atse.org.au

Submission on the Australian Government

Technology Investment Roadmap – Discussion Paper

19 June 2020

Australian Academy of
Technology & Engineering

TECHNOLOGY INVESTMENT ROADMAP – DISCUSSION PAPER

The Australian Academy of Technology and Engineering (ATSE)[1] is pleased to respond to the Australian Government's Discussion Paper on the Technology Investment Roadmap, and welcomes the preparation of this paper on technologies for low emission energy generation and use for the future of Australia. ATSE also welcomes the strategic and cyclical approach to technology investment. While the eight-stage process should be quite dynamic and adaptive, it must also have consistency and longevity, independence and integrity. ATSE would be pleased to contribute in any way that would be useful, such as evidence-based studies or support for the reference panel, noting and welcoming that the current panel already includes ATSE fellows.

In this response, ATSE proposes a range of measures that will support Australia to become a world leader in low emissions energy technology. Our strong focus is on measures that will benefit the economy and employment in the short and medium term, with a long range focus on emissions reduction and sustainability.

With this lens, ATSE believes that the key energy priorities for Australia are:

- Long-term and resilient solutions for a low-emissions economy, including low and zero emissions electricity and accelerated transformation of the electricity market
- Development of a world-leading clean energy industry, including energy technology and export

The Government has an outstanding opportunity through this process to fast-track Australia's transformation to a leading clean energy economy. To this end, ATSE recommends:

1. Support continued rapid (and growing) deployment of solar photovoltaic (PV) and wind generated electricity. This should be facilitated by design and construction of material additions to the transmission network, and the development of zero carbon large scale storage such as pumped hydro.
2. Facilitate a rapid transition to technologies such as electric vehicles and electric heat pumps for air conditioning and water heating in buildings, powered by renewable electricity, through appropriately designed policy interventions and incentives.
3. Support the development of a renewable energy-driven hydrogen production and export industry in Australia.
4. Support continued research, development, and demonstration of technologies to facilitate Australia's low-carbon energy transition, including reducing industry's emissions footprint.
5. Support and encourage education and skills development needed for the transition to a low carbon future.
6. Analyse and assess all new and emerging energy technologies, with a focus on applicability in Australia, time frame for deployment, emissions reduction potential, and cost.

ATSE would welcome an opportunity to discuss our recommendations and evidence-base with the Australian Government to support Australia's transition to a low-emissions future.

[1] The Australian Academy of Technology and Engineering is a Learned Academy of independent, non-political experts helping Australians understand and use technology to solve complex problems. Bringing together Australia's leading thinkers in applied science, technology and engineering, ATSE provides impartial, practical and evidence-based advice on how to achieve sustainable solutions and advance prosperity.

ATSE's Energy Vision for Australia

Australia's energy future will be clean, affordable, and reliable.

Australia's goals should ultimately be to reach net zero emissions at acceptable cost and reliability, and that Australia is the world leader in clean energy.

The declining cost of renewable energy generation will drive an ongoing reduction in our reliance on coal and gas for electricity and a shift towards sustainable wind and solar energy generation, along with the implementation of support technologies such as energy storage, demand side management and integrated grid management. Australia is demonstrating that a rapid switch to solar PV and wind, with storage, is feasible at low and decreasing cost with consequent substantial reduction in national CO_{2e} emissions.[2]

The rapid reduction in the cost of renewable electricity is also likely to lead to our economy becoming increasingly electrified, with the greater use of efficient heat pumps, battery storage and pumped hydro, electric vehicles and new uses of fuels such as hydrogen made from zero emission sources.

ATSE's vision is that during the 2020s PV, wind and grid-scale storage will replace gas and coal for electricity generation, resulting in a 33% reduction in emissions. Between 2020 and 2035 electricity and green hydrogen will increasingly replace oil in internal combustion vehicles resulting in a further reduction of up to 16%. The progressive greening of the natural gas network and the electrification of heating loads will eventually lead to the substantial reduction of natural gas consumption, particularly for domestic applications. This will contribute a further reduction of up to 19%. In this way, by 2035, Australia's emissions could fall by two thirds. Electricity production, supported by PV and wind, would need to double to around 500 Terawatt-hours (TWh) per year to achieve this. The remaining sources of emissions can be eliminated prior to 2050, with renewable electricity production further increased to 750 TWh per year by that time.

The technology and social motivation needed to make this vision a reality already exists; all we need to do now is solve the challenges to implementation. These include meeting a skills deficit, reducing the cost of infrastructure, and developing, coordinating and implementing an appropriate policy approach across all states and territories.

In this submission, ATSE takes an evidence-based approach to realising this future for energy in Australia in:

- Energy generation
- Energy systems balancing
- Energy usage

Electricity Generation

As demonstrated in the Technology Roadmap, there are many ways in which electricity can be generated. Each has its advantages and disadvantages, both in terms of cost, reliability, and CO_{2e} emissions. A brief analysis of the key feasible generation technologies is provided in the **Appendix** to this ATSE response.

---

[2] Blakers A. and Stocks M. 'Australia's emissions are peaking' ANU Briefing, 2019. http://re100.eng.anu.edu.au/resources/assets/191024Emissionsarepeaking.pdf

Solar PV and wind energy are likely to dominate new electricity generation investment for the foreseeable future. PV and wind energy in 2019 generated 17% of Australia's electrical energy, climbing from around 12% in 2014.[3] Moreover, PV and wind now constitute two thirds of net annual global capacity (GW) additions; in Australia, the comparable statistic is 99%.[4]

In 2010 an ATSE study[5] showed that renewable technologies were promising, but more development was required. Wind was the lowest cost renewable energy generation technology at the time, with solar PV showing cost reductions that would come to fruition in around 2030. Since that time, solar PV costs have reduced remarkably, and new solar PV and wind installations currently produce the cheapest electricity (not including storage). Market penetration of these technologies has rapidly increased, to the point where renewable energy from these sources is now almost 20% of total electrical energy generation in Australia[6] and their low cost is starting to disrupt the economic viability of existing fossil fuel generators.

The cost of wind and solar electricity is currently around $50 per Megawatt-hour (MWh)[7], and ATSE expects this will fall towards $30/MWh by 2030 (not including 'firming' and electricity storage). This is well below current costs for other new-build technologies (see Appendix). Based on the current trend, PV and wind will undercut the operating cost of existing black coal power stations during the 2020s, leading to a wave of retirements of these older fossil fuel generators as they reach the end of their lives.

Arguably, Australia is the global pathfinder for solar PV and wind. Capacity statistics from the International Renewable Energy Agency (IRENA) for 2018 and 2019[8] show that Australia is deploying new renewable capacity ten times faster per capita than the global average and four times faster per capita than in Europe, China, Japan or the United States. In 2019 Australia had:

- The most solar per person (625 Watts per person)
- The fastest deployment rate of solar per capita (168 Watts per person per year), and
- The fastest deployment rate of PV and wind per capita (216 Watts per person per year)

About 6GW of extra PV and wind capacity is being deployed per year in Australia. Renewable generation capacity is likely to pass black coal energy generation capacity in 2023 when Liddell retires, and is tracking toward 50% of Australia's electrical energy generation (MWh) in 2025-26. Gas generates about 9% of National Electricity Market (NEM) electrical energy, mostly to meet peaking loads. However, load shifting through storage (such as batteries, hydrogen and pumped hydro) and demand management may reduce demand for peak load generation (from sources such as gas) in future, as will high gas prices.

Solar PV and wind are already the lowest-cost generation, at least without storage or 'firming'. The task now is to develop and apply cost optimisation and stability systems (firming and storage technology), to enable them to supply reliable, low-cost, zero emission electrical energy to Australia.

---

[3] National Electricity Market. https://opennem.org.au/energy/nem

[4] Blakers A., Stocks M., Lu B., Cheng C. and Stocks R., 'Pathway to 100% Renewable Electricity' in IEEE Journal of Photovoltaics, vol. 9, no. 6, pp. 1828-1833, Nov. 2019. www.https://ieeexplore.ieee.org/document/8836526

[5] Australian Academy of Technology and Engineering. Low-carbon Energy – Evaluation of New Technology Choices for Electric Power generation in Australia. 2010. https://www.atse.org.au/research-and-policy/publications/publication/low-carbon-energy-evaluation-of-new-energy-technology-choices-for-electric-power-generation-in-australia/

[6] Commonwealth Department of the Environment and Energy, Australian Energy Statistics (2019)

[7] Blakers A., Stocks M., 'Technology leaps driving cost of solar PV electricity in Australia to just A$30/MWh', 7 May 2020. https://reneweconomy.com.au/technology-leaps-driving-cost-of-solar-pv-electricity-in-australia-to-just-a30-mwh-42052/

[8] International Renewable Energy Agency. https://www.irena.org/Statistics

Electricity Control Systems and 'Balancing'

As renewable technologies are increasingly taken up in the existing supply system it is crucial to develop and deploy cost-effective systems to ensure system stability and reliability.

Strong long-distance transmission grids allow energy from a region with windy or sunny weather to be moved to compensate for poor weather in another area. The amount of required storage is reduced through these systems by an order of magnitude. Examples include the proposed Marinus link from Tasmania to the mainland and the proposed link between South Australia and New South Wales. The Australian Energy Market Operator (AEMO) is developing an integrated system plan for locations with strong wind and solar resources and access to reliable transmission capacity to bring solar and wind energy to urban centres.[9]

It is clear that a key element of future systems will be energy storage. Joint work by AEMO and CSIRO has shown that the cost of batteries is falling rapidly.[10] Associated control electronics and software systems will need to be further developed to 'firm' renewables and overcome intermittency and non-dispatchability, while retaining system stability without need for physical synchronous system inertia. Research in this field is progressing rapidly. For example, the University of Queensland recently reported that their 1.1MW Li-Ion battery system with associated optimisation and a forward-predicting AI system was able to provide to the NEM very rapid Frequency Control Ancillary Services (FCAS) during bushfires and network outages associated with storms in early 2020.[11] In fact, this service provided a significant fraction of the sales revenue for this system. When scaled-up, this type of approach will be applicable to grid-scale solar PV and wind generating systems with storage. Other systems that also need to be further introduced are Network Support and Control Ancillary Services (NSCAS) and System Restart Ancillary Services (RSAS), with significant storage at the centre of these developments.

Batteries provide valuable grid services but bulk electricity will require pumped hydro and other systems that can be deployed at scale. A global survey of greenfield pumped hydro energy storage undertaken at the Australian National University found about 3,000 potential pumped hydro sites in Australia, which is several hundred times more than required to support 100% renewable electricity for the entire country (albeit further work may be required to analyse applicable land-use planning constraints). Australian examples of planned pumped hydro include Snowy 2.0, Tasmania's Battery of the Nation, Kidston/Genex in Queensland and several proposals in South Australia.

Utility, home and electric vehicle batteries are another large-scale, quick response storage that complements pumped hydro. Pumped hydro provides much cheaper energy storage over a period of hours to days, while batteries are useful for sub-seconds to hours. A further approach to consider would be to use the future electric vehicle fleet as a large storage device when not in use.

Batteries and demand management are more suitable for quick response than gas turbines because they can respond far more quickly to stability-reducing events and are not dependent on volatility in gas prices. The Australian Energy Market Commission (AEMC) has recently approved a rule change that will also allow a wholesale demand response mechanism[12] that will allow large energy users to trade reductions in electricity use in the electricity market.

---

[9] Australian Energy Market Operator, AEMO, Integrated System Plan, July 2018.

[10] Hayward J.A. and Graham P.W. 2017, Electricity generation technology cost projections: 2017-2050, CSIRO, Australia. Also Graham P.W., Hayward J, Foster J., Story O. and Havas L. 2018, *GenCost 2018*. CSIRO, Australia.

[11] Wilson A., Esterhuysen D., Hains D., 'The Business Case for Behind-the-meter Energy Storage', University of Queensland, 2020.

[12] Australian Energy Market Commission. https://www.aemc.gov.au/rule-changes/wholesale-demand-response-mechanism

Energy Usage

ATSE has also considered how energy is, and will be, used in Australia. Diverse needs are represented across industry, transport/mobility, export, and remote and urban populations. There is also a role for greater focus on energy efficiency and the circular economy.

A number of technologies should be supported to ensure Australia's low-emissions future, including low- and zero-emissions vehicles, heat pumps for hot water and air conditioning, in-factory thermal storage, renewable remote power supplies, and demand-side management. Reducing energy waste also remains an area where achievable gains can be made, including through speeding up the capital asset replacement cycle – new appliances are generally more efficient than those they replace.

Gas uses additional to electricity generation will need to be addressed to support Australia in reaching our emission reduction goals. Electrification to substitute for gas heating is part of the solution but not all industrial applications of gas currently have access to alternative technologies. The decarbonisation of industrial processes should be a priority for research and development.

Hydrogen

Australia's hydrogen potential has been investigated as part of the preparation of a National Hydrogen Strategy by the Chief Scientist[13] and CSIRO[14]. These studies show that the production of hydrogen has the potential to be an important new industry and a valuable export opportunity for Australia. In particular, renewable hydrogen produced through electrolysis using zero emissions electricity. An emerging hydrogen industry has the potential to initially supplement, and in the longer term replace, Australia's liquid natural gas exports.

Exporting renewable hydrogen by ship, either in liquefied form at low temperature (-253^{o}C) (Kawasaki Heavy Industries)[15] or in the form of ammonia (CSIRO)[16] is another potential export industry for Australia. The latter technology, still at the pilot stage, converts ammonia to hydrogen using catalyst-packed metal tubes that act as metal membranes for hydrogen separation. Again, cost reduction will be critical so further research and development in this field must be supported, in collaboration with international research groups, CSIRO, Australian universities and industry.

Renewable hydrogen can also be utilised as a pipeline-reticulated fuel, and admixtures of hydrogen to natural gas pipelines are already being trialled in Australia. Blending hydrogen into the gas network can also reduce the emissions associated with natural gas use. Hydrogen also has the potential to support the electricity system by providing short to long term energy storage options and services such as FCAS.

Developing a hydrogen industry in Australia will require support for further research and development, and hydrogen production, storage and network integration, which the Government has already begun. ATSE recommends governments give priority to actions that could drive down the cost of hydrogen production and storage, using the National Hydrogen Strategy as the framework.

---

[13] Finkel A. et al., 'Hydrogen for Australia's Future', Hydrogen Strategy Group, COAG Energy Council, 2018

[14] Bruce S., Temminghoff M., Hayward J., Schmidt E., Munnings C., Palfreyman D., Hartley P. National Hydrogen Roadmap. CSIRO, Australia, 2018.

[15] Kawasaki. 'Hydrogen Road: Powering the way for a hydrogen based society', https://global.kawasaki.com/en/stories/hydrogen/

[16] CSIRO. 'Metal membrane for hydrogen separation' https://www.csiro.au/en/Research/EF/Areas/Renewable-and-low-emission-tech/Hydrogen/Hydrogen-membrane

Transport

ATSE's 2019 report on the technology readiness of Australia's transport sector found that the deployment of low and zero-emission vehicles will be key to reducing transport emissions.[17] ATSE therefore recommends the Australian Government implement policies to encourage their rapid and widespread uptake. This should be driven by a national target and associated regulatory mechanisms such as emissions standards, and incentives for low and zero emission fleet vehicles.

Electric vehicles can use Li-Ion batteries, and also hydrogen fuel cells. The latter are likely to initially be most applicable to large vehicles such as trucks, buses, or delivery vehicles.[18] Fuel cell vehicles are also more likely to cope with the long distances experienced in remote Australia, particularly on long and remote freight routes where large vehicles and heavy loads are the norm.

Aviation and shipping are global problems in a future where net zero emissions by 2050 is the goal. The Technology Investment Roadmap does not suggest an obvious way forward. Australia could benefit from contributing to the creation of a solution for both aviation and shipping. ATSE recommends assessment of the potential for investment in a research and development program that can take potential solutions such as hydrogen, biofuels, synthetic hydrocarbons, and super lightweight batteries, and turn them into cost-effective solutions that can be produced here in Australia.

Green steel

Renewable hydrogen can potentially also be used to reduce mineral ores to metals – another potential low-carbon use of hydrogen from sunlight. Australian iron ore could be processed to steel using a combination of iron ore reduction to solid iron and subsequent processing of that iron to steel using electricity.[19] The technology is technically feasible, with research and development on the concept currently being conducted in Sweden and Germany using existing technologies – reduction of iron ore pellets (Midrex[20] technology) and electric steelmaking furnaces[21] The combination of available ore and hydrogen could create an opportunity for application of this technology in Australia.

Energy in remote Australia

There are inherent differences between the power systems of remote Australia and those in the NEM. For example, unlike the NEM, the Northern Territory's power systems comprise many standalone power systems each needing to be inherently resilient and with local redundancy. This is particularly true across the tropical north where monsoon weather can bring cloud for weeks at a time and there is up to four months a year without road access to enable any major repairs. This applies whether the energy use is for the mining industry, or remote towns and households. Solar microgrids are being installed, but even with battery storage they are inadequate in the monsoon season. At present diesel or compressed natural gas supplements and backups are the norm. Using hydrogen to store solar energy when available and hydrogen fuel cells to produce power is a potential future solution to this problem.

[17] Australian Academy of Technology and Engineering. Shifting Gears: Preparing for a Transport Revolution. 2019 https://www.atse.org.au/news-and-events/article/shifting-gears-preparing-for-a-transport-revolution/

[18] For example: https://www.greencarcongress.com/2020/02/20200202-asko.html

[19] Wood T. and Dundas G. Start with steel: A practical plan to support carbon workers and cut emissions. Grattan Institute, 2020: https://grattan.edu.au/wp-content/uploads/2020/05/2020-06-Start-with-steel.pdf

[20] Midrex. https://www.midrex.com/wp-content/uploads/MIdrex_Process_Brochure_4-12-18.pdf

[21] Danieli. https://www.danieli.com/en/products/products-processes-and-technologies/electric-arc-furnace_26_83.htm#

Agriculture

Just as Australia is in an excellent position to lead the way in transforming energy systems to carbon-neutral methods, it could also do so for food production, leading to more sustainable and climate-smart systems. The National Farmers Federation 2030 Roadmap[22] aspires to agriculture-wide carbon neutrality, while maintaining productivity and profitability.

The Grains Research and Development Corporation, Meat and Livestock Australia and CSIRO are already working together to develop baseline metrics in their respective sectors. Private investors such as Indigo Agriculture and MIRA's Viridis Ag have attracted equity investment from the Clean Energy Finance Corporation,[23] but a greater acceptance of the impact of opportunities in the agriculture sector is needed.

There are several ways Australia can reduce the footprint of its agriculture sector on the environment. One is carbon sequestration, which will probably occur through perennial woody vegetation on non-arable lands. Agriculture also views increasing soil carbon as very desirable because the productivity benefits are far greater than any financial benefits from sale of current carbon credits. In good rainfall years, this could also increase profitability. At adoption rates of 10-25 per cent in arable and rangeland environments, carbon-sequestering methodologies could offset 55-163 Mt CO_{2e} per year. Even at the minimum level, these figures are close to agriculture's annual production of greenhouse gases.[24]

The large-scale generation of renewable energy through wind and solar PV will largely occur, but not exclusively, on agricultural land. With careful planning and sensitive development, the compatibility of these joint land uses is becoming increasingly synergistic as the requirements of each sector are mutually understood. Further work is required on removing barriers and incentivising this dual use.

Emerging and future technologies

ATSE has focused in this submission on technologies that are already available and, in many cases, economically viable options for deployment. However, new technologies will emerge on both the supply and the demand sides. It will be important to continually analyse and assess emerging technologies so that the technology investment roadmap can be updated as appropriate, if and when new energy technologies emerge. This might include technologies such as small modular reactors of even fusion power. Potential for such developments should be built into the update schedule for the Technology Investment Roadmap.

Further information

ATSE would be pleased to assist further with this inquiry as appropriate. Please feel welcome to contact Alix Ziebell, Director of Policy and Government Relations on (03) 9864 0909 or alix.ziebell@atse.org.au.

[22] National Farmers' Federation. 2030 Roadmap: Australian Agriculture's Plan for a $100 Billion Industry. 2020. https://nff.org.au/wp-content/uploads/2020/02/NFF_Roadmap_2030_FINAL.pdf

[23] Clean Energy Finance Corporation. Annual Report 2018. https://annualreport2018.cefc.com.au/performance/cefc-finance-in-action/farmers-harvest-clean-energy-benefits/

[24] Chartres C., 'The road to climate-smart agriculture'. https://www.policyforum.net/the-road-to-climate-smart-agriculture/

Appendix – Energy Generation Technologies

The costs of all energy-generating technologies should not only be based on the 'bare equipment' costs of generation, but also the costs and benefits of associated ancillaries and plant, including any requirement for energy storage (electrical, pumped hydro), 'firming' of renewable supply with gas generation, provision of grid stabilisation services, contingencies for new technologies, contingencies for capital costs in Australia, costs associated with remoteness, and so on. The costs of electricity transmission are also important and are related to system stability issues related to the variable nature of renewable energy generation. Electricity costs and value-creation should also consider the 'cost learning curves' of the new low-carbon technologies. CSIRO has analysed these in depth with their global economics optimisation GALLM model,[25] including the learning curve effects of unsubsidised solar PV and wind with battery technologies under global Paris agreement emission scenarios.

Australia's present **coal generators** are less efficient than current new designs and reaching the end of their lives. They emit large amounts of CO_{2e} and other pollutants. Their operating and maintenance costs are increasing, and they have limited ability to respond quickly to load changes. They do, however, provide system stability through generator turbine inertia. New high efficiency low emissions (HELE) coal plants partially reduce but do not eliminate CO_2 emissions. In the absence of a carbon price, new HELE plants produce electricity in the $80/MWH range,[24,26] which is higher than both existing generators and renewable sources without storage. They would also suffer from the same inability to respond quickly to load changes. Further, it has become extremely difficult to finance any new investment in coal-fired generation because of perceived high investor risk associated with climate change measures.

Carbon Capture and Storage (CCS) to remove CO_2 from the flue gases of coal combustion has been studied now to pilot-stage and demonstration-stage stage globally over at least two decades. The most recent study involving EPRI in 2015 shows that CCS still adds significantly to the cost of electricity generated by coal plants (to around $160/MWh), considering both capital and operating costs and loss of efficiency. The cross-over price of CO_2 to make CCS economic over coal plant without CCS is greater than $100/t CO_2.[26]

Gas generators in different forms generally derived from aero derivative gas turbines, can provide both rapid response load following capability (open cycle gas turbines – OCGT) and base load generation (closed cycle gas turbines – CCGT). The latter CCGT units have high capacity factors, high efficiency and relatively low CO_{2e} emissions.[27] However, the economics of gas-fired power is very dependent on gas price, which has been high and volatile in recent years. The Australian Council of Learned Academies (ACOLA, including ATSE) undertook a study on 'unconventional gas' (shale gas) in Australia, and reported that capital costs of drilling deep wells in Australia was double that in the United States leading to high gas cost.[28] Coupled with demand from overseas for liquefied natural gas (LNG) with associated net-back export price, gas prices in Australia are too high to have a large

[25] Hayward, J.A. and Graham, P.W. 2017, Electricity generation technology cost projections: 2017-2050, CSIRO, Australia. Also Graham, P.W., Hayward, J, Foster, J., Story, O. and Havas, L. GenCost 2018. CSIRO, Australia.

[26] Burgess JM FTSE, Analysis of HELE coal plant with and without CCS, 2015 data, Melbourne Energy Institute Energy Finance Course, University of Melbourne, 2019.

[27] Emissions of CCGT are approximately 500kg CO_{2e}/Mwh, compared with existing black coal of about 1000 kgCO_{2e}/MWh. Source: Australian Power Generation Technology Report, Electric Power Research Institute USA (EPRI) et al, 2015.

[28] Cook P, et al., Engineering Energy: Unconventional Gas Production, Report for the Australian Council of Learned Academies, 2013. https://acola.org/saf06-energy-unconventional-gas-production/

fraction of electricity generated by gas here. Gas may, however, provide a niche role in firming of renewables and perhaps some base load using CCGT if gas prices fall.

Investment in **nuclear energy** generation is illegal in Australia. Notwithstanding this, there have been several Commonwealth and State-based studies on nuclear energy over the years.[29,30,31,32,33] Despite this, nuclear energy remains illegal. ANSTO provides leadership in Australia for nuclear medicines, nuclear waste disposal technologies and nuclear research and development. Also, Australia's uranium exports contribute substantially to international nuclear power generation and Australia has significant uranium reserves.

Nuclear energy delivers 10% of the world's primary electricity supplies and is deployed in 30 nations. France generates 70% of its electricity from nuclear and exports power to other countries in Europe.

Nuclear energy has high capital costs, but relatively low fuel and operating costs. Once installed, the facilities last for upwards of 60 years. However, new reactor developments (e.g. in Finland and the UK) have demonstrated high and escalating costs and delays and overruns. For example, the power purchase agreement for the under-construction Hinkley station in England is reportedly $AUD175/MWh for over 30 years, with an escalating capital cost in 2019 of over $AUD 40 billion.[34][35] A German paper has reported essentially 100% value-at-risk for investors for all feasible economic scenarios for nuclear energy.[36] The nuclear industry in France and South Korea, however, does produces lower cost electricity.[37] In Japan, there have been widespread closures of nuclear plant facilities following the Great East Japan earthquake in 2011 due to safety concerns and also closures in Germany.

Small Modular Reactors (SMRs) have also been proposed. The design of these is based on nuclear-powered submarines and ships. There still remains considerable uncertainty around what the actual costs for an SMR will be. Until many SMRs have been built, these costs will remain uncertain.

Nuclear energy produces low-carbon and base-load electrical energy.[38] Previous studies have stated that around twenty years would be required for the first nuclear power station to be built in Australia (assuming legislative change occurs).[39] ATSE does not believe this timeline has changed since.

If nuclear energy becomes legal; sufficient skills are available; it is timely; and public questions on social licence to develop and operate nuclear energy in Australia can be answered; nuclear energy could possibly offer a base-load, low-carbon electricity generation option here for part of the generation mix in the longer term. This would require: acceptably low capital costs of such an option in Australia; careful consideration of the environmental aspects of plant operation and fuel handling;

---

[29] Australian Academy of Technology and Engineering. Nuclear energy for Australia – conference report. 2013. https://www.atse.org.au/research-and-policy/publications/publication/nuclear-energy-for-australia-conference-report/

[30] Australian Government, Uranium Mining, Processing, and Nuclear Energy Report, UMPNER, 2006. http://environmentvictoria.org.au/wp-content/uploads/2016/08/nuclear_report.pdf

[31] South Australian Nuclear Fuel Cycle Royal Commission. 2016. http://nuclearrc.sa.gov.au/

[32] Australian Government Inquiry: Pre-requisites for Nuclear Energy in Australia, 2019.

[33] NSW Government Legislative Council: Uranium Mining and Nuclear Facilities Prohibition Repeal Bill 2, 2019.

[34] https://www.world-nuclear-news.org/NP-Hinkley-Point-C-contract-terms-08101401.html

[35] https://www.theguardian.com/uk-news/2019/sep/25/hinkley-point-nuclear-plant-to-run-29m-over-budget

[36] 'Value-at-risk' is the proportion of investment returns less than zero NPV at the firm's cost of capital discount rate. Deutsches Institut für Wirtschaftsforschung e.V., 2019. https://www.diw.de/de/diw_01.c.670590.de/publikationen/weekly_reports/2019_30/high_priced_and_dangerous_nuclear_power_is_not_an_option_for_the_climate_friendly_energy_mix.html

[37] France's EDF has said a price of $AUD70/MWh is 'too low' for economic viability of nuclear generation in France. See for example: https://www.reuters.com/article/us-france-electricity/france-wants-edf-to-sell-more-nuclear-power-to-rivals-price-could-increase-idUSKCN1TP1OV.

[38] Buongioro J., The Future of Nuclear Energy in a Carbon-Constrained World', MIT, 2018.

[39] Australian Government, Uranium Mining, Processing, and Nuclear Energy Report, UMPNER, 2006.

taking public attitudes and concerns into account; safe and long-term fuel waste disposal and storage; legislation and regulation allowing nuclear energy; acceptable provision of ancillary services such as water; and consideration of location issues in Australia's fragile environment.

Hydro-power capacity, essentially in the NSW Snowy Mountains and in Tasmania, provides renewable low-carbon energy and system stability. It can also provide the opportunity for pumped hydro energy storage to support other renewable energy generation.

Renewable energy other than hydro is variable in nature and its output is not necessarily linked to market demand at any given location unless energy storage is employed. However, the costs of renewable energy (**solar PV and wind** without backup storage) have decreased markedly recently. The cost of wind and solar electricity is currently around $50 per Megawatt-hour, and ATSE believes this will fall towards $30/MWh by 2030 (not including 'firming' and electricity storage, which currently more or less double the price). The solar PV form of energy generation now produces the lowest cost electricity of all new-build generation, even without subsidy. This generation cost and the cost of storage is still falling. The objective now for Australia should be to cost-optimise and minimise the generation, storage, and transmission costs of renewable energy.

Balancing 50-100% renewable electricity to ensure a reliable electricity supply is straightforward using off-the-shelf technology. The cost of balancing an 80-90% renewable electricity grid is kept low by using strong interstate interconnection (to smooth-out local weather), storage (batteries, pumped hydro, thermal storage), demand management and legacy coal and gas generators (to cover the occasional wet and windless week in winter). When the legacy coal and gas is finally phased out the balancing cost rises to about $25/MWh.[40]

Australian-trained scientists and engineers have made an immense contribution to the technology of photovoltaics and to developing the PV manufacturing industry, especially in China, The PERC (passivated emitter and rear cell) solar cell, which was developed in Australia, now has 70% of the global solar market. Its capacity is being deployed at a faster rate than any other method of electricity generation and has accumulated global sales of $70 billion to date. PERC technology is currently mitigating 0.5% of global emissions through displacing coal generation.

[40] Blakers A., Bin L., Stocks M., '100% Renewable Energy in Australia' in Energy, vol. 133, 471. 2017.

Glossary

Acronym	Definition
ACOLA	Australian Council of Learned Academies
AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
ANSTO	Australian Nuclear Scientific and Technology Organisation
ATSE	Australian Academy of Technology and Engineering
CCGT	Closed cycle gas turbines
CCS	Carbon capture and storage
CO_{2e}	Equivalent carbon dioxide
CSIRO	Commonwealth Scientific and Industrial Research Organisation
FCAS	Frequency control ancillary services
GW	Gigawatt
HELE	High efficiency low emissions
IRENA	International Renewable Energy Agency
Li-Ion	Lithium ion
LNG	Liquefied natural gas
MW	Megawatt
MWh	Megawatt-hour
NEM	National Electricity Market
NSCAS	Network support and control ancillary services
OCGT	Open cycle gas turbines
PERC	Passivated emitter rear cell
PV	Photovoltaic
RSAS	System restart ancillary services
TWh	Terawatt-hour