VAST SOLAR

The 2022 Low Emissions Technology Statement (LETS 2022)

Vast Solar Submission

6 February 2022

Contents

1. Executive Summary

Australia's Energy Transition

Australia's transition to a decarbonised future can be seen in the rapid uptake of variable renewable energy (VRE) generation, mostly photovoltaic (PV) but also wind. Indeed, rooftop PV alone is forecast to become Australia's single biggest electricity generator by 2025 and to generate more than coal and gas combined by 2030.[1]

As the amount of VRE being generated increases, an equally rapid increase in firm generation enabled by storage will be required to maintain grid stability and to time-shift excess perishable energy (e.g., the excess generated by solar PV during daylight hours). At present, firm generation capacity is provided by conventional power plants. However, as these plants retire over the next 10 to 20 years, alternative forms of firm generation (e.g., renewable energy firmed by storage) will be required.

Energy storage is the key to enabling this accelerated VRE take up and to meeting our net zero emissions commitments by 2050 in accordance with Australia's Long-Term Emissions Reduction Plan.

The Technology Investment Roadmap

The Federal Government's Technology Investment Roadmap, together with the supporting and annually updated Low Emissions Technology Statement (LETS), also recognises the importance of dispatchable renewable energy storage in Australia's future energy mix. The LETS identifies long duration renewable energy storage, dispatched at less than $100/MWh, as a key investment priority.

Potential dispatchable renewable energy options include PV + batteries, pumped hydro energy storage (PHES), green hydrogen and concentrating solar thermal power (CSP). Each option has a role to play in Australia's future energy mix (e.g., at different locations and with varying storage durations) with both the LETS and the Australian Energy Market Operator (AEMO) highlighting the need for an integrated mix of complementary energy storage and generation technologies to meet Australia's future energy needs.

The Technology Investment Roadmap also recognises CSP's potential in the mix of dispatchable technologies: "Solar thermal energy storage (charged by solar thermal generation) will become increasingly cost competitive and will be suitable in places where pumped hydro is unavailable" [2].

Our LETS 2022 Submission

We support the approach taken in LETS 2021. ARENA's ultra low-cost solar PV ($15/MWh) initiative will also reduce the levelised cost of energy (LCOE) of 24x7 CSP+PV hybrids that use solar PV in the daytime and CSP at night. Cheaper PV will also increase the need for grid-scale storage to stabilise grids and time shift energy.

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[1] Australia's emissions projections (2021), Department of Industry, Science, Energy and Resources, p19

[2] Technology Investment Roadmap: First Low Emissions Technology Statement (2020), p20

Our view, supported by the International Renewable Energy Agency (IRENA)[3], is that there will be a role for batteries for short term grid services and storage capacity of up to 4 hours to smooth wind and PV output, but that the lack of scale-driven cost economics will make them too expensive for longer duration (overnight generation) applications:

> *"CSP in areas of high direct normal irradiance (DNI) therefore potentially represents a bridge from solar PV, with four hours of storage, to very high shares of solar in the system, as CSP still represents the cheapest source of long duration storage"*

As such, we suggest that LETS 2022 include:

- A mix of storage durations: we suggest the LETS 2022 adopt the 2020 Integrated System Plan categorisations[4] of shallow storage (0-4 hours for capacity, ramping and FCAS), medium storage (8-16 hours for intra-day shifting) and deep storage (48+ hours for VRE droughts and seasonal smoothing)
- A mix of storage technologies: consideration of a complementary mix of technologies and solutions best suited to each duration. For example, medium duration storage could be provided by CSP, flow batteries and compressed air storage, while pumped hydro and hydrogen are suited to deep storage
- CSP 50 10: a competitive funding round for a NEM-connected 50MW CSP project with 10 hours storage. The successful applicant would bid the lowest offtake price (a $/MWh floor from ARENA, facilitating stapled finance from the CEFC), with the project having the option of generating excess return (above the ARENA revenue floor price) on a merchant basis
- Storage 10^2 30 ("10 squared thirty"): building on ARENA's Solar 30 30 30, there be an ARENA funding initiative (e.g., competitive funding round) for storage targeting $100/MWh at 10 hours duration, with a 30 year life

We would welcome the opportunity to present these suggestions to the Technology Investment Advisory Counsel, to ARENA and to the CEFC.

CSP – Flexible Storage for the Energy Transition

In the global transition from fossil fuel to renewable power, providing reliable renewable energy at night is vital. CSP, with its integrated thermal energy storage (TES), is a proven solution, delivering night time renewable energy generation with the certainty of daytime sunshine.

IRENA notes as a price point the 700 MW CSP + 250 MW PV DEWA plant in Dubai, with an offtake at US$73/MWh for 15 hours of storage:[5]

> *"… in areas with excellent solar resources, extremely competitive solar PV can naturally be paired with CSP to allow round the clock generation. The confluence of extremely low-cost*

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[3] Renewable Power Generation Costs in 2020 (2021), International Renewable Energy Agency, p117

[4] 2020 Integrated System Plan (2020), AEMO, p51

[5] Renewable Power Generation Costs in 2020 (2021), International Renewable Energy Agency, p117

> *solar PV, onshore and even offshore wind – as well as the expansion of CSP – could transform the electricity systems of countries in the sunbelt"*

Given Australia's abundant sunshine and land, CSP is a renewable energy solution with the potential to provide low-cost, utility-scale, firm and fully dispatchable energy (via multi-hour storage) in the form of heat or electricity. With its TES, CSP can generate power or heat at any time of day or night.

Indeed, CSP's main value proposition is its multi-hour energy storage. The ability to store thermal energy which can be dispatched on demand as power or heat has significant value. The energy storage provides firm capacity, which will increase in value as the level of VRE increases. We think this value will need to be captured by a market mechanism in the NEM (e.g., capacity payments) to deliver investment in an efficient mix of firm capacity that complements widespread VRE at lowest cost, enabling Australia to continue to meet its energy and emissions reduction objectives.

TES can also be used for arbitrage, to store excess renewable energy (e.g., from PV and wind) for use at a later time.

The International Energy Agency (IEA) is forecasting a 10x increase in CSP installations globally by 2030 to a total of 73 GW[6]. Australia has the sun, the land, the leading technology and the expertise to build a world leading CSP industry to capture the growth in this market, both domestically and internationally.

Vast Solar's CSP – Use Cases in Australia

In sunbelt countries such as Australia, Vast Solar's modular CSP plants unlock renewable electricity and process heat with capacity factors in excess of 85%, powering:

- Overnight on the NEM: dispatchable CSP technology with thermal storage is ideally positioned to support the grid as fossil fuel fired dispatchable generators go offline
- 24x7 off-grid operations (e.g., mining): the night time renewable energy provided by CSP can increase the decarbonisation of the power generation for mining operations from ~35% with PV to ~85% with CSP at night at a cost well below the total cost of diesel or gas generation
- Storing excess PV and wind generation: thermal storage can be configured to store excess generation from intermittent generators such as solar PV, as well as to support grid stability
- Green hydrogen: capacity factors in excess of 85% drive down capital costs and, coupled with high temperature process heat, will unlock next generation hydrogen production technologies
- Green steel and minerals processing: continuous electricity and heat with thermal energy storage enables heavy industrial processes, which are by nature difficult to ramp up and down, to decarbonise efficiently

At scale, the Vast Solar system produces power at a lower cost than coal or gas fired power plants and other renewable storage technologies and it will meet the stretch target of $100/MWh in the LETS.

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[6] Net Zero by 2050: A Roadmap for the global energy sector, International Energy Agency (2021), p198

2. Background

2.1. Vast Solar

Vast Solar is an Australian company that, with support from the Australian Renewable Energy Agency (ARENA), has developed the world's leading CSP generation and storage technology to deliver low-cost renewable energy that is reliable, controllable and dispatchable.

Vast Solar's CSP system is smart, modular and highly cost effective to construct and operate, and it was awarded the International Energy Agency's SolarPACES 2019 Technical Innovation Award.

Our vision is continuous carbon free energy for the world, and we deliver that by making the sun shine at night. We deploy CSP and complementary technologies (e.g., intermittent PV and wind) to deliver 24x7 renewable and dispatchable electricity, heat and storage.

Since its founding in Sydney in 2009, the company has been following the evolution of the Australian electricity markets and monitoring international developments, giving us a unique perspective on the current state and future direction of the national electricity market (NEM).

The Vast Solar CSP technology can also be installed in remote mining communities away from the NEM, many of which are currently embracing solar PV to reduce both cost and the carbon embedded in their products. The renewable energy provided by CSP at night can increase the decarbonisation of the power generation for mining operations from ~35% with PV to ~85% with CSP at a cost well below the total cost of diesel or gas generation at night.

ARENA's investment in Vast Solar recognises the potential value of CSP in Australia's future energy mix and the need to support it as a technology option moving forward. It also reflects current government policy that there is no one single technology solution for Australia, and that investment in a mix of low-emission technologies will be required to meet our future energy needs.

At scale, the Vast Solar system produces power at a lower cost than coal or gas fired power plants and other renewable storage technologies and will meet the stretch target of $100/MWh in the LETS.

See further Appendix A – Vast Solar.

2.2. Concentrating Solar Thermal Power

Dispatchable CSP with thermal energy storage (TES) will grow substantially as the world transitions towards clean energy and dispatchable fossil fuel fired generators leave the market.

Studies by the IEA, IRENA and others have shown that 73 GW of CSP power plants, a 10x increase in CSP installations globally, need to be operating by 2030 in a pathway to net zero by 2050[7].

There are clear technical and economic reasons for a strong increase in the CSP market globally as evidenced, among others, by national CSP auctions already announced by Spain and Namibia for 2022

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[7] Net Zero by 2050: A Roadmap for the global energy sector, International Energy Agency (2021), p198

and growing interest from governmental and non-governmental stakeholders in other sunbelt countries. The existence of competitive technologies with a track record of price reduction through research and development, such as Vast Solar's technology, is fundamental to the expected growth of the global CSP market.

CSP in Australia

CSP is a dispatchable renewable generation technology with massive potential in a sunbelt country like Australia. CSP, with its long duration energy storage, reliable and dispatchable renewable electricity and grid strengthening services, delivers the reliability that Australia and the NEM need to replace its retiring coal plants and to support new export industries like green hydrogen.

CSP is also much quicker to implement, less expensive and less environmentally challenging compared with pumped hydro which could offer similar grid support functions.

See further Appendix B – Concentrating Solar Power (CSP).

2.3. Challenges of the Australian Grid Transformation

The NEM has changed dramatically over the last 10 years but it is far from equilibrium.

The near-term exit of the coal plants that currently underpin the NEM represents a major challenge to energy affordability and security. These exits are being driven both by the age of the plants and by the impact of variable (non-dispatchable) renewable generation negatively impacting the economic viability of the plants.

The impact from the exit of the coal plants will be immense unless dispatchable renewables are constructed in sufficient time to fill the void that the exit of coal generators will create.

See further Appendix C – Australian Grid Transformation.

Dispatchable Renewables

There are only a small number of economically viable dispatchable renewable generating technology options. The most cost competitive technologies today are hydroelectric (although Australia has developed its best hydro sites already) and CSP plants.

Synthetic renewable dispatchable plants can be configured by combining variable renewable generators with energy storage such as batteries or pumped hydro, but such projects have significant drawbacks and challenges.

See further Appendix D – Dispatchable Renewables.

3. Submission

3.1. LETS 2021

We support the approach taken in LETS 2021:

- Solar 30 30 30: ARENA's ultra low-cost solar PV ($15/MWh) initiative has the potential to reshape the Australian energy market, increasing the take up of PV
- Storage: cheaper PV will also lead to an excess of daytime variable generation, increasing the importance of grid-scale storage to stabilise grids and to time shift energy
- Storage duration: the most pressing need for storage is for durations of "several hours, such as for storing solar in the middle of the day to use in the evening"
- Mix of storage technologies: an "evolving mix" of storage technologies are needed to provide system security and reliability, providing dispatchable clean energy over "different durations"
- Solar thermal energy storage: is a complementary "storage technology that can provide deep storage of be used for high-temperature industrial process heat applications", becoming "cheaper as their scale and efficiencies increases"

We think that the most pressing need for the "several hours" of storage will be at 8+ hours for early morning and evening peaks and that CSP will be a key part of that storage mix. At scale, Vast Solar CSP will meet the stretch target of $100/MWh in the LETS.

Role of CSP

ARENA's Solar 30 30 30 initiative along with the accelerating take up of rooftop PV (already forecast to be Australia's single biggest electricity generator by 2025[8]) will boost the role for CSP in the following key ways:

- Cheaper CSP+PV 24x7 hybrids: ultra low-cost solar PV ($15/MWh) will also reduce the LCOE of 24x7 CSP+PV hybrids that use solar PV in the daytime and CSP at night
- Storage: cheaper PV will exacerbate an excess of daytime variable generation, increasing the importance and value of grid-scale storage to stabilise grids and to time shift energy
- Merchant storage: Vast Solar's system can be configured to use cheap or negatively priced excess generation from intermittent solar PV[9] and wind to create heat which is stored and used to generate electricity at times when demand and price are higher. Projects of this sort are being trialled in offshore markets (Germany, the USA and others) and would be well-suited to NEM conditions

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[8] Australia's Emissions Projections (2021), Department of Industry, Science, Energy and Resources, p19

[9] Average South Australian spot price during peak solar production (between 1000 hrs and 1530 hrs) = negative $12/MWh (source: AEMO 2021 Q1 Quarterly Energy Demand)

3.2. LETS 2022

We suggest that the LETS 2022 include:

- A mix of storage durations: we suggest the LETS 2022 adopt the 2020 Integrated System Plan categorisations[10] of shallow storage (0-4 hours for capacity, ramping and FCAS), medium storage (8-16 hours for intra-day shifting) and deep storage (48+ hours for VRE droughts and seasonal smoothing)
- A mix of storage technologies: consideration of a complementary mix of technologies and solutions best suited to each duration. For example, medium duration storage could be provided by CSP, flow batteries and compressed air storage, while pumped hydro and hydrogen are suited to deep storage
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We would welcome the opportunity to present these suggestions to the Technology Investment Advisory Counsel, to ARENA and to the CEFC.

The Opportunity to Act / the Risk of Inaction

Since 1985, the global CSP industry has installed 6.5 GW of power plants with 30 GWh of daily storage and has achieved power price parity with new fossil-fired power plants. However, none have been constructed in Australia despite several attempts at commercial standalone or thermal boost projects. This will change in coming decades, driven by the increasingly urgent need for storage to replace the overnight energy provided by 23 GW of baseload coal-fired power plants that will retire in coming decades.[11]

The question is whether Australian technology is used, or whether the country will miss another opportunity to commercialise technology developed here, only to end up again importing equipment that embodies our IP. Much of the solar PV installed in Australia today is manufactured in China using technology developed at UNSW.

Australia has the sun, the land, world-leading technology and the expertise to build a substantial export industry, capturing growth in this market, both domestically and internationally. We were encouraged to see the specific mention of solar thermal in the LETS 2021, including that solar thermal energy

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[10] 2020 Integrated System Plan (2020), AEMO, p51

[11] 2020 Integrated System Plan (2020), AEMO, p44

complements existing pumped-hydro energy storage and gas-fired electricity generation, providing deep storage and high-temperature industrial process heat applications.

Support for CSP in LETS 2022 will allow CSP to build on Australia’s comparative advantage. Development of a domestic industry means Australia will be well placed to capture a leading share of the additional 66 GW of CSP plants that should be installed by 2030, with a further 210 GW expected to be installed between 2030 and 2040, representing a global investment in CSP of the order of A$1,600 bn over 18 years[12].

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[12] Net Zero by 2050: A Roadmap for the global energy sector, International Energy Agency (2021), p198

Appendix A – Vast Solar

Vast Solar – Dispatchable Renewable Energy at Scale

Vast Solar is an Australian company that, with support from the Australian Renewable Energy Agency (ARENA), has developed world leading CSP technology, delivering less risky, less complex, cheaper and more efficient dispatchable electricity generation.

At scale, the Vast Solar system produces power at a lower cost than coal or gas fired power plants and other renewable storage technologies and will meet the stretch target of $100/MWh in the LETS.

SolarPACES 2019 Technical Innovation Award

Since its founding in Sydney in 2009, Vast Solar has been developing solutions to address the issues that have held back the adoption of CSP both in Australia and internationally.

The core differentiator in Vast Solar’s technology is its use of liquid sodium as the heat transfer fluid (HTF) to collect solar energy, unlocking the economic and performance advantages of heliostats in modular solar arrays.

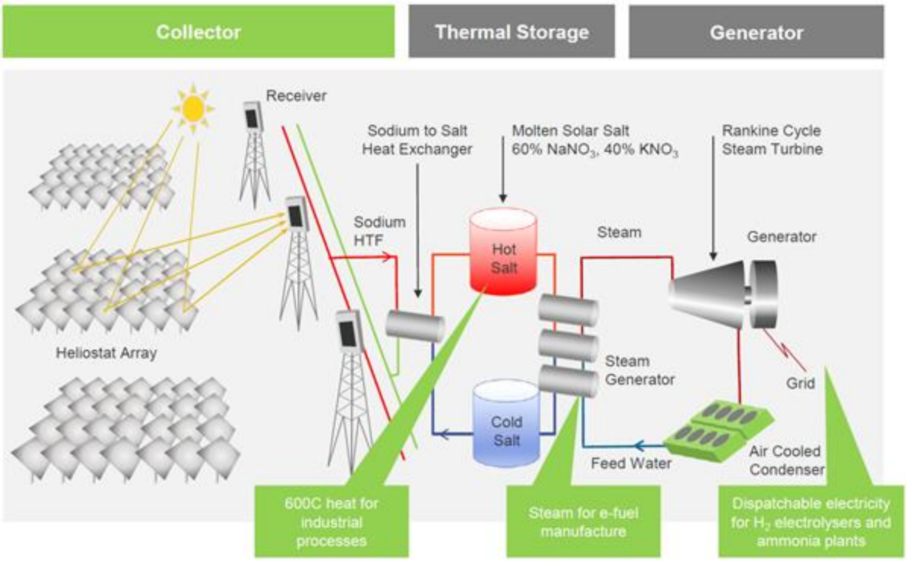

Figure 1 – a schematic of Vast Solar technology highlighting various end use cases

Vast Solar’s significant contribution to the progress of CSP globally has been recognised by the international CSP community with the International Energy Agency’s SolarPACES 2019 Technical Innovation Award. The technology has been developed with support from the CSIRO, Australian Universities, the Australian Solar Thermal Research Institute (ASTRI) and a consortium of industry leading partners.

Vast Solar’s modular solar array is a world-first, and its pioneering use of sodium in CSP is attracting international attention from leading energy researchers and companies including the USA’s National Renewable Energy Laboratory (NREL), the French Alternative Energies and Atomic Energy Commission (CEA) and German nuclear scientists from the Karlsruhe Institute of Technology (KIT).

Pilot Plant

Our modular tower CSP system takes advantage of the benefits and addresses risks of previous generations of CSP technology.

The technology has been refined, tested and proven in three successively larger projects, the latest of which is a world-first 1.1MW grid-connected pilot plant (Pilot Plant) located at Jemalong, near Forbes in NSW that was successfully and safely operated from early 2018 until its scheduled decommissioning in 2020.

The Pilot Plant brought together the components previously developed by Vast Solar to allow testing of a complete sun-to-grid system. The plant consists of five modules in the solar field, each containing 699 heliostats, a receiver and a tower, linked by the sodium HTF loop to a steam generator and ultimately to a steam turbine and 1.1MW electrical generator.

The Pilot Plant achieved its objectives of demonstrating that Vast Solar's modular solar array using sodium as the HTF can be operated safely and effectively to export dispatchable renewable electricity to the grid.

Figure 2 – the Pilot Plant at Jemalong, NSW

Appendix B – Concentrating Solar Power (CSP)

CSP – Solar that Works at Night

In the global transition from fossil fuel to renewable power, providing reliable renewable energy at night is vital. Concentrating solar thermal power (CSP) is a proven solution that delivers night time renewable energy generation with the certainty of daytime sunshine.

Using mirrors, CSP plants collect the heat of the sun during the day, transfer the heat to a fluid for storage in insulated vessels, then use the stored heat to generate electricity on demand at night using traditional turbines. Since 1985, the global CSP industry has installed 7 GW of power plants with 30 GWh of daily storage, and has achieved power price parity with new coal fired power plants.

CSP requires good levels of direct normal irradiation (DNI) and thus is best suited to hot dry climates, such as Australia's. Over 60 CSP plants are now operating in utility scale power generation markets. CSP is typically cost-effective at large scale, where its multi hour storage can provide markets with firm and fully dispatchable clean power. However, CSP's large scale comes at a cost. Accordingly, deployment typically requires policy measures and incentives that value daily, long-duration (8+ hours), fully dispatchable clean power generation. Most global deployment of CSP Systems has been in Spain, the USA, South Africa, Morocco, China and the UAE.

The LCOE of solar PV has fallen 82% since 2010, while the global weighted-average LCOE of CSP plants commissioned during the same period fell by 68% to US$108/MWh.[13] The CSP power prices per megawatt hour produced in sunny regions are now in the range of conventional power plants. The World Bank expects that PPA prices will continue to decline in the coming years as CSP projects "incorporate technological improvements, improve economies of scale and unlock efficiencies in both the construction and operation of CSP plants".[14]

IRENA notes as a price point the 700 MW CSP + 250 MW PV DEWA plant in Dubai, with an offtake at US$73/MWh for 15 hours of storage:[15]

> *"… in areas with excellent solar resources, extremely competitive solar PV can naturally be paired with CSP to allow round the clock generation. The confluence of extremely low-cost solar PV, onshore and even offshore wind – as well as the expansion of CSP – could transform the electricity systems of countries in the sunbelt"*

The IEA forecasts that a further 66 GW of CSP plants should be installed globally by 2030, with a further 210 GW expected to be installed between 2030 and 2040, representing a global investment in CSP of the order of A$1,600 bn over 18 years[16].

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[13] Renewable Power Generation Costs in 2020 (2021), International Renewable Energy Agency, p117

[14] Concentrating Solar Power - Clean Power on Demand 24/7 (2020), World Bank, p9

[15] Renewable Power Generation Costs in 2020 (2021), International Renewable Energy Agency, p117

[16] Net Zero by 2050: A Roadmap for the global energy sector, International Energy Agency (2021), p198

CSP in Australia

CSP is a technology solution that is well suited to Australia given our high solar irradiance levels. It uses sunlight to create thermal energy, which can be used or stored, for end-use applications in the form of power or heat. The use of thermal energy in Australia's energy mix is not a new concept. Conventional power generation using coal and gas convert thermal energy into power.

Australia's abundant solar resource coupled with falling solar PV panel costs will mean daytime grid generation is dominated by solar PV. Complementary wind resources (e.g., at night) will also play an important role.

We see the following roles for the key storage technologies:

- Battery energy storage systems: for short-term frequency response and short term energy storage
- Pumped hydro: for long-duration storage subject to water availability, permitting and arbitrage model bankability
- CSP: for long-duration storage everywhere else, including as part of hybrid power systems in off-grid applications

CSP is not as geographically constrained as stored or pumped hydro which require catchments, reservoirs and hydraulic head. CSP needs only flat land in a sunny location which Australia has in abundance. In addition, CSP plants only require a very small amount of water for the steam cycle and mirror washing, unlike the enormous water consumption requirements (evaporation and pass-through) for hydro plants.

CSP is a dispatchable renewable generation technology with massive potential in a sunbelt country like Australia. CSP, with its long duration energy storage, reliable and dispatchable renewable electricity and grid strengthening services, delivers the reliability that Australia and the NEM need to replace its retiring coal plants and to support new export industries like green hydrogen. CSP is also much quicker to implement, less expensive and less environmentally challenging compared with pumped hydro which could offer a similar grid support function.

Given Australia's high solar irradiance levels, CSP is a renewable energy solution with the potential to provide low-cost, utility-scale, firm and fully dispatchable energy (via multi-hour storage) in the form of heat or electricity. With its thermal energy storage (TES), CSP can generate power or heat at any time of day or night.

Two other inherent advantages of CSP are the improved economic performance of large-scale plants and the standardised nature of plant design. These are important factors for Australia because over 19GW of high capacity factor coal plants must be replaced by dispatchable generation infrastructure during next 20 years (by comparison, that is 2.5 times the current capacity of all hydro in Australia). Modular design principles (particularly in the Vast Solar approach) mean that CSP plants can be rapidly rolled out across the country. The two years required to build a Vast Solar CSP plant is one quarter of the estimated time to plan, design and build a pumped hydro plant.

Counterintuitively, Australia's historical reliance on coal benefits CSP plant roll out as a trained steam turbine operations and maintenance workforce already exists. This will benefit CSP plant owners but is far more important for coal power station workers as a transition into the renewable energy sector.

While other technologies will have their place, such as lithium ion batteries for grid stabilisation, CSP is the ideal technology to replace the aging coal fleet in Australia. In a country as sunny, dry and flat as Australia, the economics of CSP and its technical characteristics make it the ideal backbone generation technology. This view is supported by the LETS.

Vast Solar's Modular CSP – Use Cases in Australia

In sunbelt countries such as Australia, Vast Solar's modular CSP plants unlock renewable electricity and process heat with capacity factors more than 85%, powering:

- <u>Overnight on the NEM</u>: dispatchable CSP technology with thermal storage is ideally positioned to support the grid as fossil fuel fired dispatchable generators go offline
- <u>24x7 off-grid operations (e.g., mining)</u>: the night time renewable energy provided by CSP can increase the decarbonisation of the power generation for mining operations from ~35% with PV to ~85% with CSP at night at a cost well below the total cost of diesel or gas generation
- <u>Storing excess PV and wind generation</u>: thermal storage can be configured to store excess generation from intermittent generators such as solar PV, as well as to support grid stability
- <u>Green hydrogen</u>: capacity factors in excess of 85% drive down capital costs and, coupled with high temperature process heat, will unlock next generation hydrogen production technologies
- <u>Green steel and minerals processing</u>: continuous electricity and heat with thermal energy storage enables heavy industrial processes, which are by nature difficult to ramp up and down, to decarbonise efficiently

At scale, the Vast Solar system produces power at a lower cost than coal or gas fired power plants and other renewable storage technologies and will meet the stretch target of $100/MWh in the LETS.

Appendix C – Australian Grid Transformation

The Changing NEM

Utility scale power generation technologies can broadly be categorised into three groups:

1. Perishable (variable) generation technologies that generate power when external factors allow – these include wind turbines, PV and run-of-river hydro
2. Dispatchable generation technologies that can make and dispatch power to a schedule – these include nuclear, coal, gas, CSP and stored hydro power plants
3. Storage technologies that can generate power once they have been charged from power generated from renewable or fossil fuelled power plants – these include lithium ion or flow battery energy systems, pumped hydro, flywheels, compressed air storage and gravity storage

The electricity supply infrastructure in Australia has historically been of the second type with coal (brown and black) providing the bulk of energy supply supported by stored hydro and gas generation to manage daily and seasonal variability.

Over the last 15 years, the proportion of perishable generation in the grid has expanded significantly as the input cost of these technologies has fallen and they have been able to take advantage of historical electricity pricing structures. This is due to the relatively low cost of PV and wind generation compared with alternative forms of power generation. However, as the amount of perishable generation increases, a commensurate increase in dispatchable generation capacity will be required to balance the variable generation profile.

At present, firm generation capacity is provided by conventional power plants. However, the coal fleet that underpins supply will not be replaced as it reaches end of life. Carbon intensity is now a consideration of all investor decisions for new power infrastructure, due to net zero by 2050 commitments, public sentiment and the debt and insurance sectors' increasing unwillingness to take on carbon emissions risk. As such, as these plants retire, alternative forms of firm generation capacity, using renewable energy, will be required.

Coal Fleet Retirement

The Australian coal fleet is aging and, due to the increasing penetration of intermittent renewables and particularly daytime PV generation, it is being subjected to duty cycles for which it was not designed. Retirement of these assets and the dispatchable energy they provide the NEM is certain. Only the timing is not.

Over the next 15 years, the Australian Electricity Market Operator (AEMO) has noted the expected retirement of almost all of Australia's conventional coal-fired generation capacity. While the lost generation capacity is expected to be replaced by gas generation and renewable energy over time, it is the loss of the firm dispatchable capacity, as currently provided by these generators, that creates one of the greatest transitional challenges. Current power plants provide the system with firm generation, which delivers a high degree of system reliability and resilience. However, as these power plants close, coupled with an increase in perishable generation, there will be a loss of firm capacity, which will have an adverse impact on overall system reliability and resilience.

Put another way, as coal retires, the grid will lose most of its dispatchable generation and associated grid stabilisation services. An increase in high efficiency combined cycle and fast response open cycle gas turbines can fill part of this gap and, while gas is low-emissions when compared to black and especially brown coal, it is not renewable.

AEMO's 2020 Integrated System Plan (ISP) has forecast an emerging need for 6-19 GW of new dispatchable resources to firm the inherently variable distributed PV and wind generation[17]. The 2022 draft ISP reaffirms this forecasting an emerging need for 45 GW / 620 GWh (gigawatt hours) of storage, **in all its forms**[18].

The ISP includes electricity storage as a mechanism for dispatchability and considers 'shallow, medium and deep' storage requirements for the grid. Australia's most mature medium or deep storage technology is pumped hydro energy storage (PHES). However, it is expensive as significant civil engineering is required on each PHES project, it is challenging to finance on the back of arbitrage business models and it ties up and consumes substantial volumes of water which will become an increasing issue if Australia's climate becomes drier. For these reasons, we do not see pumped hydro playing a major role beyond projects under construction. By contrast, CSP is modular, site agnostic and does not require custom civils – hence the tagline 'hydro for deserts'.

The 2020 ISP makes clear that the current coal fleet will be largely retired by 2040, with the bulk retiring by 2036[19]. We think it will be sooner than that.

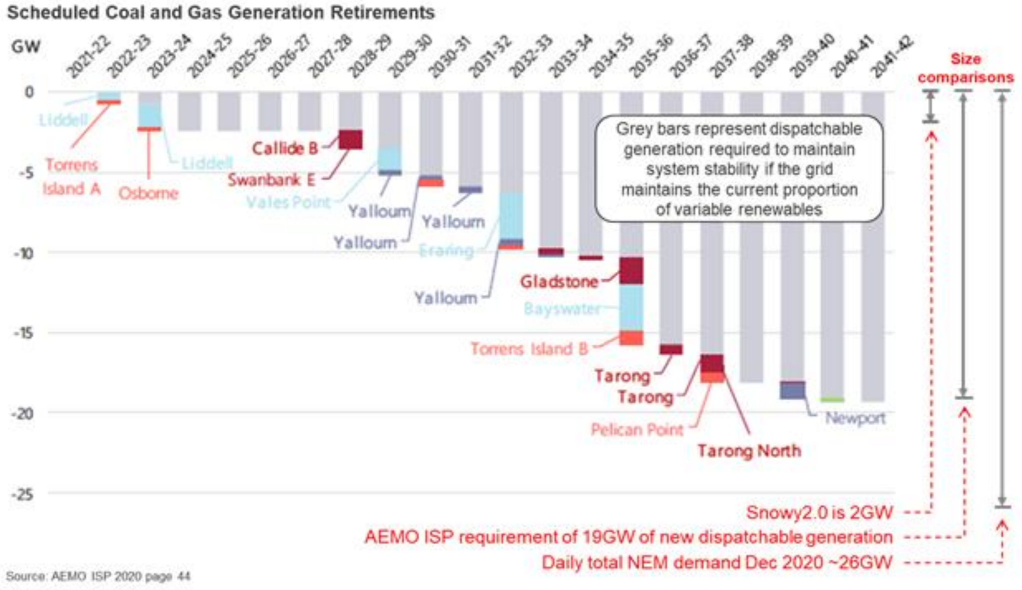

Figure 3 – visualising the magnitude of the dispatchable renewables challenge

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[17] 2020 Integrated System Plan (2020), AEMO, p12

[18] AEMO 2022 Draft Integrated System Plan (2021), p10

[19] 2020 Integrated System Plan (2020), AEMO, p44

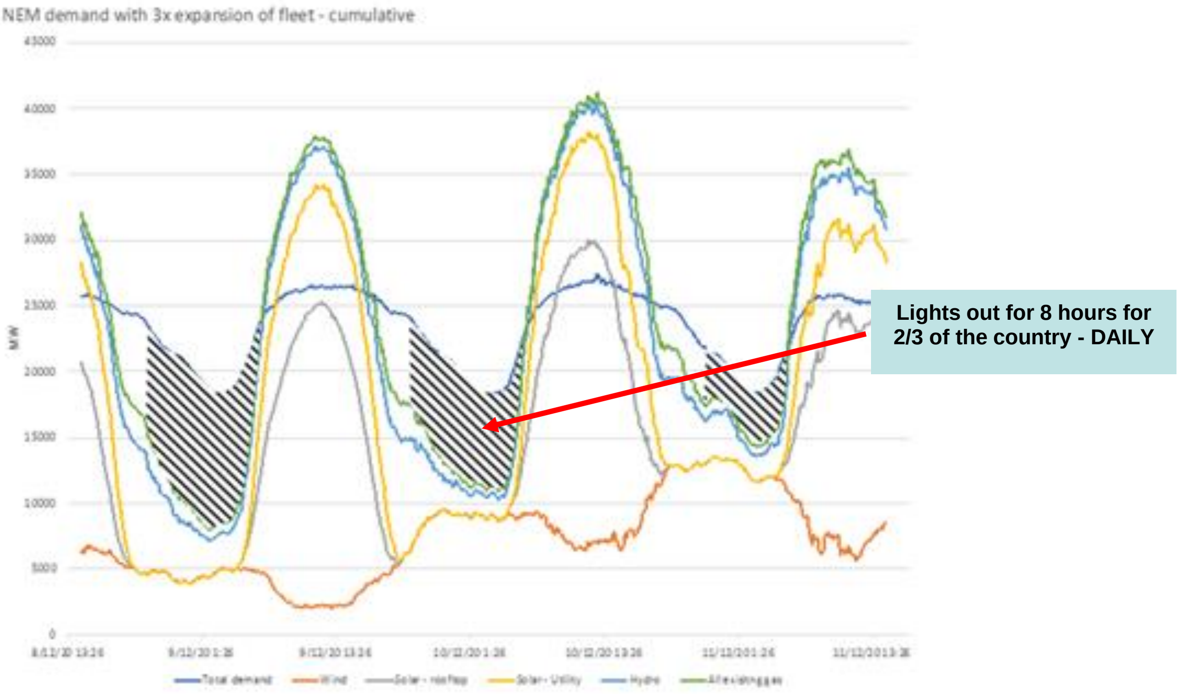
An Australian Grid Thought Experiment

The following is a simplistic but illuminating thought experiment highlighting the impact of the loss of dispatchable generation from the grid as it is currently configured.

The thought experiment goes like this:

1. Pick three sunny days on the national grid in December: plenty of days each year are far worse
2. Turn off the coal: likely to happen quicker than current expectations
3. Triple all rooftop PV: it's already at 29% penetration and not all roofs point north => 50-75% maximum
4. Triple all utility-scale PV: challenging given network curtailment, impeding additional capacity build
5. Triple all wind: challenging given community resistance plus the best sites are already to be developed
6. Triple all hydro: challenging given environmental concerns and bespoke civils.
7. Run all existing gas assets: could be run more (emissions) but uncertain given high cost of exportable gas
8. Add 10GW of 2-hour batteries: 10x the current installed base globally
9. Assume demand remains unchanged: e.g., assume no EVs, no industrial electrification, etc

The results can be seen below. Such a grid would not meet daily demand and frequent brown-outs would result.



Lights out for 8 hours for 2/3 of the country - DAILY

Figure 4 – an Australian grid thought experiment

The data to replicate this study is available through services such as https://opennem.org.au or from AEMO.

Appendix D – Dispatchable Renewables

A Taxonomy of Technologies

Dispatchable renewable generation technologies are required to support the transition of the Australian grid. In the public media, dispatchable renewables are often conflated with the adjacent technologies of variable renewable energy (perishable renewables) and energy storage technologies (which are only as renewable as the energy used to charge them, and only 'dispatchable' when full).

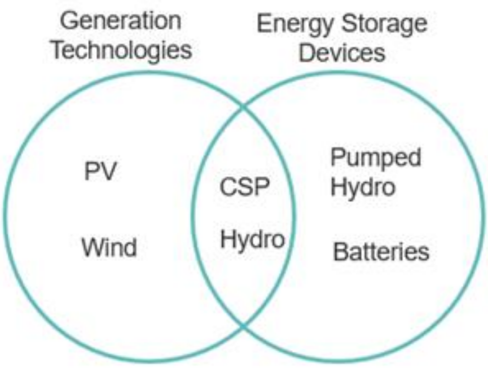
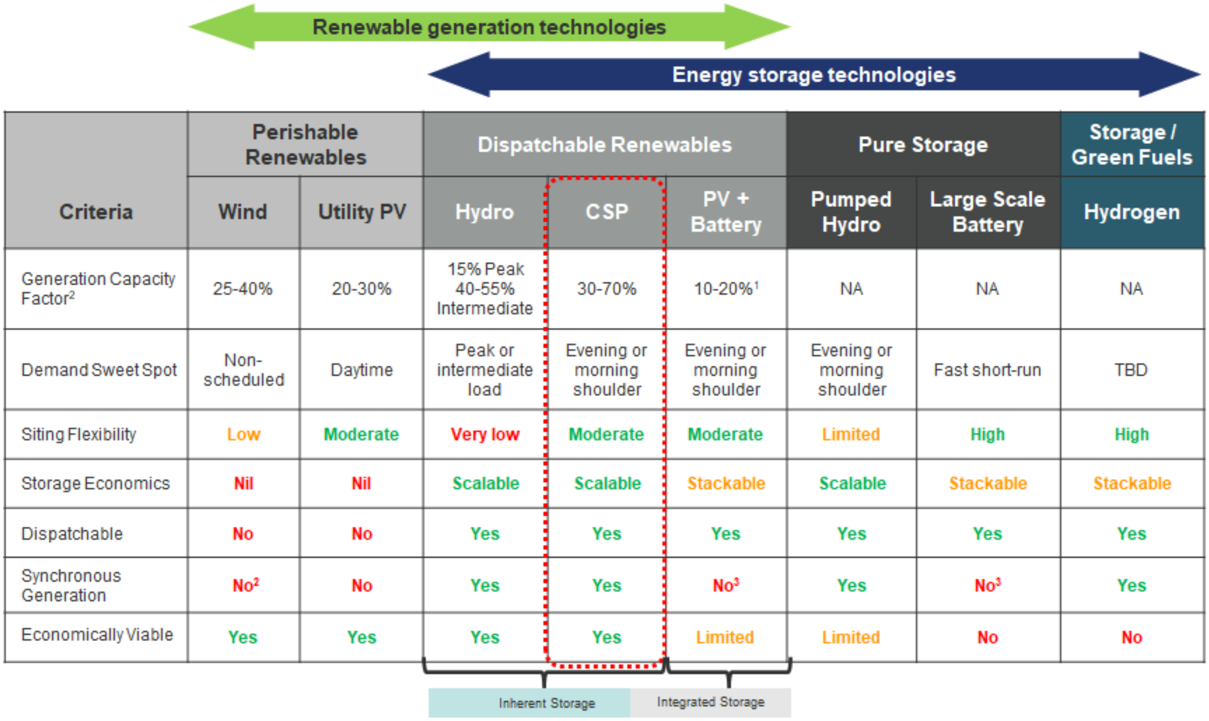


Figure 5 – CSP as both generation and storage

The table below contrasts the current commercially-viable dispatchable renewable generation technologies[20].



Criteria	Perishable Renewables		Dispatchable Renewables			Pure Storage		Storage / Green Fuels
	Wind	Utility PV	Hydro	CSP	PV + Battery	Pumped Hydro	Large Scale Battery	Hydrogen
Generation Capacity Factor[2]	25-40%	20-30%	15% Peak 40-55% Intermediate	30-70%	10-20%[1]	NA	NA	NA
Demand Sweet Spot	Non-scheduled	Daytime	Peak or intermediate load	Evening or morning shoulder	Evening or morning shoulder	Evening or morning shoulder	Fast short-run	TBD
Siting Flexibility	Low	Moderate	Very low	Moderate	Moderate	Limited	High	High
Storage Economics	Nil	Nil	Scalable	Scalable	Stackable	Scalable	Stackable	Stackable
Dispatchable	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Synchronous Generation	No[2]	No	Yes	Yes	No[3]	Yes	No[3]	Yes
Economically Viable	Yes	Yes	Yes	Yes	Limited	Limited	No	No

Figure 6 – a taxonomy of renewable energy generation technologies practical in Australia

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[20] Notes to Figure 6 - 1. estimated. 2. typically. 3. synthetic services possible with specialist equipment

The table above describes the high potential candidate technologies in the Australian market. Most of these already exist in the energy supply stack. This graphic excludes gas generation given that, while cleaner than coal and part of the supply solution for the foreseeable future, it is not renewable. Also excluded are fission, fusion generation and fossil fuel plants with carbon capture and storage for legislative and technical maturity reasons. Scale-limited renewables such as biomass, geothermal and wave are also excluded for simplicity.

Dispatchable Renewable Energy Generators – Inherent Storage

CSP plants are dispatchable renewable energy generators. Their primary competitors in the Australian grid today are new build hydroelectric plants (storage-only pumped hydro plants are discussed later). Both technologies collect renewable energy, store it, then release as instructed. Each technology has advantages and disadvantages and they are generally complementary rather than competing technologies. Sites with lots of mountains and rain are bad places for CSP plants, while flat, arid regions are suboptimal for hydro development. Besides geographic preferences, the other primary difference is that hydro plants typically manage their stored energy (water) over an annual cycle (wet season/dry season, etc.) while CSP optimises energy over a day or several days.

CSP is a clean dispatchable generation technology whose primary energy source is solar energy. In contrast to PV which converts the incoming photons into electrical energy at the panel, CSP utilises the solar energy as heat by using mirrors to focus the energy onto thermal receivers. The heat can be easily transported to central storage tanks where it is stored in low cost media with low losses. When demand for electricity occurs, the heat is used to make steam to drive a steam turbine and generator. This decoupling of energy collection from electricity generation provides two significant advantages:

1. Dispatchable output: energy collected during the day can be stored for a several hours and used in the evening, at night and/or early morning before the sun comes up
2. Controllable output: output from the plant is completely controllable as, when the CSP plant is operating, supply does not vary up or down as clouds pass over the plant as is the case with PV plants

Dispatchable Renewable Energy Generators – Integrated Storage

We start with the current leading variable renewable energy generation technologies (wind and PV) and the two leading energy storage contenders (batteries and pumped hydro). The question then becomes will there be a place in the generation portfolio for CSP or will wind/PV coupled with batteries/pumped hydro dominate the industry?

It is clear that wind and PV can provide bulk energy in the grid of the future at the lowest cost. The open questions are:

1. Storage providing dispatchable energy: which storage technology could be coupled to intermittent generation to provide the dispatchable energy needed to operate the power system?
2. Centralised or distributed storage: in a market such as the NEM, must these technologies be ‘hard-wired’ together or can they exist as independent services?

Batteries

Our view, supported by IRENA[21], is that there will be a role for batteries for short term grid services and storage capacity of up to 4 hours to smooth wind and PV output, but that the lack of scale-driven cost economics will make them too expensive for longer duration (overnight generation) applications:

> *"CSP in areas of high direct normal irradiance (DNI) therefore potentially represents a bridge from solar PV, with four hours of storage, to very high shares of solar in the system, as CSP still represents the cheapest source of long duration storage"*

Batteries outperform all other technologies, including thermal and mechanical devices like steam or gas turbines, in terms of responsiveness. For this reason, many grids around the world have or intend to use batteries to provide short term grid services, and they are often proposed to smooth the rapid fluctuations in output from wind and PV plants. The downsides of batteries are the high capital costs, short useful life, energy losses and end-of-life recyclability issues.

Industry reports show that the cost of batteries has fallen dramatically to now be economic in special situations, but with further to go to reach broad application. The primary drivers of the high cost of batteries are their base materials and the cost dynamics of battery energy storage systems at utility scale, being that they are stackable, rather than scalable. The fixed costs for the energy management system (inverters, etc.) are a small part of the total plant cost, so cost essentially goes up linearly with scale. Contrast this with a CSP molten salt tank, where doubling the capacity of the tank requires some additional steel and salt at an incremental additional cost relative to the total cost of the CSP plant.

The round trip efficiency for a battery is in the order of 90% (depending on application, battery chemistry, ambient conditions and other factors) at the beginning of its life, and it degrades over time. That means that, for every 1MWh required from a battery, 1.1MWh must be purchased to charge it. In addition, batteries degrade as they get hot, so air conditioning equipment is required which consumes more input energy.

Pumped Hydro

As with batteries, we believe that all economically viable pumped hydro projects in Australia should be built (subject to environmental and cultural considerations). The challenges, as described below, are that pumped hydro has significant limitations in its ability to underpin the transition of the grid as depicted in Figure 4 – an Australian grid thought experiment.

Pumped hydro is the other medium-duration energy storage technology often proposed as a 'sink' for overgeneration from variable PV and wind. It is excellent at storing large volumes of energy so long as there is adequate water available, which is an increasing risk if the Australian climate becomes drier under the influence of climate change. However, the biggest impediment to greater deployment is the unique engineering challenges of each project that make pumped hydro plants hard and expensive. Despite several having been proposed, very few have been built in Australia and none in the recent

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[21] Renewable Power Generation Costs in 2020 (2021), International Renewable Energy Agency, p117

past (besides Snowy 2.0 and Genex Kidston). By comparison, CSP is replicable with standardised designs that can be rolled out at suitable sites.

Alongside cost, the other major challenge limiting pumped hydro deployment is securing finance. Most projects are based on an arbitrage business model that assumes a daily cycle of charging with cheap or free electricity followed by resale at higher prices. The assumption of a spread sufficient to repay debt throughout a typical 30-year initial project life has not been palatable to financial markets to date.

Other Considerations

In comparison to mature technologies such as pumped hydro and lithium ion batteries, CSP is a renewable energy collection, storage and dispatch system rather than just storage and dispatch.

Similar to pumped hydro, the core technologies at the heart of a CSP system (steam generation, turbines etc) are well understood and can be sourced from many different suppliers. Unlike pumped hydro the site specific engineering requirements are much lower. CSP benefits from economies of scale to a much larger degree than lithium ion batteries and is better suited to medium duration storage. We see all three technologies playing a role in the Australian grid portfolio. The Snowy 2.0 project will add a 2,000MW and 350GWh of storage to the NEM (for comparison this will increase the global installed base of pumped hydro by 1% on a power and 21% on an energy basis) and a small number of smaller projects may reach financial close. Utility scale batteries with short durations have been commissioned and more will no doubt be rolled out to address grid stability concerns.

Two other emerging storage technologies that offer promise are vanadium flow batteries and compressed air energy storage (CAES). The attractive feature of flow batteries is a scalable cost structure. Their storage cost dynamic is more like hydro, with high fixed costs based on power capacity, then cheaper cost to add marginal storage capacity. In CAES systems, air is pumped into geological or undersea structures, or liquefied. When electricity is needed, the air is released through turbine generators.

Both flow batteries and CAES are net consumers of energy (they take in more than they return), they need a reliable supply of low cost renewable energy and an assurance of high priced periods on a regular (ideally daily) basis to enable debt servicing from electricity price arbitrage. By contrast, CSP plants are dispatchable renewable energy generators that collect and store solar energy, then deliver power when required.