shown in Table 1.

Table 1: Leading countries and states with high contributions of non-hydro[a] renewable energy to the electricity grid and ambitious renewable energy targets

Country or state		RE penetration[b] in 2014	Target
Country	Denmark	Wind 39% of domestic consumption + bioenergy 7%	Wind 50% by 2020; 100% renewable electricity and heat by 2035.
	Scotland	RE 44%, of which wind is 29%	100% net[c] renewable electricity by 2020
	Germany	Total RE 30% of domestic consumption from biomass, wind solar & hydro in order from largest	≥80% of consumption by 2050
	Portugal	Wind 23%	
	Spain	Wind 21% + solar 4%	
State	Mecklenburg-Vorpommern, Germany	RE over 100% net[c], almost entirely wind	
	Schleswig-Holstein, Germany	RE 100% net[c], almost entirely wind	N/A
	South Australia	Wind 33%; rooftop solar 6%	
	Iowa, USA	Wind 27%	
	South Dakota, USA	Wind 26%	
	California, USA	RE 24%, including 5% from utility scale solar	RE 33% by 2020; 50% by 2030 proposed

Sources: Compilation of many reports that don't all distinguish between % of generation and % of consumption.

Notes: a. Countries like Iceland (100% RE from hydro and geothermal) with high contributions from hydro have been excluded because of their low relevance to SA.
b. Percentage of annual electricity generation or consumption.
c. 'Net' takes account of electricity trading by transmission line.

Like the German states Mecklenburg-Vorpommern and Schleswig-Holstein, SA could attain 100% net RE, provided it increases its sales of RE to the eastern states. This would entail expanding the capacity of its transmission links to Victoria (a modest expansion is under way) and building a direct transmission link to NSW.

This study addresses SA's RE resources (Section 2); the challenge of developing a reliable 100% renewable electricity system (Section 3); economic aspects (Section 4); risks, benefits and safety (Section 5) and policies for 100% RE (Section 6). On the way it comments briefly on the reliability, costs, risks and technical feasibility of nuclear energy in SA. Appendix 1 summarises the refutations of 11 common myths about RE disseminated by its opponents. Appendix 2 summarises the refutations of 12 common myths about nuclear energy disseminated by its proponents. Appendix 3 addresses the technical issue of maintaining the frequency of alternating current in grids with high contributions from variable RE.

2. Renewable energy resources

Australia in general and SA in particular have huge resources of wind and solar (Carson 2014). The solar resource spans large regions suitable for concentrating collectors, which require direct sunlight, as well as even larger regions suitable for flat-plate solar collectors, which accept both direct and diffuse sunlight. The SA wind and solar resources far exceed the capacity to utilise them within that state alone. In addition, SA has potential for producing biofuels sustainably from agricultural and plantation forestry residues that may be sufficient in quantity for fuelling peak-load gas turbines, but not for a large fraction of the motor vehicle fleet. Also, for possible electricity generation in the medium- to long-term, SA has huge resources of hot rocks under the Great Artesian Basin and significant wave power resources.

SA, with scarce water resources in a dry climate, lacks a conventional hydropower resource. However, there may be potential for seawater pumped hydro, as a possible supplementary source of peak-load RE. For instance, there are hills 500-600 m high about 15 km from the coast near Port Pirie, and 500-800 m high 20-26 km from Port Augusta. Excess wind and solar PV power that would otherwise be curtailed could pump the seawater uphill during periods of low demand and high RE supply. Only small dams would be required to enhance the reliability of a 100% RE system (Blakers et al. 2010; Hearps et al. 2014) and reliability is one of the key issues in considering 75–100% renewable electricity for South Australia.

3. Reliability

The large-scale electricity system of the NEM has to maintain a continuous balance between supply and demand. Reliability is a property of the whole electricity supply-demand system, not simply a property of a single power station or type of power station. It can be measured in different ways, for example:

- Loss-of-Load Probability, which is the average value of the number of hours per year that supply fails to meet demand—such events are known as 'outages';
- frequency and duration of outages;
- unserved energy, that is, the annual energy shortfall in meeting demand; the NEM reliability standard for unserved energy is currently set at 0.002% of annual electricity demand.

Reliability standards recognise the fact that no electricity supply system can be 100% reliable; such an idealised system would require an infinite amount of back-up and hence would have an infinite cost. A real system has a finite amount of back-up and beyond this handles shortfalls in supply in various ways: accepting a tiny reduction in frequency of the alternating current within tight limits; if those limits are likely to be exceeded, offloading a large source of demand such as an aluminium smelter for a short critical period; in extreme cases, accepting a blackout.

There are two principal sources of uncertainty in operating a traditional electricity supply system: electricity demand and the availability to generate of conventional power stations, which break down unexpectedly from time to time. The system is designed to handle these uncertainties with a high probability within the reliability standard. When variable RE power stations (e.g. wind and solar PV without storage) are added to the system, a third type of uncertainty is added: the weather.

Small amounts of variable RE can simply be handled as negative demand, reducing the operational challenge of balancing supply and demand to managing two uncertainties again. In this case the existing back-up can easily handle the fluctuations in variable RE. In practice, it turns out that adding small amounts of variable RE actually increases the reliability of the whole system. If sufficient amounts of variable RE are added, one or more conventional power stations can be retired while restoring reliability to the previous standard. Thus wind and solar PV can substitute for some conventional generating capacity as well as the fuel it burns.

3.1 Reliability of supply with high penetrations of RE

How is reliability maintained when large amounts of wind and/or solar PV are substituted for conventional base-load power stations, which are coal-fired in most of mainland Australia and nuclear in France? Until recently, some critics of wind power claimed that base-load power stations would have to be kept running at great expense 24/7 to back-up wind power, even when the winds were strong. Base-load power stations are inflexible; they are designed to operate continuously at rated power and cannot be ramped up and down, quickly without incurring much higher maintenance costs. Some base-load power stations take 1–2 days to be brought from cold to rated power.

The claims about the need for base-load back-up have been refuted by both practical experience and computer modelling. Other myths about RE are refuted concisely in Appendix 1.

3.1.1 Practical experience

SA is one of several states or countries around the world with high penetrations of RE that demonstrate that base-load power stations are unnecessary. SA's fossil fuelled power stations with capacity (rated power) greater than 80 MW are listed in Table 2. SA has two base-load coal-fired and several gas-fired power stations. In 2014 wind power supplied one-third and residential solar PV 6% of annual electricity generation, making a total of 39% annual electricity coming from variable RE. Partly as a result of the growth of wind and solar power, one coal station (Playford B) was shut down for the whole year and the other (Northern) for half the year. Torrens Island A, originally operated as a base-load gas-fired power station, is scheduled to be closed by its owner AGL in 2017.

Table 2: South Australia's fossil fuelled power stations with capacities of at least 80 MW

Name	Rated power (capacity) (MW)	Fuel	Type	Capacity factor 2009/10 (%)	Capacity factor 2013/14 (%)
Northern	540	Coal	Boiler	76	45
Playford B	240	Coal	Boiler	48	0
Torrens Island A	480	Gas	Boiler	11	8
Torrens Island B	800	Gas	Boiler	24	19
Pelican Point	478	Gas	Combined cycle	71	44
Osborne	180	Gas	Boiler; cogen.	75	93
Hallet	180	Gas	Gas turbine	1.7	2.1
Ladbooke Grove	80	Gas	Gas turbine	27	33
Snuggery	103	Gas/other	Gas turbine	0.4	0
Mintaro	90	Gas	Gas turbine	1	1
Dry Creek	156	Gas	Gas turbine	0.7	0.2
Quarantine	215	Gas	Gas turbine	15	12

Source: Capacities from Geoscience Australia's database of Australian fossil-fuelled power stations, http://www.ga.gov.au/fossil_fuel/; capacity factors from AEMO (2014, Fig. 11).

At noon on 26 December 2014 wind and solar PV together supplied 60% of electricity demand and for the whole of that day (midnight to midnight) supplied 52% of demand (Parkinson 2015a). On 5 May 2015, at midnight and at 9:00 am, wind power alone supplied two-thirds of demand on the grid (Parkinson 2015b). The system has operated reliably and stably, even though, over a year, there has been no increase in gas-fired generating capacity or in the operation of existing gas-fired power plants. There has been a small increase in imports of electricity from Victoria, however the net import in 2014 was still much less than that in 2004–05 and 2005–06 when there was much less wind power capacity in the SA grid (AEMO 2014, Fig.11).

If SA wind power capacity increases further in the future, it may become necessary to install some additional low-cost gas turbine capacity, which would be operated infrequently as required to avoid further increase of net imports from Victoria. Indeed, new gas capacity proposals amounting to 720 MW, along with new wind capacity of 3377 MW, have been publicly announced (AEMO 2014, Table 7), although there is no guarantee that all of these will actually be implemented.

3.1.2 Computer simulations

Hourly computer simulations spanning 1–8 years from many countries and regions, confirm and extend the growing practical experience with high penetrations of RE (Diesendorf 2014, Chapter 3). They include studies from the USA (Mai et al. 2012), Europe (e.g. Heide et al. 2011; Rasmussen et al. 2012; Henning & Palzer 2014; Palzer & Henning 2014) and Australia (Elliston et al. 2012, 2013, 2014; AEMO 2013). Each hour the simulations strive to balance wind and solar supply from actual weather data against actual demand. They find that 80–100% annual electricity generation from RE, with most of this supplied by variable RE sources, is technically feasible and reliable. Many of these simulations are based entirely on commercially available RE technologies that are scaled up in the computer models.

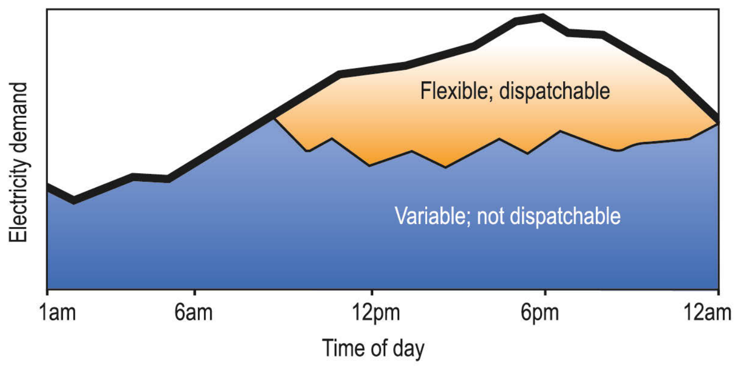


Figure 1: Reliably meeting daily demand with a combination of variable and flexible power stations.

Notes: Figure 1 shows demand and supply on a typical summer day. In the UNSW hourly computer simulation models of the NEM (Elliston et al. 2012, 2013, 2014), variable sources are wind and solar PV; flexible, dispatchable sources are hydro with dams, biofuelled gas turbines and CST with thermal storage. Variations in wind and solar PV are relatively small as a result of geographic dispersion.

For 75–100% renewable electricity, reliability is achieved by:

- a mix of variable RE and flexible (fast response) dispatchable RE sources such as gas turbines (either biofuelled or fossil fuelled), CST with thermal storage and hydro with dam, as illustrated in Figure 1;
- geographic dispersion of RE power stations together with a few new major transmission links;
- in some cases, demand modification by means of 'smart' meters and switches in a 'smart' grid.

The best use of CST is not as base-load (which it cannot do anyway in winter), but rather as a valuable, flexible, dispatchable source of RE.

In Australia, the USA and similar climatic regions there is no need for new types of storage technologies, such as advanced batteries or compressed air, or to install very large amounts of conventional storage. Combinations of CST with thermal storage and gas turbines with fuel storage are sufficient for maintaining the reliability of large-scale RE generation. In the computer simulations of the NEM by Elliston et al. (2012; 2013; 2014), gas turbines are only needed to supply a few percent of annual electricity generation. Hydro with dams (including pumped hydro) is an optional extra for further enhancing reliability. In Europe, where there is less solar resource, new types of storage and large amounts of conventional storage may be required to achieve 100% RE.

It should be noted that all the types of flexible power stations considered here – gas turbines, CST and hydro – provide rotational inertia to the supply system and hence contribute to power system frequency control (see Appendix 3).

Preliminary results of hourly computer simulations by UNSW of the operation of the SA electricity grid find that the system could be operated reliably with 100% renewable energy. South Australia could even do this without any connection to the eastern states' electricity markets, though costs would be higher due to reduced geographic diversity of wind and solar power stations (Elliston & Diesendorf, to be published).

3.2 Reliability of supply with high penetration of nuclear

Base-load power stations, such as coal and nuclear, are inflexible in operation. They perform best, technically and economically, when they are operated continuously at rated power. Their power outputs cannot be ramped up and down rapidly to follow variations in demand or variations in supply by other power stations. Even ramping them down slowly adds considerably to maintenance costs and reduces their electricity sales needed to pay off their high capital costs.

Computer simulations confirm that base-load power stations are not needed to balance the fluctuations in wind and solar PV. Indeed, the inadequate operational flexibility of nuclear and coal makes them poor partners for high penetrations of variable RE into the grid. Lack of operational flexibility is one of several reasons why France is proposing to decrease its nuclear contribution to total annual electricity generation from 77% to 50%. In SA, with 39% of annual electricity consumption generated by RE, the appropriate partners for achieving reliability of supply are flexible, dispatchable power stations, not inflexible base-load.

Capacity factors (annual average power output divided by rated power) are an important element in the economics of all kinds of power station. For base-load power stations like coal and nuclear, capacity factors are a rough measure of reliability of individual power stations (see Section 4.2 for more on nuclear capacity factors). Capacity factors of intermediate- and peak-load power stations are determined mainly by operational strategies; capacity factors of variable RE sources are determined mainly by the weather. Although nuclear power generally has a much higher capacity factor than wind and solar PV, it has reliability challenges resulting from extreme weather (Jowit & Espinoza 2006) and severe accidents such as occurred at Chernobyl and Fukushima that can put nuclear power stations offline for months or years or forever. This cannot happen with a wind or solar farm.

4. Economics

The principal elements determining the levelised cost of electrical energy (LCOE) in dollars per megawatt-hour ($/MWh) or cents per kilowatt-hour (c/kWh) from a power station are:

- capital cost, including interest during on-site construction/installation and costs of installation, usually measured in dollars per kilowatt of installed generating capacity ($/kW);
- capacity factor, which is annual average power output divided by rated power;
- interest or discount rate for loans that provide all or part of the capital cost;
- fuel (where relevant), operation and maintenance costs;
- scale of project; and
- any subsidies received.

A formula for calculation LCOE, based on the first four of these factors, is given by Diesendorf (2014, pp.128–130).

4.1 Renewable energy economics

With the exception of bioenergy, RE technologies have no fuel cost and their operation and maintenance costs are generally very low. Capital costs of the new RE technologies, notably solar PV and wind, have fallen substantially over the past decade and continue to decline as the result of market growth, technological improvements and experience in installation. Their capacity factors depend sensitively on the choice of site and associated weather conditions. Fortunately SA has excellent solar and wind potential and hence high capacity factors compared with most Australian and overseas sites. Installation of new RE technologies is rapid, ranging from one day for a residential rooftop solar PV system to 1–2 years for a large wind farm or solar power station. Therefore interest incurred during on-site construction is generally tiny for non-hydro RE.

The principal subsidy for small-scale RE systems are the certificates (STCs) associated with the Small-scale Renewable Energy Scheme (SRES) (Clean Energy Regulator website). In most states feed-in tariffs are no longer mandatory and, at the discretion of electricity retailers, generally are 0–8 c/kWh.

Rooftop solar PV is now economically competitive with retail prices of grid electricity in most of Australia. Provided it can offset purchase of significant amounts of retail electricity from the grid, costing typically 25–50 c/kWh during the daytime, solar PV pays for itself. However, for homes and businesses with low daytime electricity use, solar PV may not be economically viable in the absence of fair feed-in tariffs. As battery prices decline, they will be used increasingly to store sufficient solar energy captured in the daytime to meet the evening peak in demand. However, it may be 5–10 years before battery prices become so low that significant numbers of suburban households disconnect from the grid.

The uncertain future of the Large-Scale Renewable Energy Target (LRET), created by current federal government policies, has almost terminated proposals for new wind farms and on-ground solar power stations. In May 2015, after a long hiatus and negotiating period, the federal government and opposition finally reached agreement to reduce LRET from 41,000 GWh/year in 2020 to 33,000 GWh/year in 2020. If this is passed in Parliament, it will lead to a modest growth in wind and solar farms. Until this occurs, the only driver is the ACT's renewable electricity target and associated reverse auction scheme (ACT Government website). Community RE projects could also play a role, provided they receive supportive state and territory government policies, but any projects with capacity of 100 kW or more also suffer from the uncertain future of the LRET.

Since experience with, and scale of, medium-to-large solar power stations is limited in Australia, costs are still higher than overseas. In Chile a contract for electricity from a large-scale solar PV power station to be built in 2016 has been signed for US 8.9 c/kWh without any subsidy; in addition, for generation in 2017, a contract has been signed for US 8.5 c/kWh (Roselund 2014). In Brazil in 2014 contracts for solar power were awarded at a reverse auction for a clearing price of US 8.7 c/kWh and previously in Uruguay for US 9.15 c/kWh (also unsubsidised) (Bloomberg New Energy Finance 2014). While not all contracts will be fulfilled, the global trend of declining prices is clear. In New Mexico, USA, a Power Purchase Agreement for US 5.79 c/kWh has been signed for electricity from the Macho Springs 50 MW solar PV power station; federal and state subsidies bring the actual cost to around USD 8–9 c/kWh. Once investor confidence is restored in Australia, unsubsidised prices below USD 9 c/kWh will inevitably spread to Australia and the market for medium-to-large solar power stations will grow rapidly.

On world markets the capital costs and the costs of energy from wind farms have declined steadily since 2008. At excellent sites in the USA wind power is now generating electricity at power purchase prices of US 2–4 c/kWh. The US government subsidises wind with a Production Tax Credit of US 2.3 c/kWh over 10 years, so the unsubsidised price range becomes USD 4.3–6.3 c/kWh plus any state incentives. In Brazil in 2014 contracts for wind power were awarded at a reverse auction for a clearing price of US 5.74 c/kWh (unsubsidised). In Australia the levelised cost of wind energy at good sites is about AUD 8–10 c/kWh. Once investor confidence is restored in Australia, the Australian prices will continue to decline too. The high capacity factors of SA wind farms, the vast majority in the range 30–41% (see Ramblings website), show that SA has the least cost wind energy of all Australian states.

CST is a young technology with 4.8 GW installed worldwide by the end of 2014. It is currently the most expensive of the commercially available RE technologies, with weighted average levelised costs of energy (LCOEs) until recently in the range US 20–25 c/kWh. However, costs continue to fall and at present projects are being built with LCOEs of US 17 c/kWh, and power purchase agreements are being signed at even lower values where low-cost financing is available (IRENA 2015). With market growth over the next decade the installed cost of CST will inevitably fall much further.

Although CST is currently much more expensive than utility scale solar PV, it has the advantage that it can have low-cost thermal storage. Adding thermal storage to CST does not necessarily lead to an increased LCOE, because the cost of storage and the additional solar collectors required to fill the store on a sunny day are offset by the increased capacity factor. Thus, as its cost declines, dispatchable CST can play a valuable complementary role to solar PV and wind, generating during evening peaks and contributing to the stability of the grid (Appendix 3).

Based on conservative projections of technology costs to 2030 by the Australian Bureau of Resources and Energy Economics, a UNSW research group (Elliston et al. 2013, 2014) finds that 100% RE would be economically competitive with:

- a new 'efficient' fossil fuelled supply system, if either a carbon price of at least \$50/tonne CO_2 were introduced; or, in the absence of a carbon price, if current subsidies to the production and use of all fossil fuels were transferred temporarily to RE;
- a new all-gas scenario, if wholesale gas prices in the NEM region are equal to current prices in Queensland (which have been dragged up by high export prices);
- new coal or gas power with carbon capture and storage almost everywhere, except possibly in southern Victoria.

With less conservative cost projections, 100% RE may already be economically competitive with new fossil fuel mixes. That is the view of the financial planning corporation Lazard (2014), discussed in Section 4.3).

Feed-in tariffs for RE, although initially high in Europe and Australia, are being reduced to low levels as the technologies mature and markets grow. Over the past decade feed-in tariffs were very successful in Germany in bringing down both the capital cost and installation cost of solar PV.

As the penetration of renewable energy into the grid increases, the wholesale price of electricity decreases. This can be seen in Germany (Morris 2015), The Netherlands and several other European countries (Tennet website) and South Australia (Saddler 2014). Sometimes the wholesale spot price of electricity even goes negative during periods of low demand and high wind and sun (GE Look ahead 2014). The principal cause is known as the Merit Order Effect, explained in detail in the context of Germany by Agora Energiewende (2013, see Insight 7) and Diesendorf (2014, pp.244–247).

To summarise, at each time-step, the spot price of electricity is determined by the highest successful bid. The market operator accepts bids to operate from various power stations in ranked order from the lowest to the highest required to meet demand at that time-step. Wind and solar PV power stations, with lower operating costs than fossil fuel or nuclear power stations, can bid the lowest prices (based on their short-run marginal costs). So they displace some fossil- or nuclear-fuelled power stations that have to bid higher prices, thus reducing the spot price. This reduction is increased in markets, such as the NEM in 2015, with an excess of generating capacity.

For those concerned about climate change, this displacement of fossil fuelled power stations is potentially a good situation. The reduction in wholesale price also brings with it two problems that need to be resolved. Firstly, flexible peak-load plant, initially burning fossil fuels and later renewable fuels, may also be displaced as well as base-load. This can be resolved by awarding peak-load plants a capacity payment (see Section 6.6), so that they can be kept on stand-by and brought on line rapidly when required.

Secondly, if the wholesale price is reduced too much, the owners of wind and solar power stations will not receive sufficient revenue to pay off the loans originally taken out to pay for the capital cost of their power stations (Agora Energiewende 2013, see Insight 8). Low wholesale prices also discourage investment in new RE power stations for the same reason. To resolve this more difficult challenge will involve more radical changes to the NEM. However, in the case of the NEM, which has considerable over-capacity, the first step is obvious: to pressure old, polluting, base-load power stations to retire. This can be done by applying and gradually tightening emission standards.

In theory, declining wholesale electricity prices should result in declining retail electricity prices, but this has not happened in practice in South Australia or overseas. Other factors must be operating, such as gold-plating of electricity distribution and increased profits taken by electricity retailers.

4.2 Nuclear energy economics

Despite a history of over half a century, it is difficult to find evidence of a single nuclear power station that has been built without huge subsidies. Nuclear subsidies around the world include research and development, subsidies to fossil fuels used in uranium mining, uranium enrichment, nuclear waste management, decommissioning of nuclear power stations and other facilities, limitation of insurance liability for accidents, no liability for the proliferation of nuclear weapons, loan guarantees and stranded assets paid for by electricity consumers and taxpayers (Schneider et al. 2009, pp.70–88; Union of Concerned Scientists 2011).

Even without allowing for the value of subsidies, the price of nuclear energy is about double that of on-shore wind energy and is greater than the cost of solar energy from large-scale solar PV power stations in high-insolation regions of the USA and elsewhere (see Section 4.3). Since the construction time is long, on average in the USA nine years on top of a long planning period (Koomey & Hultman 2007), interest during construction can become a large fraction of the original capital cost.

It is difficult to determine the true costs of nuclear power reactors under construction in China and Russia; the best data comes from western countries. Two so-called Generation III+ reactors are under construction in Europe and two in the USA. In Finland, Olkiluoto-3 is nearly a decade behind schedule and nearly three times budgeted cost (World Nuclear Association 2015). In France, Flamanville-3 is five years behind schedule and also nearly triple budgeted cost (McPartland 2015; Matlack 2015). In Georgia USA, Vogtle is 18 months behind schedule and at least USD 650 million over budget (Patel 2014).

The proposed two new Generation III+ reactors, Hinkley C in the UK, each 1600 MW in capacity, will cost £8 billion each, or £5 million/MW (about AUD 10 million/MW). They will receive a guaranteed inflation-linked price for electricity over 35 years, commencing at 9.25 British pence/kWh (p/kWh), which is about AU 18 c/kWh, double the current wholesale price of electricity in the UK and more than triple the wholesale price in Australia. At an inflation rate of 2.5%, this guaranteed payment would rise to AU 42.7 c/kWh (2015 dollars) in its 35th year of operation. Hinkley C will also receive a loan guarantee of £10 billion (about AUD 20 billion). Its inadequate insurance will be backed by the British taxpayer. For comparison, on-shore wind in the UK will receive much less over its lifetime, initially 9.5 p/kWh, then *reducing* over time until 2020 and then possibly zero (Parkinson 2015c). Thus the guaranteed price for nuclear energy in the UK starts at 9.25 p/kWh and rises, while the guaranteed price for on-shore wind starts at 9.5 p/kWh and falls rapidly.

If a nuclear power station were ever to be installed in SA, its electricity cost could be even higher than that of the Hinkley C reactors, if they are ever built. Commercial nuclear power reactors have large generating units, typically 600–1600 MW electrical in capacity. Yet the SA grid is small by world standards and even by eastern Australian standards, with a maximum demand in 2013–14 of 3,304 MW (AEMO 2014, p.1). The grid infrastructure would have to be upgraded to cope with a 600 MW unit in SA. Furthermore, such a large single unit would need lots of back-up. So far, SA's largest generating units have been 270 MW at Northern Power Station.

Non-military small modular reactors (less than 300 MW electrical) have been under development for years, but do not seem to be near commercial maturity and licensing. Until such time as they are mass-produced, their capital costs in dollars per kW and their LCOEs in c/kWh will be much higher than for a standard sized reactor unit. However, at this stage of development, any estimate of the actual costs would have low credibility.

Nuclear power stations have higher variable costs (fuel + operation + maintenance) than wind or solar farms. Hence, under existing market rules, the operation of any nuclear power station in SA would be displaced by wind and solar as a result of the Merit Order Effect described in Section 4.1. This would further reduce nuclear's economic competitiveness. Since there is unlikely to be any coal-fired power stations remaining in SA by the time a nuclear power station could be generating there, nuclear could possibly displace base-load gas in SA. But if base-load gas has already been displaced by wind and solar, then nuclear could not operate in base-load mode in SA under existing market rules.

In the eastern mainland states of the NEM, where renewables are playing a much smaller role in relative terms than in SA, nuclear could possibly displace the operation of any remaining base-load coal power, provided its high capital costs did not stop it from being installed in the first place.

Theoretical estimates of the cost of nuclear power station proposals by nuclear proponents are often reduced to apparently low values by a number of misleading devices, including:

- choosing an unrealistically low interest/discount rate for a technology with high capital cost that is financially and physically risky;
- choosing an unrealistically high capacity factor (see below);
- assuming huge uncosted subsidies, listed above;
- choosing a manufacturer's cost estimate for a type of nuclear power station that is still under construction or even for a Generation IV reactor, neither of which is commercially available;
- ignoring the huge interest on loans incurred during the long construction periods;
- ignoring the costs of infrastructure and back-up capacity.

It is hoped that the Nuclear Fuel Cycle Royal Commission will give short shrift to cost estimates based on these misleading assumptions.

In particular, claims that nuclear reactors generally have capacity factors of around 90% are grossly misleading. Capacity factors of US nuclear stations have reached 85–90% in the 2000s after much maintenance following decades of poor performance, with capacity factors consistently below 60% before 1987, so that their lifetime average capacity factors are actually around 70% (Nuclear Energy Institute website). Global average capacity factors in 2013, which include the closures in Japan following the Fukushima disaster, were estimated to be 72% (Chabot 2015). As discussed above, the new generation of nuclear power reactors

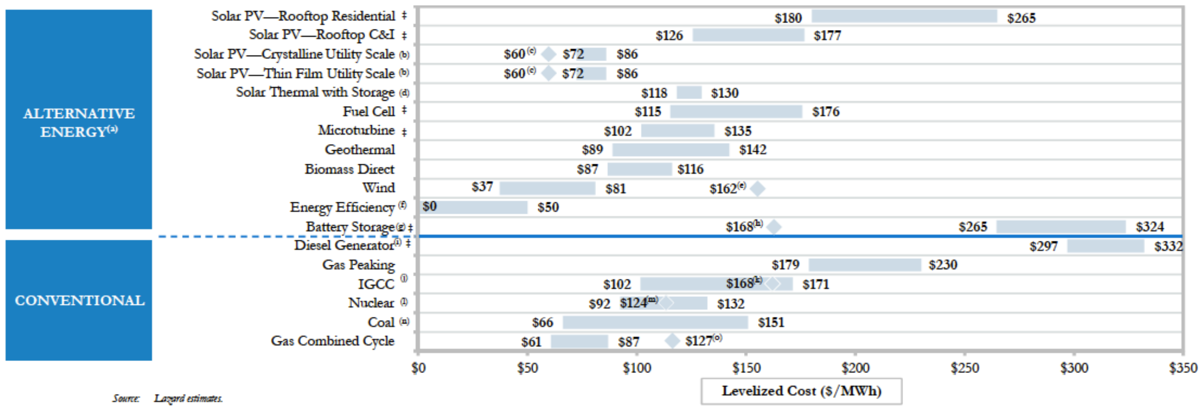
(Generation III and III+) is experiencing long delays and cost escalations while under construction in Europe and the USA. It seems unlikely that these reactors will be able to commence operation with high capacity factors.

Other myths about nuclear energy are refuted concisely in Appendix 2.

4.3 Comparing costs of renewables and nuclear

Comparisons of levelised cost of energy (LCOE) of different energy technologies depend critically on assumptions. Figure 2 (below and blown up in Appendix 4) draws upon the assumptions and analysis of Lazard (2014), which describes itself as 'the world's leading independent financial advisory and asset management firm'. This multinational corporation has no predilection for any particular energy technology. Lazard attempts to evaluate the unsubsidised costs, excluding the external environmental and social costs, for new energy technologies installed in the USA. However, this approach underestimates the hidden subsidies to nuclear discussed in Section 4.2.

Figure 2: Comparative levelised energy costs (LCOE) of new energy technologies in USA



Source: Lazard (2014).
Notes: To convert $/MWh to c/kWh, divide by 10.
Nuclear costs exclude decommissioning, federal loan guarantees and many hidden subsidies such as inadequate insurance.
Costs of rooftop solar PV should be compared with retail electricity prices, not wholesale.
Lazard's detailed assumptions, together with a blown-up version of the diagram, are given in Appendix 4 of the present report.

Lazard (2014) finds that the range of (partial) nuclear costs (12.4–13.2 US c/kWh) is roughly double that of unsubsidised onshore wind (3.7–8.1 US c/kWh) and also much greater than that of large solar PV power stations (7.2–8.6 c/kWh). It should be noted that Lazard's 'maximum' estimate of nuclear LCOE is lower than the guaranteed price of the proposed new Hinkley C reactors in the UK (9.25 p/kWh or about US 14 c/kWh).

5. Benefits, risks and safety

5.1 Benefits

With its excellent wind and solar resources and its already quite high penetrations of wind energy into the grid and solar PV onto its residential rooftops, SA has the opportunity to become the first Australian state to reach 100% renewable electricity and in so doing to cut its greenhouse gas emissions substantially. The transition to RE would also reduce air pollution and associated respiratory diseases from the combustion of fossil fuels (Burt et al. 2013).

Large-scale RE reduces the price of wholesale grid electricity, as discussed in Section 4.1. Consumers who install rooftop solar PV reduce their electricity bills.

With improved and new transmission lines, SA could export large quantities of renewable electricity to the eastern states and possibly, in the long term, overseas (Blakers et al. 2015).

RE offers considerable potential for job creation, much greater than current levels. Annual direct fulltime-equivalent employment in RE activities in Australia was 12,590 in 2013-14. This figure is a decline of 2,300 or 15 per cent from the peak of 14,890 recorded for 2011-12 (ABS 2015). The decline can be attributed to federal government policies threatening the RET, ARENA and CEFC, and state government policies that allow the reduction to very low, unfair levels of feed-in tariffs paid by electricity retailers.

The dominant contribution to RE employment was from solar energy, both PV and hot water. In the ABS figures employment in solar rooftop PV activities comprises all activities required to install small-scale solar power infrastructure. This includes site preparation; roof modifications; electrical preparations (e.g. powerboard upgrade and/or meter replacement); installation of racking for solar panels, solar panels and inverter; and testing and certification of installed systems. It also includes related retail activities and project management (ABS 2015). Solar hot water provides similar jobs together with manufacturing in Australia.

At present employment in wind power primarily involves activities related to installation of wind power infrastructure such as concrete slabs, towers, turbines, grid connection and access roads. This work is carried out by employees of businesses engaged in engineering and construction, transport and similar businesses (ABS 2015). Appropriate state and/or federal government policies would also open up manufacturing opportunities.

Unlike large fossil-fuelled and nuclear power stations, solar and wind technologies are mass-produced. This means that local manufacturing in Australia of components is possible, especially of large components of RE systems that are expensive to transport between continents. Indeed, during 2005–06 when Australia government policies appeared to support the expansion of RE, a global company dedicated exclusively to wind energy, Vestas, established factories to manufacture blades for large wind turbines in Portland, Victoria, and hub components in Wynyard, Tasmania. Australian companies manufactured the towers and other components. Unfortunately the delay of several years before the RET was increased resulted in closure of the Vestas factories and job losses in the Australian businesses as well.

In undertaking the transition to 100% RE, SA could create a wide range of new jobs for manufacturing components of wind turbines, CST power stations and electric vehicles; engineering jobs for installation and grid connection of RE power stations; and technical jobs for the installation of rooftop solar PV and solar hot water. However, it is challenging to compete with China in manufacturing conventional solar PV modules. In SA, Tindo Solar has found a niche, supplying panels with micro-inverters that supply alternating current (AC) instead of direct current (DC) (Solar Choice website).

Nuclear energy is a capital-intensive technology with few benefits. Apart from digging the foundations and pouring the concrete, most of the modest number of jobs from building an SA nuclear power station would be overseas.

5.2 Risks and safety

The physical risks of commercially available wind and solar technologies to the environment and health are negligible. The main RE technologies that require careful scrutiny for environmental sustainability and social justice are big hydro and some types of bioenergy (Diesendorf 2014, Chapter 5).

On the other hand, the risks of nuclear energy are well-known (Diesendorf 2014, Chapter 6; Sovacool 2011):

- nuclear war resulting from proliferation of nuclear weapons;
- rare but devastating accidents;
- high potential for terrorism;
- managing high-level nuclear wastes for 100,000 years or more;
- integrated risks over 100,000 years from low-level radiation emitted from uncovered waste mountains at uranium mines.

6. The key challenges and policies for solving them

6.1 A key challenge

A key challenge in transitioning to a predominantly or entirely renewable electricity system is to balance continuously a fluctuating supply from the variable RE technologies, wind and solar PV, against a fluctuating demand. Since conventional power stations break down unexpectedly from time to time, this challenge is qualitatively the same as in a fossil fuelled electricity supply system. A conventional system already manages uncertainty in supply and demand. However, quantitatively, the challenge is greater in a system in which the variable sources wind and solar PV together supply most of annual electricity consumption.

Meeting this increased challenge requires flexibility on both the supply and the demand sides, increased storage, and geographic distribution of RE power stations facilitated by improved transmission links. As discussed in Section 3.1, the supply-side part of the solution is to balance the variable RE technologies with dispatchable, fast-response technologies, namely open-cycle gas turbines (which can be fuelled initially on natural gas and subsequently on renewable liquids or gases), CST with thermal storage and, where the resource is available, hydro-electricity with dams. There is no role for inflexible coal and nuclear stations in this mix.

Since the weather inputs to wind power, solar PV and CST are site dependent, it is essential that strategic planning and design are used to achieve geographic distribution of new wind, solar PV and CST in order to obtain a configuration that is efficient for the whole system, instead of for individual projects. Market incentives may be needed to implement the more efficient distribution and deployment of RE, rather than accepting neoliberal economic dogma that the ‘free’ market should determine such projects at the margin. For instance, in order to avoid concentrating all its wind farms in the high-wind region along its northern coast, Germany offered higher feed-in tariffs for wind farms in medium-wind locations further inland.

The demand side part of the solution is to use demand management to shift the demand for electricity to times when more wind and sun are available.

Thus, to address the key challenge of balancing continuously a fluctuating supply from the variable RE technologies, wind and solar PV, against a fluctuating demand, SA will need new policies to address technological and infrastructure issues, pricing and incentives. The first step is to set well-defined targets. The remaining steps are to develop and implement, with public consultation, policies to ensure that the targets will be achieved.

6.2 Targets

In the absence of effective federal government policies, this submission recommends:

- strong targets for greenhouse gas reductions for 2020, 2025 and 2030;
- strong targets, in GWh per year, for large-scale renewable electricity for 2020, 2025 and 2030, reaching either 75% or 100% of annual electricity consumption in 2030;
- if the 75% RE target is chosen for 2030, then the additional target of 100% in 2040 is recommended.

SA has a target of 50% renewable electricity by 2025, but this is subject to the continuation of the LRET (Renewables SA website). We recommend that the target be freed from its tie to LRET and that an additional target of at least 75% renewable electricity be set for large-scale electricity generation in 2030.

6.3 Renewable energy incentives

SA has several options for incentives for implementing the RE targets:

- for large RE power stations, either a certificate scheme, similar to the national Renewable Energy Certificates (RECs) but associated with state RE targets, or a reverse auction together with feed-in tariffs of contracts for difference;
- for small- and medium-scale RE, fair feed-in tariffs funded by a small increase in retail electricity prices;
- fair retail prices for grid electricity;
- smart meters and smart switches;
- a new transmission spine joining SA to NSW.

These are explained in the next sections.

6.4 Renewable energy certificates

In Australia under LRET, generators of RE are issued with tradable certificates called RECs, with each certificate equivalent to 1 MWh of electricity generation (St John 2014). This gives investors an incentive to invest mainly in the cheapest RE technology, wind power. Neoclassical economists see this as an advantage, because it gives the least-cost investment at the margin. But to RE strategic planners, it's a disadvantage, because one cannot operate an electricity grid on wind alone. To build a reliable, stable, supply system, we need a mix of RE technologies and also a mix of locations. Those mixes must be established as RE capacity grows. Fortunately the certificate scheme can be readily modified to do this.

Therefore we recommend that the SA government disaggregate the proposed 2025 and 2030 targets into separate targets for wind, solar PV, CST with thermal storage and hydro/marine power. Geographic diversity can be achieved by interstate trading (see Section 6.9). However, introducing a state certificate scheme would run counter to federal RET legislation and so an alternative approach is suggested.

6.5 Reverse auction

As an alternative to the state certificate scheme for meeting the proposed targets for large-scale RE, reverse auctions are recommended for each of the principal RE technologies (del Rio & Linares 2014). Reverse auctions should be designed carefully to ensure that a large number of credible bidders participate and that the winners are bound by contract build the RE power stations they have won. The winners should receive sufficient feed-in tariffs, or contracts for difference (McConnell & Kallies 2015), to enable them to make an appropriate profit.

The success of the ACT reverse auction scheme (Buckman et al. 2014) in rapidly rolling out solar PV, wind and, soon, solar with storage, with feed-in tariffs that decrease over time, suggests that the reverse auction approach is preferable to the certificate scheme for SA. It is also preferable because it does not depend on the federal government passing legislation to permit a state RET scheme to be introduced (McConnell & Kallies 2015). The remaining policy options, Sections 6.6–6.10, are recommended independently of whether certificates or reverse auction is chosen.

6.6 Capacity payments for flexible, fast response power stations

To address the problem, discussed in Section 4.1, of low wholesale electricity prices displacing flexible, fast response, dispatchable peak-load power stations, it is recommended that these stations receive payments for capacity. Higher payments could be made to gas turbines burning renewable fuels compared with fossil fuels.

6.7 Fair feed-in tariffs for small- and medium-scale renewable energy

To resist the threat they perceive to their business model from the growth of rooftop solar PV and other small-to-medium scale grid-connected RE, electricity retailers have successfully lobbied several state governments to remove the mandatory requirements on feed-in tariffs. As a result, feed-in tariffs offered by retailers now range from zero to 8 c/kWh, with most in the range 6–8 c/kWh, while electricity purchased from the grid is generally in the range 25–35 c/kWh, depending upon category of user and time of use. In SA the minimum feed-in tariff to be paid by retailers is 6.0 c/kWh, but the Essential Services Commission of SA proposes to reduce this to 5.3 c/kWh (ESCOSA website). Such low feed-in tariffs are unfair, because they don't value the environmental benefits of RE and they assume that the electricity fed into the grid must use and pay for the whole distribution network, which is unrealistic.

On the other hand, in the USA, producing on-site energy from a solar panel has been treated much like any other activity reducing electricity use. Energy produced from solar is subtracted from the amount of electrical energy used each month, and the customer pays for the net amount of energy consumed. It is argued that this is unfair to the utility, because it doesn't allow for the value of the (partial) network service provided for the feed-in.

The US state of Minnesota has devised a preliminary 'value of solar' that takes account of eight beneficial factors of solar. For Minnesota it gives an intermediate feed-in tariff US 14 c/kWh (Farrell 2014).

The next step would be to allow the feed-in tariff to vary by time of feed-in, according to the varying supply and demand on the grid. This would be even fairer to the retailer and would encourage the solar PV owner to purchase some battery storage as battery prices decline.

6.8 Fair prices for retail electricity

Demand for grid electricity from the NEM (and SA in particular) has decreased each year for the past five years[2] (Pitt & Sherry 2015). This is the result of:

- growth in rooftop solar PV;
- increased demand reduction, including from energy efficiency, stimulated in part by high retail electricity prices; and
- ongoing decline of manufacturing.

In an attempt to delay the 'death spiral' resulting from the collapse of their business model (Diesendorf 2014, pp.247–250), retailers are raising the fixed component (known as the 'service' or 'supply' charge) of electricity bills. This has the negative effects of discouraging grid electricity consumers from installing rooftop solar PV and from improving their efficiency of energy use. Therefore, it is necessary to devise a price structure for purchase of grid electricity that maintains the distribution network while not restricting the growth of energy efficiency, rooftop solar PV and the installation of battery storage by grid-connected electricity consumers. While a detailed analysis of this challenge and its possible solutions is beyond the scope of this submission, two key policies are recommended for improving the operation and fairness of the retail market:

1. State governments should mandate that electricity retailers be required to offer households and commercial electricity consumers fair fixed charges that are proportional to the maximum demand nominated by the consumer. (This is already occurring to some degree for some large commercial and industrial electricity consumers, but is not mandated and controlled by state governments.)

2. State governments should foster the implementation of a 'smart' grid so that electricity prices for all consumers, including households, can vary by time of use and are governed by the levels of supply and demand at any time. This would encourage consumers to shift non-essential electricity uses to times when demand is low and supply high. It would also enable solar PV owners to install sufficient batteries to reduce their use of grid electricity during peaks in demand on the grid, as battery prices decline.

6.9 A new transmission spine

The official website of Denmark, in a piece entitled 'Independent from Fossil Fuels by 2050' says: 'By tying our electrical grid into a regional framework and by having a spare capacity backed by biomass, Denmark will continue to have a stable energy system.' (Denmark website). A similar rationale applies to SA.

At present SA is directly connected only to Victoria. The two existing lines, Murraylink and Heywood, have relatively small capacities. Murraylink has a nominal rating of 220 MW, although its actual limit depends on flow direction and local conditions. Heywood has a nominal capacity of 460 MW, but many factors can limit flow to less than this (AEMO 2014, pp.22–23). Hourly computer simulations of the operation of the NEM with 100% RE indicate that a new direct transmission link between SA and NSW, specifically between Port Augusta

[2] The declining trend levelled out, at least temporarily, in March and April 2015.

and the eastern NSW 500 kV transmission lines via Broken Hill, would enable SA to generate much more wind power and sell it to NSW. The new line would have the additional benefit of feeding power from a huge proposed wind farm near Broken Hill, and solar power from inland NSW, to Sydney and other population centres on the east coast. If hot rock geothermal power in central Australia becomes commercially available, it could be connected to the proposed interstate line at Broken Hill. Since the line would benefit both SA and NSW, it could be funded jointly by the two states and federal infrastructure funds.

6.10 Seawater pumped hydro

It is recommended that the SA government fund a consultancy to determine the resource size and costs of seawater pumped hydro for SA. While the distances for pumping the seawater in SA are much greater than that of the coastal Okinawa Yanbaru plant in Japan, the heights of some of the hills in SA (500–800 m) are much greater than that of the upper reservoir of the Okinawa plant (150 m). The upper reservoirs can be quite small, since the requirement is to generate for short periods at high power during lulls in the wind or fluctuations in sunshine due to passing clouds. The height of a reservoir above sea-level, which determines the power output, is much more important than its size, which determines the energy stored.

7. Conclusion

The transition to a 75–100% renewable electricity system, based on scaled-up commercially available technologies, is technologically feasible and affordable for the Australian National Electricity Market in general and for SA in particular. It offers new jobs, reduced greenhouse gas emissions, less air pollution and associated respiratory diseases and, once the initial investments have been made, a cap on electricity prices. All it needs is the political will.

This study refutes the myth that high penetrations of RE into the grid are necessarily unreliable and need large amounts of back-up. Practical experience and computer simulation modelling show that reliability can be achieved by implementing some of the following:

- a mix of variable RE (wind and solar PV) and flexible (fast response), dispatchable RE sources (such as CST with thermal storage, biofuelled gas turbines and hydro with small dams);
- geographic dispersion of RE power stations together with one or two new major transmission links;
- demand modification by means of 'smart' meters and switches in a 'smart' grid.

Large-scale wind energy is about half the cost of nuclear energy. Large-scale solar in parts of the USA and South America is already cheaper than nuclear. As far as Australia is concerned, nuclear energy could not compete with RE. The cost of a 75–100% renewable electricity system depends on one's choice of future cost projections for both RE and gas. It is certainly affordable if one takes into account the environmental costs of fossil fuels.

In the absence of a carbon price, the policies required to drive the transition involve targets, new price structures for both grid electricity and feed-in tariffs, and either tradable certificates associated with the LRETs or reverse auctions together with feed-in tariffs or contracts for difference. The ACT's approach using reverse auctions is preferable. The transition could be facilitated by introducing a 'smart' grid to foster improved demand management and by building a new high-capacity transmission line between SA and NSW to foster geographic diversity of RE supply to the NEM.

Compared with scenarios involving nuclear power, the RE scenarios are equally reliable; much less dangerous; less expensive; emit less life-cycle CO_2 (see Appendix 3); offer a wider range of environmental, health and employment benefits; and can be implemented much more rapidly.

A nuclear power station is not a serious option for SA for the foreseeable future. Not only would it be too expensive. With a reactor size of 600 MW or more it would be too big for the SA grid system (maximum demand 3400 MW) and would need a huge amount of back-up. Yet small modular reactors (SMAs) are not commercially mature. If/when they first become commercially available, their capital costs in $/kW and LCOEs in c/kWh will be inevitably even higher than the already high costs of the existing generation of reactors. In the foreseeable future they are unlikely to be mass-produced, because there is little if any evidence of non-military demand for small expensive reactors. Even if SMAs are eventually mass-produced, it is not obvious that the benefits of mass production would outweigh the higher costs resulting from the reduced scale of the reactor. Furthermore, in order to complement the present and future high penetration of RE into the SA grid, a nuclear reactor would have to be designed to be flexible in operation, the opposite of the present situation.

In a nutshell, nuclear is too expensive, too inflexible, too dangerous, too CO_2-intensive, too slow a technology to introduce, and too big for South Australia.

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Appendix 1: Renewable Energy Myths

Myth	Refutation
MYTH: Renewable energy is too variable or 'intermittent' to reliably make the major contribution to electricity supply	Hourly computer simulations, spanning 1–32 years of data on electricity supply and demand, show that 80–100% renewable energy can supply electricity just as reliably as conventional power stations. Reliability is achieved by having a mix of variable renewables (eg, wind and solar photovoltaics (PV)) and flexible, dispatchable renewables (eg, hydro with large dams, gas turbines burning renewable gases and liquids, and CST with thermal storage). Geographic dispersion of renewable energy generators and reductions in demand peaks in 'smart' grids further increase reliability. As of mid-2014, about 30 simulation studies have been published for different countries and regions and most use commercially available renewable energy technologies.
MYTH: Base-load power stations are necessary and renewable energy cannot provide them	Base-load power stations, such as coal or nuclear, are unnecessary for supplying base-load demand reliably. This is shown by both hourly computer simulations of electricity supply from 100% renewable energy and practical experience with high penetrations of wind power into electricity grids. In a 100% renewable electricity system, reliability is achieved by the means explained in the previous refutation.
MYTH: Coal-fired power stations must be operated continuously as back-up for variable renewable energy systems	Again, both practical experience and computer simulations bust this myth. In South Australia, where 33% of annual electricity is generated from wind, one of the two coal-fired power stations has been shut down and the other is now only operated for half the year. No additional gas-fired power stations have been installed. Computer simulations confirm that base-load power stations, such as coal and nuclear, are too inflexible to be partners with large amounts of variable renewable energy. The necessary partners are flexible, peak-load power stations, which can be entirely renewable.
MYTH: Renewable energy is too expensive	Once true, but now no longer. In many countries rooftop solar PV has become economically competitive with retail electricity prices and in a few locations large solar PV power stations are already becoming competitive in the wholesale market. On-shore wind is competing with new conventional power stations in the wholesale market in several countries. Both solar PV and wind are continuing to become cheaper, while coal and nuclear power stations are becoming more expensive.
MYTH: Renewable energy receives huge subsidies	Subsidies to renewable energy have been decreased to the point where they are generally much smaller than the direct economic subsidies to the production and use of fossil fuels and to nuclear energy. In addition, fossil and nuclear energies receive huge indirect subsidies resulting from the failure to include in their prices their huge environmental and health costs and risks.
MYTH: Renewable energy is not ready to replace fossil fuels	A sufficient variety of commercially available renewable energy technologies are ready to replace fossil-fuelled electricity in Australia and many other countries. Of course renewable energy has to be

	scaled up, however this can be done much more quickly than for fossil and nuclear power stations, because wind and solar technologies are mass-produced in factories and the installation is very rapid. For urban transport, cycling, walking, improved mass transit and vehicles fuelled by renewable electricity can replace most fossil-fuelled vehicles. For long-distance rural road and air transport, renewable energy still needs further development: 2nd and 3rd generation biofuels may be the solution.
MYTH: Renewable energy is too diffuse to run an industrial society	There is ample marginal land on the planet, together with rooftops, to provide all the solar energy required, while wind farms are compatible with almost all forms of agriculture and occupy only 1–2% of the land they span. While not all countries are equally blessed with renewable energy resources, trade in renewable energy by transmission lines and by transporting renewable hydrogen in LNG tankers could supply disadvantaged regions. After all, fossil fuels and uranium are traded internationally.
MYTH: Energy payback periods (in energy units, not money) for renewable energy systems are comparable with their lifetimes	This was once true in the early uses of solar PV in satellites. Nowadays energy paybacks for solar PV modules are typically 0.5–1.8 years and for wind turbines 0.25–0.75 years, depending on location and technology type. The lifetimes of these technologies are about 25 years each. For comparison, energy payback periods for nuclear energy are 6.5–14 years, depending on whether high- or low-grade uranium ore is mined and milled.
MYTH: Danish electricity prices are among the highest in Europe, because of the high use of renewable energy in Denmark	Danish electricity prices are among the highest in Europe, because the tax on electricity is very high in Denmark. This tax goes into consolidated revenue; it does not specifically subsidise renewable energy. When European electricity prices without taxes are compared, Denmark's is in the lowest quartile.
MYTH: The doubling of retail electricity prices in Australia in recent years is primarily the result of the carbon price and the Renewable Energy Target	By far the biggest contribution to the increase in electricity prices in Australian states comes from the costs of upgrading the distribution system (poles and wires) resulting primarily from increasing demand for air conditioning and new suburbs. In 2013–14 the distribution network was responsible for the major part of average retail electricity price, the carbon price 9% and the Renewable Energy Target about 2%. However, the latter would be offset by the reduction in wholesale electricity price from wind farms, ***if*** it were passed on to retail customers.
MYTH: Infrasound (sound that is too low in frequency to be heard by the human ear) from wind turbines causes a wide range of ill health symptoms	Despite numerous studies, there is no scientific evidence to support this claim. Evidence against it is that infrasound from air conditioners, motor vehicles travelling on roads and waves breaking at a beach is generally much greater than infrasound from a wind turbine. Furthermore, a randomised, controlled, double-blind trial shows that people cannot distinguish between infrasound and sham infrasound (silence) and that illnesses attributed wrongly to infrasound can be psychologically induced.

Appendix 2: Nuclear energy myths

Myth	Refutation
MYTH: There is a renaissance in nuclear energy.	Annual global nuclear electricity generation peaked at 2660 TWh in 2006 and dropped to 2359 TWh in 2013. In percentage terms, nuclear energy's share of global electricity generation has dropped from its historic peak of 17.6% in 1996 to 10.8% in 2013. Reductions in nuclear capacity are expected over the next decade and beyond as Germany closes nuclear and France reduces its nuclear fleet. Retirements are expected from other countries too, since the world nuclear fleet is ageing, with 44% having operated for 30 years or more.
MYTH: Base-load power stations are necessary, so the only choice is between coal and nuclear.	As explained in Section 3.1 and Appendix 1 of this submission, electricity supply systems based on 100% renewable energy can be designed to be reliable, even when the energy mix has the major contribution from variable sources such as wind and solar PV. This is shown by both hourly computer simulations of electricity supply from 100% renewable energy and practical experience with high penetrations of wind power into electricity grids.
MYTH: Nuclear energy could fill in the alleged gap in clean energy supply until renewable energy is ready.	Nuclear power stations are a very slow technology to construct, taking typically in the USA 9–10 years plus planning years. In Australia even the nuclear industry admits that it would take 15 years to plan and build the first nuclear power station and to this should be added the time required to convince the public. On the other hand, large wind and solar power stations can be planned and built in 2–3 years. There is no gap in clean energy supply—only the political will to embrace renewable energy is lacking in some countries with powerful vested interests in fossil fuels or nuclear energy.
MYTH: Nuclear weapons cannot be made from reactor grade plutonium (the type of plutonium made in a civil nuclear power station).	This claim has been refuted by a leading nuclear bomb designer (Dr Theodore Taylor), a Commissioner of the US Nuclear Regulatory Commission (Dr Victor Gilinsky) and the US Department of Energy. Indeed the USA has tested nuclear bombs that use reactor grade plutonium.
MYTH: Fourth generation nuclear reactors – fast breeder, integral fast or thorium – are either commercially available or will be very soon	None is commercially available. The fast breeder has been stuck at the demonstration stage of maturity for decades. The integral fast reactor was only built as a pilot plant in the USA. Thorium has been researched for 40 years as a potential nuclear fuel, but the commercialisation of thorium reactors still looks expensive and distant.
MYTH: Nuclear weapons cannot be made from the thorium fuel cycle	Nuclear reactors are fuelled on fissile elements, i.e. those whose atomic nuclei can be split. If the fuel is fissile, it can be split either in a controlled way in a reactor or in an uncontrolled chain reaction in a bomb. Since thorium is not fissile, it has to be converted into a fissile element, uranium-233, by bombarding it with neutrons. The USA and India have exploded nuclear bombs with uranium-233 as the explosive.

Myth	Refutation
MYTH: Nuclear weapons cannot be made from the integral fast reactor.	The integral fast reactor is a hypothetical reactor whose spent fuel would be separated on-site, using an experimental process called pyroprocessing, into medium-life fission products and long-life transuranic (aka actinide) elements including plutonium-239, a nuclear weapons explosive. In theory the transuranics could be fed back into the reactor and 'burned' up, without separating the plutonium. But in practice the plutonium could be extracted from the other transuranics by chemical reprocessing and used in nuclear weapons. This extraction would be easier and safer from the spent fuel of an integral fast reactor than from a conventional reactor, because the highly radioactive fission products would have already been separated by pyroprocessing.
MYTH: Only 30-64 people died as the result of the Chernobyl disaster.	This misleading statement refers only to the relatively small number of short-term deaths from acute radiation syndrome and ignores the major contribution to deaths and disabilities, namely long-term induced cancers. Estimates of cancers by reputable authorities range from 16,000 to 93,000.
MYTH: Nuclear power emits no or negligible greenhouse gas emissions.	This misleading statement ignores life-cycle CO_2 emissions which are already greater than those of wind power and are expected to increase substantially over the next few decades as high-grade uranium ore is used up and low-grade ore has to be mined and milled using fossil fuel (diesel).
MYTH: Nuclear power stations have capacity factors (annual average power divided by rated power) of around 90%.	Although this misleading statement is correct for the operation of US nuclear power stations in recent years, it omits to mention that lifetime average capacity factors are much lower. It has taken much expensive maintenance over several decades to lift the performance to current levels. Global average capacity factors in 2013 were about 72%. It is unlikely that the new generation of reactors (Generation III and III+), with their teething problems, could achieve high capacity factors in their early years of operation.
MYTH: The quantity of nuclear wastes is tiny compared with that of coal wastes.	This misleading statement is based on comparing all coal wastes with the volume of high-level nuclear wastes only, while ignoring the much larger volume of low-level nuclear wastes, e.g. Olympic Dam uranium and copper mine has a waste mountain of about 150 million tonnes blowing in the wind.
MYTH: Nuclear energy is cheaper than wind and solar PV.	On-shore wind energy is already half the price nuclear energy; utility scale solar PV power stations are just starting to become competitive with nuclear power in a few regions of the world. Fourth generation nuclear reactors, which are being presented by enthusiasts as the future hope of the nuclear industry, are more complex and hence likely to be even more expensive than the current third generation that are under construction.

Appendix 3: Power system frequency control

The 50 Hz frequency of alternating current (AC) in NEM is currently maintained by the rotational inertia of large turbines driving synchronous generators. The majority of modern wind turbines do not contribute significant rotational inertia to the system and PV contributes none[3]. When the system has insufficient inertia, frequency control and handling of fault conditions become more difficult. Disturbances, such as the loss of a large generator or the sudden, large increase or decrease in demand, cause the system frequency to deviate from the standard and must be mitigated very quickly to avoid a collapse of the wider system and blackouts (AEMO 2012; 2013 pp.96–97).

When a disturbance suddenly lifts supply or decreases demand, so that supply becomes greater than demand, the power system frequency increases above 50 Hz. When a disturbance suddenly reduces supply or increases demand, so that demand become less than supply, the power system frequency decreases below 50 Hz. Currently Frequency Control Ancillary Services (FCAS) in the NEM are supplied mostly by coal-fired power stations and at present the system can easily accommodate large variations from wind and solar.

For several reasons, including concern about frequency control, some grids (such as Ireland) have placed limits on the total contribution to the grid from wind and solar PV. However, practical experience and computer simulations with high penetration RE indicate that these limits can be set high and are not rigid. Advances in power electronics, battery technology and the controllability of wind turbines could lift such a limit further and may ultimately make operation on 100% non-synchronous generation possible.

It should be noted that 100% renewable electricity does *not* entail 100% non-synchronous generation. In the simulation modeling by UNSW published to date, the optimal mix of 100% RE has 66% of annual electricity generation coming from wind and solar PV. The remainder comes from CST, hydro with storage and biofuelled gas turbines (a few percent), all of which supply rotational inertia to the supply system

In the future, as wind and solar PV replace coal, they could contribute FACS. With appropriate control technologies that are commercially available, but not widely disseminated at present, disturbances that increase the frequency could be controlled rapidly by automatically reducing slightly the output of the wind turbines and/or solar PV power stations so that demand and supply are once more in balance. Conversely, disturbances that decrease the frequency could be controlled rapidly by automatically offloading some demand in a future 'smart' grid. In the long-term future when there is a very large contribution from wind plus PV, some wind and PV could be operated under normal conditions slightly below their maximum outputs at prevailing weather conditions, holding some power in reserve for frequency response and could respond to a disturbance that lowers frequency by briefly increasing their outputs (Miller et al. 2014).

The NEM already has a market to provide financial incentives for FCAS. Unlike the wholesale spot market for electrical energy, where generators are paid according to their actual dispatch, registered providers of FCAS are paid whether or not their capabilities are called upon. Wind farms and solar PV power stations are not excluded from being FCAS providers. They can provide rapid downward response and, in the long-term future, could also provide rapid upward response as explained above. In the long run the NEM may need to

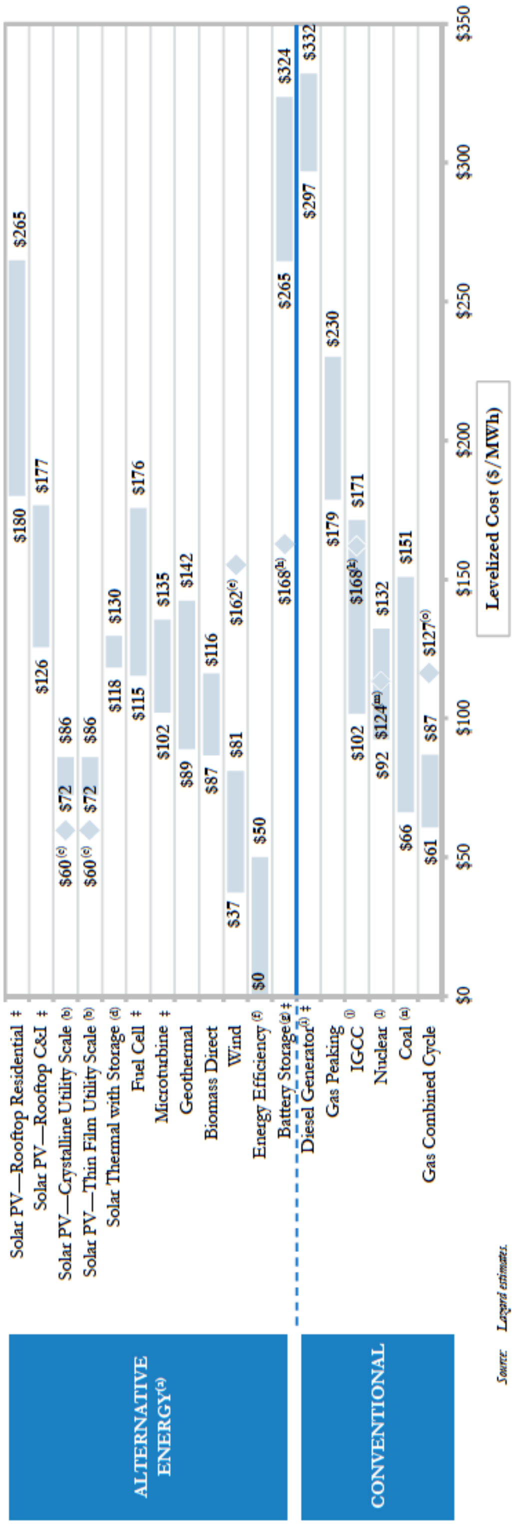
[3] Sophisticated power electronics can provide an 'artificial' inertial response from these technologies, although this is still experimental and has not yet been implemented at a commercial scale.

introduce incentives for the provision of inertia, as a possible supplement to existing FCAS services – although other alternatives exist (Riesz et al. 2015).

AEMO (2013 pp.96–97) sums up the frequency control situation as follows:

> It is likely therefore that while a NEM with the higher non-synchronous generation penetration levels…will pose some frequency stability challenges, at this stage it might be considered as a problem of detailed investigation and design rather than a fundamental limit on the 100 per cent renewable generation portfolios.

Appendix 4: Figure 2 with detailed assumptions, reproduced from Lazard (2014)



Note: Here and throughout this presentation, unless otherwise indicated, analysis assumes 60% debt at 8% interest rate and 40% equity at 12% cost for conventional and Alternative Energy generation technologies. Assumes Powder River Basin coal price of $1.99 per MMBtu and natural gas price of $4.50 per MMBtu. Analysis does not reflect potential impact of recent draft rule to regulate carbon emissions under Section 111(d).

‡ Denotes distributed generation technology.

(a) Analysis excludes integration costs for intermittent technologies. A variety of studies suggest integration costs ranging from $2.00 to $10.00 per MWh. [0.2 to 1 c/kWh]

(b) Low end represents single-axis tracking. High end represents fixed-tilt installation. Assumes 10 MW system in high insolation jurisdiction (e.g., Southwest U.S.). Not directly comparable for baseload. Does not account for differences in heat coefficients, balance-of-system costs or other potential factors which may differ across solar technologies.

(c) Diamonds represents estimated implied levelized cost of energy in 2017, assuming $1.25 per watt for a single-axis tracking system.

(d) Low end represents concentrating solar tower with 18-hour storage capability. High end represents concentrating solar tower with 10-hour storage capability.

(e) Represents estimated implied midpoint of levelized cost of energy for offshore wind, assuming a capital cost range of $3.10 – $5.50 per watt.

(f) Estimates per National Action Plan for Energy Efficiency; actual cost for various initiatives varies widely. Estimates involving demand response may fail to account for opportunity cost of foregone consumption.

(g) Indicative range based on current stationary storage technologies; assumes capital costs of $500 – $750/kWh for 6 hours of storage capacity, $60/MWh cost to charge, one full cycle per day (full charge and discharge), efficiency of 75% –85% and fixed O&M costs of $22.00 to $27.50 per kWh installed per year.

(h) Diamond represents estimated implied levelized cost for "next generation" storage in 2017; assumes capital costs of $300/kWh for 6 hours of storage capacity, $60/MWh cost to charge, one full cycle per day (full charge and discharge), efficiency of 75% and fixed O&M costs of $5.00 per kWh installed per year.

(i) Low end represents continuous operation. High end represents intermittent operation. Assumes diesel price of $4.00 per gallon.

(j) High end incorporates 90% carbon capture and compression. Does not include cost of transportation and storage.

(k) Represents estimate of current U.S. new IGCC construction with carbon capture and compression. Does not include cost of transportation and storage.

(l) Does not reflect decommissioning costs or potential economic impact of federal loan guarantees or other subsidies.

(m) Represents estimate of current U.S. new nuclear construction.

(n) Based on advanced supercritical pulverized coal. High end incorporates 90% carbon capture and compression. Does not include cost of transportation and storage.

(o) Incorporates 90% carbon capture and compression. Does not include cost of transportation and storage.