# Building power system resilience with pumped hydro energy storage

July 2019

An Insights paper following the 2018 Integrated System Plan for the National Electricity Market

# Important notice

## PURPOSE

AEMO publishes the Integrated System Plan (ISP) pursuant to its functions under section 49(2) of the National Electricity Law (which defines AEMO's function as National Transmission Planner) and section 5.20 of the National Electricity Rules and its broader functions to maintain and improve power system security. The first ISP was published in July 2018, and the 2019-20 ISP will be published in the first half of 2020.

This ISP Insights paper provides stakeholders with updated information, based on newer data and improved modelling, and is intended to support action to increase the future resilience of the power system in the National Electricity Market (NEM), without waiting for the 2019-20 ISP to be published.

All net present value (NPV) figures are accumulated values to 2035, unless otherwise specified. All costs and benefits are expressed in 2018-19 real dollars.

## DISCLAIMER

# ISP Insights – introduction

## Why is AEMO publishing this ISP Insights paper?

The National Electricity Market (NEM) continues to undergo an unprecedented and rapid transition, changing the way in which the power system will be operated. The transition also fundamentally affects future investment priorities. AEMO's 2018 Integrated System Plan (ISP)[1] articulated a whole-of-system development pathway, to design and execute the transition in a way that maximises benefits at lowest cost and risk to consumers. This ISP Insights paper is intended to:

- Provide better understanding of proposed pumped hydro developments and their associated transmission infrastructure, based on updated data and improved modelling.
- Deliver timely information to stakeholders to support action to increase the future resilience of the power system in the NEM, without waiting for the next ISP, which will be finalised next year.

## What does this ISP Insights paper explore?

In the 2018 ISP, AEMO identified that a portfolio of utility-scale renewable generation, energy storage, distributed energy resources (DER), flexible thermal capacity, and transmission would best support the transformation of the NEM and provide opportunities for new investment. It is important that the future power system be developed for greater energy resilience, particularly to events that are outside the broader market's control. That may include climate resilience (to renewable energy droughts or heatwaves), and resilience to critical failures of plant, economic withdrawals of existing capacity, or changes in market structures that may create opportunities for disruptive operational behaviours.

The 2018 ISP recognised there could be strategic value from deeper consideration of bringing forward some identified transmission development, as well as strategic storage, as a potential pre-emptive measure to increase power system resilience against climate change or early, unexpected exits of coal-fired generation.

When the 2018 ISP was published, energy storage projects with the potential to critically influence the future of the NEM were under active consideration, including Snowy 2.0 and Battery of the Nation (BoTN). The Commonwealth Government has since committed to constructing Snowy 2.0 and developing an underwriting mechanism for BoTN through its Underwriting New Generation Investments (UNGI) program.

As these strategic developments progress, and new information becomes available, AEMO has been working with project proponents to refine and update its assumptions and models related to existing hydro schemes and new pumped hydro energy storage (PHES).

Based on these modelling refinements, this ISP Insights paper provides new perspectives and deeper insights on the potential for these large PHES projects to deliver market benefits to consumers, and at the same time increase the NEM's resilience to future risks, such as declining reliability and early exit of existing generators.

This ISP Insights explores the following key questions:

- What role does PHES play in delivering reliable, resilient electricity supply in the future?
- What transmission development is needed, by when, to maximise the market benefits of these large PHES projects?
- What additional benefits do these power system developments deliver?
- What are the next steps to drive co-ordinated development in the long-term interests of consumers?

## What is new in this ISP Insights paper?

AEMO has improved its modelling of new strategic storage initiatives (Snowy 2.0 and BoTN) and existing hydro schemes (Snowy Hydro and Hydro Tasmania), and its modelling approach, to more fully and deeply

[1] AEMO, ISP, July 2018, at http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Integrated-System-Plan.

capture weather variability and hydro availability. AEMO gratefully acknowledges the support of Snowy Hydro and Hydro Tasmania in providing greater clarity on the physical characteristics and capabilities of projects.

AEMO has also updated key input assumptions around demand forecasts, committed generation and transmission projects, gas costs, and future generation costs, to reflect current assumptions published in AEMO's February 2019 Draft Inputs and Assumptions Workbook[2]. The analysis does not include the full refresh of inputs and assumptions that are currently being finalised for use in the 2019-20 ISP.

## What are the key insights about pumped hydro energy storage?

**Insight 1 – the NEM needs a portfolio of varying energy storage durations to efficiently distribute available renewable energy and support smooth operation of less flexible existing generation.**

- Storages of six to eight hours are enough in most cases to complement solar, while Snowy 2.0 or BoTN offer valuable seasonal storage and insurance against drought risk.
- With Snowy 2.0 committed, and existing hydro generators already storing potential energy in deep reservoirs, market signals for an additional suite of complementary PHES are subdued until further significant coal-fired generation closures occur (currently expected to be in the late 2020s to mid-2030s).

**Insight 2 – new transmission development that strengthens the NEM backbone is necessary to access benefits delivered from large-scale deep storages.**

- Increased transfer capability between the Snowy area and Sydney (HumeLink) would maximise the reliability and resilience benefits from Snowy 2.0 at lowest cost for New South Wales consumers following the 2022 closure of Liddell Power Station.
- Increasing transfer capability between the Snowy area and Melbourne (KerangLink) would maximise the reliability and resilience benefits from Snowy 2.0 at lowest cost for Victorian consumers in time for the next expected closure of brown coal-fired generation in Victoria.
- Increasing transfer capability between Tasmania and Victoria (Marinus Link) would allow additional renewable generation and storage capability to be exported to the mainland.

**Insight 3 – early, pre-emptive development of KerangLink and HumeLink would increase the resilience of the power system to coal-fired generation closing earlier than expected.**

- Advancing augmentations between Snowy Mountains and Bannaby is projected to help support Sydney under peak load conditions.
- If there is more than a 20% chance of Yallourn Power Station closing earlier than currently scheduled (or an equivalent supply reduction in Victoria), then building KerangLink prior to the closure date would be a least-regrets strategy. For the purposes of this analysis, AEMO assumed an early closure by 2028-29.
- Marinus Link would similarly increase system resilience in case of early plant closure.

**Insight 4 – KerangLink and/or Marinus Link provide additional market benefits to consumers.**

- These new interconnectors will reduce the transmission costs involved in integrating renewable generation, reduce the decline in marginal loss factors, and increase overall power system security.

## What happens next?

Transmission augmentations require significant planning, community consultation, economic cost-benefit analysis, and regulatory engagement so investments are in the best interest of consumers. Under the current regulatory regime, a Regulatory Investment Test for Transmission (RIT-T) is required; RIT-Ts for transmission infrastructure associated with Snowy 2.0 and BoTN are already underway, and a RIT-T for KerangLink should be progressed as soon as practicable. Next steps are summarised at the end of this ISP Insights paper.

[2] AEMO, Inputs and Assumptions workbook, February 2019, at https://www.aemo.com.au/Stakeholder-Consultation/Consultations/2019-Planning-and-Forecasting-Consultation.

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# Insight 1: A portfolio of varying energy storage durations

**The NEM needs a portfolio of varying energy storage durations to efficiently distribute available renewable energy and support smooth operation of less flexible existing generation.**

- Storages of six to eight hours are enough in most cases to complement solar, while Snowy 2.0 or BoTN offer valuable seasonal storage and insurance against drought risk.
- With Snowy 2.0 committed, and existing hydro generators already storing potential energy in deep reservoirs, market signals for an additional suite of complementary pumped hydro energy storage (PHES) are subdued until further significant coal-fired generation closures occur (currently expected to be from the late 2020s to mid-2030s).

The NEM is a geographically spread system that is exposed to significant variability associated with weather, consumer demand, and renewable generation availability. Hot summer days currently present the greatest risk to supply in most regions of the NEM, with high electricity demand associated with air-conditioner loads continuing after sunset when solar generation has reduced.

Energy storage helps build power system resilience to weather events (including wind, solar, and hydro droughts) by storing surplus renewable generation for use at times when these resources are scarce and allowing more constant operation of less flexible existing generation. This, in turn, creates a more dispatchable and reliable power system, while helping to keep prices down for consumers by maximising use of existing, low-cost, thermal generation assets.

A portfolio comprising shallow and deep[3] large-scale energy storage systems – with the appropriate transmission infrastructure and complemented by consumer-driven battery systems – will provide an 'all weather' supply mix to deliver maximum economic efficiency for consumers.

This ISP Insights analysis of PHES, incorporating improved modelling of storage diversity and weather variability, indicates that:

- When renewable energy availability is low, long-term storage such as Snowy 2.0 and BoTN delivers higher fuel costs savings than short-term storage solutions.
  - For example, one week's storage in Snowy 2.0 in 2030-31 saves approximately $86 million more on average in fuel costs (ultimately benefiting consumers), compared to equivalent storage capacity with only six hours storage, across weather years modelled.
  - In drier years, storage depth becomes even more valuable, as PHES enables re-use of limited hydro resources.
- Shallow developments, with six to eight hours storage potential, are the most valuable in providing intra-day and day-ahead energy shifting, complementing generation from utility-scale solar and rooftop photovoltaic (PV) systems.

[3] In referring to energy storage systems, 'depth' often refers to the energy to capacity ratio, where a 'deep' storage system has a high energy to capacity ratio, such that it can operate for long periods at high output before exhausting its energy storages. 'Shallow' storage systems have relatively low energy to capacity ratios, such that they operate for relatively short periods before exhausting their storage reserves. Storage 'depth' is independent of the peak capacity of the system; rather, it is a reference to how long that storage would last.

- Distributed storage (batteries) with shorter discharge times can provide value through capacity firming to support the grid at peak times.

## The projected need for future storage is at a scale not seen before in the NEM

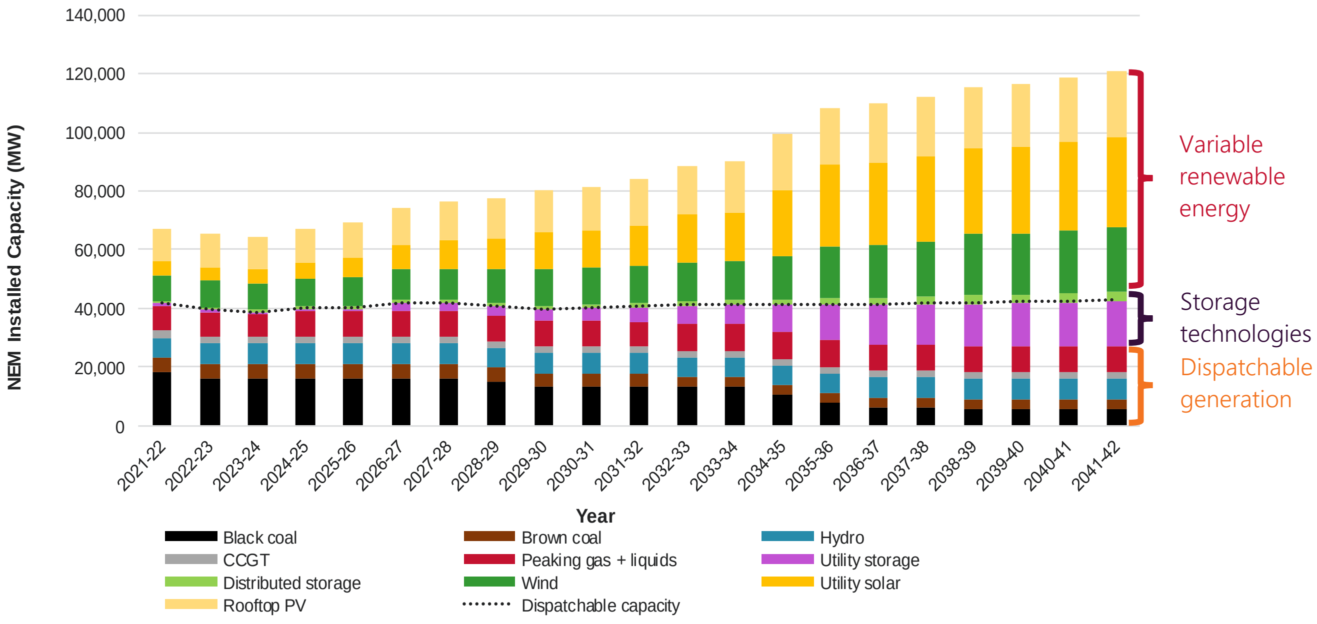
This ISP Insights study projects, consistent with the 2018 ISP Neutral scenario, a portfolio of technologically diverse generation mix, dominated by increasing integration of renewable generation. By 2042, wind and solar generators (including rooftop PV) are expected to represent approximately 62% of the NEM's installed generation and storage capacity and generate over 60% of energy consumed. Intermittent and variable generation sources would be complemented by increasing development of storage solutions with a variety of capabilities, as shown in Figure 1.

AEMO forecasts the development need for utility-scale storage installations will exceed 15 gigawatts (GW) by the early 2040s, with opportunities for six-hour and 12-hour storage solutions most able to complement deeper storage solutions such as Snowy 2.0 and/or BoTN.

Figure 1 shows the generation development outlook for a Neutral scenario (based on February 2019 ISP consultation assumptions settings, and transmission development identified in the 2018 ISP Neutral scenario). It shows the projected mix of renewable generation, reduction in thermal generation, and addition of new storage, to maintain dispatchability at levels similar to today.

With Snowy 2.0 now committed, incentives for additional seasonal storages are expected to weaken until the mid-2030s. At that time, the rate of coal-fired power station retirements is expected to accelerate, creating increasing opportunities for, and value from, new sources of firm and flexible capacity to provide resilience against hydro drought risk. By the end of the next 20 years, the projected need for storage to assist with energy shifting is at unprecedented scale.

**Figure 1 Forecast NEM generation capacity in the ISP Insights development plan, Neutral scenario**




## Deep pumped hydro provides both daily and seasonal energy shifting

Figure 2 shows projected typical winter operation of the NEM in 2030, with Snowy 2.0 and several other new storage plants in service. In this study, a total of 4.1 GW storage capacity is assumed to be installed by 2030.

Pumped hydro enables variations in renewable energy to be absorbed and coal-fired power stations to operate at more stable levels, acknowledging that existing coal-fired generators are also becoming increasingly flexible. It also contributes to capacity needs in peak hours, especially in the evening. Storages charge mostly from excess solar generation during the day. Deeper pumped hydro[4] can also store excess night-time wind generation to use later during peak periods.

**Figure 2 Typical winter NEM generation profile in 2030, with portfolio of storages**

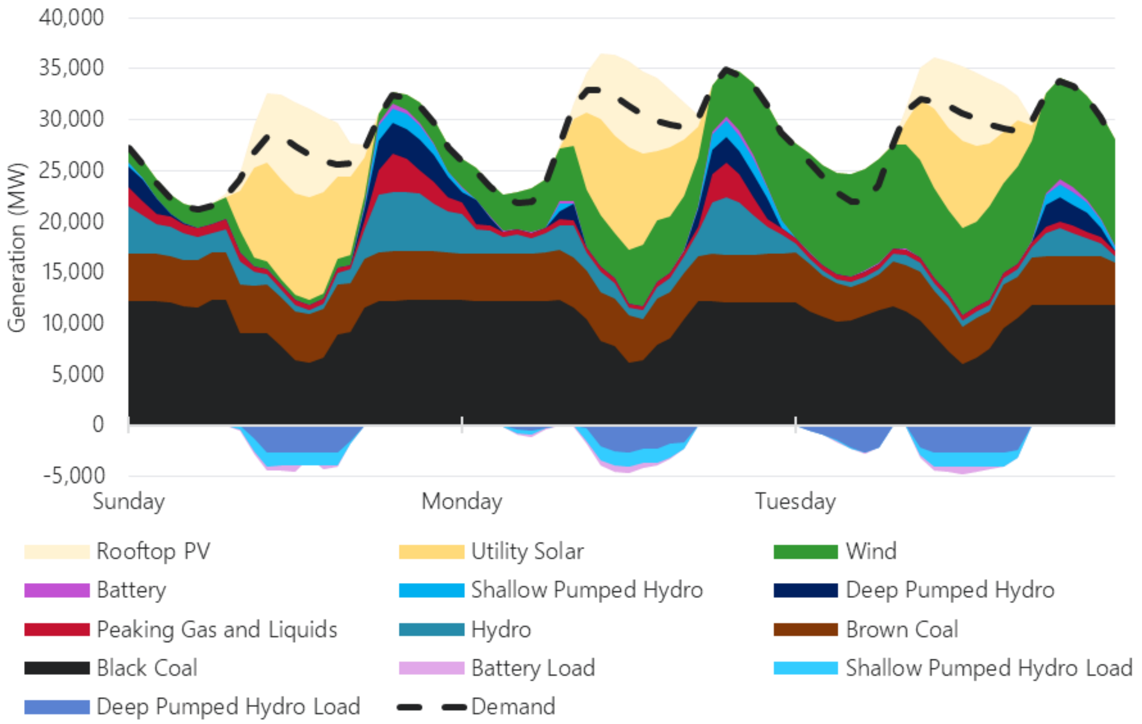
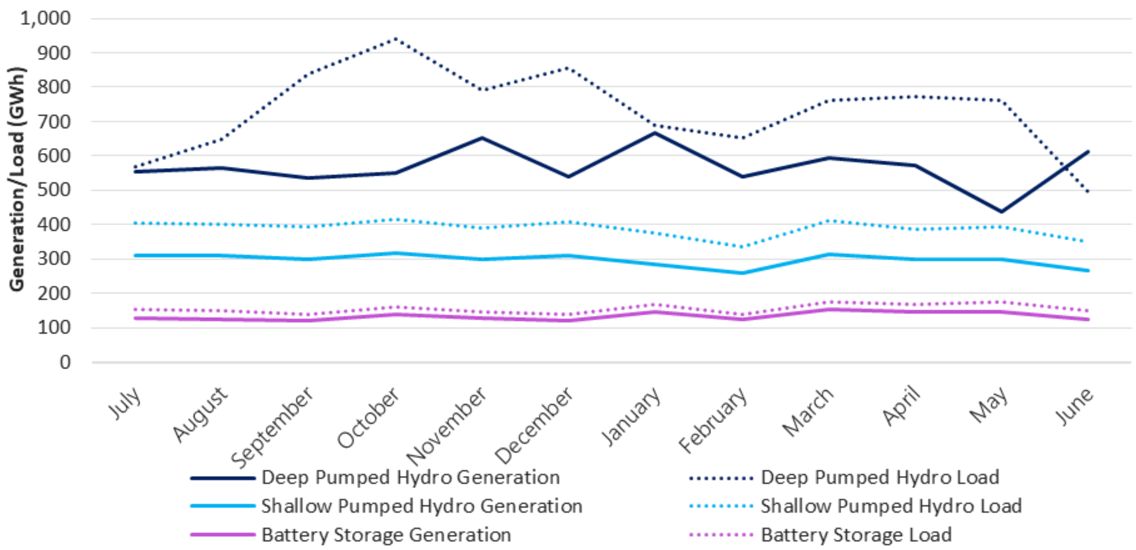



Figure 3 shows that, in this study, the deep pumped hydro stations (Tumut 3 and Snowy 2.0 in this example) are projected to be able to take advantage of spare energy during the shoulder seasons and use this for pumping, particularly during spring, and then generate to meet high demand periods throughout the year.

**Figure 3 Projected monthly storage utilisation**




Note: Across the year, load is higher than generation due to losses during charging and discharging. PHES has an assumed round-trip efficiency of 70%-80% and batteries 80%-90%.

[4] In this analysis, deep PHES includes Snowy 2.0 and Tumut 3, and shallow PHES encompasses Wivenhoe, Shoalhaven, and new-built facilities in South Australia, Queensland, and Victoria with six-hour to 12-hour depth.

Similarly, these deep storages would provide more flexibility to support a tightening maintenance window during the shoulder season for transmission and generation, and gas pipelines and production.

These storages operate in a similar manner to conventional hydro generation, and, being a closed system, do not rely on natural inflows that may vary seasonally. They are forecast in this analysis to provide daily energy cycling as well as longer-term energy shifting, with roughly equal time spent in both operating modes.

Shallow pumped hydro (like Wivenhoe and Shoalhaven) can provide value through intra-day shifting and may empty and fill multiple times in a month.

Batteries, including customer DER, hold less energy and are forecast to only provide intra-day energy shifting.

### The value of deep storage – building power system resilience to weather variability and climate change

The **Snowy 2.0** storage scheme, assumed for this study to be operational in 2026-27, will provide up to 2,000 megawatts (MW) increased capacity, and approximately one week's storage capability (350 gigawatt hours [GWh]) at maximum discharge before it would require refilling[5].

**BoTN** describes a suite of PHES brownfield and greenfield developments accessing deep reservoirs in Tasmania that can be staged as required, and in total could deliver an additional 2,500 MW[6] of dispatchable capacity with reservoirs of between 12-hour and 31-hour storage depth.

Using an improved representation of the Snowy and Tasmanian hydro schemes, AEMO's latest modelling shows that the Snowy 2.0 and BoTN projects[7] both deliver at least $55 million greater market benefits to consumers on a net present value (NPV) basis than was estimated in the 2018 ISP, provided they are not constrained by network limitations. Much of this increase is due to improved modelling of annual weather variability.

Based on the supply mix projected in 2030 in this latest modelling, and leveraging a larger dataset provided by DNV-GL, AEMO now forecasts that the annual availability of renewable energy (across wind, solar, rooftop PV, and traditional hydro generators) may vary from 106 terawatt hours (TWh) to 115 TWh depending on weather conditions over the year (a swing of approximately 8% or 9,000 GWh).

Weather variability affects many aspects of the energy system:

- The magnitude and coincidence of peak demand levels across regions.
- The availability of renewable energy resources.
- The derating of thermal generation units and transmission lines.

Traditional hydro generation operates with lakes filling and emptying over cycles of several months and is exposed to rainfall variability which may lead to highly variable contributions from these long-standing deep storages.

With a week of storage, Snowy 2.0 can shift surplus renewable energy (and low-cost coal generation if renewable energy was unavailable) from the shoulder seasons of spring and autumn to cover summer heatwaves and winter calms. In drier years, Snowy 2.0 is expected to cycle more as it takes on the role of smoothing the use of gas-powered generation (GPG) which is performed by conventional hydro in wetter conditions.

To estimate the value of having deeper PHES in the system, AEMO has examined an alternate configuration of the Snowy 2.0 project, with storages re-sized to provide a shallower storage depth of six hours (at maximum discharge) rather than seven days.

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[5] Snowy 2.0. Final Investment Decision, at https://www.snowyhydro.com.au/our-scheme/snowy20/fid/.

[6] ARENA, Battery of the Nation, at https://arena.gov.au/projects/battery-of-the-nation/.

[7] This is a conservative estimate for BoTN, as only a fraction of the full 2,500 MW potential was considered in this analysis, enabled by an initial 600 MW of a staged Marinus Link.

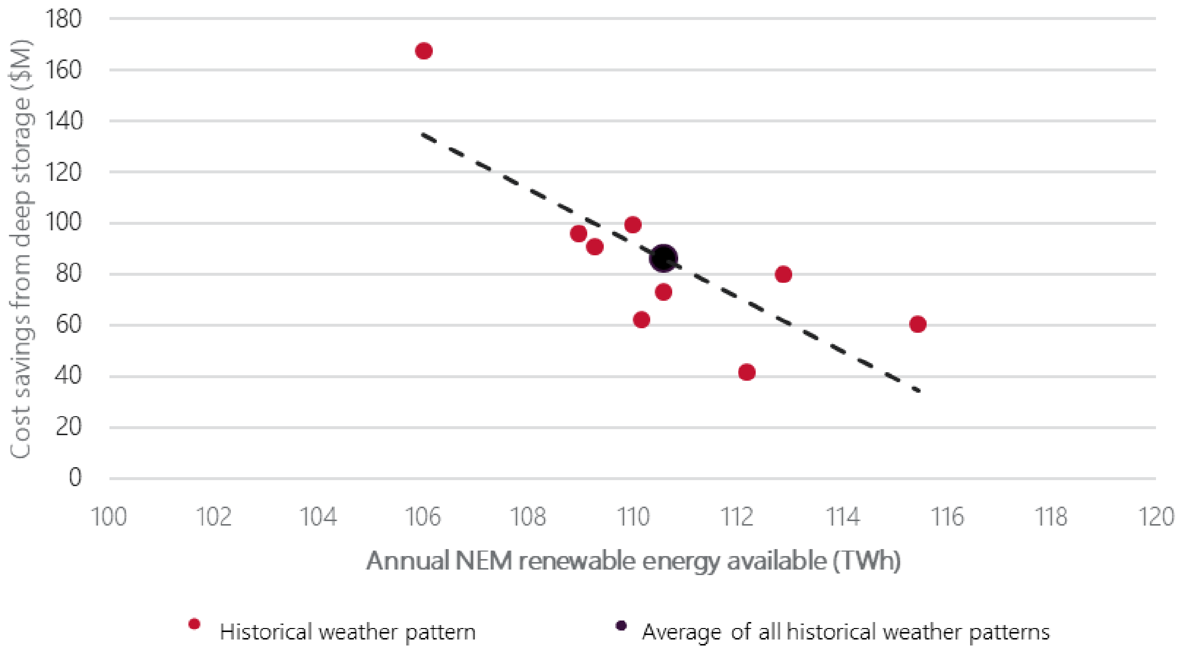
With only six hours storage, Snowy 2.0 would be restricted to focus more on daily energy cycling, rather than seasonal energy shifting. Under this configuration, its 2 GW capacity would still be available to service peak demand during heatwaves, however, fuel cost savings (ultimately passed through to consumers) would be lower due to the reduced flexibility of seasonal energy shifting.

Figure 4 shows the value (measured as cost savings) of having a week's storage under a range of weather years which capture natural annual variations in wind, solar, and annual rainfall.

Compared against six-hour alternatives, Snowy 2.0's week of storage is projected to provide greatest value in years of hydro droughts, or when wind and solar generation is low. Operating costs (fuel and variable operating and maintenance costs) would be reduced by between $40 and $100 million per year with the deeper storage, depending on the weather and the broader availability of thermal plant.

Over the nine historical weather years simulated, the analysis found on average an $86 million annual cost saving (the black dot on the Figure 4 chart) from Snowy 2.0 at its designed one-week storage depth, compared to six-hour storage.

**Figure 4 Expected cost savings as a declining function of available renewable energy, 2030-31**




The value of storage depth is expected to increase as more coal-fired generation capacity exits. Without this storage depth, there would be a greater forecast reliance on GPG to meet demand, and gas supplies may not be available when required.

During drought conditions, such as those experienced in 2006-07, storage depth would be more valuable and savings in operating costs could reach $167 million, due to deeper storages being more resilient to rainfall variability.

# Insight 2: Transmission investment to complement storage

**New transmission development that strengthens the NEM backbone is necessary to access benefits delivered from large-scale deep storages.**

- Increased transfer capability between the Snowy area and Sydney (HumeLink) would maximise the reliability and resilience benefits from Snowy 2.0 at lowest cost for New South Wales consumers following the 2022 closure of the Liddell Power Station.
- Increasing transfer capability between the Snowy area and Melbourne (KerangLink) would maximise the reliability and resilience benefits from Snowy 2.0 at lowest cost for Victorian consumers in time for the next expected closure of brown coal-fired generation in Victoria.
- Increasing transfer capability between Tasmania and Victoria (Marinus Link) would allow additional renewable generation and storage capability to be exported to the mainland.

**Figure 5 Major transmission required to connect strategic storage initiatives**

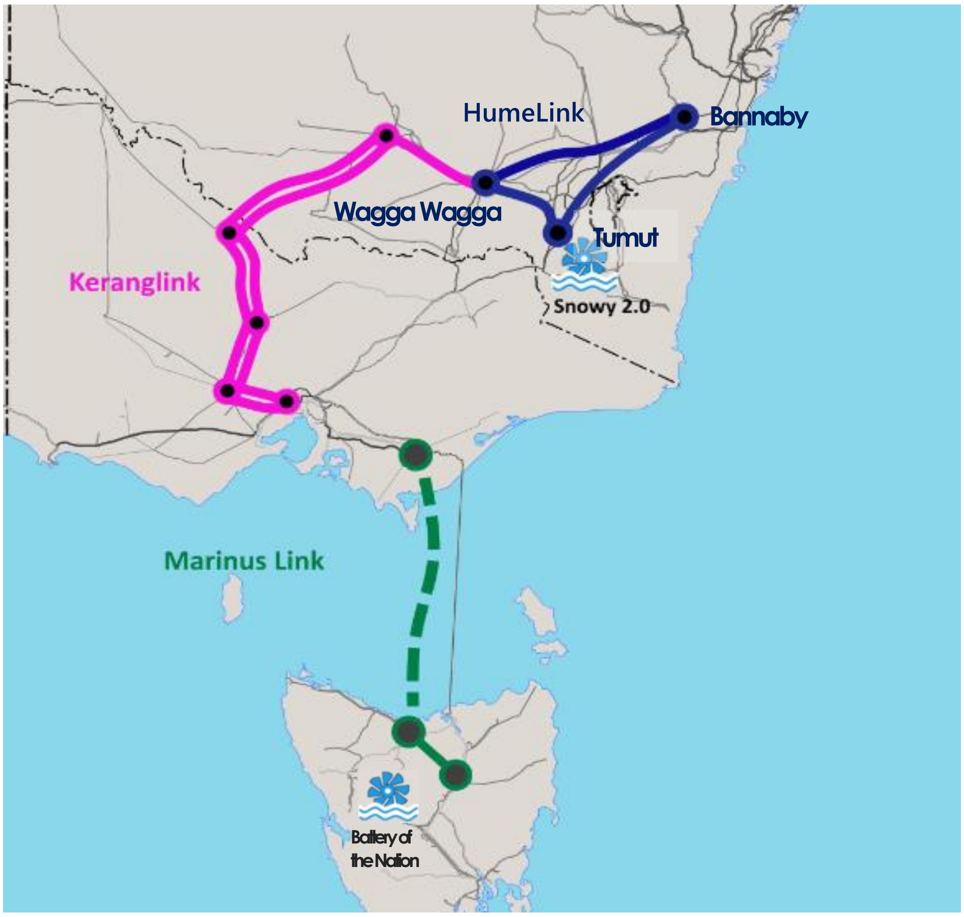


Figure 5 shows tentative routes for the three new transmission developments that the 2018 ISP identified would be needed for PHES projects to deliver their benefits to consumers in the NEM:

- **HumeLink** (new transmission developments that can reinforce the New South Wales network to increase transfer capacity between the Snowy Mountains, southern New South Wales, and the major load centres of Greater Sydney), to allow Snowy 2.0 to supply Sydney during high demand periods[8].
- **KerangLink** (new interconnection between Victoria and New South Wales), to better utilise resources across the NEM, thereby reducing generation costs following closure of more coal-fired generation.
- **Marinus Link** (new interconnection between Tasmania and Victoria), to deliver the benefits from BoTN.

In mid-2018, AEMO and TransGrid jointly initiated a **Victoria – New South Wales Interconnector (VNI) upgrade RIT-T** to assess network and non-network options that are considered technically and economically feasible to address short-term needs. The VNI RIT-T is testing a two-year acceleration of network augmentations between the existing Snowy Hydro scheme and Bannaby as part of a suite of credible options to alleviate current and projected power transfer limitations which impact on the efficient sharing of generation resources between regions.

The VNI RIT-T Project Specification Consultation Report (PSCR)[9] was released in November 2018. Stakeholder submissions closed in February 2019, and AEMO and TransGrid are jointly preparing a Project Assessment Draft Report (PADR) for publication later in 2019. The PADR will identify the preferred option for augmentation, quantify the expected net market benefits for consumers, and describe the optimal timing for investment.

Following the need identified in the 2018 ISP, TransGrid has also initiated formal consultation on investments that can **reinforce the New South Wales Southern Shared Network to increase transfer capacity between the Snowy Mountains, southern New South Wales, and the major load centres of Sydney, Newcastle, and Wollongong**. TransGrid's RIT-T will test larger network options which may also include bringing forward the transmission developments between the Snowy Hydro scheme and Bannaby assessed by the VNI RIT-T, although as part of a long-term package. A PSCR on this development, outlining credible network and non-network options, was released on 25 June 2019[10].

A RIT-T is also underway for **additional interconnection between Tasmania and Victoria**. As part of a wider assessment in partnership with the Australian Renewable Energy Agency (ARENA), TasNetworks is progressing formal assessment of a new Bass Strait interconnector. A PSCR[11] outlining the identified need and two credible network options was released in July 2018, and a PADR is expected mid-2019.

**As a prudent risk mitigation strategy, AEMO has already commenced preliminary technical studies on options that would improve transfer capability with New South Wales and provide resilience against uncertain future step-changes in supply. AEMO expects to build on these studies to commence a formal KerangLink RIT-T process in the near future, to identify the most economic option to build future interconnection with New South Wales[12].**

### Optimal timing of each link is event-driven

The optimal timing of these strategic transmission developments is projected to coincide with development of the corresponding PHES they are able to unlock.

[8] The 2018 ISP called this potential development 'SnowyLink North'.

[9] AEMO, Victoria to New South Wales Interconnector Upgrade RIT-T, at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/Victorian_Transmission/2018/Victoria-to-New-South-Wales-Interconnector-Upgrade-RIT-T-PSCR.pdf.

[10] TransGrid PSCR – Reinforcing the New South Wales Southern Shared Network to increase transfer capacity to the state's demand centres, at https://www.transgrid.com.au/what-we-do/projects/regulatory-investment-tests/Documents/TransGrid%20PSCR_Reinforcing%20NSW%20Southern%20Shared%20Network.pdf.

[11] TasNetworks, Project Marinus PSCR, at https://projectmarinus.tasnetworks.com.au/wp-content/uploads/2019/05/Project-Specification-Consultation-Report.pdf.

[12] For more information, see AEMO, Victorian Annual Planning Report, June 2019, at http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Victorian-transmission-network-service-provider-role/Victorian-Annual-Planning-Report.

The optimal timing of KerangLink is not linked to any one energy storage project, but rather to the closure of coal-fired generation:

- In the 2018 ISP Neutral scenario, it was projected to be beneficial to share resources across the NEM via KerangLink when more coal-fired generation retired in the mid-2030s.
- The optimal timing of KerangLink was earlier in the 2018 ISP Fast change scenario, with that scenario integrating higher levels of renewable generation in Victoria and higher demand. The earlier timing was because this transmission would provide reliability benefits in Victoria at times of high demand, while also enabling more renewable generation to be used at other times.

Since the 2018 ISP:

- The Victorian Government has announced an expansion of the Victorian Renewable Energy Target (VRET) policy to a 50% target by 2030[13].
- The Commonwealth Government has committed to progressing the Snowy 2.0 project.
- AEMO has published higher demand forecasts in the 2018 Electricity Statement of Opportunities (ESOO) for the NEM[14] (relative to those considered in the 2018 ISP).
- Yallourn Power Station has submitted expected closure years for its four units, from 2029 to 2032, as part of the new generator three-year notice of closure rule requirements[15].

As a result of these changes, the input assumptions for Victoria used in this ISP Insights modelling are more in line with those in the 2018 ISP Fast change scenario than with the Neutral scenario, and KerangLink is now projected to deliver net market benefits earlier than previously assessed.

The ISP Insights analysis indicated the optimal timing of KerangLink would be in time for the next power station closure in Victoria, currently reported to be the staggered closure of Yallourn between 2029 to 2032.

This new interconnector, if delivered by 2030-31, is estimated to provide net market benefits accrued up to 2035[16] of approximately $147 million to consumers. These net market benefits are primarily delivered by:

- Increasing capacity to export surplus generation from Victoria, saving fuel costs in other regions.
- Providing efficient access to firm supply options, including Snowy 2.0, to support reliability outcomes in Victoria.
- Reducing intra-regional transmission capital expenditure, as the route selected passes nearby renewable energy zones (REZs) in Victoria.

[13] See https://www.energy.vic.gov.au/renewable-energy/victorias-renewable-energy-targets.

[14] AEMO, ESOO, August 2018, at http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/NEM-Electricity-Statement-of-Opportunities.

[15] Expected closure dates are provided by Registered Participants and published on AEMO's Generation Information page, at https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Generation-information.

[16] For this assessment, only those benefits up to 2035 are considered in the calculation of net present value, although residual benefits would be expected, particularly as the life of the asset would far exceed this modelled horizon.

# Insight 3: Increasing power system resilience

**Early, pre-emptive development of KerangLink and HumeLink would increase the resilience of the power system to coal-fired generation closing earlier than expected.**

- Advancing augmentations between Snowy Mountains and Bannaby is projected to help support Sydney under peak load conditions.
- If there is more than a 20% chance of Yallourn Power Station closing earlier than currently scheduled (or an equivalent supply reduction in Victoria), then building KerangLink prior to the closure date would be a least-regrets strategy. For the purposes of this analysis, AEMO assumed an early closure by 2028-29.
- Marinus Link would also increase system resilience in case of early plant closure.

With the new PHES information, improved assumptions, and enhanced modelling, AEMO identifies benefits in advancing some of the transmission developments identified in the 2018 ISP, to increase NEM resilience by providing insurance against coal-fired generation retiring earlier than currently expected.

AEMO notes that resilience has not been prescriptively defined for the NEM yet, either in respect of the risks that threaten it or the available responses to maintain or restore it. It is not, however, a new concept, as it is good utility practice to design a resilient power system that can withstand, or recover quickly from, high impact events that threaten reliability, security, or consumer survivability. The following definition encapsulates the meaning given to resilience in the context of this ISP Insights paper.

> "The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and function.
>
> United Nations Resolution 69/283 Sendai Framework for Disaster Risk Reduction 2015-2030[17]

### Advancing augmentations between the Snowy Mountains and Bannaby is projected to help support Sydney under peak load conditions

Accelerating investments that can reinforce the New South Wales Southern Shared Network before Snowy 2.0 is projected to increase access to existing Snowy Hydro capability during peak demand periods and support reliability of supply in New South Wales following the closure of the Liddell Power Station in 2022.

AEMO's analysis indicates there may be additional benefits if components of the investments that can reinforce the New South Wales Southern Shared Network currently being assessed by TransGrid are delivered ahead of commissioning of Snowy 2.0, because this would increase the capacity to supply Sydney load during peak demand periods, from the existing Snowy Hydro scheme and imports from Victoria.

If feasible to build earlier, reinforcing the flow path between the Snowy Hydro scheme and Bannaby would reduce reliability risks in New South Wales by increasing access to lower-cost hydro generation and imports from Victoria. AEMO's analysis in this ISP Insights indicates that network solutions relieving congestion in this

[17] At https://sustainabledevelopment.un.org/index.php?page=view&type=111&nr=7738&menu=35.

area could deliver net reliability benefits to consumers of approximately $50 million if delivered a year earlier than Snowy 2.0.

In addition to strengthening the network between the existing Snowy Hydro scheme and Bannaby, further transmission augmentations through to Sydney will be needed to unlock the full benefit of the Snowy 2.0 storage project, enabling Snowy 2.0 to contribute to the flexibility and reliability of the NEM.

These upgrades also form part of TransGrid's RIT-T, and if completed in 2026-27[18] would deliver net market benefits to consumers of an additional $56 million based on current cost estimates, driven by savings in deferring additional capital investment to develop alternative generation capacity elsewhere to maintain system reliability.

### Advancing KerangLink provides insurance against earlier-than-expected closure of Yallourn Power Station (or loss of equivalent capacity)

Advancing KerangLink to enable Snowy 2.0 is projected to support Victoria if coal-fired generation retires earlier than expected. If the likelihood of an early coal-fired generation closure in Victoria exceeds approximately 20%, then, based on current assumptions, it is projected to be beneficial to have KerangLink built in time for delivery of Snowy 2.0.

The timing of new interconnectors such as KerangLink is particularly sensitive to assumptions on closure of coal-fired generation in Victoria. Under recent National Electricity Rules changes, generators are now required to provide at least three years' notice of closure. However, transmission infrastructure can take much longer than that to plan and build. As such, the power system, and Victorian consumers, remain exposed to risks of unplanned early retirements or extended outages of coal-fired generation.

In the absence of any regulatory mechanism to support the co-ordinated exit of coal-fired generation and development of replacement infrastructure, planning for a more strongly interconnected system ahead of closures of coal-fired generation can avoid or delay substantial investment in more expensive alternatives to support reliability and security of supply.

Earlier development of the KerangLink interconnector would also support Victoria in the case of early closures by delivering greater access to Snowy 2.0 generation capacity.

If construction of KerangLink was to commence now, in time for commissioning of Snowy 2.0 instead of the mid-2030s, AEMO forecasts positive net market benefits only start materially accruing after Yallourn Power Station retires[19]. This suggests the optimal timing to deliver KerangLink is around 2030-31, to coincide with Yallourn's expected staggered closure. However, this analysis does not make any assumptions around further deterioration of generating units as they near end of life, the impact reductions in reliability would have on higher-cost GPG and gas availability, or potential scarcity pricing behaviours that would drive price increases for consumers. Consideration of these factors alone could justify bringing KerangLink in ahead of any further power station closure.

The expected closure timing for all generation is also uncertain and subject to variation, depending on projected future viability and/or condition of assets as they near end of technical life. That means the timing of KerangLink development needs to be determined without certainty around timing of generation closures in Victoria.

Commissioning KerangLink in 2026-27 (in this analysis) rather than 2030-31 ahead of the next closure would bring forward transmission investment costs of approximately $214 million over the life of the asset, but would provide significant insurance value when considering the relative cost of inaction in the event of an unexpected closure of a major coal-fired plant in Victoria.

Figure 6 represents a decision tree with options to build KerangLink in 2026-27, 2030-31, or 2034-35 (the original 2018 ISP timing). Each branch of the tree shows the net market benefits of the different investment

[18] TransGrid's PCSR identified that early development of HumeLink could take place as early as 2024, supporting the conclusions in this report that early development may be beneficial.

[19] For this modelling, AEMO assumed that Yallourn full closure occurs in 2031-32, consistent with 2018 ISP Assumptions.

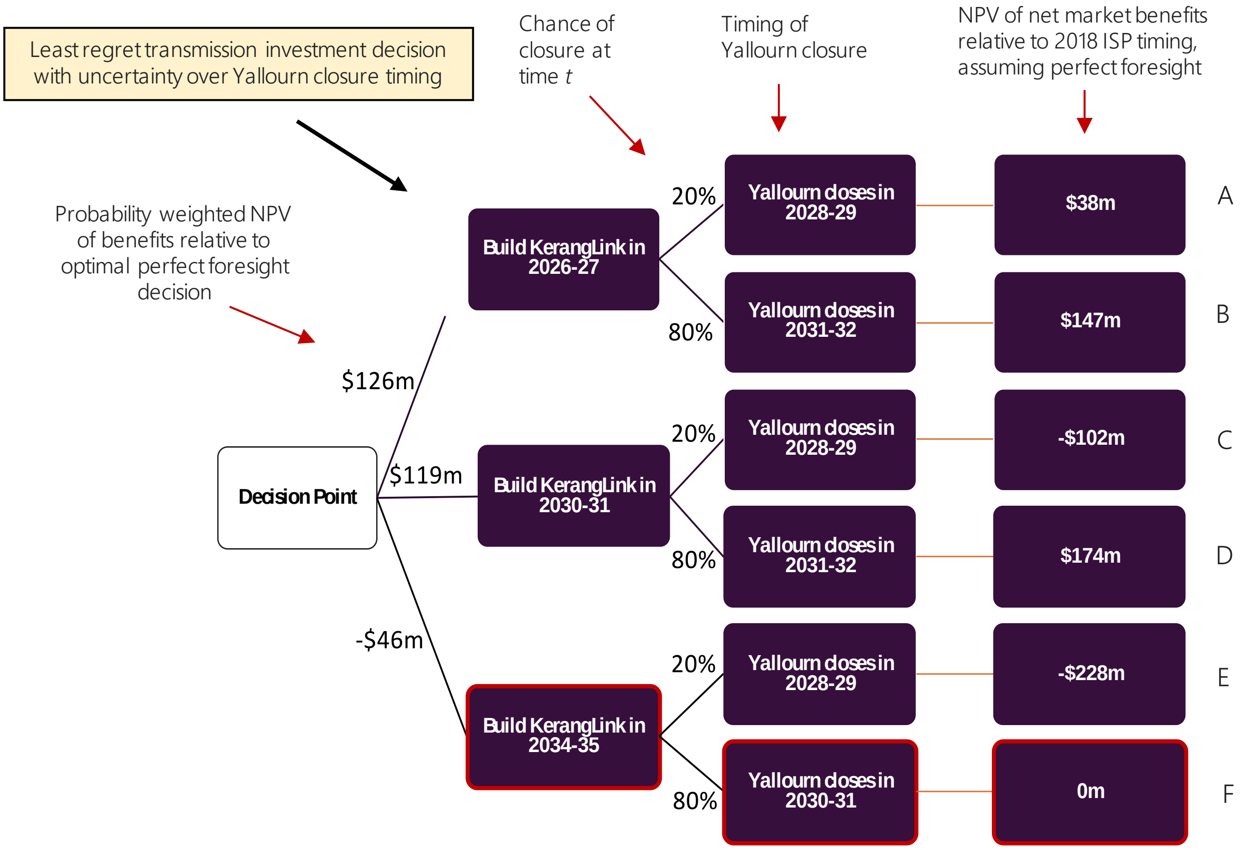
timings to 2034-35 under different hypothetical Yallourn closure timings, compared against effectively not having KerangLink built until beyond the planning horizon (2034-35). It shows that:

- If it was known with certainty that Yallourn would close in 2031-32, the optimal decision would be to build KerangLink in 2030-31, delivering net market benefits of $174 million (to 2034-35): (Branch D - Branch F).
- If, on the other hand, Yallourn was to close early (say in 2028-29), KerangLink having been built in 2026-27 would be the most beneficial of the three decision timings, delivering net market benefits of $266 million: (Branch A - Branch E).
- With uncertainty around the timing of Yallourn's closure, the regret cost of building early (2026-27 in the test case) is not as high as the regret cost of building too late:
  - Building early in anticipation of a possible early closure that did not eventuate would result in $27 million additional net market cost, compared to the optimal timing decision: (Branch B - Branch D).
  - Building in 2030-31 based on optimal timing and then having Yallourn (hypothetically) retire early in 2028-29 would result in $140 million additional net market cost: (Branch C - Branch A).

AEMO carried out a preliminary assessment to determine the value of increasing system resilience by building KerangLink early for different theoretical probabilities of Yallourn closure timing, based on the weighted NPV of market benefits, under the alternate decision points shown in Figure 6.

Given the cost asymmetry explained above, the analysis shows that if the probability of losing Yallourn by 2028-29 exceeds approximately 20%, it would be more beneficial having KerangLink available early, just in case. In this example, building KerangLink in 2026-27 as insurance against early generation closure would be worthwhile, as it would represent the 'least-worst regret' outcome. The exact timing would need to be determined through further analysis, and delivering this level of project acceleration may require acceleration of regulatory, planning, and procurement processes.

**Figure 6 Estimated resilience value of KerangLink if there was a 20% probability of Yallourn closing early**



# Insight 4: Other benefits to consumers

**KerangLink and/or Marinus Link provide additional market benefits to consumers.**

- These new interconnectors will reduce the transmission costs involved in integrating renewable generation, reduce the decline in marginal loss factors (MLFs), and increase overall power system security.

The network investments outlined in this ISP Insights paper will allow the transmission system to better access the benefits of emerging storage initiatives, and increase the resilience of the NEM when supply resources are unpredictably scarce due to:

- Variable weather conditions.
- Hydro droughts.
- Reductions in coal or gas generation or fuel availability.
- Prolonged transmission outages.

The investments will also deliver other market benefits by reducing the rate of decline in MLFs, integrating renewable generation through REZs, and strengthening power system security.

### Marginal loss factors – KerangLink

Transmission expansion will deliver additional benefits through improvements to MLFs, which may decrease risks for renewable investments.

Electrical energy is lost as power flows from a generation source to a load centre, due to resistive heating of transmission equipment (including lines and transformers). These transmission losses are represented as MLFs at each connection point on the network.

For a generator, the MLF reflects the marginal difference between the generator's output and the actual energy that would be delivered to consumers at the regional reference node (RRN).

A number of key factors feed into a generator's MLF:

- If a generator is located in a remote area with very little demand to supply locally, the power generated must travel large distances to feed load centres. This incurs losses, and results in that generator having a low MLF.
- Electrical losses across a transmission line increase with increased loading, so the more congested a transmission pathway is from the generator to load, the higher the losses accrued and the lower the MLF.

In the case of Western Victorian generation, as large amounts of power are being generated in this remote region and transferred long distances over congested transmission lines to feed load in the greater Melbourne area, generator MLFs in this region are some of the lowest in the NEM.

Without transmission investment to reduce network congestion in the area, MLFs are likely to continue to decline in these remote locations, as installed generation continues to grow, and this power must be transferred considerable distances to load centres.

Large changes in MLFs can have material financial implications for existing and intending market participants – as energy losses on the electricity network are factored in to ensure the lowest cost supply of electricity to consumers, generators that have higher losses (lower MLFs) are paid less per megawatt hour (MWh) than generators that have lower losses (higher MLFs).

MLFs provide a strong locational signal to investors. Network developments that strengthen the transmission system between generation centres and load centres will improve MLFs by reducing line losses along major pathways between REZ areas and demand centres. MLFs can be influenced by a wide range of factors, and comprehensive studies should be performed to quantify the benefits of network developments on MLFs, particularly if these network developments are expected to materially change interconnector flow directions and volumes.

AEMO's high-level studies indicate that renewable developers in both Western Victoria and Murray River REZs could benefit significantly from improved MLFs if the Western Victoria, EnergyConnect, and KerangLink network developments progress.

Given the electrical distance between Marinus Link and the critical connection points in the west and north of Victoria, this interconnector is not projected to improve MLFs in these locations as much as the Western Victoria, EnergyConnect, and KerangLink developments.

MLF modelling is complex, and comprehensive analysis is required to further expand on these results.

### Additional benefits – Marinus Link

Although not directly considered in this modelling investigation, Marinus Link will deliver ancillary services from Tasmania that can help improve frequency and voltage control in Victoria, as well as reduce Tasmania's own ancillary service requirements during flow reversals on Basslink[20]. TasNetworks has estimated these benefits at $12 million over 25 years, for the Tasmanian benefits in isolation.

The interconnector may also deliver system restart ancillary services (SRAS) to Tasmania and Victoria, reducing AEMO's requirement to procure these services from other generators. The benefits to consumers associated with reduced SRAS costs have also been estimated by TasNetworks at $42 million[21], based on existing SRAS costs.

Project Marinus is a necessary enabler for new generation in Tasmania, which could lead to investment in new pumped hydro investments under BoTN, or equally open the way for new investments in wind or alternative generation. Importantly, in the NEM as an open access regime, these new investments will compete for the available Tasmanian energy market and available interconnection capacity. For example, new interconnectors between Tasmania and Victoria could lead to greater commercial utilisation of existing synchronous generation in Tasmania, promote additional investment in new pumped hydro generation under BoTN, or promote further private investment in wind and alternative generation.

System strength and inertia are currently critical for secure operation of the Tasmanian network. To date, requirements have been satisfied mostly by synchronous hydroelectric machines operating to provide sufficient power and inertia – dispatched by the market or run in synchronous condenser mode. Provided appropriate choices of technology design are made, pumped hydro investments have the potential to provide essential services that are critical for power system security in Tasmania, such as system strength, inertia, voltage control, and system restart services.

[20] AEMO has not independently verified the modelled benefits by TasNetworks in this assessment.

[21] AEMO has not independently verified the benefits estimated by TasNetworks in the Project Marinus Initial Feasibility Report, February 2019, at https://projectmarinus.tasnetworks.com.au/wp-content/uploads/2019/02/Initial-Feasibility-Report-Project-Marinus-Feb-2019.pdf.

# Next steps

Transmission augmentations require significant planning, community consultation, economic cost-benefit analysis, and regulatory engagement so investments are in the best interest of consumers. Under the current National Electricity Rules, the economic cost-benefit analysis takes the form of the RIT-T.

AEMO is working with the Energy Security Board (ESB), Australian Energy Market Commission (AEMC), and the Australian Energy Regulator (AER) to develop a package of changes to the National Electricity Rules to convert the ISP into an actionable strategic plan. A key objective of this work program is to enable projects identified in the ISP to undergo a streamlined RIT-T and regulatory approval process that builds on the detailed cost benefit analysis undertaken as part of the ISP.

At this time, TransGrid has commenced the RIT-T for transmission infrastructure associated with Snowy 2.0 (Humelink), TasNetworks has commenced a RIT-T for Marinus Link, and AEMO has commenced preparatory work for a RIT-T for KerangLink, including technical studies.

Going forward, AEMO proposes the following next steps:

- TransGrid and TasNetworks should expeditiously progress their RIT-Ts in collaboration with AEMO via the joint planning process, building on ISP analysis as far as possible.
- AEMO will continue preparatory work for KerangLink, with a view to commencing a RIT-T in the near future.
- HumeLink, Marinus Link, KerangLink, and all future transmission projects identified via the ISP should be subject to an expedited post RIT-T regulatory approvals process in accordance with the ESB's Rule change package.
- Transmission Network Service Providers should immediately commence 'no regrets' actions in terms of early works and activities to support route selection.
- Opportunities to accelerate environmental and planning approvals should be explored.

The analysis also reinforces the need for a planning environment that is capable of incentivising investment in a portfolio of generation resources, storage, DER, demand response, and transmission in a timely manner. In addition to measures to accelerate regulatory approvals, AEMO considers that:

- Government and industry must actively work together to manage an orderly exit of existing resources at end of life without disruption to reliability, and at lowest cost to consumers.
- Gas and electricity sector coupling in planning and decision-making should be enhanced to better understand the whole-of-system costs to consumers.
- A study to better understand the risks of deterioration in generator reliability towards end of technical life is warranted.
- A risk framework that clearly articulates the need for consideration of resilience and 'least-worst regret' outcomes as part of best practice transmission planning should be developed.

# A1. Appendix: Modelling improvements

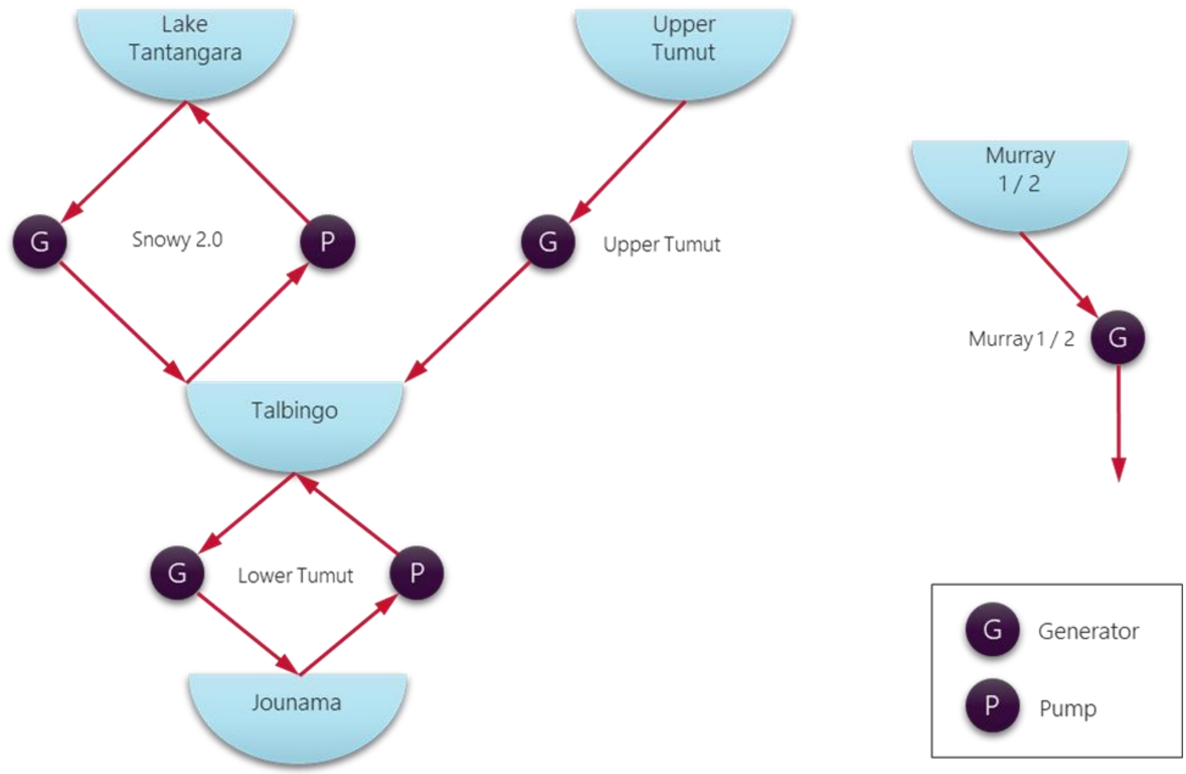
Capacity outlook modelling until the 2018 ISP used a simplistic representation of hydro assets, based on yearly energy constraints reflecting an average water year. This simplified approach does not well capture pumping operations or the impact of new developments on existing hydro operation, and does not capture the flexibility of different hydro assets to operate across seasons with respect to weather variability.

AEMO has liaised with stakeholders to enhance the representation of key existing and proposed hydro schemes and improve the modelling representation to better capture these dynamics. This collaboration has allowed AEMO to incorporate a more realistic representation of the Snowy Hydro and Hydro Tasmania schemes, addressing previous limitations by explicitly and discretely modelling inflows, reservoir sizes, pumping and generation efficiency, and cascading water flows from pond to pond.

## A1.1 Snowy Hydro and Snowy 2.0

Since the 2018 ISP, AEMO has improved the modelling detail associated with the Snowy Hydro scheme and proposed Snowy 2.0 project, including updated rainfall inputs as well as a revised generation and pond storage topology. Figure 7 presents a representation of the refined topology modelled.

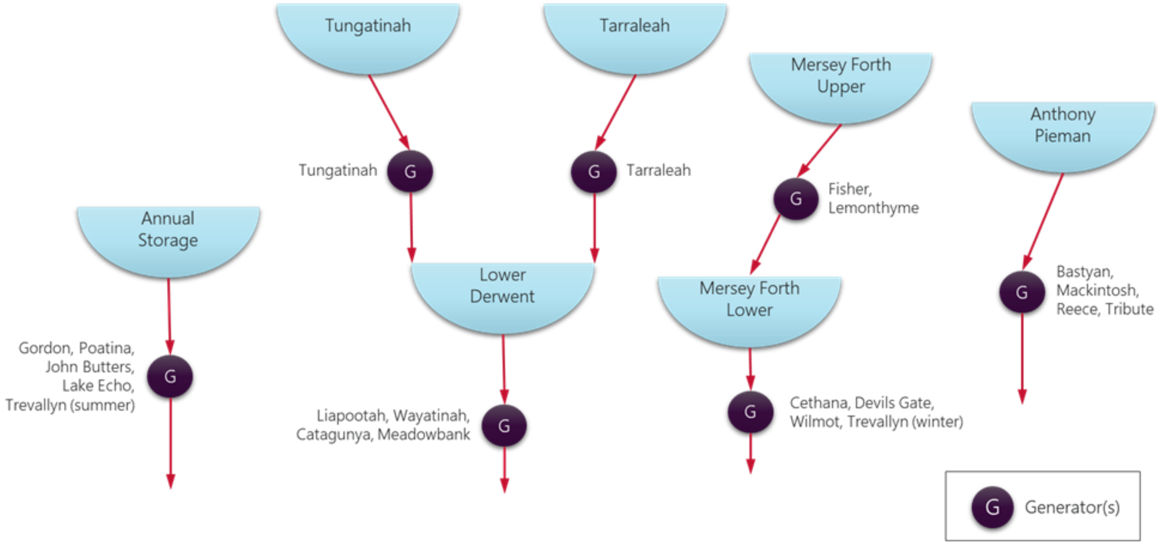
**Figure 7 Snowy Hydro scheme topology in ISP Insights modelling**



## A1.2 Hydro Tasmania and BoTN

AEMO's approach to modelling the existing Tasmanian hydro schemes has improved and now uses a more detailed topology designed to better capture different levels of flexibility associated with long- and short-term storages and 'run of river' generators. Figure 8 shows this revised topology.

**Figure 8 Hydro Tasmania scheme topology in ISP Insights modelling**




The approach to modelling the BoTN project has also improved since the 2018 ISP. Improvements to the mathematical optimisation of capacity outlook models now allow the model to identify the optimal timing and size of the project more accurately. This improvement reduces the need for detailed iterative modelling to verify the market value of BoTN.

ISP Insights modelling has also catered for a number of brownfield upgrades that are likely to materialise with the commitment of the Marinus Link interconnector, resulting in approximately 340 MW of additional hydro capacity[22]. The data improvements extend to capturing small and non-scheduled generators more effectively.

## A1.3 PHES diversity

The 2018 ISP considered a limited number of storage candidates representing either six-hour pumped hydro or two-hour large-scale batteries. The ISP Insights modelling better captures PHES diversity by modelling four storage depths (six-, 12-, 24-, and 48-hour) in addition to Snowy 2.0 and BoTN. Assumptions for new large-scale batteries have remained unchanged, at a two-hour duration.

PHES costs and available capacity are highly uncertain and site-specific. AEMO has collaborated with industry stakeholders, hydro operators, hydro consultants, and the CSIRO to improve the implementation and operational considerations for these inputs, particularly regional variations and sizing. Inputs used in ISP Insights modelling are consistent with those published in the 2019 Planning and Forecasting Consultation[23].

[22] Hydro Tasmania, at https://www.hydro.com.au/docs/default-source/clean-energy/battery-of-the-nation/unlocking-tasmania's-energy-capacity_december-2018.pdf?sfvrsn=8d159828_6.

[23] AEMO, 2019 Inputs and Assumptions workbook, at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/Inputs-Assumptions-Methodologies/2019/2019-Input-and-Assumptions-workbook.xlsx.

## A1.4 Weather variability and climate change

To manage the mathematical complexity of long-term optimisation problems, the 2018 ISP capacity outlook model focused on forecasting the optimal generation and transmission mix with due consideration of demand and renewable generation from the historical data of a single year. Weather variability was captured then in time-sequential modelling to validate the development plans.

The capacity outlook model has been improved in this ISP Insights modelling to capture weather diversity. The model now utilises eight historical weather years known as 'reference years'. These reference years capture the variability of available renewable generation, water inflows affecting hydro availability, and demand profiles.

The updated modelling therefore captures a broader range of weather patterns affecting demand shape and timing of peaks, hydro inflows, and the wind and solar resources affecting both large- and small-scale generators (including rooftop PV systems). The modelling inherently captures the risks of renewable energy 'droughts' which occasionally are observed, representing extended periods of very low output from renewable generators in a given area, sub-region, or region. The availability of renewable energy (including hydro) is important given the degree of penetration of renewable energy forecast over the medium term in the 2018 ISP, and the model improvements allow greater capture of the value of energy storage and transmission developments to support technological and geographical generation diversity.

For hydro generation, this approach captures the impact of wet and dry years (which exhibit higher or lower rainfall than typical averages). The availability of traditional hydro generation may be a critical consideration, given the role of large hydro schemes such as Snowy and Hydro Tasmania in the current market in providing energy flexibility, and in identifying the value of major transmission investments between Tasmania and Victoria and between Melbourne and Sydney via Snowy.

Demand and renewable profiles and hydro inflows based on the past eight reference years have been combined to produce a time series that would capture a broader variety of weather patterns throughout the planning horizon. To appreciate the effect of climate change and its potential impact on long-term hydro yield, AEMO has also modelled an additional water year representative of a severe water drought.

Within the capacity outlook model, reference years are matched to the planning years by rolling through and repeating each of the input reference years. This approach results in a repeating sequence of reference years across the study period, as Figure 9 shows.

**Figure 9 Rolling reference years in ISP Insights capacity expansion modelling**