Shoalhaven Pumped Hydro Scheme

Knowledge Sharing Report

This project received funding from ARENA as part of ARENA’s Advancing Renewables Program.

The views expressed herein are not necessarily the views of the Australian Government, and the Australian Government does not accept responsibility for any information or advice contained herein.

Origin Energy

May 2020
Executive Summary

On 28th August 2018, Origin and ARENA executed a Funding Agreement for the provision of $2m of funding by ARENA to support Origin’s Full Feasibility Study into the expansion of its existing Shoalhaven Pumped Hydro Scheme (SPHS). This Full Feasibility Study aimed to investigate the following:

- Geotechnical assessment
- Spoil management planning
- Optimal asset design
- Technical feasibility
- Financial feasibility
- Planning & environmental processes
- Impact on water users

The completion of these assessments would provide Origin with a detailed understanding of the feasibility of an expansion of the Shoalhaven Pumped Hydro Scheme and would ensure that an expansion is designed to a high technical, environmental and commercial standard.

Under the terms of the Funding Agreement, Origin was required to deliver three Knowledge Sharing Reports, two for public release, and one commercially sensitive report for ARENA’s internal consideration. In February 2019, Origin submitted its first Knowledge Sharing report. This report detailed the market and commercial considerations required to support the development of a Pumped Hydro Energy Storage (PHES) in Australia.

This second public report provides a complete overview of the findings of the Full Feasibility Study. This Study determined that the addition of a 235MW unit is technically feasible. In contrast to the existing design, the Project can be undertaken with a single reversible 235MW Francis machine due to advances in technology since the original construction. Geotechnical conditions present a viable project area and there are no grid connection or other technical issues which would entirely preclude development of the Project.

However, the Study also determined that the expansion of the scheme is not commercially feasible in the current economic and regulatory conditions. While there are opportunities to capture the arbitrage value in the NEM, particularly with the increasing penetration of non-dispatchable renewable energy, and benefits of utilising existing pumped hydro and dam infrastructure at Shoalhaven to develop a competitive “brownfield” opportunity, these do not outweigh the commercial risks of the Project. Of note, the capital costs of the Project were significantly higher than predicted in the Pre-Feasibility Study and are subject to exchange rate fluctuations. Furthermore, revenue generated by PHES projects in the NEM is likely to be significantly impacted by the development of Snowy 2.0 alongside the impact of batteries in the FCAS markets.

Origin has paused the development of the Project; however the additional unit remains an option for further exploration pending beneficial changes to the economic and regulatory environment influencing the Shoalhaven Pumped Hydro Scheme. Origin will continue to consider this expansion Project as an option for development in the future.
# Contents

Executive Summary 2  
Contents 3  
1 Knowledge Sharing Objectives 5  
2 Project 6  
2.1 Overview of the development of the expanded PHES Scheme 6  
2.2 Key challenges and findings of the Project 7  
2.3 Decision whether to proceed with Final Investment Decision 9  
3 Technical 10  
3.1 Key technical risks and opportunities 10  
3.1.1 Health, Safety, Environment & Community 10  
3.1.2 Geotechnical 14  
3.1.3 Design for construction costs, performance and reliability 21  
3.2 Grid connection arrangement 24  
3.2.1 Ownership 25  
3.2.2 Capacity review 25  
3.2.3 Next steps for Connection 25  
3.3 Early Contractor Involvement (ECI) Strategies 26  
3.3.1 OEM Strategy 26  
3.3.2 Commercial & contracting model 26  
3.3.3 Request for Tender Outcomes 27  
3.4 Technical Conclusion 28  
4 Commercial 29  
4.1 Basis for capital costs 29  
4.2 Basis of operating costs; 29  
4.3 Overview of the approach to market modelling 29  
4.3.1 Overview of Modelling Methodology 29
1 Knowledge Sharing Objectives

As agreed with ARENA in our Shoalhaven Funding Agreement, Origin has compiled a detailed report on the technical, market and commercial considerations of PHES in Australia, with a specific focus on the PHES Scheme:

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
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</table>
| **Project**   | ✓ Overview of the development of the expanded PHES Scheme;  
                ✓ Key challenges and findings of the Project (including an outline of the public benefits of the Project); and  
                ✓ Decision whether to proceed with Final Investment Decision.                  |
| **Technical** | ✓ Key technical risks and opportunities;  
                ✓ Grid connection arrangement; and  
                ✓ ECI strategies.                                                                |
| **Financial/ Commercial** | ✓ Basis of capital costs;  
                            ✓ Basis of operating costs;  
                            ✓ Overview of the Recipients approach to market modelling including:  
                            - Overview of methodology and scenarios considered;  
                            - Description of revenue stream considered (including ancillary revenue services);  
                            - Historical information on spot price arbitrage; and  
                            - Aggregate/summarised revenue ranges for the different scenarios considered through to 2030/2040 (including ancillary revenue services).  
                            ✓ Economics of the Project, based on National Electricity Market (NEM) modelling (presented in a way that ensures the Recipient’s commercially sensitive inputs/assumptions are protected), including:  
                            - Impact to the economics of NEM scenarios with and without Snowy 2.0;  
                            - Analysis and modelling of the future potential ancillary market revenues for the project; and  
                            - High-level comparison to various technologies such as battery storage and demand side management resources.  
                            ✓ Lessons learnt on securing project financing, if applicable; and  
                            ✓ Key commercial risks and opportunities of the development. |
| **Development** | ✓ Approach to developing the Project including unique project aspects when compared to publicly available information on similar PHES projects (in relation to project planning/approvals/etc) and comparison to other similar PHES projects (i.e. Snowy Hydro 2.0);  
             ✓ A qualitative overview of the value that the Project, should it proceed to development, would provide to the NEM. This includes enabling the transition to a lower emissions market, reduced cost of other supporting technologies, contract supply and liquidity and improved security, reliability and lower supply costs;  
             ✓ Process on environmental and planning applications and approvals;  
             ✓ Key risks and challenges and how these were mitigated and resolved. |
2 Project

2.1 Overview of the development of the expanded PHES Scheme

The original Shoalhaven Pumped Hydro Energy Storage and Water Transfer Scheme was constructed over the 1970’s and 1980’s and was designed with the capacity and concept in mind to add an additional two Pumped Hydro units at the Kangaroo Valley Power Station. Expansion of the scheme would necessitate the construction of the following:

- a parallel surface pipeline from the Fitzroy Falls Control Structure;
- an underground penstock (pipeline) from the end of the overland pipe to the Kangaroo Valley Station;
- Shallow underground and above ground powerhouse (replicate the current powerhouse); and
- Two 40MW generators with separate underslung pumps as per the existing units design.

Consideration of the original scheme had been undertaken by Eraring Energy, whilst under NSW State Government ownership in the 1990’s and 2000’s, however the cost of the Project could not be justified when compared to other generating options.

Upon acquisition in 2013, Origin further considered this option and agreed with previous assessments that the Project as originally conceived would not be viable, however valued the underutilised energy opportunity available via the water storages and topographical height difference of the scheme that are well suited to a PHES project.

In 2017, Origin undertook an options assessment and Pre-Feasibility of this opportunity with GHD and concluded that a development of an additional 235MW could be achieved by constructing a fully independent generating facility that utilises the entire hydrostatic head available from the topology. Following the completion of this pre-feasibility study, Origin selected a singular primary option for consideration in a Full Feasibility Study, the results of which are examined in this report.

The new 235MW underground power station option, which is independent of the existing Kangaroo Valley and Bendeela Power Stations, is shown in Figure 2 below:
This configuration was considered preferential given its utilisation of the entire water head, with two sub options for examination:

- Connection via overland pipe from the surge tank to the Fitzroy Falls Control Structure; and
- Connection via underground tunnel from the surge tank to the Fitzroy Falls Control Structure.

This proposed development has been progressed in the following areas to date:

- Planning requirements under NSW Planning and Assessment Act (including environmental, social and economic considerations) have been fully scoped;
- Development of a Reference Design and Technical Specification;
- Design and completion of a Geotechnical Investigation Program;
- Conceptualisation and execution of a detailed Project Tender and subsequent processes with qualified contracting and supplier parties;
- Community engagement including elected representatives and media coverage;
- Electricity market analysis, and;
- Transmission connection considerations.

### 2.2 Key challenges and findings of the Project

The expansion of the Shoalhaven PHES Project was developed as an option to assist Origin in the transition to high levels of renewable energy within the National Energy Market (NEM). Pumped Hydro is a mature technology and proven provider of both energy and storage services to balance non-dispatchable or semi-dispatchable renewable generation.

The construction of additional pumped hydro generation and storage capacity at the existing Shoalhaven Scheme would provide NSW with several public benefits, including:

- Additional energy storage capacity which would allow for the storage of non-dispatchable or semi-dispatchable renewable energy generated at sub optimal or low demand periods;
An additional, and independent generation unit in the Shoalhaven Scheme that would contribute to the security and stability of the NEM through the creation of additional redundancy in the system;

An independent water pumping pathway for the Shoalhaven Scheme’s water transfer function for Water NSW, further enabling the provision of water to the Greater Sydney Catchment during times of drought, creating resiliency and eliminating risks from single points of failure;

Development of a scheme with a materially lower impact as compared to other PHES schemes which require new transmission, dams and other potentially disruptive infrastructure requirements to construct. The Shoalhaven Project can be constructed on Water NSW land and requires no new dams or transmission lines.

The potential for creation of between 400 and 500 direct jobs in the region, including significant in-direct job creation effects providing employment and other economic benefits locally, regionally and nationally.

Prior to undertaking the Full Feasibility Study, Origin identified several key risks that needed to be investigated, including:

- How to achieve timely and workable planning approvals in today’s context, given the time lapse since pumped hydro has been developed in Australia (40+ years) and that PHES developments were traditionally undertaken by or on behalf of Government;
- Understanding the geotechnical risk associated with constructing the required tunnels and underground cavern with a cost-effective outcome;
- Mitigating the impact of likely increased cost of construction compared to costs estimated in the GHD Pre-Feasibility (desktop) Study and competing energy and storage projects with NSW;
- Minimising the cost of equipment exposed to exchange rate volatility;
- Understanding the impact of other proposed generation projects, particularly Snowy 2.0 (2000 MW) on forecast energy market dynamics and on the transmission system; and,
- The impact of the changing regulatory and political environment on investment in and operation of the Australian electricity sector.

Additional challenges were identified during the Study, as below and further addressed in Section 3:

- Construction costs were estimated to be much higher than expected, driven largely by the high cost of civil works, pipeline development and tunnelling;
- High cost volatility in relation to proposed tunnelling works, particularly across varied geotechnical ground conditions;
- Increased difficulty in undertaking the required grid modelling necessary for the grant of a Connection Approval by AEMO and TransGrid given the high number of applications for intermittent generation in NSW;
- The significant impact Snowy Hydro 2.0 will have on the NSW energy, ancillary and energy storage markets;
- Increased volatility, and decreased value of the Australian Dollar against the US Dollar and the Euro, which are generally used to purchase PHES hardware;
- Increased volume of civil works being undertaken across Australia has reduced the availability and increased timeframes for securing quality EPC resources and materials, driving up costs and challenging construction durations;
- Approval process to complete the Project Environmental Impact Statement, as defined by the NSW Department of Planning, proved more onerous than originally anticipated;
- Complexities associated with the control requirements for works within the Water NSW “Special Zone” to ensure water quality in the system is maintained to required standards;
- Limited Tunnel spoil disposal options when considering community impacts due to the lack of major road networks; and
- Lack of clarity in relation to Water NSW requirements on the waterway and future scheme use.

Detail on these challenges, and how Origin has addressed them, is outlined in further detail within this report.
2.3 Decision whether to proceed with Final Investment Decision

Origin has undertaken significant analysis on this potential development option, investing time and resources over a 3-year period with support from PHES, geotechnical and civil works experts across Australia and internationally. Following the completion of the Full Feasibility Study, Origin has concluded that, based on this analysis and the current forecast of energy market conditions, further development of the expansion of the Shoalhaven PHES is not commercially feasible at this time.

Origin notes that an increase in the cost of PHES following detailed and site-specific reviews has been seen across multiple proposed projects in Australia. At the time of writing, with the exception of Snowy 2.0, no PHES project has reached a successful Final Investment Decision in Australia in recent years.

There may be several reasons for this situation including:

- The lack of recent PHES construction experience in Australia;
- Limited local contractors capable of the works (commercially and physically) to assist with the development of a competitive pool of EPC and civil work contactors; and
- The current peak of infrastructure projects being undertaken across Australian, such as the Sydney WestConnex network, Brisbane Cross River Rail, Perth Forrestfield Airport Link, Melbourne Metro Tunnel and numerous similar major projects in the South East Asia region creating significant increase in demand and price for these services.

Following completion of the assessments required under the Full Feasibility Study, including receipt of construction costs based on fully optimised design, and a detailed consideration of potential operating regimes and market conditions, the Executive Leadership Team of Origin’s Energy Supply & Operations Group (who led the Full Feasibility Study) elected not to present the Expansion Opportunity to the Origin Investment Committee or the Origin Board. This was due to a failure, under current and forecast energy and auxiliary market conditions, to meet Origin’s investment criteria and expected levels of commercial return. This decision was endorsed by Origin’s Chief Executive Officer, Frank Calabria.
3 Technical

3.1 Key technical risks and opportunities

The expansion of the Shoalhaven Pumped Hydro Scheme has a range of technical risks associated which have been considered in detail as follows:

- Health, Safety, Environment and Community;
- Geotechnical conditions; and
- Design for construction costs, performance and reliability.

3.1.1 Health, Safety, Environment & Community

Some of the key technical risk in relation to Health, Safety, Environment and Community issues are as follows:

1. Safe excavation and tunnelling;
2. Disposal of excavation spoil;
3. Construction dust during tunnelling;
4. Fire and life safety; and
5. Undertaking of Geotechnical Investigations.

1. Safe excavation and tunnelling

These activities require deep consideration of the geotechnical conditions, which includes factors of not only rock type but strength, water ingress, ground fractures and depth of excavations. During consideration of the Project in consultation with experienced Bidders and Origin’s Owners Engineer it was concluded the most practicable methods for tunnel, shaft and cavern excavations are as follows.

Tunnels and cavern (powerhouse) construction is to be undertaken by road header equipment depicted in Figure 3, with some possibility of drill and blast methods shown in Figure 4 for specific areas, and/or where rock strengths exceed the economics of road header use.

![Figure 3: Road Header Machine](image-url)
The vertical shaft construction is achievable via either Downhole Reaming or Raise Boring. Ultimately the selection of the final method is dependent on the Early Contractor Involvement (ECI) outcomes as different Bidders had preferences for different methods.

Downhole Reaming, as shown in Figure 5, could improve project schedule, as the majority of the shaft can be constructed independently from that of the main tunnel construction. Spoil would be evacuated from the surface likely necessitating the establishment of a secondary spoil dump in the Fitzroy Falls area.

Raise Bore excavation methods allow for a wider range of available equipment as this is a common methodology in the mining industry, however, as depicted in Figure 6, the excavated material is designed
to collapse into the horizontal tunnel therefore requiring the tunnel to be completed and remain unlined to allow spoil to be removed to Kangaroo Valley via the tunnel. This creates a potential constraint in construction timeline as the shaft cannot be constructed until the horizontal tunnel is completed.

2. Disposal of excavation and spoil

The material excavated from the tunnels and cavern is referred to as spoil, and handling and disposal of this spoil is a key factor in consideration of any excavation works. An estimated 260,000m³ of spoil is anticipated to be generated and Origin carefully considered the overall impacts of how to dispose of this material with two options as outlined below:

Option 1 – Offsite disposal and potential re-use.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material has potential re-use in roads or other fill requirements.</td>
<td>Significant heavy vehicle movements on minor roads within a community, with the potential risk of traffic incidents.</td>
</tr>
<tr>
<td>Material disposed away from waterways reducing the risk of sediments.</td>
<td>Potential impacts to tourism by vehicle movements.</td>
</tr>
<tr>
<td>Environment impacts of significant fuel use to transport the material away, and potential increase in fauna strike/death.</td>
<td>Increase in amenity impact of local community from increase traffic, including noise and dust etc.</td>
</tr>
<tr>
<td>Costs of disposal likely to make the Project unviable.</td>
<td></td>
</tr>
</tbody>
</table>

Option 2 – Onsite disposal.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduced impact to local road users reducing traffic incident risks.</td>
<td>Risk of sediment run off if adequate controls are not implemented.</td>
</tr>
<tr>
<td>Reduced impacts to the local tourism industry.</td>
<td>Requirement to clear vegetation regrowth over the previous spoil disposal area.</td>
</tr>
</tbody>
</table>
Lower cost solution making the Project more viable. Vegetation offset for the clearing would likely be required.

Origin’s Owners Engineer undertook drone LIDAR surveying of the areas adjacent to the current Bendeela Pondage as this was the location of the previous spoil disposal area. While this area has had significant flora and fauna regeneration since the original construction, it is thought to be suitable for future disposal as indicated in Figure 7 below.

![LIDAR survey - Bendeela Pondage](image)

Additionally, there is the risk of the presence of acid forming rock in some sections and such material would require complete encapsulation onsite, treatment, or removal from site to a suitable location to avoid any potential environmental impacts.

3. Construction dust during tunnelling

Management of the heath of workers undertaking excavations is also a key consideration to avoid respiratory illnesses caused by airborne materials which can have significant long-term impacts. Excavation dust may include respirable crystalline silica and other harmful exposures may also be present during concreting and other dust creating activities.

Such risks require the use of respiratory protection, the installation of significant forced ventilation at the excavation face as well as implementation of positive pressure air conditioning systems on earthmoving equipment as a minimum. Ongoing monitoring systems and dust controls are important construction design considerations.

4. Fire and life safety

Fire and life safety is a material consideration for an underground installation due to the presence of high levels of electrical energy and potentially combustible materials such as lubrication oils and electrical cables. Central to the consideration in design is to follow the Safety in Design concepts in addressing risks early in the design process. Key considerations to be fully resolved in the ECI process are as follows:

- Transformer location considering fire and explosion risk;
- Potential flooding of the cavern;
- Air quality and ventilation both in normal operation and fire situations;
Alternative egress in case of emergency; and
Fire detection and fire containment systems.

Certain components can be significant cost drivers such as separate escape tunnels, elevators, jet fans or smoke spill fans, flood pumps, electrical design and selection of low combustible materials. Fire and life safety studies are a key portion of the Safety in Design process in the ECI process.

5. Undertaking of Geotechnical Investigations

During the investigation significant Health, Safety, Environmental & Community (HSEC) controls were implemented by Origin to ensure a safe and environmentally sustainable outcome. Key HSEC statistics at the completion of the Geotechnical Investigation Program are as follows:

<table>
<thead>
<tr>
<th>Activity</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drilling Site Inductions</td>
<td>32</td>
</tr>
<tr>
<td>Drug &amp; Alcohol Testing</td>
<td>Complete crew tested 5 times across the program</td>
</tr>
<tr>
<td>First Aid or Medical Treatments</td>
<td>0</td>
</tr>
<tr>
<td>Safety Observations and Step Back Processes</td>
<td>65</td>
</tr>
<tr>
<td>Hazard Observations</td>
<td>1</td>
</tr>
<tr>
<td>Incidents or Near Misses</td>
<td>4</td>
</tr>
<tr>
<td>Community Complaints</td>
<td>0</td>
</tr>
</tbody>
</table>

In relation to safety the most significant near miss was a Methane release from a borehole when the drill encountered a gas pocket at Bore Hole 3 at a depth of around 77m. The work crew had been prepared for this potential with this hazard identified in the Project HAZID and suitable monitoring and Emergency Response Plans were in place and executed without further incident. The encountered gas was at very low pressure and was able to naturally disperse. Worksafe NSW were consulted and were satisfied that the situation was safely controlled and there was a comprehensive testing plan put in place to ensure any remaining gas had dispersed prior to recommencement of drilling.

Weather delays, specifically wind related, were encountered during drilling given the impacts of wind on the mast of the drilling rig and the proximity of large mature trees in the investigation area which posed a risk to workers. Substantially after the works, there were also bushfires in the region which may have impacted on the remaining data loggers installed into the boreholes, however inspections post the fires have confirmed that there were no impacts on the equipment.

Origin, Jacobs and the relevant contractors were able to manage activities in a way which met community standards by early engagement with landowners and understanding their needs, constraints and preferences. Origin did not undertake works on private land however was cognisant of potential traffic, noise or other concerns from neighbours. All works were able to be undertaken meeting not only the requirements for the Development Consent Approval but also developing and maintaining relationships with the local community.

3.1.2 Geotechnical

As this Project is primarily a series of underground tunnels and a large cavern, a significant risk to the Project is the potential for unfavourable and variable ground conditions through which the tunnels and machine house would be located. This risk has been mitigated as far as practicable through the identification of a nominal route linked with a credible design along which a series of strategically located boreholes, chosen to best represent the most plausible and comprehensive geological and geotechnical profile that would give optimum benefit.

In considering the civil risks Origin undertook a range of activities to better understand and mitigate geotechnical risks. The activities included:

- Preliminary geotechnical review; and
- Geotechnical investigation program.

Jacobs undertook a preliminary geotechnical assessment which identified expected risks and scenarios largely developed from available information and localised site visits to interpret surface landforms and
features. Jacobs undertook site and localised region walkovers to identify formations and gather information to better inform the design team confirming formations visible in regional locations as well as identifying acid forming rock formations and potential fault and/or historic land slip localities. The information collected was used to inform the scope of the Geotechnical Investigation Program.

Figure 8 below identifies the expected geotechnical formations from both regional geological information and data collected from the original scheme construction.

![Figure 8: Geotechnical configurations](image)

The previously collated construction data was classified in line with the Snowy Scheme Rock Mass Classification which is articulated in Table 1 below.

### Table 1: Rock Classification Data

<table>
<thead>
<tr>
<th>Rock Mass Classification</th>
<th>Rock Condition</th>
<th>Summary Characteristics</th>
<th>Typical Support Used on Works of the Snowy Mountains Authority</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Excellent</td>
<td>Sound, compact, usually dry rock, either un-jointed or with tightly closed strongly cemented joints.</td>
<td>No support, except in large excavations such as power stations.</td>
</tr>
<tr>
<td>5S</td>
<td>Excellent (but highly stressed)</td>
<td>As above, but “spalling” or “popping” occurs.</td>
<td>Generally rock bolting if appropriate.</td>
</tr>
<tr>
<td>4</td>
<td>Good</td>
<td>Hard rock generally dry with tightly closed, weakly cemented joints, some slightly open joints with water seepages or flows may occur. May contain some narrow sheared or crushed zones.</td>
<td>Mainly unsupported or with few rock bolts to pin shoulders. If orientation of excavation is adverse in relation to main jointing. Generally, less than one bolt per linear ft for 20ft (6.1m) diameter tunnel.</td>
</tr>
<tr>
<td>3</td>
<td>Very fair</td>
<td>Mainly hard rock, but considerably loosened by the opening of weakly cemented joints on excavation or due to the presence of slightly open joints, or narrow sheared or crushed zones. May be dry but usually wet. Tends to break entirely along joint planes on excavation, regardless of the orientation of excavation surfaces in relation to the joint planes.</td>
<td>Light steel set or “completely” supported in roof by rock bolts, occasionally supplemented by steel channels and wire mesh. Usually 2 to 3 bolts per linear foot for a 20ft (6.1m) diameter tunnel.</td>
</tr>
</tbody>
</table>
A significant Geotechnical Investigation Program was then designed by Origin's Owners Engineer, Jacobs, with 8 locations selected as shown in the table below to determine a reasonable sample size to anticipate and validate potential ground conditions in the proposed Project area where significant infrastructure would be installed.

Table 2: Bore Hole Locations

Table 2 below identifies the locality and depth of the investigation bores which were executed with Figure 9: Bore locations providing a map overview of the physical localities.
The cross-sectional view of the proposed installation shown in Figure 10 identifies the planned depths of each of the key elements of the scheme expansion in reference to the geological formations. The Geotechnical Investigation Program was developed to interpret the ground in each representative area, each Bore Hole is prefaced as BH on Figure 10 below.
Further considerations in selecting the borehole locations included drill rig accessibility, remaining within easements, avoiding impacts to the Moreton National Park and consideration of flora and fauna species in the local area.

Jacobs engaged a highly experienced drilling company to complete the drilling program by way of track mounted drill rigs with two locations in concurrent operation for the majority of the field works period. Figure 11 below depicts the drilling equipment deployed with Figure 12 and Figure 13 showing examples of extracted core samples and the finalised borehole with monitoring instrumentation installed.
Rock parameters that have been measured during the Shoalhaven Geotechnical Drilling Campaign include strength tests, weathering, density, porosity, water loss, Rock Quality Designation (RQD), and abrasivity tests. A study was also performed on the regional stress regime and local stress fields. This was assessed using raw and processed data from image logs, Dipole sonic logs, gamma ray logs, laboratory density results to calculate log derived stress magnitudes.

A summary of the observed geotechnical conditions and the potential Project impacts is presented in Table 3 below.
### Table 3: Geotechnical Conditions Observed

<table>
<thead>
<tr>
<th>Observation</th>
<th>Project Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>The rockmass permeability was found to be similar to that generally encountered for similar rocks in the region and initially assumed, which also include the occasional presence of open joints reflected in the water losses experienced during the recent investigations.</td>
<td>Tighter rockmass and the high lateral insitu stresses measured may have a positive outcome on reducing thickness of steel liner or replacing it with concrete in the headrace over certain sections given the anticipated tight rock mass and high cover thickness. It is expected that steel lining will remain in the vertical shaft. This is likely to be due to the encountered deeply weathered rock profile within the shaft area, occasional open jointing and expected high internal operating hydraulic pressures in the shaft. This price benefit has been previously presented in the pricing normalization sensitivities.</td>
</tr>
<tr>
<td>Certain assumptions were initially made on the groundwater levels given the absence of any groundwater levels in the area. The results of the investigations found the depth to the water table in the pressure shaft area at about 250m (BH2), in the reference design cavern location (BH3) at 103m, and at the tailrace tunnel end (BH6) at 25m and (BH7) at 13m below the surface.</td>
<td>The depth of the regional watertable was found to be generally deeper than initially assumed. In view of the low groundwater storativity of the rockmass the volume of groundwater inflows into underground excavations is expected to be small. There maybe occasional requirements for grouting such as for the proposed cavern location and where faults are in hydraulic connection with water storage facilities (Bendeela Pondage). The price benefit is unlikely to be material; however, it may also be less likely that ground water impacts will result in unfavorable price variations during construction assuming the agreed thresholds have been competently assessed.</td>
</tr>
<tr>
<td>The potential for acid rock generation was found in most of the main tunneling units (Berry, Wandrawadrian and Snapper Point Formations).</td>
<td>This could contribute unfavorably to aspects such as the cost of storing and managing the spoil storage site. These are not considered significant material price variation factors, and unlikely to impact the project schedule materially.</td>
</tr>
<tr>
<td>High horizontal stresses were assumed initially for the reference design and were encountered during the insitu stress testing during the investigations.</td>
<td>This is likely to increase the extent of ground support for the proposed new location of the cavern in view of its greater depth of cover and possibly in other areas. Based on pricing information the direct materials cost is not high, however, this requirement could contribute to extending time of construction. The extent of this is not considered material.</td>
</tr>
<tr>
<td>The thickness of soil/weathered rock in the lower region of the scheme may be lower than expected, but this is not conclusive.</td>
<td>This could contribute to more favorable tunneling conditions in the tailrace (at depth) with less complex primary support construction. The price and schedule benefit is not considered material; however, more competent conditions would reduce uncertainty in price variations from unforeseeable latent conditions. Further geotechnical investigation is recommended in the future along this alignment but can be included in the EPC scope of services. This in not currently priced.</td>
</tr>
<tr>
<td>The ground conditions in the vicinity of the location of the reference design power house cavern are more fractured than expected at the cavern depth.</td>
<td>This strongly supports the decision to relocate the power house within 700m of the shaft and use this as the new project baseline configuration. This fracturing is associated with a fault feature that was anticipated. This fracturing is unlikely to be extensive in the plane of the proposed tailrace tunnel and therefore tunneling through this location is not considered a technical concern. Nor is it considered that the price or schedule will be materially impacted.</td>
</tr>
<tr>
<td>Methane was encountered in BH03 only. It dissipated relatively quickly.</td>
<td>Practices will need to be deployed to monitor for methane hazards during tunneling. This geohazard is not unusual and is commonly managed by tunneling Contractors. Methane was not encountered in any other borehole. The source of the methane is unknown but most likely from rocks within the lower part of the Sydney Basin and migrated though open joints. However there are no indications that it is widespread based on the investigation sample set.</td>
</tr>
<tr>
<td>The stratigraphy and layer thicknesses encountered in the vertical shaft did not vary materially from the assumptions. However the ECI contractor will need to review the rockmass conditions to confirm appropriate methods of raise-</td>
<td>There may be some material variation from the assumptions made on the price or schedule from a positive or negative point of view.</td>
</tr>
</tbody>
</table>
bore construction and primary support requirements.

The geological classifications and ground behavior types for tunneling are yet to be determined; however, there is no basis from the site investigation to modify the assumptions used in the reference design.

Future interpretation of the geotechnical investigation data will be used to prepare the geological baseline report (GBR). This report will inform key parameter thresholds / ranges to be agreed technically and commercially such as:

- Expected production rates (cost and time)
- Associated excavation support classes for drill and blast construction
- Geological overbreak
- Rock abrasivity class
- Ground water levels over the alignment
- Forward probing requirements
- Pre grouting requirements
- Acid rock profile over the alignment

These factors can influence price and schedule variations if parameters are encountered outside the thresholds.

The GBR will include interpreted long-sections of the project alignment including:

- Lithology
- Ground Type
- Ground Behavior type
- Baseline excavation support classes, primary support classes and lining class distribution %
- Estimated Groundwater inflow (L/min/100m)
- Other hazards (hot water, methane etc.).

### 3.1.3 Design for construction costs, performance and reliability

To select a Design & Construction (D&C) contractor, where a project design has not yet been completed, required Origin to work with Jacobs to develop 6 key documents, or Volumes, to define a constructible project design which could be value engineered in the ECI process.

These Volumes provide for the key technical documents for the Project to ensure all potential contractors considered the same methodologies, standards and other requirements to define a budgetary price for the Project.

Table 4 below outlines the developed documentation to define the project therefore providing contractors scope to price to and develop construction timelines and key risks.
Table 4: Development Documentation

<table>
<thead>
<tr>
<th>Project Document Volume</th>
<th>Description</th>
<th>Provides specification for</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume 0: Feasibility Study</td>
<td>Volume 0 provides background information including studies that were undertaken to support the definition of the Reference Design.</td>
<td>ECI Selection Phase</td>
</tr>
<tr>
<td>Volume 1: ECI Services Information</td>
<td>Volume 1 describes the ECI Phase up to FID and includes the scope of work for the ECI Services.</td>
<td>ECI Selection Phase &amp; ECI Design Phase</td>
</tr>
<tr>
<td>Volume 2: Origins Project Requirements</td>
<td>Volume 2 describes Origins minimum requirements for the standard and minimum requirements for execution of the Project.</td>
<td>ECI Selection Phase &amp; ECI Design Phase</td>
</tr>
<tr>
<td>Volume 3: EPC Scope of Works</td>
<td>Volume 3 describes the EPC scope of works including such things as terminal points, Origin and Contractor responsibilities and description of the scope of works.</td>
<td>ECI Selection Phase &amp; ECI Design Phase</td>
</tr>
<tr>
<td>Volume 4: Technical Specification</td>
<td>Volume 4, amongst other things specifies the minimum technical and functional requirements, Origins preferences, design criteria, and basis of design for the Scheme.</td>
<td>ECI Selection Phase &amp; ECI Design Phase</td>
</tr>
<tr>
<td>Volume 5: Reference Design</td>
<td>Volume 5 describes a credible design concept with sufficient definition to enable a preliminary baseline EPC Price and EPC Schedule to be developed and for informed value engineering to be performed.</td>
<td>ECI Selection Phase</td>
</tr>
<tr>
<td>Volume 6: Response Schedules</td>
<td>Volume 6 describes the specific items for which the Respondent must provide a response and the form of the schedule which the Respondent must complete and return with their Tender.</td>
<td>ECI Selection Phase</td>
</tr>
</tbody>
</table>

Volume 5 describes a Reference Design which was developed as a conservatively constructible project design which would form the basis of tendering with the option for the Bidders to offer alternatives which offer value to the Project. The proposed powerhouse shown in Figure 14 identifies a portion of that design.

*Figure 14: Proposed Powerhouse*
Additionally supplied in Volume 0 was the Pre Feasibility study as well as other minor studies performed in preparation for the Project Tended. As an example, bathymetric surveying of Lake Yarrunga was undertaken to better understand the proposed location of the inlet/outlet structure required for water flows. As shown in Figure 15 following suitable water depths are shown reducing or eliminating the need for dredging in the lake therefore excluding this works from the Project.

![Figure 15: Bathymetric survey of Lake Yarrunga](image1)

During the tendering phase constructability of the overland pipe section identified more significant challenges than expected given the narrow construction easement available and the steepness of some of the terrain. It became evident that a cable crane, as shown in Figure 16, would be required at additional cost.

![Figure 16: Cable Crane](image2)
Further to these additional installation costs, the cost of the pipeline sections and the underground penstock liner was higher than anticipated due to steel costs, exchange rates and transport drivers. Management of these costs by alternate design or procurement methodologies was identified as a key material item requiring optimisation to assist with Project affordability.

Electrical Connection

Given that the Project design calls for an underground powerhouse, consideration was made as to the most effective power evacuation from the units and connection to the Kangaroo Valley switchyard. Key consideration here was to assess the potential of installing the Generator Step Up Transformer (GSUT) underground nearby the generator or on the surface closer to the switchyard.

Option 1 – GSUT Underground installation

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shortest length of Medium Voltage (MV) connection reducing electrical losses</td>
<td>Potential underground source of fire making Fire Life Safety design more complex</td>
</tr>
<tr>
<td>Proven design</td>
<td>Cavern needs to be larger to accommodate the transformer</td>
</tr>
<tr>
<td></td>
<td>Access tunnel may need to be larger to allow transformer to be driven in</td>
</tr>
</tbody>
</table>

Option 2 – GSUT Surface installation

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smaller cavern</td>
<td>Longer MV connection resulting in higher electrical losses</td>
</tr>
<tr>
<td>Potentially smaller access tunnel</td>
<td>Significant vertical runs of large diameter cable or Isophase Bus Duct</td>
</tr>
<tr>
<td>Lower underground fire risk</td>
<td></td>
</tr>
</tbody>
</table>

Option 1 was selected for the reference design as the design and construction of this method is well proven however Option 2 offers a potential value improvement in the ECI process.

3.2 Grid connection arrangement

The Project is to be connected into the existing Shoalhaven scheme’s high voltage assets that provide connection to the national transmission network. The high voltage single line diagram is shown in Figure 17.

Figure 17: Single Line Diagram
The existing connection arrangement with the Shoalhaven scheme will be modified to have both Kangaroo Valley generators share a single connection point, and the additional unit for the Shoalhaven Expansion will take up the “spare” connection bay.

3.2.1 Ownership

All assets beyond the Kangaroo Valley switchyard into the generators (i.e. asset fence line / boundary) are owned by Origin. TransGrid own the switchyard and line assets. Existing connection arrangements will need to be modified to facilitate the new generator.

3.2.2 Capacity review

Two methods of determining capacity in the connection assets have been used. The first is via the transmission line conductor type which shows the basic capacity of the line. The line conductor normally has the lowest rating of all the complete connecting assets (substation bay and line) and therefore is usually the limiting factor. The second method is to review the data provided in the AEMO ratings database. Cross comparison of both sources of information then gives a reasonable sense of the capacity of the network and connection assets.

Checking the AEMO ratings database, the following limits for summer normal (i.e. 90°C conductor operating temperature, +1m/s) apply for the complete feeder and substation assets:

- Feeder 18 (Dapto to Kangaroo Valley) rating = 915MVA
- Feeder 3W (Capital Wind Farm to Kangaroo Valley) rating = 915MVA

So, comparing this capacity (in a secure state) to the Project and existing Scheme load level requirements:

- Total generation transmission capacity (secure) = 915MVA
- Spare capacity after expansion = 235MVA (existing) + 240MVA (proposed) = 475MVA spare

It is worth noting that the existing assets for the Kangaroo Valley switchyard were all constructed at the same point in time. As such, all circuit breakers and associated bay hardware have the same ratings as the feeder 18 and 3W hardware. From this, it can be accurately inferred that the minimum rating of the remaining connection assets will be (at least) 915MVA per bay.

The original construction details were reviewed which shows the key conductor information for the existing switchyard and the short 3km connection to Bendeela Power Station. This has a rating for 2000A, which is a rating of 1989MW, much higher than the nominal network capacity of 915MVA.

In summary, a review of the plant and line ratings inside and around the Kangaroo Valley Switchyard has shown that there are acceptable levels of spare capacity to allow the connection without any major upgrades.

3.2.3 Next steps for Connection

The following two steps are required in the connection process:

1. National Electricity Rules

As this is the modification of an existing connection, to conform to the National Electricity Rules (NER) requirements, a letter outlining the “NER 5.3.9 Procedure to be followed by a Generator proposing to alter a generating system” has been lodged by Origin, with details received and accepted by TransGrid. All commercial arrangements for the TransGrid evaluation are ready for the due diligence to commence.

2. Generator and Customer Performance Standards

The following phase of work would be for Origin to develop and submit the detailed draft Generator and Customer Performance Standards, modelling and associated reports for AEMO and TransGrid due diligence. It was to be carried out as a parallel activity during the Early
Contractor Involvement stage as key technical information on the plant was to be developed and confirmed at that stage (for example transformer ratings, cable sizing and lengths, turbine type and so on).

The acceptance by AEMO and TransGrid of these draft Generator and Customer Performance Standards would be a key output of this process.

3.3 Early Contractor Involvement (ECI) Strategies

There is a relatively small worldwide pool recognised as technically capable and experienced contractors in PHES. In response to this, Origin designed a detailed contracting strategy by examining both its own needs as well as the contracting market feedback in relation to project delivery methods.

3.3.1 OEM Strategy

Origin identified suitably qualified Original Equipment Manufacturers (OEMs) and construction contractors to participate in an Expressions of Interest process. During this process it became evident, due to the scale and nature of the Project, that it was unlikely that one contractor would be willing to offer a competitive Engineer, Procure & Construct (EPC) contract. This style of contracting offers the lowest risk profile to an owner and is often preferred by owners. OEM suppliers had a strong preference for a supply and commission only arrangement and construction contractors were generally more likely to offer competitive pricing where they are not required to offer a performance guarantee on OEM equipment in a Design & Construct (D&C) arrangement. This was further evidenced by one Bidder having a strong preference to only undertake the project in an Engineer, Procure, Construct & Manage (EPCM) contract arrangement whereby their risk exposure was significantly reduced, or in fact, eliminated.

Thus, it was decided to follow a Design and Construct (D&C) methodology with the constructor being the Principal contractor and the OEM supplying the equipment for installation under a separate supply contract to Origin. All parties would then be joined together under a Tripartite Agreement to ensure optimal collaboration to achieve project success. This allows for significant risk margins to be removed and offers a “best for project” approach.

3.3.2 Commercial & contracting model

Origin’s preliminary commercial concept was to negotiate an agreement based on a Geological Baseline Report (GBR) framework that acknowledges tunnelling risks and treats them in a fair way, but the commercial model would be further developed through discussion with the ECI Contractor during the ECI Phase where there is an opportunity to improve project value to Origin. Origin and Jacobs also consulted the Conditions of Contract for Underground Works (2019 Emerald Book) published by FIDIC (International Federation of Consulting Engineers) as potential guidance to the contractual models.

Origin chose the Early Contractor Involvement (ECI) approach as a specific strategy to improve the Project value by allowing Origin and an ECI Contractor (anticipated to become the constructor) to gain an informed understanding of the Project requirements, how they shall be delivered and transparency on the cost and risks and how they are dealt with through the Project contracts. As such Origin required that the ECI Contractor demonstrate value through the ECI phase and this would be reflected in the final project outcomes by improving the certainty of the cost, safety and schedule outcomes.

The design of the ECI was to contract the lead constructor to undertake the process and co-ordinate required materials from the Turbine Original Equipment Manufacturer as a fully paid arrangement over a period of at least 6 months.

Origin’s objectives of the ECI Phase of the Proposed Works were to:

- Confirm that the technical and commercial outcomes of the Project meet Origin’s Project Objectives;
- Reduce the level of technical, cost and schedule uncertainty to the extent that Origin and the ECI Contractor understand commercial risk and can agree a commercial contract to adequately deal with it;
✓ Complete detailed engineering (~30%), market pricing and cost estimating to agree a technical design and specification that underpins an agreed commercial model, price and schedule for the Project contracts;
✓ Attain a sound understanding of the Project risks and define the confidence levels (P10 – P90) to adequately inform the FID;
✓ Understand risk and establish robust risk management plans to confidently manage within these confidence levels; and
✓ Agree a firm, binding and executable contract for the Project.

This program was designed such that at the end of the ECI Phase, the ECI Contractor will have developed a de-risked design that is fully compliant with Origin’s technical and operational requirements, has achieved the lowest risk weighted capital cost and best whole of lifetime cost. The ECI process would be collaborative, open and transparent between the ECI Contractor, Original Equipment Manufacturer (OEM), Origin and the Owner's Engineer during development of the Project design, cost estimate and commercial agreements. The ECI Contractor was not required to complete full detailed design and engineering during the ECI Phase, but rather early engineering works for the purposes of forming a reliable project contract.

The Request for Tender process required the ECI to provide the following:
✓ Participation by the ECI Contractor in the selection and engagement of an OEM for the main power block, as well as provision of all key OEM modelling information necessary to feed into the Generator Performance Standards studies;
✓ Transient analysis to confirm the hydraulic design of the power block and water tunnels;
✓ Preliminary design to Origin’s minimum functional specifications for the power block;
✓ Preliminary design of services to Origin’s minimum functional specifications;
✓ Defining the construction methods and schedule;
✓ Interpreting geotechnical data and agreeing base assumptions including rock classes and percentages;
✓ Preliminary design of tunnels and portals; and
✓ Value engineer the technical solution and cost.

3.3.3 Request for Tender Outcomes

Origin intended to select only one ECI Contractor, however during the Request for Tender Process it was identified, via pricing against the Reference Design, that the estimated projects costs were materially higher, and Origin did not enter into the full ECI process.

In an attempt to improve estimated pricing prior to committing to a full ECI process Origin further engaged with Bidders to identify possible cost savings, value improvements and optimising commercial risk mitigations. This process was well supported by Bidders and there were multiple options identified. Origin took those options and risk assessed the likely outcomes with Jacobs to arrive at an estimated cost range of the Project.

Additionally, Origin undertook reviews of three reference projects supplied by bidders to better understand the approaches and risks to PHES works. These reviews identified various approaches to undertaking such projects however some common risks were identified as follows:

✓ Tunnelling risks with each project reviewed encountering a significant problem or having a significant incident;
✓ Groundwater inflows were a significant problem in two of the projects requiring material changes to design and construction;
✓ Project schedules were significantly challenged on all projects due to emergent geotechnical and tunnelling issues therefore having a knock-on effect to the schedule;
✓ Environmental management was a key planning and execution risk given the presence of waterways and public lands;
✓ The long duration of the projects also identified that over the course of the project some suppliers or contractors may cease trading requiring new parties to be found; and
Again, over the long durations of these projects, some projects encountered negative aspects of legislative or market changes.

3.4 Technical Conclusion

The expanded PHES scheme is technically feasible and, in contrast to the existing design, it can be undertaken with a single reversible 235MW Francis machine due to advances in technology since the original construction. Geotechnical conditions present a viable project area and there are no grid connection or other technical issues which would entirely preclude development of the Project.

The Full Feasibility Study identified the following key technical risks:

- Difficulty in performing construction works in the terrain, particularly regarding the pipeline works, necessitating the use of a cable crane to facilitate the works;
- The variability of geotechnical conditions requiring various methods of excavation due to design requirements and safety in execution of the works;
- Direct proximity to the Moreton National Park and private lands and the associated management of environmental and social impacts which may limit construction methodology and timing;
- Execution of the construction and management of the rock spoil, within a Water NSW drinking water catchment zone, to ensure we do not impact the water quality; and
- Fire & Life Safety considerations for management.

And the following key technical opportunities:

- Potential for beneficial ground conditions to enable concrete to be used in several tunnel areas instead of steel lining, therefore reducing costs;
- Possibility to reduce project costs through optimisation of the electrical design and location of the transformer;
- Potential opportunity to dispose of rock spoil adjacent to the expanded site, thereby avoiding vehicle movements in public areas and reducing impact on the local community and environment;
- Optimisation of tunnelling methods and design to facilitate better project value by cost reductions, improved timelines or other value drivers; and
- Optimisation of electrical systems for power evacuation to the substation.

Furthermore, the utilisation of a Reference Design and Owner Requirements (the Volumes) was identified as an optimal approach. The ECI methodology was identified as the preferred approach to the Project as it allows for the Owners Requirements to be embedded into a Contractors Design and Construct contract in an agreed way. Undertaking ECI with a single party can carry a negative risk of committing to a Contractor without a finalised price and design, however this can be mitigated through the ECI process by “Open Book” pricing methodologies and very clear change management processes.
4 Commercial

4.1 Basis for capital costs

In 2019 Origin engaged Jacobs to carry out a Full Feasibility Study for the Shoalhaven PHES Project. The scope of the study involved obtaining an estimation of the capital cost involved. Capital cost estimations received ranged from $570m to $630m, derived from an aggregation of the supplied quotes from shortlisted EPC providers, against a specific tender requirement.

The following indicative breakdown uses the lower bound of $570m as an example;

<table>
<thead>
<tr>
<th>Cost component</th>
<th>Cost ($million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Civil &amp; structural</td>
<td>290</td>
</tr>
<tr>
<td>Equipment</td>
<td>50</td>
</tr>
<tr>
<td>Balance of plant</td>
<td>32</td>
</tr>
<tr>
<td>Other</td>
<td>29</td>
</tr>
<tr>
<td><strong>Direct cost</strong></td>
<td><strong>401</strong></td>
</tr>
<tr>
<td>Indirect cost &amp; contingency</td>
<td>170</td>
</tr>
<tr>
<td><strong>Total cost</strong></td>
<td><strong>571</strong></td>
</tr>
</tbody>
</table>

Indirect costs include a 10% contingency cost.

4.2 Basis of operating costs;

Origin’s estimate of the incremental operating costs of SPHS due to the expansion is approximately $4.6m per annum. The majority of the operating costs relate to the electricity connection cost while the remainder includes staffing and other related expenses. In addition to the above, plant maintenance is expected to average ~$0.9m per annum.

4.3 Overview of the approach to market modelling

4.3.1 Overview of Modelling Methodology

For the consideration and valuation of new energy generation opportunities, Origin has developed a scenario framework approach which represents a range of potential energy market outcomes. New opportunities under consideration are tested against several market scenarios, which are broad enough to capture the range of market dynamics expected to impact a proposed investment decision, such as the decision to expand the existing SPHS.

AEMO’s 2018 Integrated System Plan (ISP) forms the foundational inputs of Origin’s modelling assumptions. The AEMO ISP models a least cost solution to system reliability and security in the NEM over the long term. A summary of AEMO’s modelling approach utilised for the development of the ISP is outlined below;
The 2018 ISP is described by AEMO as “a holistic and technology-neutral approach, integrating existing and new resources on both the supply and demand side, at utility-scale and distributed at consumers’ premises, at the lowest overall consumer expense. It takes into consideration a broad set of thermal and renewable generation, transmission, and storage investment opportunities across the NEM in assessing the requisite transmission development to deliver the ‘least resource cost’ future energy mix. Capital and operating costs for all technologies are provided for reference in the 2018 ISP Assumptions Workbook. The same weighted average cost of capital was applied for all technologies to convert capital costs into an equivalent annual cost stream for assessment”.

For the purposes of valuing the Shoalhaven expansion, Origin has maintained consistency with the inputs of the 2018 AEMO ISP database, unless an assumption leads to an unsustainable market outcome, such as pricing outcomes consistently above new entrant pricing or below operating costs of existing plants. Origin has elected to utilise its own internal viewpoint in determining inputs relating to asset operational behaviours and retirement of existing generation assets.

These scenarios also utilise inputs derived from market announcements (such as transmission planning reports, commitments to development of new assets, closure or retirement announcements) and Origin’s internal expertise developed through the long-term operation and management of a ~6,000MW portfolio of generation assets across the NEM.

Assessing the future market conditions in which a generation asset will operate requires consideration of:

- Forecast market prices for fuel supply (primarily gas and coal);
- Forecast energy demand, including uptake of distributed PV and storage;
- Current and potential energy and emissions reduction policy;
- Forecast new build (including uptake of distributed energy, storage and demand response technologies);
- Forecast technology cost curves;
- Forecast retirement of existing generation fleet;
- Forecast operational performance of existing generation fleet;
- Implementation of demand response technologies; and
- The internal consistency between the input assumptions themselves.
To understand the breadth of possible economic outcomes for a proposed energy generation project, several potential future wholesale electricity price scenarios are utilised for valuation purposes. These scenarios will include a variety of differing assumptions around several key market dynamics that are likely to impact the Project.

Origin’s scenarios, and specific modelling inputs, are developed through consultation with a wide range of subject matter experts across the Origin business and public information, including:

- Load forecasting experts;
- Regulatory and Government Relations teams;
- Third party sourced weather forecasts;
- Economic forecasters (including expertise in fuel price forecasting); and
- Portfolio managers, electricity, gas and financial product trading teams.

This scenario testing approach to financial modelling provides a potential range of investment returns for an expansion of SPHS.

To value a potential pumped hydro opportunity such as the expanded Scheme, Origin has focussed on three market price scenarios to capture the key risks and opportunities to the Project. Each scenario has a multitude of variables, with the key variables (and the variances between scenarios) outlined in detail in this report.

To develop the price forecasts arising from these scenarios, Origin utilises a third-party software ‘PLEXOS’, which is widely utilised by market participants within the Australian energy market. PLEXOS is an energy market simulation tool that allows for multiple inputs (including load, fuel prices, market dynamics, operational and physical constraints) to be considered simultaneously, generating expected half hourly electricity dispatch volumes and half hourly price forecasts across the National Electricity Market to apply to a project valuation.

For the proposed SPHS expansion, the run profile is solved within the model to maximise profit subject to given operating constraints. PLEXOS accounts for the physical hydrology of the water ways including the connection pathways between the storages, the water utilisation rate of each hydro unit and the limitation on water usage under its total water license. The model incorporates a one day 'look ahead' to ensure that there is some discretion around when hydro utilisation occurs. An example of the selectiveness of the dispatch / pumping profile from the modelling is provided in Figure 19.

![Figure 19: Example of a pumping and dispatch regime](image-url)
Once simulated, the outputs of the PLEXOS market analyses are then input into Origin’s in-house financial model to assess the valuation impact to the Project.

4.3.2 Overview of scenarios considered

For the purposes of understanding the range of economic outcomes for a potential pumped hydro project such as the proposed SPHS expansion, Origin has developed and applied three market scenarios.

1. Reference Case
2. Snowy 2.0 Case
3. High Renewables Case

The three market scenarios developed by Origin and the key inputs underpinning them, are outlined in further detail below;

1. Reference Case – Based on AEMO’s 2018 ISP Neutral Case and consistent with a 28% reduction in emissions from the NEM by 2030.

The Neutral case assumed a range of central, or mid-point projections of economic growth, future demand growth and fuel costs. This includes:

<table>
<thead>
<tr>
<th>Inputs</th>
<th>Setting</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand (Economic Growth)</td>
<td>Neutral</td>
<td>Neutral growth outlook for consumption and demand from AEMO’s March 2018 electricity demand forecasts.</td>
</tr>
<tr>
<td>Demand (DER Uptake)</td>
<td>Neutral</td>
<td>Moderate Distributed Energy Technology (DER) uptake, including; Rooftop PV growth continues, providing 12% of underlying consumption by 2030. Battery systems provide up to 10% of operational maximum demand by 2030, and 45% of battery systems are coordinated by 2030. Electric vehicle update is moderate, with 10% of the vehicle fleet electrified by 2030.</td>
</tr>
<tr>
<td>Renewable energy / emissions reductions settings</td>
<td>Renewable energy targets, emission reduction trajectories</td>
<td>All existing announced policies are included, as described by various Governments (LRET, VRET, and QRET). The NEM is assumed to achieve at least a proportionate share of the Commonwealth</td>
</tr>
</tbody>
</table>
Government's emission reduction commitment by 2030, and for emissions to continue a similar path to 2050.

<table>
<thead>
<tr>
<th>Supply Settings</th>
<th>Retirements</th>
<th>The modelling approach for the ISP is one of least cost generation expansion to meet consumer needs within the confines of policy, demand and market settings.</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Supply Settings</th>
<th>Technology Costs</th>
<th>Technology costs have been selected from current, reputable public forecasts. CSIRO's December 2017 projections provide a primary reference.</th>
</tr>
</thead>
</table>

Note that our Reference Case diverts from the ISP’s neutral case assumptions in the areas of expected asset operational behaviour and retirements, instead utilising Origin’s internal viewpoint.

The Origin view taken for retirements and operational behaviour incorporates an iterative approach, benchmarked against economic outcomes with the aim of achieving recovery of fixed and operating costs, if these are not recovered the plant is retired.

2. **Snowy 2.0 Case** - Based on Reference Case with inclusion of the Snowy 2.0 project included from FY2025.

   Snowy 2.0 scenario adopts all assumptions of the Reference Case with the inclusion of the proposed Snowy Hydro expansion – a 2,000MW pumped hydro project with up to 350GWh of storage potential. Snowy 2.0 would be in direct competition with the SPHS expansion and so is a key risk to the Project. The objective of the sensitivity is to examine the potential impact on SPHS operation and revenue stream when the large storage project is developed.

   Snowy 2.0 scheme is modelled in a time sequential model with its hydrology configurations such as waterway and reservoir capacities incorporated. It is assumed to run to maximise profits from the wholesale market. The pumped hydro is operated opportunistically based on the forward view of daily price differentials while considering the round-trip efficiency of the unit. Furthermore, to better capture the arbitrage opportunity between days, the model also incorporates a look ahead function to ensure sufficient storage is available to perform arbitrage across a longer time horizon. Origin has also considered operational limitations such as intra/inter-regional constraints to best mimic the behaviour of Snowy 2.0.

3. **High Renewables Case** - Based on renewable uptake consistent with the AEMO ISP Fast change scenario. Excludes Snowy 2.0.

   This scenario is consistent with delivering a carbon abatement scenario that limits a rise in emissions to maintain temperatures at less than 2 degrees C above pre-industrial levels. This scenario excludes the development of Snowy 2.0. Relative to the Reference Case, the High Renewable scenario considers a future market with higher levels of renewable and utility scale battery penetration. The amount of renewable uptake is consistent with the AEMO ISP fast change scenario, achieving a 52% emission reduction trajectory by 2030. Transmission network upgrades are also considered to adapt to the faster power system transformation. The purpose of this scenario is to examine the impact on investment...
requirement and market benefits of the Scheme when the NEM undertakes a faster transition pace with more renewable energy resources available.

Key changes from the Reference Case used in High Renewables case are:

- Greater uptake of utility scale renewable capacity.
- Faster overall cost reductions in utility-scale storage technologies.

4.3.3 Origin’s forward market outlook

Origin has evaluated the economics of the Project under a range of plausible scenarios of how the NEM may develop over the life of the proposed SPHS project. The main drivers of the range of outcomes relate to the development (or not) of Snowy 2.0, the timing and level of abatement targets and coal retirements.

Interconnection plays a significant role in the supply demand dynamics by allowing capacity sharing between regions. This can be both a risk and an opportunity for the Project depending on the coincidence of tight market supply conditions in NSW with interconnected regions. The 2018 ISP projects that there will be an increase in NSW’s import capability of 3.6 GW by 2040. The assumption is consistent across the scenarios.

Figure 20: Interconnector Capability

Figure 21 illustrates the projected generation mix in NSW across the three scenarios. All scenarios capture that in the long term there is a significant change in the generation mix, characterised by coal retirement and its replacement with renewable generation and storage (both battery and pump hydro). Predominantly this occurs post 2030 which coincides with AEMO’s assumption of coal plant having a 50-year life.

The Reference case is relatively unchanged until the retirement of Eraring (2032, as announced by Origin), increased import capability into NSW (an additional 1.5 GW by 2034 and 3.6GW by 2040) and
increasing renewables, which also displaces energy from the remaining coal fleet. Storage (including a potential expansion of the SPHS) shifts significant amounts of solar PV from the middle of the day to the peak demand periods.

The Snowy 2.0 case has a similar generation mix to the Reference case, although with increased storage capacity, additional solar generation can occur due to higher midday loads. Coal generation is reduced as a result. Being in direct competition with SPHS and with similar supply-demand outcomes to the Reference case, this case represents a downside risk to the Project.

The High Renewables case sees renewable generation come online earlier than the other cases and provides an opportunity for SPHS to capitalise on the resulting price swings, until other storage enters the market. In this scenario the increased renewables are predominantly from solar, meaning there is a greater role for storage to play in balancing.

4.4 Analysis of historical spot price arbitrage

The following section analyses the historical opportunity for spot price arbitrage. For the purposes of this analysis, spot prices have been capped at $300/MWh. Peaking generation, such as pumped hydro, can provide a hedge against very high prices (e.g. over $300/MWh). This ‘insurance’ is often more valuable than measured directly from spot price outcomes and a price series such as ASX $300 Cap prices provides a better measure of value.

This analysis examines two potential modes of operation, two hour operation and five hour operation. Two hour operation refers to a pumped hydro scheme that generates during the four highest priced half-hour periods of a day and pumps during the four lowest priced half-hours periods. Five hour operation refers to a pumped hydro scheme that generates during the ten highest priced half-hour periods of a day and pumps during the ten lowest priced half-hours periods. The annual spot price arbitrage revenue is then calculated as the revenue received from generating electricity less the cost of electricity due to pumping.
Figure 22 and Table 1 below show:

- the average price profile for each hour of the day for selected years,
- the average daily price spread for two modes of pumped hydro operation, and
- the annual spot price arbitrage revenue for two modes of pumped hydro operation.

### Average price profile for each hour of the day for selected years

![Average price profile for each hour of the day for selected years](image)

**Figure 22: Typical Daily Price Profile FY2011, FY2015 and FY2019**

### Table 5: Average Price Spread and Spot Price Arbitrage Revenue FY2011, FY2015 and FY2019

<table>
<thead>
<tr>
<th>Financial Year</th>
<th>Average Price Spread ($/MWh)</th>
<th>Spot Price Arbitrage Revenue ($ per MW p.a.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2 Hr Mode 5 Hr Mode</td>
<td>2 Hr Mode 5 Hr Mode</td>
</tr>
<tr>
<td>2011</td>
<td>22 17</td>
<td>12,000 20,000</td>
</tr>
<tr>
<td>2015</td>
<td>30 21</td>
<td>16,000 24,000</td>
</tr>
<tr>
<td>2019</td>
<td>95 70</td>
<td>56,000 91,000</td>
</tr>
</tbody>
</table>

**Figure 22: Typical Daily Price Profile FY2011, FY2015 and FY2019**

Since 2015, the opportunity for spot price arbitrage has increased. While price levels rose during all hours of the day, the price increases were larger in the evening peak hours than in the early morning off-peak hours leading to a greater daily price spread. In 2019, a pumped hydro in 2 hour operation mode would have earned an average spread of ~$95/MWh and an annual spot price arbitrage revenue of $56,000 per MW p.a and a pumped hydro in 5-hour operation mode would have earned an average spread of ~$70/MWh and an annual spot price arbitrage revenue of $91,000 per MW p.a.
Throughout the historical period, the general trend is that the lowest prices are in the early morning and the highest prices are in the evening. In the future, it is expected that low priced periods will also occur during hours of high solar generation.

4.5 Analysis of Historical Pumped Hydro Revenue Opportunity

A combined revenue opportunity for a pumped hydro can be calculated by combining revenue from:
1. spot price arbitrage from prices below $300/MWh (discussed in the prior section)
2. selling ‘insurance’ that protects the buyer against very high prices

For this purpose, the ASX $300 Cap price is used as a proxy for the historical value of protection against very high prices. The table below shows the total revenue opportunity during 2017 to 2019 for a pumped hydro operating in 5 hr mode.

<table>
<thead>
<tr>
<th></th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spot Price Arbitrage Revenue</strong></td>
<td>83,000</td>
<td>45,000</td>
<td>91,000</td>
</tr>
<tr>
<td><strong>ASX Cap Revenue</strong></td>
<td>53,000</td>
<td>103,000</td>
<td>58,000</td>
</tr>
<tr>
<td><strong>Combined Revenue</strong></td>
<td>136,000</td>
<td>148,000</td>
<td>149,000</td>
</tr>
</tbody>
</table>

4.6 Analysis and modelling of the future potential ancillary service market revenues

4.6.1 Ancillary Services Markets Overview

In the NEM, there is a market for Frequency Control Ancillary Services (FCAS). There are also non-market ancillary services such as Network Control services and System Restart services. These services are procured by AEMO under long-term contracts. This section focuses on FCAS services.

4.6.2 FCAS Markets

FCAS services are used by AEMO to ensure that the frequency of the electrical system is maintained at close to 50 hertz. FCAS consists of regulation services and contingency services. Regulation services are continually used to correct for minor changes in the demand / supply balance while contingency services are used to correct the demand supply balance when a major contingency event occurs, such as the loss of a generating unit, major industrial load, or a large transmission element.

FCAS is also split into raise services and lower services. Raise services are used to raise the frequency of the system and require additional generation or a reduction in load. Lower services are used to lower the frequency of the system and require a reduction in generation or an increase in load. FCAS contingency services are then split further into three different response times (six second, sixty second and five minutes).

FCAS services are procured by AEMO based on a bidding system. When a FCAS provider's bid is accepted, their unit is enabled to provide that FCAS service and they will be paid the FCAS service price regardless of whether that unit is called upon to raise or lower the frequency of the system. Once enabled, a unit must be capable of providing that FCAS service. In the case of a generator, this requires the unit to be able to raise its generation to provide raise or lower its generation to provide lower. In the case of a pump this requires the unit to lower its pumping to provide raise or raise its pumping to provide lower.
In comparison to the energy market, FCAS markets are small and, if the unit is technically capable, individual units can be enabled in multiple FCAS markets. In Q4 2019, AEMO procured on average 467 MW of regulation services (across both raise and lower) and 1,963 MW of contingency services (across all six contingency markets). Fluctuations in FCAS demand can be driven from local FCAS requirements being imposed when contingent transmission events occur. These events often lead to increases in the prices of the FCAS commodities that find themselves in short supply.

The figure below shows the average FCAS price by quarter during CY2019 for each service. This shows that:

- the most valuable services are raise and lower regulation,
- the value in the three raise contingency services is smaller, and
- there is negligible value in the three lower contingency services.

4.6.3 Existing Pumped Hydro and FCAS

Of the three pumped hydro units currently in the NEM (Shoalhaven, Wivenhoe and Tumut 3), only Wivenhoe and Tumut 3 are registered for FCAS. Wivenhoe (pumping and generating) and Tumut 3
(pumping) are primarily only registered for raise contingency services. Tumut 3 (generator) is registered for all services but it should be noted that Tumut 3 is hydro powerplant capable of pumping so has a capacity factor higher than would be expected from a pure pumped hydro facility.

Table 7: Pumped Hydro FCAS Registrations

<table>
<thead>
<tr>
<th></th>
<th>Shoalhaven Generator</th>
<th>Shoalhaven Pump</th>
<th>Wivenhoe Generator</th>
<th>Wivenhoe Pump</th>
<th>Tumut 3 Generator</th>
<th>Tumut 3 Pump</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raise - Reg</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>500 MW</td>
<td>-</td>
</tr>
<tr>
<td>Lower - Reg</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>500 MW</td>
<td>-</td>
</tr>
<tr>
<td>Raise – 6s</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>490 MW</td>
<td>60 MW 800 MW</td>
</tr>
<tr>
<td>Raise – 60s</td>
<td>-</td>
<td>-</td>
<td>570 MW</td>
<td>490 MW</td>
<td>250 MW</td>
<td>1200 MW</td>
</tr>
<tr>
<td>Raise – 5min</td>
<td>-</td>
<td>-</td>
<td>570 MW</td>
<td>490 MW</td>
<td>500 MW</td>
<td>600 MW</td>
</tr>
<tr>
<td>Lower – 6s</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>40 MW</td>
<td>-</td>
</tr>
<tr>
<td>Lower – 60s</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>500 MW</td>
<td>-</td>
</tr>
<tr>
<td>Lower – 5min</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>500 MW</td>
<td>200 MW</td>
</tr>
</tbody>
</table>

Source: AEMO

4.6.4 Shoalhaven Expansion and FCAS

Under usual operating conditions, Shoalhaven Expansion is expected to be generating during periods of high prices, pumping during period of low prices and otherwise idle. When not in operation, it is difficult to provide FCAS services due to the time it takes to move a large column of water. When generating, Shoalhaven expansion (with appropriate control systems) could provide all FCAS services however, there would be an opportunity cost in providing FCAS raise services as Shoalhaven would need to generate at less than full capacity while enabled for FCAS raise. Similarly, when pumping, Shoalhaven expansion could provide all FCAS services however, there would be an opportunity cost in providing lower services as Shoalhaven would need to pump at less than full capacity.

Example of Raise Opportunity Cost when Generating

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Current Market Price</td>
<td>$90/MWh</td>
</tr>
<tr>
<td>Average Pumping Price</td>
<td>$30/MWh</td>
</tr>
<tr>
<td>Margin from Generating</td>
<td>$60/MWh</td>
</tr>
<tr>
<td>FCAS price required to supply FCAS &amp; not generate</td>
<td>$60/MWh</td>
</tr>
</tbody>
</table>

4.6.5 Future Supply of FCAS

Batteries and demand response are starting to become major suppliers of FCAS, particularly in the more valuable raise FCAS markets. In Q4 2019, the supply of FCAS from batteries was on average 204 MW higher than the same quarter in 2018.

Figure 25: Change in FCAS Supply by Source (Q4 2019 versus Q4 2018) Source: AEMO
Batteries, which tend to have a large output capacity but limited energy storage, are very well suited to suppling FCAS as this service is paid based on the capacity enabled and supplying FCAS does not generally require a large amount of energy. It is expected that batteries and demand response share of FCAS supply will continue to increase.

4.6.6 Shoalhaven Expansion FCAS Value

FCAS is not expected to be a significant value driver for the Shoalhaven Expansion Project. Shoalhaven expansion could be technically capable of suppling FCAS while operating if investment is made in the appropriate systems. However, pumped hydro is not well suited to supplying FCAS as it is difficult to supply FCAS when idle and, when operating, there will generally be an opportunity cost to providing FCAS services.

Furthermore, it is very difficult to be confident that pumped hydro will benefit materially from FCAS markets over pumped hydro’s 50 + year life. This is due in part to the small size of FCAS markets. Given the market size, small changes in how AEMO operates the FCAS markets or changes in the supply demand balance can have significant impact on price outcomes and the trend towards batteries and demand response entering the FCAS markets is likely to put downward pressure on prices.

4.7 Project economics

The following section describes the economics for the proposed expansion.

4.7.1 Revenue Sources

Three revenue sources have been considered for SPHS expansion. These are:

- spot price arbitrage excludes prices over $300/MWh
- selling ‘insurance’ against very high prices
- FCAS

Of these revenue sources, spot price arbitrage and selling ‘insurance’ against high prices are the primary revenue sources. FCAS is not expected to be a significant revenue source.

Figure 26 shows the forecast revenue for SPHS expansion under the market scenarios described in Section 4.3. Under the Reference Case, the annual revenue increases from current high levels to forecast levels of $170,000 – $180,000 per MW p.a. The addition of Snowy 2.0 has a large impact on the forecast revenues reducing revenues to ~$110,000 per MW p.a. immediately after Snowy 2.0 comes on-line. Forecast revenues then slowly return to close to current levels reaching ~$150,000 per MW p.a. in 2035.
4.7.2 Costs

Pumped hydro projects are very capital intensive. For the expansion, the primary cost is the $570 - $630m of capital to build the Project. At ~$2.5 million per MW of capacity, the capital costs are 15 to 20 times the forecast annual revenue. Operational expenses are expected to be approximately ~$5.5m p.a. This excludes electricity costs associated with pumping which is included in the arbitrage revenue.

4.7.3 Project Economics Summary

The economics of the Shoalhaven expansion under the current and forecast market conditions are challenging. In order for the expansion to proceed, either the capital (equipment and construction) costs need to reduce or the forecast revenues need to increase for the Project to achieve a level of commercial return consistent with Origin’s investment criteria.

The table below compares the typical annual forecast revenue over the life of the Project under Origin’s market scenarios with the annual costs. The capital charge is based on the revenue required to give typical commercial returns on capital.

<table>
<thead>
<tr>
<th></th>
<th>Reference Case</th>
<th>Snowy 2.0 Case</th>
<th>High Renewables Case</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Annual Revenues</strong></td>
<td>$165,000</td>
<td>$125,000</td>
<td>$140,000</td>
</tr>
<tr>
<td><strong>Operating Costs</strong></td>
<td></td>
<td>$23,000</td>
<td></td>
</tr>
<tr>
<td><strong>Capital Charge</strong></td>
<td></td>
<td>$170,000 - $285,000</td>
<td></td>
</tr>
<tr>
<td><strong>Total Costs</strong></td>
<td>$190,000 - $310,000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.7.4 Pumped Hydro versus Batteries

A pumped hydro plant is akin to a large battery. Both can store energy which in the case of pumped hydro is potential energy and in the case of a battery is chemical energy. This stored energy is then converted to electrical energy when required.

The benefit of pumped hydro is the greater amount of energy storage generally available compared to a large battery. While both store energy, there are important differences. A battery can react very quickly and operate in markets which require very fast response whereas pumped hydro requires moving a column of water resulting in a delayed response if called upon when not operational.

The project costs relate primarily to powerplant items such as turbines, generators and water conveyance. As this Project is an expansion of an existing pumped hydro scheme and does not involve increasing the capacity of the associated reservoirs, the cost of the Project would not change significantly if a lower amount of energy storage was required. There are generally large economies of scale with pumped hydro projects resulting in few projects proposing storage levels less than 6 – 8 hours. On the other hand, battery costs are predominantly driven by the amount of energy storage required therefore increasing storage has more limited economies of scale.

The difference between pumped hydro and batteries can be shown clearly on a Levelised Cost of Storage Basis. The Levelised Cost of Storage amortises the capital cost of a storage project across the
amount of energy that is expected to be stored throughout the life of the project. It can be interpreted as the minimum revenue required to give a commercial return on the cost to build a storage project. Figure 27 below shows that for low levels of energy storage, pumped hydro is more expensive than batteries but at higher levels of storage, pumped hydro becomes the cheaper option. Industry forecasts point to a decline in battery costs as a result of technology advancements and manufacturing economies of scale. This leads to an expectation that batteries will become a cheaper option than pumped hydro at increasingly larger levels of energy storage.

Figure 27: Levelised Cost of Storage

![Graph showing Levelised Cost of Storage](image)

Figure 27 illustrates that batteries are better suited to meet frequent short duration energy shifting than pumped hydro. Pumped hydro is better suited than batteries to provide longer duration energy shifting.

It should be noted that while increasing the amount of storage decreases the cost of pumped hydro on a $ per MWh of energy storage basis, there are also diminishing marginal returns in increasing the amount of energy storage. The first hour of energy storage captures the largest spread and is used the most frequently. Each additional hour of available storage captures a lower spread and is used less frequently until some energy storage is not used because there are insufficient hours of spread available in the day.

An important distinction between batteries and pumped hydro is that the faster response capability of batteries enables them to take part in the FCAS markets. Batteries are particularly well suited to supply FCAS as generally FCAS markets do not require significant levels of energy storage.

4.7.5 Pumped Hydro versus Demand-Side Management (DSM) Resources

Demand-Side Management (DSM) resources refer to customer load reductions or generation from customers’ embedded generators. Customers use DSM resources to decrease their energy costs through reducing the network charges that they incur and reducing their exposure to high energy prices if they are not on fixed-price energy contracts.

A retailer can make arrangements with the customer so that the retailer can call on the customer’s DSM resources. The details of these arrangements vary, but through these a retailer could use DSM
resources to help manage their peak demand providing retailers with an alternative option to peaking generation such as pumped hydro. There has also been activity to aggregate DSM resources and bid them into FCAS markets.

A key benefit of pumped hydro over DSM resources is that pumped hydro can be used on a daily basis to pump when prices are low and generate when prices are high but not necessarily at extreme levels where customers are willing to undertake load reductions.

4.8 Key commercial risks and opportunities of the development

The Full Feasibility Study identified the following key opportunities of the expansion:

- Increasing opportunity to capture the arbitrage value between periods of low demand and prices to higher demand, particularly with the increasing penetration of non-dispatchable renewable energy.
- Ability to utilise the benefits of existing pumped hydro and dam infrastructure at Shoalhaven to develop a competitive “brownfield” opportunity.
- Significance of the energy storage capacity of PHES when compared with batteries, and Demand Side Response mechanisms, to provide storage to the NEM.

The Full Feasibility Study identified the following key risks of the expansion:

- The capital costs of the Project, as identified through the Request for Tender, were significantly higher than predicted in the Pre-Feasibility Study.
- The capital costs are also subject to changes in the exchange rate against the Euro and US Dollar, which was significant less favourable at the completion of the Full Feasibility Study than at the commencement.
- Revenue generated by PHES projects in the NEM is likely to be significantly impacted by the development of Snowy 2.0.
- The suitability of Batteries to provide FCAS to the NEM, relative to the capability of PHES, reduces the revenue available to all PHES units, including Shoalhaven.
Development

5.1 Development Approach

The expansion of the Shoalhaven PHES Scheme is unique in relation to PHES development and the relative planning needs for the following reasons:

- The Project was identified as both State Significant Infrastructure and State Significant Development by NSW Government;
- No new dams are required;
- No new transmission is required;
- Although the development would pass underneath a National Park, no new disturbance on the surface of the National Park is required; and
- Additional and/or more resilient water transfer capacity could be made available to Water NSW for drought mitigation.

In relation to the planning approvals for the Project it has been required to be developed in two distinct stages as follows:

- Shoalhaven Hydro Geotechnical Investigation Works – covering the works required to undertake geotechnical drilling to inform the project of ground conditions allowing for more accurate design and costing of the Project. These works were, in terms of development, low impact and of a short timeframe; and
- Shoalhaven Hydro Main Works – covering the full construction of the Project post the Geotechnical Investigation. These works would likely span approximately 4 to 5 years and be of a more significant impact to the local area due to the scale of construction and the associated activities and workforce.

It is important to acknowledge the historical and legislative context in which the Project was proposed, when reviewing the approvals process. PHES plants have not been developed in Australia for a number of decades and were traditionally developed by Government Agencies as an essential infrastructure service. Such projects were therefore afforded various legal dispensations that private developers would not be granted in similar situations. The global environmental landscape has also changed dramatically since the development of the original Scheme, which has resulted in a much more regulated process to obtain environmental planning approvals for development, either public or private in nature.

The unique location and nature of the Project also contributed to challenges associated with the ability to obtain approvals, as well as land tenure. The site is located within a number of sensitive environments, including the Moreton National Park, and the Lake Yarrunga water catchment which provides a source of drinking water for the Sydney Basin. Furthermore, although much of the existing site is located on freehold land, the existing pipelines traverse under a section of the Moreton National Park on the escarpment, where an easement is not in place.

Therefore, the approvals process for the Project is complex and presents a number of risks and challenges for the Project.

5.2 Value of the Development

The National Electricity Market (NEM) has seen dynamic evolution in recent times with the mass development of non-scheduled or semi-scheduled renewable generation often referred to as non-dispatchable generation. Such generation projects provide for a substantial reduction in emissions and cost to serve, however energy is often not produced in line with grid demands.

A significant benefit of the Shoalhaven PHES Project is its ability to store non-dispatchable generation and return the energy to the NEM as customer demands require. This storage of cheaper renewable
energy for dispatch over higher priced periods of the day acts to reduce the overall cost of electricity in
the NEM and to the customer. Several current projects and other proposed projects also seek to solve
this energy storage need, however the Shoalhaven PHES Project does provide for a largely differential
benefit as compared to others.

Two such projects which can be contrasted with the Shoalhaven PHES Project are the Hornsdale Power
Reserve and Snowy 2.0. Each of these are significant energy storage projects however with subtle
differences, thereby providing value in differential ways.

Whilst the Hornsdale Power Reserve may act very quickly, it has a limited duration output of a little over
one hour and has a short asset life prior to requiring new battery cells. This is contrasted by the massive
2000MW/175hr Snowy 2.0 project which requires significant transmission infrastructure leading to
increased network costs to users. The Shoalhaven Expansion Project has a similar asset life and
efficiency to Snowy 2.0 however is significant in the fact that it does not require new transmission.
Additionally, Shoalhaven provides for a lower minimum load allowing for better matching between the
NEM load and non-dispatchable generation where load balancing is required.

The Shoalhaven PHES Project concept is moderate in size therefore producing lower regional risks in
the event of drought, earthquake, bushfire and other locality based events, placing only 235MW at risk
in such an event. A loss of 235MW is well below the largest generating unit in the NEM and therefore
would not result in significant impacts to energy supply. Developments of such size diversified across
the NEM not only support the concepts of the Renewable Energy Zones but reduces the risk of large
projects i.e. Snowy 2.0 at 2000MW, being lost due to a natural disaster event. In consideration of the
2019/20 bushfire season in the Snowy Mountains a possibility of classifying both the original Snowy
units plus Snowy 2.0 as Credible Contingencies or in fact requiring to cease generation could have
significant impact to the NEM.

Storage projects in general, and particularly the Shoalhaven Project due to its size and combination with
existing Scheme units, will have the effect of reducing market volatility. The volatility currently seen is
partially due to the lack of energy storage and non-dispatchable generation having a timing mismatch
with normal load demand curves which can be alleviated by energy storage projects. The combination
of units in the Shoalhaven scheme provide the ability to operate for 6 to 8 hours at peak output or for
much longer durations utilising reduced load combinations across the 5 units.

Additionally, the Project has the ability to operate in multiple modes supporting the NEM and transition
to renewables. The available modes are as follows:

- Generating energy providing active power, reactive power as well as frequency support and
  inertia to the NEM;
- Pumping water recharging the energy storage, transferring drinking water and absorbing excess
  non-dispatchable generation;
- Synchronous condensing in either pump or generation direction providing reactive power
  support; and
- System Restart Ancillary Service (SRAS) capability supporting the NEM in a “black grid”
  scenario.

The Shoalhaven Project has the ability to bring firming generation and load balancing to markets
substantially supporting the advancement of non-dispatchable renewables. The Project is moderate in
size limiting risks from regional failure exposures which is beneficial to ensuring energy security and
avoiding transmission expansions and therefore costs to consumers.

5.3 Approvals Process
In order to streamline the approvals process, Origin sought a declaration from the Minister for Planning
to have the Project declared as a ‘Critical State Significant Development’ (CSSI). In December 2018,
the Minister declared the Projects as CSSI, due to its importance to NSW’s future energy security. While
being declared ‘critical’, the Project remains subject to detailed community consultation and a full and thorough environmental assessment in accordance with NSW Government policies and standards.

This declaration enabled a coordinated approach to approvals, for both the geotechnical investigations and the Project. An Environmental Impact Statement (EIS) was prepared to obtain approval for construction of eight geotechnical boreholes which were required to better understand the underlying geology of the proposed cavern site and tunnelling routes. The EIS was publicly notified in March 2019, nine submissions were received from government agencies, and only one objection was received from a public submitter.

All matters raised in the government submissions were able to be addressed, and the (then) Department of Planning and Environment granted approval on 17 June 2019.

Origin has received the Secretary’s Environmental Assessment Requirements (SEARS) for the main Project and will prepare a full EIS if the Project becomes more viable at a future point.

5.4 Key risks and challenges for approvals

As previously identified, a number of risks and challenges relating to approvals and tenure were encountered through the process.

The first challenge was the decision by NSW Department of Planning that a full Development Approval was required for the Geotechnical Investigation Works. This required a significant amount of work to comply with this decision, whereas opportunities may have existed for a more streamlined approach to such minor works. Such approaches to minor works are more readily available to other entities maintaining similar water infrastructure or transmission infrastructure.

Legislative requirements to achieve easements, or similar tenure, for the penstock to traverse under the Moreton National Park at a significant depth also remain as a risk to the Project. There is no concern raised by any assessment as to an impact on the park however there is a premise that the park exists to an unlimited depth, potentially constraining the development. Similar matters could exist for traversing under private lands however this is a more common situation encountered and solved on roadway, sewer and other suburban infrastructure projects.

A risk remains in relation to the transport of some of the major equipment to the site via road. A transport route has been identified to move larger equipment from Port of Sydney via Mittagong to the site. This route is somewhat constrained by the steep inclines and tight turns on Moss Vale (B73) Road in the Barrengarry area. Transport specialists confirmed that movement down the incline with the required generator transformer would not be possible with a traditional “Low Loader” truck arrangement due to the length of the truck and trailer combinations. The use of a Self Propelled Modular Trailer (SPMT) was identified as a solution for the short incline with the transformer being moved by a low loader configuration for the vast majority of the trip and via SPMT for the identified section only. The transport specialists consulted identified however that Transport for NSW have not previously agreed to enable the use of SPMT units on a public road as they do not meet registration requirements. An example of a SPMT unit is shown in Figure 28.
Origin believes that these matters can be solved, however this will require co-operation from Government and Regulatory bodies to facilitate the solutions.

6 Conclusion

Origin’s Full Feasibility Study of the expansion of the Shoalhaven Pumped Hydro Scheme determined that the addition of a 235MW unit is technically feasible. However, the Study also determined that the expansion of the scheme is not commercially feasible in the current economic and regulatory conditions.

Origin has paused the development of the Project; however the additional unit remains an option for further exploration pending beneficial changes to the economic and regulatory environment influencing the Shoalhaven Pumped Hydro Scheme. Origin will continue to consider this expansion Project as an option for development in the future.