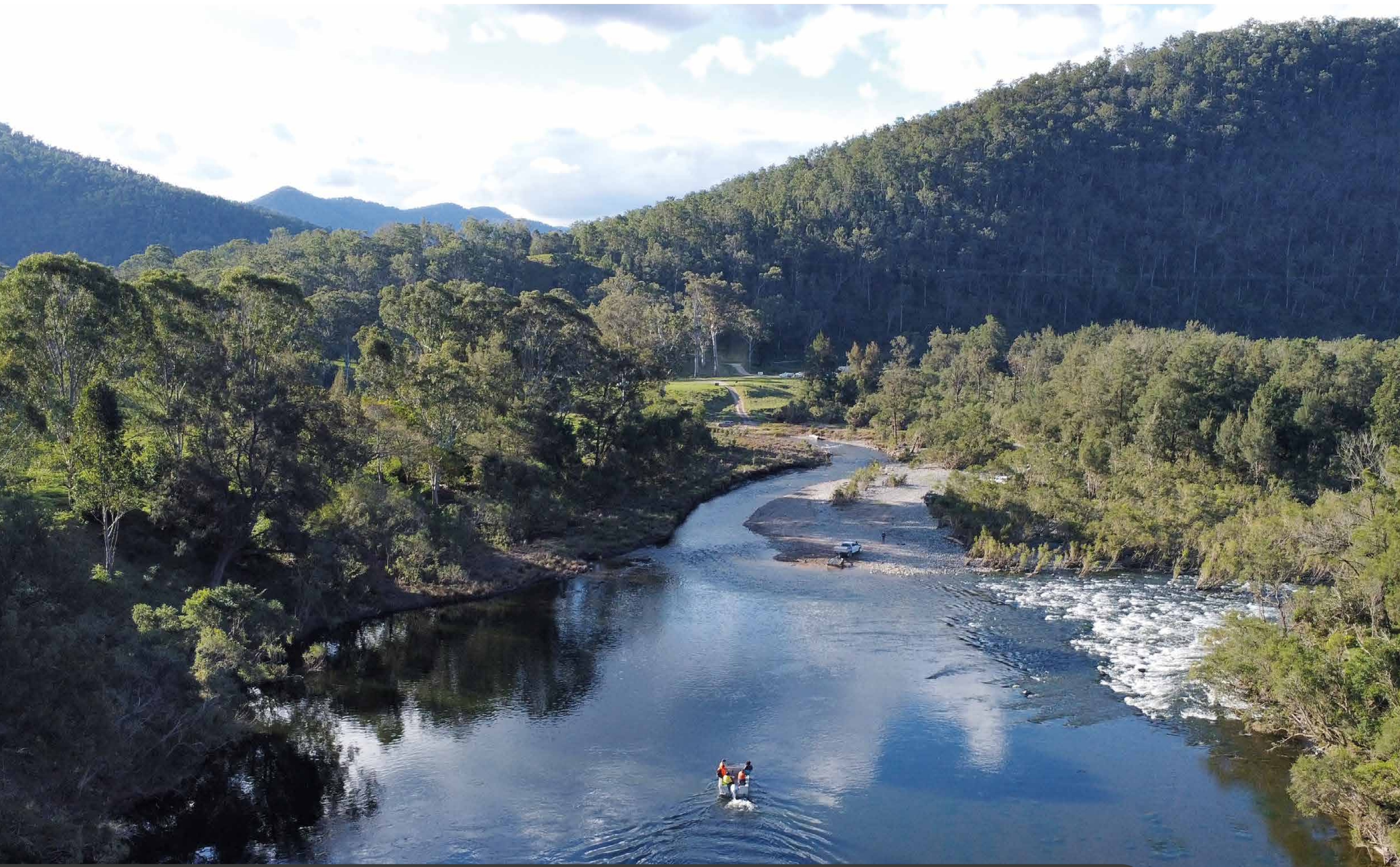
OVEN MOUNTAIN
PUMPED HYDRO STORAGE



Oven Mountain Pumped Hydro Energy Storage

January 2023

FINAL REPORT

Pumped Hydro Energy Storage:

Renewable energy zone and network benefits assessment report

by Dr Jeremy Moon

ACKNOWLEDGMENT OF COUNTRY

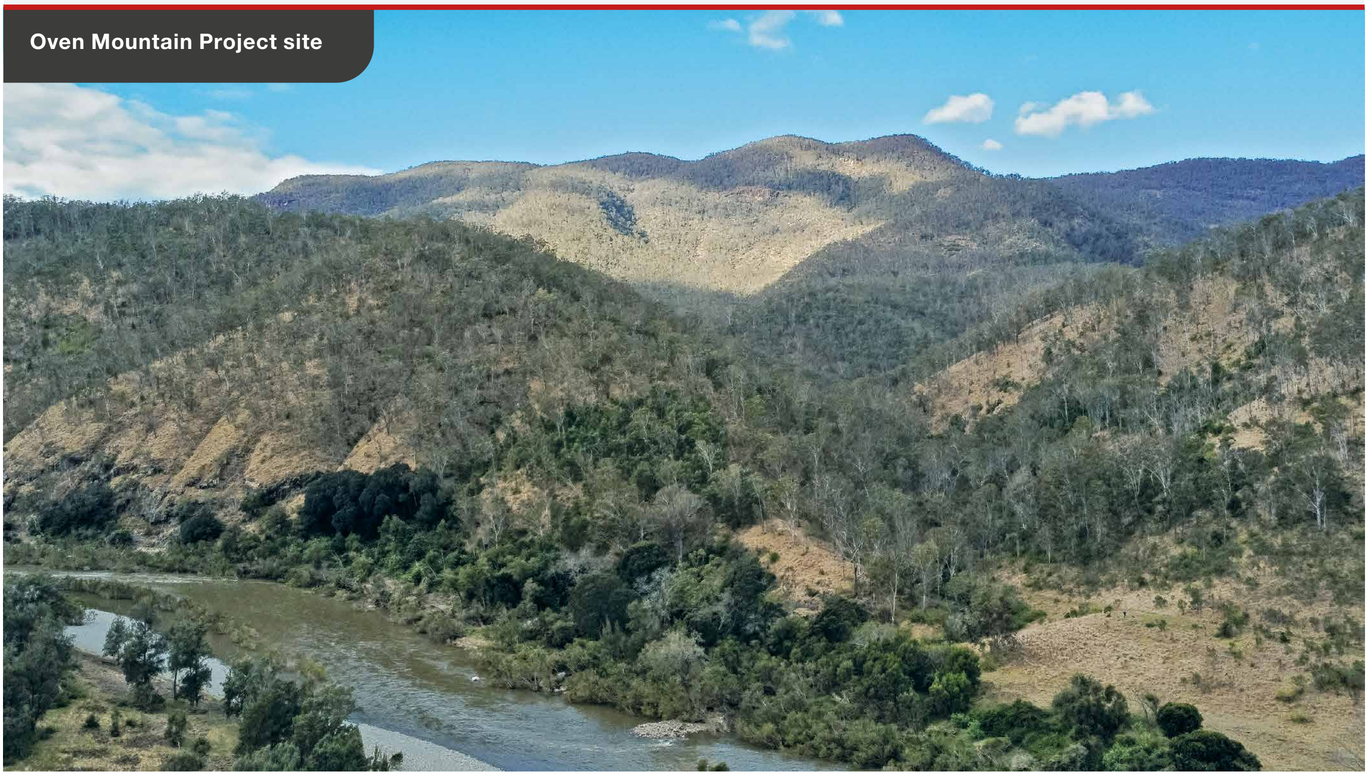
The Oven Mountain Project acknowledges the Thunggutti people, Traditional Custodians of the land on which we operate, and pay our respects to their Elders past and present.

We also extend that respect to Aboriginal and Torres Strait Islander peoples across this nation.

Thunggutti Village, Bellbrook

ACKNOWLEDGMENT AND DISCLAIMER

The Oven Mountain Pumped Hydro Energy Storage project received funding from the Australian Renewable Energy Agency (ARENA) as part of ARENA's Advancing Renewables Program.



Oven Mountain Project site

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1 FOREWARD

Energy continues to be at the forefront of government, industry, and kitchen table discussions across Australia. Whether it is the retirement of thermal powered stations, the increasing prevalence of variable renewable energy sources, or the day-to-day cost of electricity – communities and businesses alike are keenly aware of the importance of a modernised energy system that provides reliable, affordable, and clean electricity.

The changing energy landscape – termed a 'once-in-a-generation' transformation – is replete with challenges and opportunities that remain ambitious, complex, and necessary. The '*NSW Electricity Infrastructure Roadmap*' and the '*2022 Integrated System Plan*' emphasise the ongoing importance of coordinated efforts, forward-thinking planning and reform, and continued investment in transmission augmentation, variable renewable energy capacity, and energy storage capabilities.

The '*2022 Integrated System Plan*' notes that by 2050 there will be a need for "over 60 GW of firming capacity to be in place to respond to a dispatch signal…While the system today has approximately 43 GW of firming capacity, 23 GW of this is coal-fired generation. As this coal-fired generation retires, it needs to be replaced with new low-emission firming alternatives. New utility-scale battery and pumped hydro storage, located at appropriate parts of the network, will enable more effective dispatch of clean electricity on demand, increase resilience by shifting energy through time to manage weather variations, and provide critical system security services" (AEMO, 2022, p.51).

The Oven Mountain Pumped Hydro Energy Storage Project is an "off river" development located adjacent to the Macleay River between Armidale and Kempsey. Situated within the New England Renewable Energy Zone (REZ), the Project will provide clean energy generation and storage capabilities, ensuring a reliable, resilient, and renewable future energy supply for NSW and the broader National Electricity Market (NEM).

The Oven Mountain Project is currently undergoing the NSW government's environment and planning approval process. We anticipate that the Project's Environmental Impact Statement will be submitted to the Department of Planning and Environment in early 2023 for formal review and exhibition. Pending approval, construction is anticipated to commence in 2024 and last approximately four years.

Our team is pleased to have received support from the Australian Renewable Energy Agency's (ARENA) Advancing Renewables Program and continue to undertake a study analysing the benefits of a 600 to 900 MW off-river Pumped Hydro Energy Storage (PHES) facility in the New England REZ, with up to 12 hours storage.

We continue to recognise the importance of knowledge sharing activities and this final report aims to share the key findings of the study. It builds on the information and findings highlighted in the '*OMPS New England PHES Benefits Study – Knowledge Sharing Interim Report*' (April 2022). Specifically, this report examines the projected benefits the Project will bring to the New England REZ, broader electricity network, as well as to consumers in the electricity market.

Delivering major infrastructure projects is complex and involves change. We need to meet both the technical and physical requirements, as well as the community obligations associated with garnering social licence. This will mean continuing our conversations with landowners, community groups, industry partners, government stakeholders, and importantly, First Nation people, communities, and businesses.

Pumped hydro energy storage remains an integral and tested part in our journey towards a clean energy future. We look forward to sharing our work and many conversations in the years ahead.

Dr Jeremy Moon

Project Director
OMPS

2 EXECUTIVE SUMMARY

The Oven Mountain Pumped Hydro Energy Storage Project (or the Project) uses mature and tested technology to provide long-duration storage and flexible dispatchable renewable generation.

The Project has received support from the Australian Renewable Energy Agency's (ARENA) Advancing Renewables Program to undertake a study analysing the benefits of a PHES facility on the development of the New England REZ in northern NSW.

Specifically, the Project endeavoured to:

- Investigate the impact of the proposed Project on system strength and inertia
- Quantify the potential market benefit investigations of the Project, such as:
  a) impact on wholesale market and retail electricity prices, dispatch costs and emissions
  b) benefits to wind and solar projects in the New England REZ, including on their Marginal Loss Factors (MLFs) and energy curtailments.

2.1 OUTCOMES FROM GRID STRENGTH AND INERTIA INVESTIGATIONS

A key feature of the thermal generation being retired is their synchronous connection with the grid; that is, the rotation of synchronous generators is directly coupled to the grid. Accordingly, when disruption occurs on the grid - for example a big load trips off the system – the rotating mass of the synchronous generator acts against the grid deviating away from safe levels, essentially providing resilience to the grid. This concept falls under the category of grid system strength.

Modern inverter-based generators like wind energy, solar and even batteries break with that direct relationship by using power electronics. This is understandable as the rotation of wind turbines depends on available wind speed, while solar has no rotating components and neither do batteries. In breaking the synchronous relationship, the resilience levels of the grid are diminished.

Amplitude Consultants have undertaken an assessment of the benefits of PHES' grid strength contribution to both the current network and a future 2030 network using AEMO's projections captured in its '2022 Integrated System Plan'.

Analysing the current network configuration is important as there are several limitations on the grid preventing the deployment of new generation – particularly renewable energy. The limitations due to grid strength are complicated and require sophisticated modelling to be understood. When grids reach their limit on grid strength related issues, the network becomes unstable and uncontrollable – which is clearly a state to avoid from an operator perspective. The limitations in and around the current New England REZ are dominated by these grid stability limits.

In the Intermediate Stage Report, Amplitude showed that the presence of PHES within the current network was able to substantially improve the grid strength of the region and allow significantly more generation to be deployed in the REZ than when the PHES was not present. The amount of generation able to be deployed varied depending on the amount of load on network as well as the levels of wind and solar generation. Under the best conditions, PHES was able to support approximately 1.6GW of additional renewable generation while keeping the network stable. This is attributable to the key feature of PHES having synchronous machines connected to the network.

In the analysis undertaken for the Final Report, Amplitude demonstrated:

- The Project increases the available fault levels (up to 2,350 MVA) which is incredibly important to maintain clear voltage waveform signals, allowing network protection equipment to operate properly, and support voltage during faults to limit tripping of other generation as well as providing stability during the critical period after a fault has been cleared.
- A shortfall of fault current was identified in South Australia, limiting the use of more renewable energy. Four synchronous condensers were developed to resolve the issue, at a cost of $180m in 2019. The Project contributes fault current consistent with over four of these synchronous condensers.
- The Project contributes significant inertia (rotating mass electro-mechanically coupled to the grid) of up to 3,150 MWs (megawatt-second) which is consistent with three of the South Australian synchronous condensers.

These grid strength contributions are provided while the Project is operating as a storage device: in pumping, generating and synchronous condenser modes.

2.2 OUTCOMES FROM MARKET BENEFIT INVESTIGATIONS

AEMO operates the National Electricity Market by matching electricity need with generation. In the physical market, AEMO dispatches generation based on an approach which balances grid security and lowest supplied energy costs. This process is undertaken on a 5-minute basis, 24 hours a day, 7 days a week.

EY have developed software that mirrors AEMO's dispatch approach which allows testing of scenarios from a market perspective. Using this software, a future grid based on AEMO's '*2022 Integrated Services Plan*' and supplemented by the NSW Government's '*Electricity Infrastructure Roadmap*' was developed in the software model. This future grid considered the period of 2030/31, and a model of the NEM was developed to take into account retired generators, where and how much new generation was installed, new installed transmission, future electricity demand, and future fuel costs (referred to as the 'Base Scenario').

The market benefits study conducted by EY on the Base Scenario shows that in 2030-31 the Project:

- Reduces demand-weighted wholesale electricity prices by $7-9/MWh in NSW and $4-5/MWh in the other mainland NEM regions. This amounts to approximately a $1 billion reduction in total mainland customer retail bills.
- Generates $50-70 million savings in fuel costs NEM-wide.
- Results in 400,000 tonnes $CO_{2\text{-}e}$ reduction in generation emissions.

The study also showed that the Project, operating at a capacity of 900 MW, is forecast to have larger benefits compared to the alternatives assessed:

- Compared to the 600 MW Project, the 900 MW Project has a larger benefit to customer retail bills, all market benefits assessed and on reducing the forecast energy curtailment for wind and solar PV projects.

The EY report also examined an option where the New England REZ transmission augmentation was delayed until after 2030-31 (referred to as the 'Insurance case study'). In this instance, the report notes that the market would experience a transmission bottleneck between New England and the rest of NSW.

In the Insurance case study, the 900 MW project:

- Reduces demand-weighted wholesale electricity prices by $6/MWh in NSW and $12/MWh in Queensland. This amounts to approximately a $1.3 billion reduction in total mainland customer retail bills.
- Saves $60 million in fuel costs NEM-wide.
- Saves 540,000 tonnes $CO_{2\text{-}e}$ in generation emissions.
- Reduces curtailment of New England wind generation from 32% to 29% of available energy, and from 33% to 27% for solar PV generation. In total the Project is forecast to allow approximately 680 GWh of additional renewable generation to be dispatched in New England.
- Assuming a conservative PPA price of $45/MWh, this reduction in curtailment results in approximately $30 million of additional revenue for NE REZ wind and solar generators.
- Supports a 0.01 increase to solar MLFs in the NE REZ, with a further direct benefit to the market revenues for these solar projects. Solar projects benefit due to the Project pumping tending to be during the day, which is the same time as solar generation. The dispatchable load added to New England reduces network loading and hence reduces transmission losses between New England and the greater Sydney area load centre.
- Results in a neutral change to wind generator MLFs in the NE REZ. Although the prevailing MLF is higher in the daytime providing a benefit to solar generators, the prevailing MLF is relatively lower when the Project is generating over the evening resulting in a neutral impact to wind generator MLFs.

3 INTRODUCTION

3.1 THE ROLE OF PUMPED HYDRO ENERGY STORAGE

In July 2019, AEMO released an insights paper titled, '*Building power system resilience with pumped hydro energy storage*'. Coming just after the release of the '*2018 Integrated System Plan*', the paper explored key questions (AEMO, 2019, p.3);

- what role does pumped hydro energy storage (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.

The paper found that the National Electricity Market (NEM) needed a range of projects that provided varying energy storage durations to efficiently distribute renewable energy to ensure network resilience and flexible generation. The paper also highlighted the need to develop new transmission lines to strengthen the NEM backbone and importantly, to access the benefits delivered by PHES projects.

Since then, Australia has continued to see a major transformation in the way it perceives and uses energy. These changes have been marked by prevailing government initiatives (e.g., Net Zero), industry investment in variable renewable energy sources, and the ongoing and planned retirement of coal powered fire stations. The '*2022 Integrated System Plan*' notes the need for investment to "treble the firming capacity provided by new low-emission firming alternatives that can respond to a dispatch signal, with efficient network investment to access it" (AEMO, 2022, p.10).

"Technical innovation, ageing generation plants, economics, government policies, energy security and consumer choice are all driving this transformation and driving it faster than many anticipated. Some of them form part of the global push for net zero emissions by 2050, while others are independent. All the while, the NEM must continue to meet its objective – to provide reliable, secure, and affordable electricity to consumers."

2022 Integrated System Plan (AEMO, 2022, p.7).

3.2 THE NEW ENGLAND RENEWABLE ENERGY ZONE

In December 2021, the NSW Government formally declared a Renewable Energy Zone (REZ) in the New England region. This REZ will deliver new network capacity to host up to 8 gigawatts of new generation.

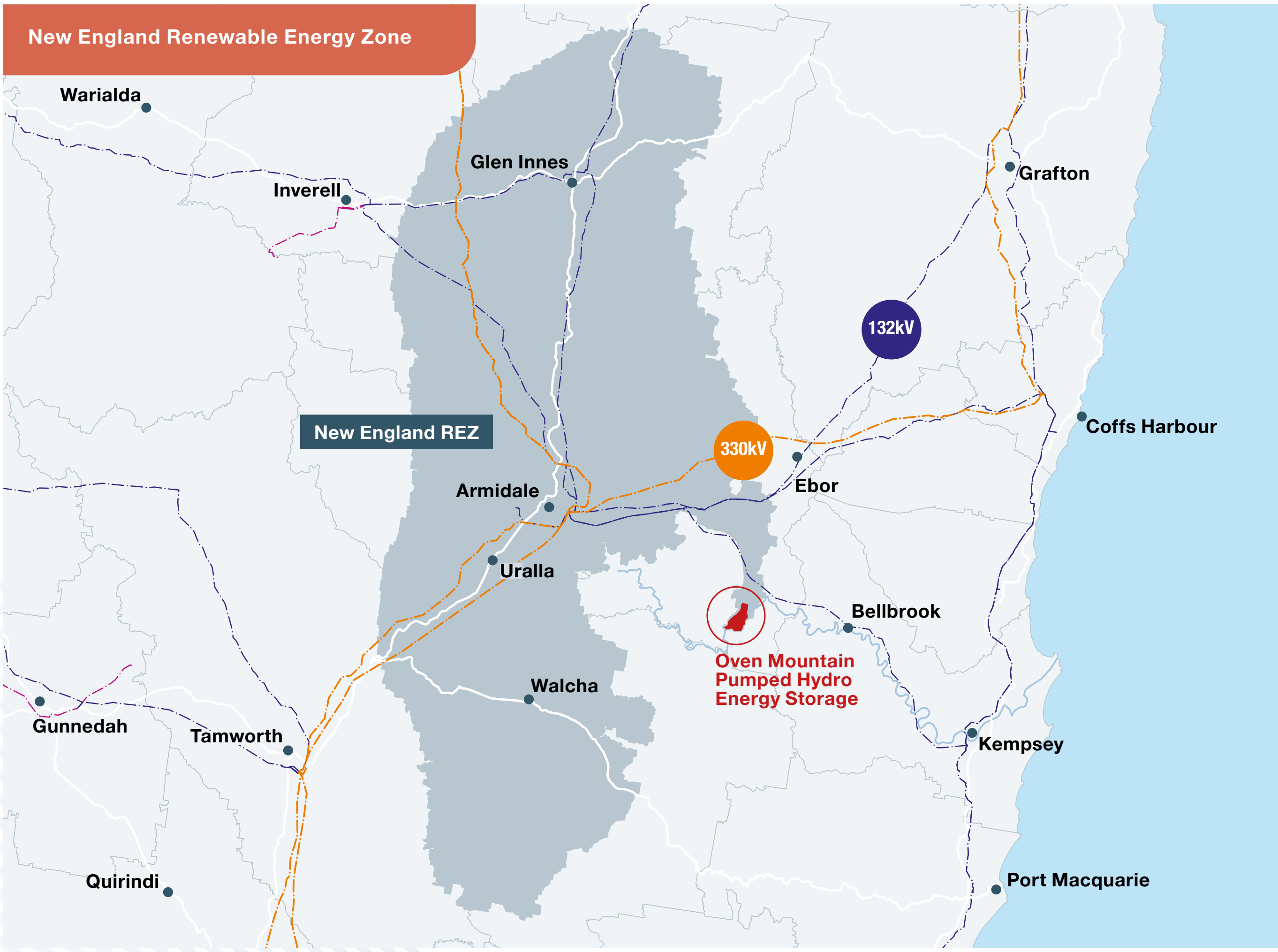
A REZ can be considered as a modern-day power station. They combine renewable energy generation such as wind and solar, storage such as pumped hydro energy storage, and high-voltage poles and wires to deliver energy to the homes, businesses and industries that need it, when they need it.

The NSW Government expects that REZs will deliver multiple benefits to NSW, including more reliable energy from significant amounts of new energy supply; energy bill savings from reduced wholesale electricity costs; emissions reduction from a cleaner energy sector; and community partnership.

The development of the New England REZ is being coordinated by the NSW Energy Corporation (EnergyCo) and includes extensive consultation with the community, government, and industry stakeholders.

Modelling undertaken as part of the '*2022 Integrated System Plan*' suggests that the New England has the potential to become one of the largest REZs in the National Electricity Market. It anticipated that the REZ – along with the delivery of necessary transmission augmentation - will unlock "approximately 6,000 MW of variable renewable energy and storage capacity in the New England REZ, helping meet the objectives of the *New South Wales Electricity Infrastructure Roadmap*" (AEMO, 2022, p.77).

The inclusion of the Oven Mountain Project within the New England REZ recognises the abundance of natural energy sources in the New England region – including the potential for pumped-hydro development – and the need for long-duration storage (of over 8 hours) and network resilience to meet current and future energy requirements.



CASE STUDY – OMPS AND NE REZ – PROVIDING POWER TO THE GRID

The Oven Mountain Project will play an integral part in the NSW Government's New England REZ. In December 2021, the Project team completed initial engagement activities with the broader New England region.

As part of our activities, we visited landowners residing near the existing Armidale-Kempsey 965 transmission Line from Jeogla to the outskirts of Armidale (approximately 50kms). The aim of our engagement was to introduce the Oven Mountain Project, offer residents a ready point of contact, and begin early discussions on renewable energy initiatives in the region.

Good engagement recognises that major infrastructure projects do not exist in isolation. Our early conversations with the New England community served to place our Project scope and energy capacity requirements in the context of broader programs planned by the NSW Government.

The Oven Mountain team met with students from Chandler Public School, situated outside of Armidale, to talk all things renewable energy and pumped hydro energy storage.

3.3 PROJECT OVERVIEW

The Oven Mountain Pumped Hydro Energy Storage Project is an off-river development located adjacent to the Macleay River between Armidale and Kempsey.

Situated within the New England REZ, the Project will provide clean energy generation and storage capabilities, ensuring a reliable, resilient, and renewable future energy supply for NSW.

The Project will be constructed on private land. Being an off-river scheme means that once filled, the Project will have little additional need for water over its operational life. Water from the Macleay River will be used for the initial fill and will be drawn under high river flow conditions.

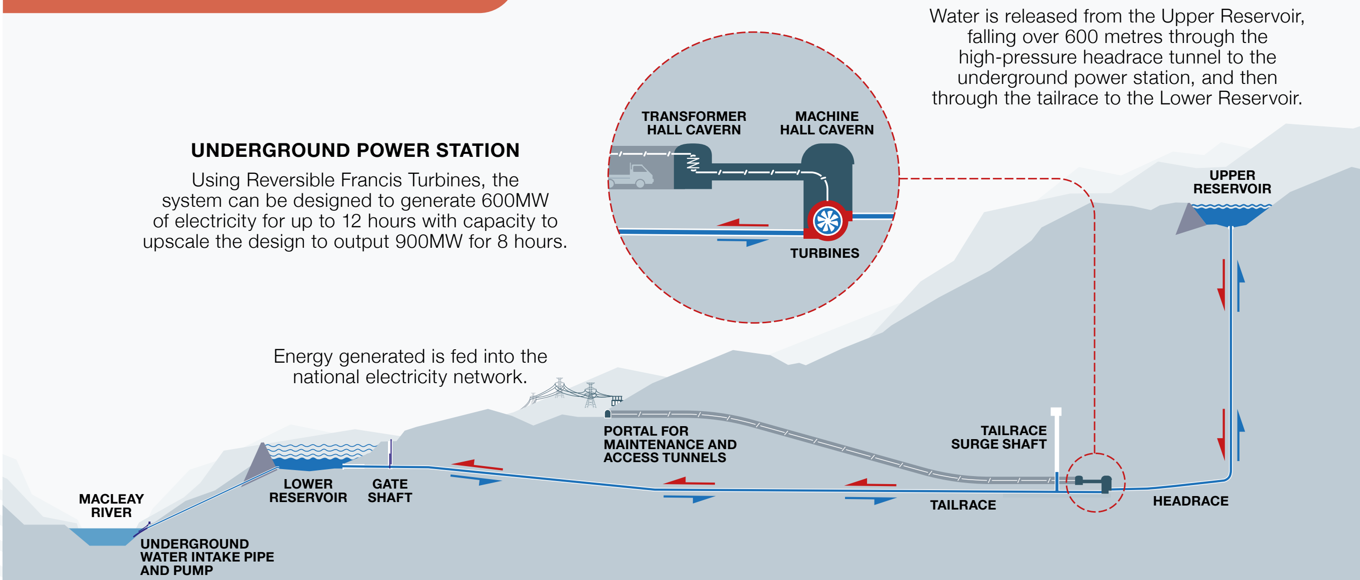
The Project has been declared by the NSW Government to be Critical State Significant Infrastructure (CSSI) under the *NSW Environmental Planning and Assessment Act 1979 (EP&A Act)*. Infrastructure projects are declared to be CSSI if, in the opinion of the NSW Minister for Planning, they are essential to NSW for economic, environmental, or social reasons.

The Project will include the construction of upper and lower water reservoirs; waterways, access tunnels; and a hydro-electric power station; and new electricity transmission network from the generation site to the Lower Creek area. It will also include upgrades to existing local and regional roads, allowing for safe construction and operation access.

The Project will provide much needed long-duration storage and offer greater reliability to the National Electricity Market. The scheme will be designed to provide up to 900 MW of electricity generation.

An indicative design of the proposed scheme is provided in Figure 1. A map of the proposed Project footprint is included in Figure 2.

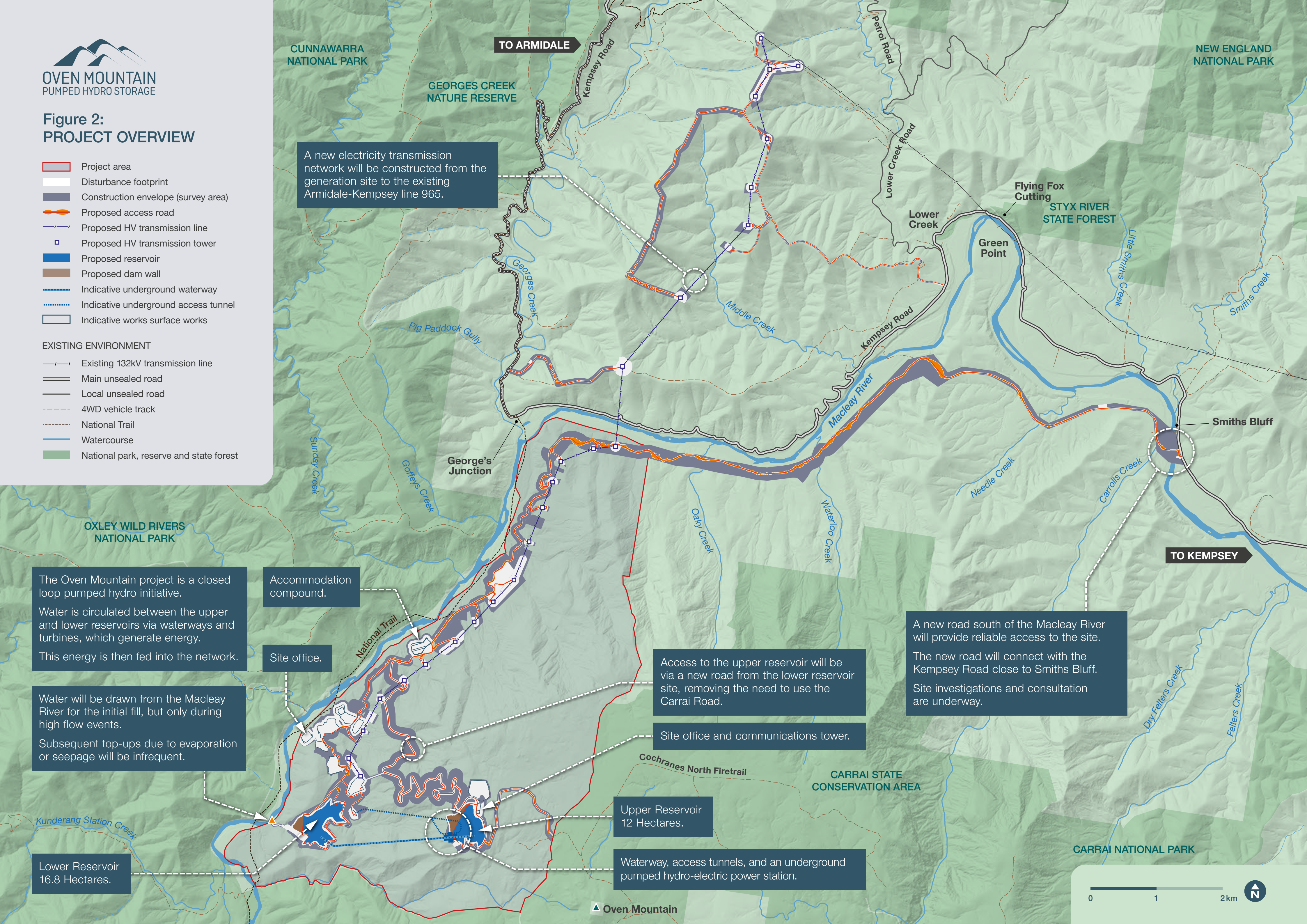
Figure 1: Proposed underground works



CAPACITY	600MW	900MW
Hours of storage (hours)	12	8
Reservoir storage capacity (MWH)	7,200	

OVEN MOUNTAIN
PUMPED HYDRO STORAGE

Figure 2: PROJECT OVERVIEW



3.4 PROJECT TIMELINE

The full EIS will be formally exhibited by DPE for community feedback. OMPS will hold information sessions and create a summary document to support the exhibition. OMPS will be required to respond to all feedback lodged with DPE.

Environmental Impact Statement (EIS) Timeline	
Critical State Significant Infrastructure Designation	September 2020
Scoping Report	January 2021
Secretary's Environmental Assessment Requirements (SEARs) issued	February 2021
Scoping Report Addendum	April 2022
SEARS Amended	June 2022
EIS site and field investigations	2021-2022
WE ARE HERE — EIS Submission to Department of Planning and Environment (DPE)	Q1 2023
Formal exhibition of the EIS by DPE (locations to be advised)	TBC
EIS Response to Submission	TBC
Ministerial Determination	TBC
Construction commencement	**Target mid-2024**
Commercial operations	**Target 2028-29**

COMMUNITY CONSULTATION

3.5 PROJECT OBJECTIVES AND STAGES

The Oven Mountain Project has received funding from ARENA as part of their Advancing Renewables Program.

The funding supports investigations on the benefits of the Oven Mountain Project and Pumped Hydro Energy Storage (PHES) to the National Electricity Market.

The study has the following objectives:

- Gain an understanding of how and to what extent PHES can support REZs, including quantifying the level of variable renewable energy that could be unlocked with the presence of the Oven Mountain project.
- Gain an understanding of PHES's capacity to provide inter-regional support.
- Examine the relative merits of PHES in providing various system services.
- Gain an understanding of PHES's potential to provide Marginal Loss Factor (MLF) support.

As part of these investigations, the Project has been broken into the following three stages:

STAGE 1: INPUTS BASELINING AND TECHNOLOGY FINALISATION

This section sets about acquiring the data and models required to undertake the modelling work, validating the models and data, consulting with Transgrid and AEMO regarding network constraints and objectives, consulting with original equipment manufacturers regarding their technologies, and settling upon final scenarios for modelling.

STAGE 2: REZ, NETWORK AND VARIABLE RENEWABLE ENERGY IMPACTS

Through the approach of a connecting generator, this section quantified the impacts of the Oven Mountain Project on the New England REZ, addressing topics including the additionality of new renewable generation to the region, impacts on networks, and impacts on constraints.

The resulting report - '*OMPS New England PHES Benefits Study – Knowledge Sharing Interim Report*' – is available from the Oven Mountain Project website. www.ompshydro.com/news

STAGE 3: FINAL REPORTING

Building on the two previous stages, this final report incorporates market modelling of scenarios to review the impact of the Oven Mountain Project within the New England REZ including elements such as curtailments and loss factors.

4 KEY CONCEPTS

Constraints and Limits are often used interchangeably but do have separate but related meanings.

A constraint (e.g. thermal or stability) will include the physics about that constraint. For example, the stability constraint limiting QNI northward transfer is dominated by network stability after a fault at Bulli Ck. In this way, there is enough information to understand what is constraining the network.

A limit is the book-end on network operation to ensure a constraint doesn't occur. For example, it may be an operational MW transfer limit on QNI to ensure that the network remains stable should fault occur at Bulli Ck.

4.1 NETWORK: CONSTRAINTS AND LIMITS

AEMO operates the NEM, coordinating over 500 participants in the market every five minutes. It achieves this by using a platform that optimises the cost of energy offered by the available generators with constraint equations -a mathematical representation of network limitations and frequency control requirements - to match the expected demand for energy.

Understanding network constraints therefore is very important and can impact the overall cost of energy. Constraints can be divided into two broad families: thermal and stability.

Thermal limits capture the bounds on a network element's ability to transfer power due to their design ratings (e.g., power flow in a transmission line may cause the line to heat and sag to an unsafe state).

Stability limits capture the extent of stable operation arising from the dynamic interaction between all NEM elements. This might be for example the behaviour of a single generator on the network after a loss of a transmission line or the complex interaction between numerous generators, loads and network infrastructure after the loss of a large generator.

CURRENT NETWORK

The complex nature of network stability and its interaction with all elements of the national electricity system makes modelling of future networks complicated and limits the applicability of modelled results. The current limitations on the New England REZ are stability based, well studied, and understood. Further, lessons learned from assessing current network stability limitations are transferrable to future stability limits if they arise.

The current network configuration was therefore used to assess the impact of PHES on a constrained network, and to examine PHES as a supporter of network resilience.

In the Interim Report, an examination of known stability limits that relate to the Queensland-New South Wales Interconnector (QNI) was undertaken. QNI was selected as the basis for the study as its limits are well documented, it is electrically very close to the New England Renewable Energy Zone (REZ), and QNI's limits set the limits on the lines passing through the New England REZ. This work was undertaken with consultation of Transgrid, Powerlink and AEMO. The stability constraints events known to impact the Queensland-New South Wales Interconnector (QNI) are provided in Amplitude's accompanying report (see Appendix A).

FUTURE NETWORK

PHES initiatives are complex to deliver. The '*NSW Electricity Infrastructure Roadmap*' notes that "pumped hydro projects can make a substantial contribution to NSW's future electricity storage needs, but they require bespoke design, face long lead times and are capital intensive, which creates a high barrier to their development" (p.30).

To appreciate the impact of PHES on a future network, the '*2022 Integrated System Plan*' was used as the information source for when the '*NSW Electricity Infrastructure Roadmap*' objectives are achieved in 2030/31. This also mirrors when the Oven Mountain Project is anticipated to be operational within the New England REZ.

4.2 SYSTEM STRENGTH AND INERTIA

System strength is best described as the ability of the network to maintain and control the voltage waveform at any location in the system during steady state operation and following a contingency. Higher system strength means that the network is less likely to be adversely impacted by a contingency on the network.

System strength is commonly associated with hosting capacity of inverter connected asynchronous generation; however, it is also important to minimise the voltage disturbance resulting from the switching of network plant as well as the proper operation of certain protection systems.

Amplitude have undertaken assessments of available fault level (AFL) to quantify the benefits the Oven Mountain Project will provide to system strength.

Inertia is best described as the ability of the frequency of the system to withstand disturbances such as sudden changes in the supply demand balance brought about by trips of loads or generators. In a system with higher inertia, the loss of a large load or generator will have a lower rate of change of frequency (RoCoF) and have more time for systems to act to counter the disturbance.

Whereas system strength is a local phenomenon governed by the network topology and distance from synchronous sources, inertia is a system property that is largely independent of the connected network topology.

Historically, system strength and inertia has been sourced from synchronous generation, predominantly baseload coal fired generating units. The operating profile of these units is changing as they are displaced by additional inverter-connected asynchronous generation. This is having the impact of declining system strength and inertia throughout the NEM and progressive changes to the National Electricity Rules are now being implemented to maintain minimum levels of system strength and inertia going forward.

5 RESULTS SUMMARY

In particular, the Project has sought to;

- gain an understanding of how PHES can support the development of REZs
- analyse PHES's capacity to provide inter-regional support
- understand PHES's potential to provide MLF support.

The table below synthesises the areas of investigations and findings to date. Importantly, the table also provides direction to accompanying reports that offer further technical information associated with the investigations. These reports are provided in full in the Appendices of this Final Report.

Area of Investigation	Topics covered	Notes	Source for additional information
Network limitations	• Description of Network. • Limitations identified via consultation.	• The Amplitude Report provides an analysis of the current energy transformation, with a focus on the New England REZ. • The Report introduce two investigation branches: stability and thermal limits. Via analysis, it links 'current' system snapshots with stability limit analysis. • Understanding PHES impact on stability limits is a key differentiator of PHES from other technologies.	Amplitude Report – 'OMPS Benefit Assessment – Network Stability Report' – Amplitude Consultants, April 2022. See Appendix A

ISP and Operations context	• Description of operational treatment of network limits.
	• Outline future Network Planning considerations for scenario testing including ISP and TransGrid's TAPR.
	• Summary of key input parameters including:
	  ◦ Generation Scenarios
	  ◦ Load Scenarios
	  ◦ Dispatch considerations
	• Summary of AEMO and TransGrid consultation input for scenario testing.
		• The future case looked at 2030/31 which is reflective of the Electricity Infrastructure Investment (EII) Act objective dates, and reflective of the planned operational date for Oven Mountain.
		• The ISP has been used as the source of key network augmentations, generator retirements and new generation deployment, load forecast inputs. As an integrated system plan, it takes and consolidates inputs from the Roadmap, Transgrid and other NSP's.
		• The ISP assesses a number (13) of candidate development pathways (CDP) for networks against a range (4) of potential future energy demand and supply scenarios, developing an optimal development path (ODP) blueprint for future network investment.
		• Through AEMO's consultation with key stakeholders, the future energy demand and supply scenario of Step Change is considered the most likely of those considered.
		• EY utilised the information in the Step Change scenario along with the CDP 1, which most aligned with the ODP at 2030/31.
		• Operational treatment of network limits were kept to thermal (c.f. stability based) for this future assessment. Considering the degree of change in network, generation retirement and new generation, the uncertainty in the ratings/technology/performance of these, this approach is reasonable.
		• Further detail on the approach to modelling scenario inputs is provided in EY's report.
			Amplitude Report – 'OMPS Benefit Assessment – System Strength and Inertia' – Amplitude Consultants, July 2022.
			
			See Appendix B
			
			EY Report – 'Assessment of market benefits of the Oven Mountain Pumped Storage Hydro project' – EY Consultants, November 2022.
			
			See Appendix C

Area of Investigation	Topics covered	Notes	Source for additional information
NER requirements	• Outline of key elements of Chapter 5 of NER relevant to modelling • Description of NER elements to be treated in modelling exercise	The key elements of Chapter 5 of the National Electricity Rules relevant to the modelling include a demonstration that the PHES: • provides significant voltage and power system frequency control in accordance with various expectations in Schedule 5.2 of the NER including S5.2.5.11, S5.2.5.13; • is resilient to power system voltage and frequency disturbances in accordance with S5.2.5.3 and S5.2.5.4 and can maintain continuous uninterrupted operation when subjected to large disturbances, as required by S5.2.5.5; • increases the maximum supportable demand in the New South Wales region under all operating conditions, consistent with the requirements in S5.2.5.12; and • does not have an adverse system strength impact in accordance with the system strength impact assessment guidelines.	Amplitude Report – 'OMPS Benefit Assessment – Network Stability Report' – Amplitude Consultants, April 2022. See Appendix A Amplitude Report – 'OMPS Benefit Assessment – System Strength and Inertia') – Amplitude Consultants, July 2022. See Appendix C
Technology and configuration	Description of technologies identified and approach to modelling including: • Network elements • Generator technologies • Pumped Hydro	• For the Current network scenario, the generator, load models exist within AEMO's supplied system snapshots. • Consultation with OEM's allowed for the development of suitable generator, synchronous condenser and load models for PHES which were used to test stability constraints. • For the 2030/31 market assessment work, representative models for wind and solar were sourced from AEMO's snapshots, and network elements were developed to reflect network developments outlined in the ISP's CDP1. Multiple candidate years and generator outages were assessed to derive a central set of results. For further detail, see the EY report.	Amplitude Report – 'OMPS Benefit Assessment – Network Stability Report' – Amplitude Consultants, April 2022. See Appendix A Amplitude Report – 'OMPS Benefit Assessment – System Strength and Inertia' – Amplitude Consultants, July 2022. See Appendix B EY Report – 'Assessment of market benefits of the Oven Mountain Pumped Storage Hydro project' – EY Consultants, November 2022. See Appendix C

Area of Investigation	Topics covered	Notes	Source for additional information
Static and dynamic studies	Key findings of Chapter 5 modelling incorporating centered around OMPS performance particularly	• Amplitude stability studies included detailed dynamic models of the PHES in a full four state mainland NEM model. The models represented the frequency and voltage control performance of the generating system accurately, consistent with the requirements in the AEMO Power System Modelling Guideline (PSMG). • The studies showed the PHES governor and voltage regulation system contributes to power system frequency and voltage stability, and the plant can remain in continuous uninterrupted operation for a broad range of contingencies, as required under Schedule 5.2 of the National Electricity Rules. • Amplitude's 3rd Stage report showed that PHES will not have an adverse system strength impact. In fact, the PHES is shown to have a significant positive contribution to system strength. This potentially defers costly system strength remediation and provides attractive non network options for the management of system strength shortfalls in accordance with Chapter 5, Clause 5.3.4B. • The PHES also provides significant inertia which helps to limit the rate of change of system frequency (ROCOF) and assist with maintaining continuous operation of other generating systems in accordance with Schedule 5.2, S5.2.5.3 requirements. • It also helps avoid maloperation of protection systems due to high rate of change of frequency and provides attractive options for the management of inertia shortfalls in accordance with Chapter 5, Clause 5.20B.3.	Amplitude Report – 'OMPS Benefit Assessment – Network Stability Report' – Amplitude Consultants, April 2022. See Appendix A EY Report – 'Assessment of market benefits of the Oven Mountain Pumped Storage Hydro project' – EY Consultants, November 2022. See Appendix C

Area of Investigation	Topics covered	Notes	Source for additional information
Network impacts	• Quantitative and qualitative description of impacts of selected scenarios • Discussion on the relative merits of different scenarios from technical perspective	• From the Amplitude work, the inclusion of synchronous equipment is shown to significantly relieve known stability limits on QNI and increase the demand that can be addressed by more generation in NSW. These results are discussed in detail in Amplitude's work supporting the Interim Report. • The insurance case undertaken in EY's work shows that PHES can provide benefit to consumers in the scenario of late New England REZ delivery. These are discussed further in EY's report.	Amplitude Report – 'OMPS Benefit Assessment – Network Stability Report' – Amplitude Consultants, April 2022. See Appendix A EY Report – 'Assessment of market benefits of the Oven Mountain Pumped Storage Hydro project' – EY Consultants, November 2022. See Appendix C
Renewable deployment impacts	• Quantitative and qualitative description of level of impact of different scenarios on networks ability to support further Renewable Energy deployment • Particular focus on the New England REZ	• Under the current network scenario where the New England REZ is subject to considerable stability based limits, the work undertaken by Amplitude illustrates that these constraints can be relieved considerably. • In assessing the degree of stability base limit relief alone – that is not considering thermal limits – the PHES could facilitate up to approximately 1,600MW of new renewable generation in the New England REZ under best case scenarios. • In all cases, the amount of demand in NSW that could be addressed by generation in New England based generation increased without adversely impacting the QNI constraints. The Amplitude report supporting the Interim Report provides more detail. • In the 2030/31 scenario, Amplitude showed that PHES can provide significant contribution to the available fault levels and inertia at Armidale. This is seen to be equivalent to approximately 4x of the synchronous condensers being constructed in South Australia for the purpose of addressing system strength and inertia shortfall.	Amplitude Report – 'OMPS Benefit Assessment – Network Stability Report' – Amplitude Consultants, April 2022. See Appendix A Amplitude Report – 'OMPS Benefit Assessment – System Strength and Inertia' – Amplitude Consultants, July 2022. See Appendix B EY Report – 'Assessment of market benefits of the Oven Mountain Pumped Storage Hydro project' – EY Consultants, November 2022. See Appendix C

Area of Investigation	Topics covered	Notes	Source for additional information
MLF impact assessment	• Quantitative analysis of the MLF impacts of PHES on the New England REZ; • Qualitative analysis of the MLF impacts of PHES in the wider network region	• EY's assessment of the 2030/31 forecast year shows modest improvements in MLF for primarily solar at approximately 1%, driven by the use case for PHES. • While the number initially appears modest, when considered in the substantial network development in the New England REZ link, being able to move MLF is more material. • The NE REZ link underpins supporting the 8GW of legislated network transfer capacity, with a generation deployment of approximately 6GW.	EY Report – 'Assessment of market benefits of the Oven Mountain Pumped Storage Hydro project' – EY Consultants, November 2022. See Appendix C
Market benefit assessment	• Quantitative assessment of market benefits of PHES relative to other technologies in resolving identified network limitations • Approach to mirror that of a RIT-T	• EY's assessment showed that PHES shows substantial benefits to the market both in terms of NSW at approximately $600M cost reduction for the one year assessed; and to the NEM generally where the benefit is approximately $1.1bn. • An insurance case where the NE REZ link delivery occurs after the 2030/31 period was undertaken and the benefits of PHES is shown to be approximately $380M cost reduction to NSW and $1.3bn to the NEM generally. • More detail is provided in EY's report.	EY Report – 'Assessment of market benefits of the Oven Mountain Pumped Storage Hydro project' – EY Consultants, November 2022. See Appendix C

6 CONCLUSION

The Oven Mountain Pumped Hydro Energy Storage Project is an "off river" development located adjacent to the Macleay River between Armidale and Kempsey.

Situated within the New England Renewable Energy Zone, the Project will provide clean energy generation and storage capabilities, ensuring a reliable, resilient, and renewable future energy supply for NSW.

As part ARENA's Advancing Renewables Program (Stage three), the Oven Mountain Project team sought to analyse the benefits that Pumped Hydro Energy Storage (PHES) would have on the development of the New England Renewable Energy Zone (REZ) in northern NSW. This work has been coordinated with the guidance of Amplitude and EY consultants and their detailed analysis can be found in Appendix B and C respectively.

Amplitude assessed the network benefits with respect to the system strength and inertia contribution that the Oven Mountain Project can provide in both the 600 MW and 900 MW configurations. The studies found that the Project can improve the system strength at the Armidale 330 kV bus by up to 2,350 MVA. From an inertia perspective, the 900 MW Oven Mountain configuration can provide up to 3,150 MWs of inertia.

The EY report sought to quantify the potential market benefits of the Project, including on wholesale market and retail electricity prices, dispatch costs and emissions. It also examined the potential benefits of the Project to wind and solar projects in the New England REZ, including on their marginal loss factors (MLFs) and energy curtailments. The report identified reductions in demand-weighted wholesale electricity prices across NSW and other mainland NEM regions; significant savings in fuel costs NEM-wide; reductions in generation emissions; and supports the growth of additional renewable generation to be dispatched in the New England.

The Oven Mountain team look forward to continuing to engage with our diverse range of stakeholders – including government authorities, industry, and community members – as we work to deliver this significant project.

REFERENCES

AEMO. *2022 Integrated System Plan. June 2022*. Australian Energy Market Operator.

AEMO. *Building Power System Resilience with Pumped Hydro Energy Storage. July 2019*. Australian Energy Market Operator.

NSW Department of Planning, Industry and Environment. *NSW Electricity Infrastructure Roadmap. November 2020*. Energy NSW.

APPENDICES

A: Amplitude Report – '*Oven Mountain Pumped Hydro Storage Benefit Assessment – Network Stability Report*' – Amplitude Consultants, April 2022.

B: Amplitude Report – '*Oven Mountain Pumped Hydro Storage Benefit Assessment – System Strength and Inertia*' – Amplitude Consultants, July 2022.

C: EY Report – '*Assessment of market benefits of the Oven Mountain Pumped Storage Hydro project*' – EY Consultants, November 2022.

OVEN MOUNTAIN
PUMPED HYDRO STORAGE

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