Battery of the Nation – Tasmanian pumped hydro in Australia's future electricity market.

Concept Study
Knowledge sharing report

April 2018

Contents

Hydro Tasmania Standard			
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1.0 Executive summary

Potential development of new pumped hydro energy storage (pumped hydro) projects in Tasmania could play an important role in supporting the National Electricity Market (NEM) transition to variable low emissions sources of generation. With the forecast increase of variable, renewable energy penetration into the NEM, the system support and energy security provided by additional hydropower capacity and energy storage would assist in achieving a secure, reliable future grid.

While significant investment is being made in new technologies such as grid scale batteries and solar thermal projects, pumped hydro remains the only viable technology for longer term storage (greater than eight hours).

Future energy markets in Australia will value the services needed by the system operators to help manage the variability of the major generation sources. The magnitude and type of those services will depend on the characteristics of each region, particularly with reference to the need for short term versus longer term firming. Energy storage of various forms is expected to play a major role in the provision of these services.

To understand the potential for pumped hydro in Tasmania, a concept study assessing project options has been completed by Hydro Tasmania (this study). This study received funding from the Australian Renewable Energy Agency (ARENA) as part of ARENA's Advancing Renewables Program.

This concept study has demonstrated that pumped hydro project opportunities in Tasmania which are likely to be technically and economically viable, could deliver an additional 2500 MW of storage capacity (more than doubling Tasmania's current capacity).The study has identified that suitable options to utilise existing hydro infrastructure in Tasmania for pumped hydro development exist and warrant further investigation. The concept study considered a wide range of potential options; however, the significant advantages of utilising existing hydro infrastructure in Tasmania were recognised early in the screening process.

Further study is required to validate assumptions used in the concept study and to identify project siting and design options that address technical, economic, social and environmental risks. In parallel, studies are underway that aim to prove the viability of pumped hydro storage in the Tasmanian and NEM context including consideration of future market scenarios and investment in additional interconnection.

The concept study has reduced a list of over 2000 potential pumped hydro options to a selection of 14 options. These options have been selected through high level technical assessment of project sites and rapid workshop assessments with a wide range of internal stakeholders from technical and scientific disciplines across the Hydro Tasmania group.

The selected options are those deemed most likely to meet key project and sustainable development objectives based on early stage analysis and will be further assessed as part of the next phase of study which is pre-feasibility. If further investigations show the selected sites do not meet these objectives, other alternative sites may be considered.

The 14 selected options represent up to about 4800 MW of cumulative installed capacity, with up to 140,000 MWh of energy in storage and high level capital cost estimates in the range of $1.1m/MW to $2.3m/MW of installed capacity. The number of selected options will be reduced further during pre-feasibility studies to meet a target of 2500 MW combined installed capacity.

While considerable pumped hydro opportunities exist in Tasmania, fully unlocking these opportunities will require additional interconnection with mainland Australia. TasNetworks is currently assessing the business case for a second interconnector with the support of ARENA.

The 14 options selected that will be assessed during pre-feasibility are described in the following table.

Option Name	Scheme Location	Nominal Capacity (MW)	Energy in Storage (MWh)	Est Unit Cost ($m/MW)	Upper Storage	Lower Storage	Comment
Conversion of existing power stations							
Wilmot Power Station Redevelopment	Mersey-Forth	32	7900	1.5	Lake Gairdner	Lake Cethana	The existing power station would be used for generation mode and a separate new surface or underground station tapped into the existing reservoirs for pumping operation.
Cethana Power Station Redevelopment	Mersey-Forth	100	9600	1.5	Lake Cethana	Lake Barrington	
Lemonthyme Power Station Redevelopment	Mersey-Forth	54	2200	1.5	Lake Parangana	Lake Cethana	
Tribute Power Station Redevelopment	West Coast	84	26 900	1.5	Lake Plimsoll	Lake Murchison	
Connecting existing storages							
Margaret – Burbury	West Coast	800	15 100	1.4	Lake Margaret	Lake Burbury	The reservoirs would connect with new tunnels and a new underground power station.
Wilmot	Mersey-Forth	270	3872	2.3	Lake Gairdner	Lake Cethana	
Tribute	West Coast	500	14 000	1.8	Lake Plimsoll	Lake Murchison	
Connecting existing storages to new off-stream reservoirs							
Lake Cethana	Mersey-Forth	600	8400	1.1	New	Lake Cethana	New off-stream reservoirs would be developed above or below existing reservoirs. The reservoirs would connect with tunnels or a combination of tunnels and surface pipelines to a new underground power station adjacent to the existing reservoir.
Lake Rowallan	Mersey-Forth	600	16 700	1.3	New	Lake Rowallan	
Lake Parangana	Mersey-Forth	300	2100	1.4	New	Lake Parangana	
Lake Margaret	West Coast	300	1800	1.7	New	Lake Margaret	
Lake Rosebery	West Coast	400	3600	1.2	New	Lake Rosebery	
Lake Echo	Derwent	200	2,000	2.3	New	Lake Echo	
Poatina	*yingina* / Great Lake	600	28 200	1.8	*yingina* / Great Lake	New	

Next phase

The objective of the next phase of investigations is to complete pre-feasibility studies for the selected options. Pre-feasibility studies will be undertaken over a period of 12 months. Completion of the pre-feasibility studies will inform which sites are suitable to proceed to full feasibility study.

If market signals, such as approval for development of a second interconnector between Tasmania and mainland Australia, suggest implementation of a pumped hydro project should occur in the near term, the feasibility study of a selected project could begin prior to completion of the program of pre-feasibility studies. Sites that may be selected to proceed to development stage following full feasibility study would be subject to development approvals processes.

Lessons learnt

The study approach resulted in a different set of potential Tasmanian projects being identified compared with previous studies conducted by Hydro Tasmania. This was not unexpected and is considered a good outcome since earlier studies were conducted without a future market context.

The involvement of a range of Hydro Tasmania and Entura subject matter experts from various disciplines in developing and applying assessment criteria brought great value to the project, particularly in applying criteria to reduce the list of over 2000 sites to 14 selected options.

Subject matter experts within Hydro Tasmania involved in assessing the options included those with knowledge of; existing hydro-electric schemes (storages and cascades), existing and potential transmission options, technical complexity associated with construction and operation of pump storage options at selected sites, environmental values associated with potential options and community and regional values potentially affected by the options.

Utilising Hydro Tasmania's knowledge of the existing hydropower infrastructure enabled decades of experience in operating Tasmanian hydropower schemes and mitigating various risks to be captured and applied to the studies.

By utilising an internationally recognised framework for the development process (in this case the International Hydropower Association (IHA) Hydropower Sustainability Assessment Protocol) key sustainability considerations including environmental, social, technical and economic aspects have been incorporated at an early stage.

2.0 Introduction

The *Battery of the Nation* initiative is investigating and developing a pathway of future development opportunities for Tasmania to make a greater contribution to the NEM.

With the support of Australian Renewable Energy Agency (ARENA) funding, Hydro Tasmania is undertaking studies into:

- Tasmanian future state NEM analysis;
- Pumped hydro energy storage[1] (pumped hydro) assessment; and
- Augmentation and improvement of the existing Tasmanian hydropower scheme.

This concept study has developed a list of potential pumped hydro sites in Tasmania that represent over 4800 MW of pumped hydro storage capacity in Tasmania. These options will be the subject of pre-feasibility studies which will reduce the list to 2500 MW of pumped hydro potential.

Previous studies have identified a number of potential pumped hydro sites in Tasmania. While many of these potential sites have merit, it is noted that each of the previous studies had its own objectives and assumptions. Therefore, it could not be ascertained that all possible sites had been identified.

To address this concern, this concept study has developed and implemented a methodology to:

- Review previous studies;
- Identify new potential pumped hydro project sites across Tasmania; and
- Screen all potential sites in a staged screening process to produce a list for future pre-feasibility studies.

2.1 Purpose of this report

This report describes:

- Pumped hydro energy storage and the key considerations in developing pumped hydro in Australia;
- The process developed and utilised to arrive at a list of selected sites for pumped hydro in Tasmania;
- Technical considerations in planning a pumped hydro project;
- The basis for estimating the capital and operating costs of pumped hydro projects;
- Land access, connection and environmental aspects to be addressed in developing a pumped hydro project in Tasmania; and
- The next steps in the process of developing up to 2500MW of pumped hydro capacity in Tasmania.

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[1] Pumped Hydro Energy Storage (Pumped Hydro); other terminologies such as Pumped Storage Project have been used in the other studies.

2.2 Glossary

$ / MW	Dollar per Megawatt
$ / MWh	Dollar per Megawatt Hour
AC	Alternating current
AEMO	Australian Energy Market Operator
E&M	Electrical and mechanical
FSL	Full Supply Level
GL	Gigalitres
GWh	Gigawatt Hour
HT	Hydro Tasmania
km^2	Square kilometres
m	Metre
m/s	Metres per second
m^3/s	Cubic metres per second
mAHD	Meter Australian Height Datum
Mm^3	Million Cubic Metres
MOL	Minimum operating level
MW	Megawatt
MWh	Megawatt Hour
NEM	National Electricity Market
TWh	Terawatt Hour

3.0 Pumped Hydro Energy Storage

3.1 Description of asset class

As the proportion of variable renewable energy (such as wind and solar) in an energy market increases, the need grows for system stability and consistency provided by utility-scale energy storage.

A functioning AC power system needs inertia, fault level, frequency and voltage control as well as energy sources to function to an acceptable standard.

Pumped hydro assets can provide all of these important contributions to a stable and reliable power system, levelling out the variability of wind and solar energy, and helping to regulate voltage and frequency.

Pumped hydro energy storage is a proven technology that is ideally suited to an energy market with higher penetration of variable renewables.

Energy storage devices like batteries and pumped hydro energy storage will become much more important in the future as Australia seeks to replace coal-fired power and get more energy from other sources, including solar and wind. This is because energy storage systems help balance energy from variable sources.

An energy system that increasingly relies on variable generation (such as wind and solar) will have extended periods of low energy production, when the sun isn't shining and the wind isn't blowing. It will need to be balanced with systems that can provide reliable energy in bulk and on demand for sustained periods.

When it comes to clean energy storage on a very big scale, the opportunity is in pumped hydro.

Conventional hydropower systems collect water in a lake or reservoir on higher ground. The water is run downhill to spin a turbine in the station below, generating electricity.

Pumped hydro energy storage systems have an upper reservoir and a lower reservoir.

The water is stored in an upper reservoir and run through a turbine to a lower reservoir when electricity is needed – such as when the sun is not shining or the wind is not blowing.

The water can then be pumped back uphill when there is excess electricity in the system (which often happens with wind and solar).

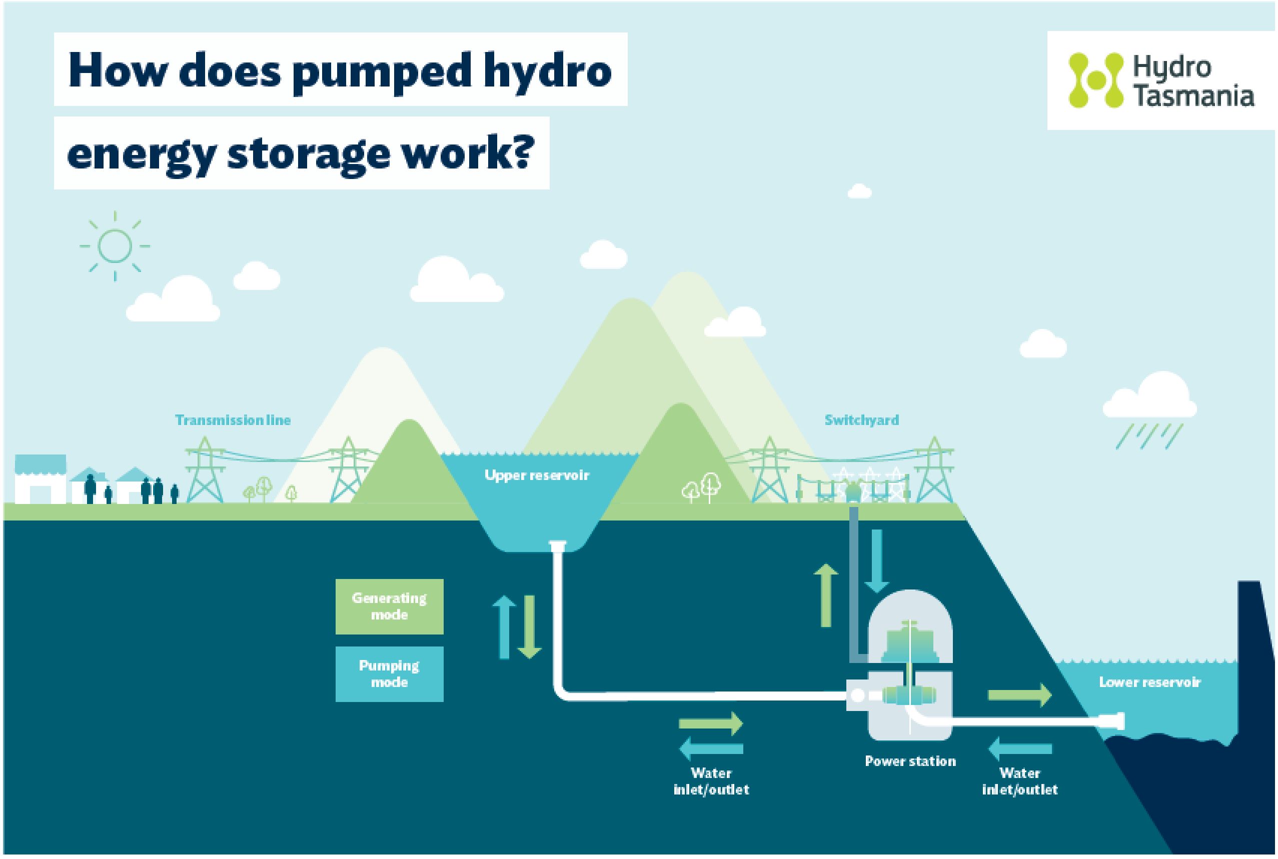

Figure 3-1: How does pumped hydro energy storage work?

3.2 Applicable market conditions

The NEM is facing a period of significant change. The ageing coal infrastructure fleet is expected to progressively retire due to age-related deterioration (and possibly market pressures) and be replaced by new energy sources.

Disruptions to electricity supply in the recent past have made Australia's electricity supply a hot topic. The debate has been driven by incidences of high prices, and a shortage of reliable generation causing (or at least threatening) black-outs and brown-outs (i.e. restrictions in available electric power).

The future NEM is expected to be vastly different to today, characterised by low-cost variable renewable energy sources being firmed by dispatchable (i.e. controllable) storage and generation. The interactions of these variable energy sources will change the nature of the power system and power system planning and modelling.

New services that can store large quantities of energy during times of energy surplus and supply back to the grid during times of relative energy scarcity will be part of a solution to produce the lowest cost supply for customers.

These changes in the physical power system are prompting reconsideration of market design.

A market design based on dependable floor prices underpinned by short run marginal cost of energy may not support the transformation of the electricity sector away from fossil fuel-based technologies. The new system services that work alongside variable energy sources to provide a steady output to meet demand will need to be properly assessed and valued. Any change to the market design will need to solve the energy trilemma[2] of energy equity (affordability), security and sustainability.

Energy storage, especially pumped hydro, is expected to play a major role in a future energy market; however, the current market method for valuing pumped hydro is not conducive to new investment and does not recognise the full value of services that it brings to the market.

Pumped hydro, as part of the *Battery of the Nation* initiative, offers a credible and cost-effective way of firming variable sources while accommodating the energy trilemma[3]. Tasmania has strong potential to further maximise the benefit of its hydropower assets through the development of pumped hydro energy storage sites. The combination of existing hydro power assets and new pumped hydro projects provides a significant set of benefits over either traditional hydro systems or pumped hydro energy storage alone. That is, there is considerable synergy between hydro generation and pumped hydro storage.

3.3 Concept study stakeholder engagement considerations

The primary internal and external stakeholders of the pumped hydro studies include:

- ARENA (project funding);
- Hydro Tasmania Board and Leadership Group (project sponsor);
- *Battery of the Nation* Steering Committee (project governance);
- Hydro Tasmania shareholder Ministers;
- Relevant local, regional, state government and non-government stakeholder groups with interests in catchment areas with pumped hydro potential;
- National government and organisational entities; and
- The broader Tasmanian community.

At this early stage of studies, the primary objective has been to raise awareness of pumped hydro and the rationale for the options study via engagement with key regional stakeholders, individuals and interest groups (local government, regional bodies, state-wide representative groups, etc.) in Tasmanian catchments with pumped hydro potential.

3.4 Analysis of existing pumped hydro energy storage

Pumped hydro is a highly effective form of large-scale energy storage. The International Hydropower Association (2017) states that 95% of global energy storage capacity comes from pumped hydro projects.

Pumped hydro has a real and growing role to play as Australia transitions to increased renewable energy generation, assisting with both energy storage issues and network stability challenges that come with wind and solar penetration.

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[2] Source: https://trilemma.worldenergy.org/, accessed on 19/01/2018
[3] Source: https://trilemma.worldenergy.org/, accessed on 19/01/2018

Pumped hydro projects can assist by levelling out fluctuations in the availability of wind and solar energy, helping to regulate voltage and frequency across the network, and bring additional stability to the grid resulting from their inherent inertia. Pumped hydro projects also have the potential to generate rapid response and flexible power for delivery into the NEM.

Based on the Hydropower Status Report (IHA, 2016), total hydropower installed capacity in Australia is 8,790MW, with an average 13.6 TWh of energy generation annually. Pumped hydro capacity in Australia is currently 1,340MW[4].

3.5 Review of existing studies

Several studies have been undertaken for mapping potential pumped hydro projects in Australia as follows:

- *"Energy Storage Technologies South Australia"* Worley Parsons, December 2011;
- *"Report on Pumped Storage modelling for AEMO 100% renewables project"* ROAM Consulting, September 2012; and
- *"Opportunities for Pumped Hydro Energy Storage in Australia"* ARUP & Melbourne Energy Institute, February 2014.

Each of these studies identified pumped storage as one of the best storage solutions that could also provide additional benefits such as inertia and frequency control to the grid.

In addition to the above, Entura (the consulting arm of Hydro Tasmania) prepared a high level report in June 2016 to identify the pumped storage potential of the Hydro Tasmania hydropower scheme.

All of these reports have been reviewed in detail as part of the concept study. The outcome of each review is summarised below including a list of the potential sites identified in these reports, and the identified advantages and disadvantages.

3.5.1 Worley Parsons/SKM-MMA, 2011

This study was undertaken particularly for Eyre Peninsula in South Australia for the South Australian State government. The main objective was to find small and large scale storage solutions of different kinds that could mainly provide for deferment or reduction in capacity of transmission network augmentation.

Other targeted benefits were frequency / voltage control and network support.

[4] Includes only pumping capacity (600MW) at Tumut 3. Generating capacity at Tumut 3 is 1,800MW

The summary of conclusions about using pumped hydro projects for energy storage based on this study is as follows:

- *Inland pumped hydro projects* (called freshwater in the 2011 report):

  Some sites were identified in the Otway Basin. It was argued that water would have to be pumped out of an aquifer which made the site less attractive than the adjacent opportunity of a compressed air storage scheme. Therefore it was not recommended to take this pumped storage scheme into next phases of the study.

- *Seawater pumped hydro projects* (called salt water in the 2011 report)

  It was concluded that seawater pumped hydro project on Eyre Peninsula has potential but still is more expensive than “Compressed Air Storage”. A financial IRR of standalone seawater pumped hydro projects was estimated to be as high as 34% assuming pump/generation size of 200 MW/150 MW. The identified sites were presented only in the form of a map (Figure 3-2).

Given the nature of study (which was identifying and comparing different small / large scale energy storage technologies), no site specific assessment was undertaken. However, the study provides insights on how the industry started to consider pumped hydro as a viable energy solution.

3.5.2 ROAM Consulting, 2012

This is the most comprehensive GIS-based study undertaken to date on potential pumped hydro projects in Australia compared to the other studies discussed in this section of the Report.

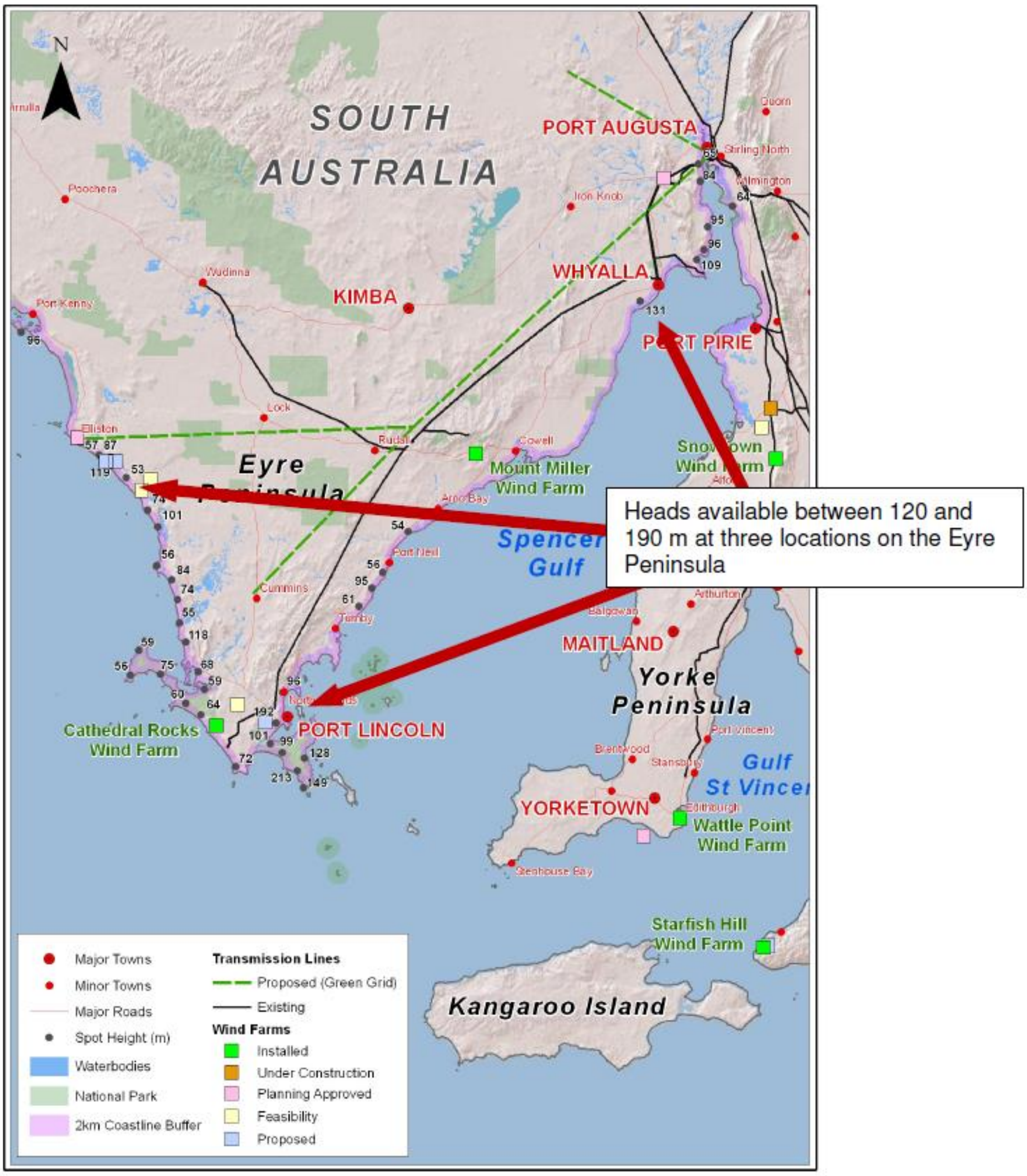
The study was undertaken for AEMO and the outcomes were used for planning by AEMO in modelling related to a 100% Renewable Energy Study requested by the Australian Government.

Limitations and assumptions

The study’s coverage is NEM-wide with the following limitations:

- Only new pumped storages in association with existing water storages (or water bodies) were considered.
- No new large dams were considered.
- No scheme with two new small dams was considered.
- Only options with a minimum of 90 metre net head difference between the upper and lower storages and maximum 3.5 kilometres in horizontal distance were considered. It is believed that this criterion was based on the initial GIS-based results obtained by ROAM during their study.
- Options were limited to those within close proximity to the NEM transmission network (within a set of polygons supplied by AEMO).
- The current operation regime of existing reservoirs and the impact of pumped storage on that are not discussed.

As such, a project like the Kidston Pumped Storage Project, which is currently being developed by Genex Power, would not have been identified under this study.



Source: WorleyParsons

Figure 3-2: Identified seawater pumped hydro sites by Worley Parsons (extracted from 2011 report)

One of the key assumptions made in this study is to consider a fixed 500 MW installed capacity for all potential sites with a total $1.6 billion of CAPEX.

It seems the cost estimation was undertaken with significant conservatism and resulted in favour of other technologies considered in AEMO's 100% Renewable Study. AEMO's report assumes $4.9M/MW for new pumped storage plants.

Although referring to any form of large-scale electricity storage system purely in MW is incorrect (i.e. rather should be referred to as per MWh of storage), this figure is nearly equivalent to battery energy storage systems or higher, which are known to be significantly higher than the cost of pumped hydro for longer term (multiple hours to days) storage.

There were no outcomes from the ROAM Consulting study materially affecting this study.

Methodology

Based on the limitations and assumptions, around 500 sites were initially identified with one of the reservoirs currently existing. These sites were then screened down to 100 based on further criteria on the to-be-built paired reservoir (whether higher or lower than the existing reservoir) with some assumed limitations such as height of the new dam (30 m, 60 m, or 90 m) and the direction of the dam wall (either NW or SE).

These 100 sites were then narrowed down to 68 potential projects by eliminating some of the upper or lower to-be-built reservoirs that were assumed to be paired with existing reservoirs.

A one-page summary was produced for each of these 68 sites with an approximate cost and energy generation. An example is extracted from that study as illustrated in Figure 3-3.

Site ID: 1295

Pond dam wall height: 90m

Site location:

Pond:

Attribute	Value	Attribute	Value
Site longitude	148.83	Pond required	Upper
Site latitude	-35.549	Distance between water bodies (km)	3.13
Polygon	36	Net Head (m)	383
Water body	Corin Dam	Pond volume (ML)	36652
Water type	Fresh	Pond wall length (m)	840
Site capacity (ML)	75500	Energy stored (MWh)	30420
Land use	Nature conservation	Capital cost per unit generation capacity ($/kW)	12163
Issues	High conservation value	Capital cost per unit of energy stored ($/kWh)	200

Figure 3-3: Sample of 1-page summary for a potential pumped storage site from ROAM's study

3.5.3 ARUP and MEI, 2014

The study was undertaken by Melbourne Energy Institute and ARUP Consulting.

A comparison was made between pumped hydro project technology and other energy storage technologies concluding that pumped hydro projects may be an economically competitive way to store energy from a few hours to one day.

Also, a review of previous studies in Australia as well as some other studies in the world was undertaken both from site identification and cost estimation perspectives.

The comparison of cost shows that the ROAM study in 2012 for AEMO is significantly different to other studies from elsewhere in the world, most of which are based on actual data (Figure 3-4 and Figure 3-5).

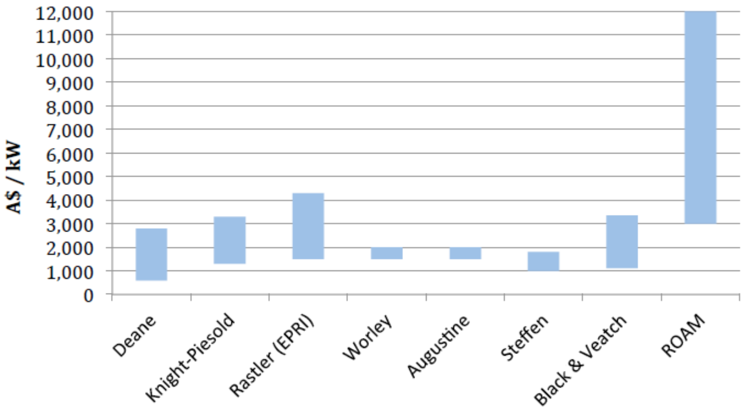


Figure 3-4: Comparison of literature capital cost per MW for pumped storage plants (extracted from MEI-ARUP 2014, Figure 21)

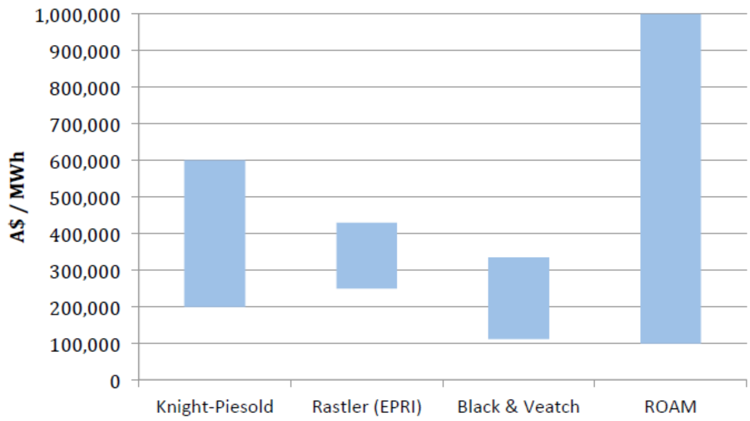


Figure 3-5: Comparison of literature capital cost per MWh of energy stored for pumped storage plants (extracted from MEI-ARUP 2014, Figure 22)

The key conclusion was that seawater pumped storage, with a turkey's nest reservoir as the upper reservoir, is the best solution in Australia.

Reference was made to Yanbaru Pumped Storage Project in Japan that was the only seawater pumped storage built in the world. The site was inspected in 2013 by a team from Melbourne Energy Institute. This pilot project was funded by government agencies in Japan mainly due to the lack of inland sites. It ceased operation in 2016 due to unfavourable market conditions.

3.5.4 Entura, 2016

The report "Review of Pumped Storage Options in Tasmania" was prepared by Entura in July 2016 for Hydro Tasmania. This is a brief report (20 pages in total) concentrating on utilising some of the existing reservoirs in the Hydro Tasmania's portfolio based on the parameters and knowledge obtained from the recent feasibility studies undertaken on the Kidston Pumped Storage Project. As a result, the following options were considered for a desktop study:

- Utilising *yingina* / Great Lake and Poatina elements;
- Coupling Lakes Margaret and Burbury;
- Coupling Lakes Gairdner and Cethana; and
- Utilising Lake Parangana.

The purpose of this study was not to identify pumped storage opportunities using GIS-based modelling and therefore did not consider any modelling, operating implications, or social/environmental implications.

3.5.5 Summary

Development of pumped hydro projects in Australia has been stalled for more than 30 years but with ageing thermal plant and the need to meet international climate change related obligations, investment in renewable energy has surged in recent years.

A number of studies into pumped hydro have been carried out to inform both developers and policy makers of the potential for energy storage in general and specifically pumped hydro.

The reports reviewed in preparing this study informed the development of the GIS database of sites and also provided data against which the current study outputs could be verified.

4.0 Site selection methodology

4.1 Method for identifying pumped hydro sites

A four-stage process was implemented to identify potential and select sites in Tasmania for further assessment.

Following a review of previous relevant studies (refer to Section 3.5) the screening was designed to streamline the process to carry out high level studies on a list of projects considered to be of high potential. As such, the screening was undertaken in a logical sequence of steps as follows:

Stage	Summary	Detail
Stage 1: State-wide screening	Stage 1 began with the detailed review of previous studies which assisted in defining the next steps.	Entura provided an initial list of projects based on prior knowledge and coarse filtering using existing data (Entura, 2017). Entura has developed a GIS based algorithm to identify potential pumped hydro sites. This algorithm was used to develop an initial list of over 2000 projects for use in future stages.
Stage 2: Identification of high potential sites	– Application of constraints – Review of high potential sites.	Stage 2 took the initial list of projects and applied constraints to reduce the number of potential sites to about 30. These constraints included: • Exclusion of projects that involved construction of new on-stream dams or were located within the Tasmanian Wilderness World Heritage Area. • Consideration of options for redevelopment of existing schemes into pumped hydro projects. • Identification of projects that link existing Hydro Tasmania storages. • Use of existing Hydro Tasmania storages as either upper or lower reservoirs. • Consideration of closed-cycle schemes for comparative purposes only.

		A one page project data sheet was produced for each project identified through the Stage 2 screening. These data sheets give a high level picture of the characteristics of the selected sites, including total energy storage, assumed installed capacity, distance to the transmission network, high level cost estimation, and cost per MWh of energy that could be generated in one full discharging cycle.
Stage 3: Selection of sites for further investigation	– Developing multi-criteria analysis assessment categories; and – Application of assessment criteria to high potential sites;	Stage 3 involved a multi-criteria analysis and detailed final screening of the 30 or so projects, which resulted in a list of 14 selected options being identified as being worthy of pre-feasibility assessment. Assessment criteria were developed during a workshop, which included experts from a wide range of disciplines across Hydro Tasmania. The assessment criteria were applied through rapid assessment workshops with internal subject matter experts. The next stage studies will validate the high level assumptions and criteria in more detail.
Stage 4: Concept design for selected sites	– Performing high level concept studies of selected sites – Recommending projects for further investigation.	Stage 4 involved high level concept studies of the 14 selected options. This stage included collection of additional available information for the respective sites, more refined engineering evaluation of the site and a risk assessment process.

4.2 Assumptions

The investigation of pumped hydro project options required a set of assumptions to be made, which effectively set the constraints for assessing options.

The assumptions are included in Table 4.1.

Table 4.1: Study assumptions and exclusions

Serial	Assumption Description
1	Bass Strait interconnection will not be a constraint.
2	Hydrological resource is not a constraint – pumped hydro is a non-consumptive use of water. Climate change considerations will be taken into account during future stages.
3	The role for pumped storage plants to provide energy storage and power system support (e.g. frequency control, inertia, system strength and flexible generation) in the Tasmanian and wider NEM regions will be considered under the Future State NEM project.
4	Pumped hydro is operationally viable in the context of the Tasmanian hydropower system – operational viability will be considered in the next stage.
5	Financial incentives: Appropriate financial incentives and adequate regulatory certainty exist for pumped hydro to provide storage and power system support in the NEM.
6	Pumped hydro projects will be connected to the closest suitable substation or HV transmission line.
7	Power system upgrades associated with pumped hydro will be completed to allow projects to connect to the NEM without constraint.
8	Bass Strait Islands will be excluded from the study as they are not connected to the Tasmanian grid or the NEM.
9	Seawater sites will be excluded from the study due to widespread availability of freshwater sources in Tasmania and technological and cost constraints.
10	Estuaries will be excluded from the study due to technological and cost constraints.
11	Hydro Tasmania infrastructure located in the Tasmanian Wilderness World Heritage Area will be excluded from the study.
12	Cities, towns and other developed areas will be excluded from the study.
13	Areas where there is insufficient head within a reasonable distance for a pumped hydro project will be excluded from the study.
14	Areas distant from suitable substations or transmission lines will be excluded from the study.
15	On-river, greenfield development will be excluded from the study.

4.3 Stage 1 – State-wide screening

4.3.1 Screening overview

Entura provided an initial list of projects based on prior knowledge and coarse filtering using existing data (Entura, 2017). The filtering process focused predominately on the interrogation and analysis of topographic information based on a series of engineering rules and assumptions in order to identify high potential sites suitable for construction of pumped hydro projects.

During this stage, potential pumped storage sites have been identified using various algorithms and rules for different pumped hydro project categories. To make the screening as practical as possible from an engineering perspective, numerous iterations were performed taking into consideration budget and time limitations.

Some parameters were deemed important enough to be part of the rules in an earlier stage rather than just a reported parameter for selected sites at the end of the screening process. Parameters such as distance to the transmission network or avoiding infrastructure in the Tasmanian Wilderness World Heritage Areas are in this category.

These parameters were included on the basis that they would certainly result in project costs being higher than other options or would be likely to result in unacceptable impacts.

In addition, information about key factors in the decision making process have been collected for each site and reported on as follows:

- Distance to the nearest wind farm/solar farm under operation or development;
- Other electricity generators within a 50 km radius;
- Proximity to the nearest substation;
- Land access and presence of buildings within the project boundaries;
- Presence of major roads within the project boundaries; and
- Annual rainfall and evaporation and associated water loss/gain for the identified pumped hydro project.

The GIS analysis was provided with inputs such as:

- Reservoir types – physical properties for turkey nest dam, mines/pits, valley dams etc.;
- Pumped hydro project types – open or closed-cycle projects;
- Limitations on head, installed capacity and storage size;
- Unit costs for various project infrastructure; and
- Operations and maintenance cost information.

4.3.2 Exclusion of seawater pumped hydro projects

Seawater pumped hydro projects have been excluded from this study on the basis that there are ample inland sites that don’t carry the same risks inherent to potential seawater projects. The reasoning behind this is as follows:

- Only one seawater pumped hydro project has been built in the world to date. The pilot project, funded by the Japanese Government, was undertaken due to limitations on inland potential (Yanbaru Pumped Storage Project on Okinawa Island).
- There are significant additional electromechanical equipment costs associated with corrosion issues.
- The outcomes of the study into the Cultana Seawater Pumped Storage Project (Energy Australia, 2017) were not available at the time of undertaking the GIS analysis. The report into the Cultana Project became available in late 2017 and after reviewing the findings, it was decided the information in that report did not alter the outcomes of this study.

4.3.3 Outcomes of state-wide screening

The initial screening process identified approximately 2000 potential project options in Tasmania along with an approximate calculation of capital costs and an estimate of energy in storage. The large number of potential projects was anticipated given the mountainous topography of Tasmania.

This results of the initial screening were later validated by the outcomes of the ARENA funded ANU Study titled "An Atlas of Pumped Hydro Energy Storage", published on 3 August 2017.

4.4 Stage 2 – Identification of high potential sites

To further refine the list of potential projects, constraints were applied on the types of projects that should be considered.

Projects that did not fall within the following categories were excluded:

- Options for redevelopment of existing schemes into pumped hydro projects;
- Projects that link existing Hydro Tasmania storages;
- Use of existing Hydro Tasmania storages as either upper or lower reservoirs; and
- Closed-cycle schemes.

In addition, projects located within the Tasmanian Wilderness World Heritage Area and sites requiring construction of new on-stream dams were also excluded.

4.4.1 Converting existing hydropower stations

Conversion of existing hydropower stations to pumped storage plants could be undertaken by means of adding new pump(s) at or adjacent to the existing power station, matching the current installed capacity of the units (or thereabout due to additional headloss whilst pumping) or at a lower capacity.

Power stations of interest in this category need to have the following characteristics:

- An existing lower reservoir just downstream of the station or close enough for connection;
- Fully pressurised existing water conveyances (tunnel/pipe/penstock);
- Reasonable head that could justify the upgrade – preferably more than 100 m head to produce acceptable cyclic efficiency and be cost effective; and
- Enough storage capacity in the upper reservoir so that water could be pumped up to the upper reservoir during off-peak hours and then be used for generation during peak hours.

Current utilisation[5] of the existing power stations is a major consideration. Additionally, the positioning of a station in a cascade scheme could have an impact on the attractiveness of the conversion, i.e. whether it is located upstream of the cascade system with a number of power stations further downstream.

Additionally, the requirement to modify an existing intake or construct a new intake and the deeper submergence requirements of pumps compared to turbines and corresponding deep settings and excavation costs were also considered.

Based on the above assumptions and considerations, an initial screening of Hydro Tasmania's power stations was undertaken followed by a workshop from which the following four power stations were recommended for further study:

- Wilmot Power Station – 32 MW (from Lake Gairdner to Lake Cethana);
- Lemonthyme Power Station – 54 MW (from Lake Parangana to Lake Cethana);
- Cethana Power Station – 100 MW (from Lake Cethana to Lake Barrington); and
- Tribute Power Station – 84 MW (from Lake Plimsoll to Lake Murchison).

4.4.2 Linking existing Hydro Tasmania reservoirs

Existing reservoirs that have sufficient head differential could be connected by new water conveyances with the addition of a new pumped storage plant. Two sub-categories of linking existing reservoirs exist:

Building new links between those currently connected

Where two reservoirs are already connected, new lower/upper intakes, water conveyances, and pumped storage plant could be designed/constructed. Constraints such as daily reservoir fluctuation, dam/reservoir rim stability, and operational limitations of the scheme will require further assessment.

Hydro Tasmania has data (e.g. geological mapping) on the alignment of existing water conveyances (which in most cases are underground) which may minimise the time and cost associated with assessment of potential new conveyances.

Building new links between reservoirs without any existing connection

There are few reservoirs in the Hydro Tasmania scheme that are both close enough to each other and with adequate differential head for pumped storage. The following options were considered for further investigation:

- Lake Margaret – Lake Burbury;
- Lake Plimsoll – Lake Margaret;
- *yingina* / Great Lake – Lake Cethana; and
- *yingina* / Great Lake – Lake Echo.

[5] Actual annual energy generation divided by potential energy generated if plant operated at full capacity 100% of the time

Potential energy storages listed above are based on a very high level estimation using an active storage in accordance with current Hydro Tasmania storage operating rules.

No cost estimation has been undertaken at this stage on any of these or other options with longer distance between two reservoirs.

It should be noted that projects that include long water conveyances, which will most likely involve tunnels or long pipelines, increase the project risk and construction time compared to the projects with shorter waterways.

Shorter water conveyances are also favourable from water start-up and response time perspectives.

4.4.3 Utilising existing reservoirs as upper/lower storage linked with a new off-stream storage

Options included the use of an existing Hydro Tasmania reservoir with a new off-stream storage installed at above or below the existing reservoir. The technical benefits of these options include:

- High head;
- Short distance between two reservoirs;
- No requirement for new on-stream dams; and
- Flexibility in selection of water conveyances alignment to manage the underground excavation risk.

Nine existing reservoirs in the Hydro Tasmania portfolio are of high potential in this category with some having a potential energy storage capacity of up to 17,000MWh storage in one cycle (assuming operational constraints allow this volume of water to be used).

Lakes Rowallan, Cethana, Barrington, Parangana, Pine Tier, Catagunya, Repulse, Margaret and Rosebery are identified with potential head between 230m and 540m.

Potential clearing/inundation and associated vegetation and habitat loss together with potential visual impacts on new off-stream storages will be considered in the assessment of these projects.

The high-level cost estimation in this category is approximately $1.0m – $2.4m/MW and depends on several factors including selected installed capacity (MW).

4.4.4 Comparative assessment of closed-cycle projects

Closed-cycle projects would include the construction of new off-stream dams in a location where head differential is large enough to make the project cost effective. Such sites would not therefore utilise existing Tasmanian hydropower infrastructure.

Three potential closed-cycle options were identified. These options were assessed as part of Stage 2 for comparison purposes only.

The benefits of using existing infrastructure, particularly reservoirs and access to transmission, together with Hydro Tasmania's ability to gain additional capacity and control within the existing hydroelectric scheme are considered a significant advantage in Tasmania.

For this reason, closed-cycle systems were excluded from short listed options. Closed-cycle projects may be assessed in the future but this study focusses on the opportunities of using existing infrastructure.

4.4.5 Outcomes of high potential site identification

The process of identifying high potential sites has resulted in the production of a list of approximately 30 potential project sites. The sites and certain technical parameters are listed in Table 4.1 (in alphabetical order).

Table 4.1: Stage 2 screening potential sites

Site	Technical Details		
	Nominal Installed Capacity (MW)	Energy in Storage (MWh)	Unit Cost ($/MW)
Barrington	600	19 042	1.30
Catagunya	302	1165	1.78
Cethana	600	8402	1.05
Cethana Redevelopment	100	9600	1.50
Lemonthyme Redevelopment	54	2200	1.50
Lake Echo	200	2012	2.28
Lake King William	300	2463	1.84
Lake Margaret	300	1828	1.72
Margaret Burbury	800	15 096	1.42
Parangana	300	2108	1.36
Pine Tier	200	968	2.38
Poatina	600	28 208	1.82
Repulse	200	2789	2.21
Rosebery	400	3593	1.24
Rowallan	600	16 740	1.28
Tarraleah	105	482	4.53
Tungatinah	107	488	4.19
Tribute Redevelopment 1	84	26 900	1.50
Tribute Redevelopment 2	500	14 017	1.81
Waddamana	200	2472	3.80
Wilmot Redevelopment 1	32	7900	1.50
Wilmot Redevelopment 2	270	3872	2.30
Woods Arthurs	300	3157	1.36
Woods Lake	300	6219	2.06
Closed-cycle East	*400*	*6277*	*1.29*
Closed-cycle North	*500*	*2575*	*1.01*
Closed-cycle North East	*400*	*12 159*	*1.50*

Closed-cycle projects are included for comparison purposes only.

4.5 Stage 3 – Selection of sites

Selection of potential pumped hydro sites across Tasmania was based on the output of a series of rapid assessment workshops drawing upon subject matter expertise across the Hydro Tasmania group and a detailed screening of project parameters against subjective assessment criteria. The next stage of studies will validate the assumptions and further develop the assessment criteria that were used in the concept study.

Assessment criteria were developed in a workshop setting and involved internal subject matter experts. Further internal focus group meetings were held to consider civil engineering, environmental and social aspects, power systems operation or engineering and system operation based on existing operational knowledge.

Once the assessment criteria were identified, a series of discipline specific meetings were held to apply the criteria to the high potential sites. The multi-criteria assessment of high potential sites served to identify a list of preferred sites, on which concept studies will be performed. The exercise also resulted in the identification of significant project risks.

4.5.1 Multi-criteria analysis workshop

Criteria were identified in a workshop setting to identify the relative risks inherent to each project considered to have high potential. The options study included a high level subjective assessment against these criteria. This process was informed by the IHA Sustainability Assessment Protocol (International Hydropower Association, 2010). Ultimately, it was decided to group the criteria into ten discrete categories, including:

- *Location* – Proximity to likely location of new Bass Strait interconnector;
- *Cost* – estimated unit cost of capacity (MW);
- *Regulatory* – compliance with existing State and National Acts and regulations;
- *Environment and heritage* – potential impacts to terrestrial and aquatic ecological values and Aboriginal and historic heritage;
- *Stakeholders* – potential impacts and opportunities (e.g. angling, recreation) based on current knowledge of existing hydropower schemes and their stakeholder impacts and benefits;
- *Socio-economic* – potential socio- economic impacts and opportunities (e.g. existing agreements and water uses) based on current knowledge of existing hydropower schemes and socio economic values);
- *Technical Complexity* – geotechnical risks, dam safety risks, ease of construction, spoil management, access to materials etc.;
- *Transmission* – available capacity on existing lines, new corridor lengths, system stability, marginal loss factors;
- *Impact on individual storage operation* – fluctuation of water levels, operational complexity, multiple use of storages, etc.;
- *Impact on cascade* – impact on control of run-of-river storages, potential for cascade failure, operational complexity, climate change, etc.

These risks align with the recommendations of the IHA Sustainability Assessment Protocol topics, ES-5, ES-6, ES-7, ES-8 and ES-9 (International Hydropower Association, 2010, pp 37 - 41). These criteria will be further assessed in future studies.

4.5.2 Application of assessment criteria

A series of focus group meetings were held to assess the projects identified in Stage 2 against the selected criteria. This multi-criteria analysis served to identify projects with potentially unacceptable levels of risk and to identify high-risk aspects that require further assessment.

Following the multi-criteria analysis, the selection of sites was finalised based on the following criteria:

- Projects with approximate installed unit costs of greater than $2.5m/MW were excluded on the basis that it is unlikely such projects would be economically and financially feasible.
- Projects with less than six hours energy storage were excluded on the basis that the minimum energy storage capacity requirement is likely to be six hours given the period of suppressed demand that will coincide with mainland rooftop solar and solar PV capacity.

Closed-cycle projects are excluded because the use of Hydro Tasmania's storages is preferred. A point of differentiation for Tasmanian projects is that using existing reservoirs could result in lower impact and cost.

Projects excluded during the detailed screening may be revisited if the selected projects do not meet the objectives for the next stage of the development process – the pre-feasibility studies.

4.5.3 Outcomes of screening process

The screening process has identified the following preferred projects (listed in alphabetical order):

- Lake Cethana pumped hydro project
- Cethana Power Station redevelopment
- Lemonthyme Power Station redevelopment
- Lake Echo pumped hydro project
- Lake Margaret pumped hydro project
- Lake Margaret to Lake Burbury pumped hydro project
- Lake Parangana pumped hydro project
- *yingina* / Great Lake pumped hydro project
- Lake Rosebery pumped hydro project
- Lake Rowallan pumped hydro project
- Tribute Power Station redevelopment
- Tribute Power Station pumped hydro project
- Wilmot Power Station redevelopment
- Wilmot Power Station pumped hydro project.

It should be noted that some of these projects are mutually exclusive: the two options for redevelopment of Tribute Power Station and the two Wilmot projects. It is considered unlikely that two major pumped storage projects would use the same lower reservoir (eg. the Wilmot and the Lake Cethana projects).

A summary of the key project data is included in Table 4.2. Additional data is provided on project data sheets in Appendix A.

Table 4.2: Summary data for preferred project sites

Site Name	Scheme Location	Capacity (MW)	Energy (MWh)	Est Unit Cost ($m/MW)	Upper Storage	Lower Storage	Comment
Conversion of existing power stations							
Wilmot Power Station Redevelopment	Mersey-Forth	32	7900	1.5	Lake Gairdner	Lake Cethana	The existing power station would be used for generation mode and a separate new surface or underground pump station tapped into the existing waterways for pumping operation.
Cethana Power Station Redevelopment	Mersey-Forth	100	9600	1.5	Lake Cethana	Lake Barrington	
Lemonthyme Power Station Redevelopment	Mersey-Forth	54	2200	1.5	Lake Parangana	Lake Cethana	
Tribute Power Station Redevelopment	West Coast	84	26 900	1.5	Lake Plimsoll	Lake Murchison	
Connecting existing storages							
Margaret – Burbury	West Coast	800	15 100	1.4	Lake Margaret	Lake Burbury	The reservoirs would connect with new tunnels and a new underground power station.
Wilmot	Mersey-Forth	270	3872	2.3	Lake Gairdner	Lake Cethana	
Tribute	West Coast	500	14 000	1.8	Lake Plimsoll	Lake Murchison	
Connecting existing storages to new off-stream reservoirs							
Lake Cethana	Mersey-Forth	600	8400	1.1	New	Lake Cethana	New off-stream reservoirs would be developed above or below existing reservoirs. The reservoirs would connect with tunnels or a combination of tunnels and surface pipelines and to a new underground power station adjacent to the existing reservoir.
Lake Rowallan	Mersey-Forth	600	16 700	1.3	New	Lake Rowallan	
Lake Parangana	Mersey-Forth	300	2100	1.4	New	Lake Parangana	
Lake Margaret	West Coast	300	1800	1.7	New	Lake Margaret	
Lake Rosebery	West Coast	400	3600	1.2	New	Lake Rosebery	
Lake Echo	Derwent	200	2000	2.3	New	Lake Echo	
Poatina	Great Lake	600	28 200	1.8	*yingina* / Great Lake	New	

4.6 Ongoing Stakeholder Engagement

Hydro Tasmania has been implementing the *Battery of the Nation* Stakeholder Management Plan alongside its existing program of stakeholder engagement. Stakeholder engagement has, and will continue to be, a key priority of the *Battery of the Nation* initiative and will continue for the duration of the project lifecycle. Stakeholder engagement will be managed through each project phase from concept through pre-feasibility, feasibility, implementation and operation.

4.7 Stakeholder Engagement Process

Table 4.3 provides an overview of the Stakeholder Engagement Program for the concept and pre-feasibility phases of the pumped hydro project. The Program has been developed in line with the *Battery of the Nation* Stakeholder Management Plan and the *Battery of the Nation* initiative objectives.

An Engagement Register has been created to capture key engagements and their outcomes and follow up actions.

Table 4.3: Overview of stakeholder engagement objectives

	Concept study	Pre-feasibility
Pumped Hydro Energy Storage Studies	• Raise awareness of the pumped hydro development process via engagement with key regional stakeholders, individuals and interest groups (local government, regional bodies, state-wide representative groups, etc.) in catchments with pumped hydro potential.	• Raise awareness of the project and inform the planning of the feasibility stage stakeholder engagement and consultation approach via engagement with local stakeholders. • Keep key external stakeholders informed and seek stakeholder input to pre-feasibility studies. • Validate assumptions and risks as input to siting and design options selection process via targeted engagement with internal and external SMEs and key stakeholders. • Engage stakeholders as required to secure access arrangements and approvals for the conduct of pre-feasibility investigations. • Plan regulatory approvals processes for projects that proceed to feasibility via engagement with regulatory stakeholders.

5.0 Technical

5.1 Design characteristics

Hydropower technology is well established. In general, the components of a pumped hydro project are the same as those of a traditional hydropower project. The main differences are in the selection of electromechanical equipment.

A designer must choose between three basic types of pump turbines:

- Fixed speed reversible pump turbines are the most common. They consist of a motor-generator and single runner, which is both a turbine and a pump. They can regulate power output in generating mode but are a fixed load in pumping mode.
- Variable speed reversible pump turbines can vary both the power supplied in generating mode and the pumping load (to within about 30% of the peak load). Like fixed speed machines, they consist of a motor-generator and a single turbine and pump runner.

  The ability to vary pumping load means the depth at which the turbines is submerged can be reduced, which can reduce civil costs and offset the extra equipment costs associated with these pump-turbines.
- Ternary sets consist of a motor-generator, a separate turbine (typically Francis or Pelton) and a pump set. As two separate hydraulic machines, the rotational direction of the motor-generator can be the same in both operational modes. This results in considerable commercial value for the power plant's operation.

  For switching between turbine and pump operation, the following components can be provided: a clutch operable at standstill, a starting turbine or a synchronizing torque converter. With the configuration of a ternary set the, so-called hydraulic short circuit within the machine set can be implemented. It offers the best answer for a very fast grid response, being carried out with the torque converter which allows fast change over between turbine and pump mode.

  Full regulating capability exists in both, the turbine and the pump mode operation from 0% to 100% of the unit output.[6]

5.2 Operational parameters

Pump turbines can operate in various modes including pumping (PU), generation (TU), synchronous condenser (SC) and stand-still (St). Figure 5-1[7] describes the time for switching between modes. This figure shows the ternary sets have a significantly faster change-over time between modes.

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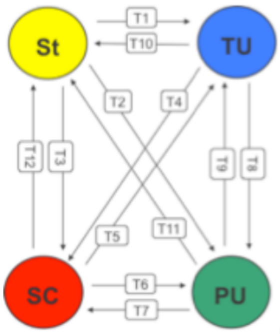
[6] http://voith.com/en/11_06_Broschuere-Pumped-storage_einzeln.pdf
[7] http://ceeesa.es.anl.gov/projects/psh/ANL_DIS-13_07_Modeling_Ternary_Units.pdf



T	Pump Turbine Mode change			time [seconds] A	B	C	D	E
1	Standstill	→	TU-Mode	90	75	90	90	65
2	Standstill	→	PU-Mode	340	160	230	85	80
5	SC-Mode	→	TU-Mode	70	20	60	40	20
6	SC-Mode	→	PU-Mode	70	50	70	30	25
8	TU-Mode	→	PU-Mode	420	240	470	45	25
9	PU-Mode	→	TU-Mode	190	90	280	60	25

Reversible PT
A – advanced conventional (2012)
B – extra fast response conventional
C – VarSpeed, DFIM

Ternary set
D – with hydraulic torque converter + hydr. short circuit, horiz, with Francis Turbine
E – same as E but vertical with Pelton Turbine

TU = Turbine, PU = Pump, SC = Synchronous Condenser

Figure 5-1 Pump turbine mode change times

5.3 Key challenges in delivering solutions

The main issue facing developers trying to prove the viability of a new pumped hydro project is that a sufficient price differential is required to pay for the pumping and to account for the efficiency losses in transmission, pumping and generation. The generation price needs to be sufficiently higher than the pumping price just to repay the variable pumping costs.

To repay the heavy capital investment, a margin is required over and above the break-even cost of pumping. This is particularly true where proposed developments are 'stand-alone' and cannot be optimised as part of a generation portfolio.

5.3.1 Finding the right site

Pumped hydro projects require significant capital for development. Minimising the cost of construction and operation is key to the successful development of a project. Choosing the right location is a matter of identifying a site with ideal topography, a source of water and good proximity to (and location within) the transmission network, among other factors relating to environment, social and technical aspects.

A wealth of information is available that is relevant to identifying potential pumped hydro sites. Concept studies for pumped hydro sites can screen potential sites quickly and offer developers greater insight into possible opportunities.

5.3.2 Access to appropriate sites for pumped storage

While a pumped hydro project generally has a significantly smaller footprint than a traditional hydropower project, the features of natural topography that are ideal for pumped storage – high, steep hillsides or cliffs – tend also to be places of great natural beauty with significant environmental and social values.

The sites selected in this study aim to maximise the use of already existing reservoirs to reduce these impacts. The potential siting of new off-stream storages as upper or lower reservoirs will require an assessment of landscape and visual impacts.

5.3.3 Environmental impacts

Depending on their location, pumped hydro projects can impact terrestrial and aquatic environmental values as a result of new off-stream reservoirs being constructed and potential changes to the operation of existing reservoirs. Terrestrial environmental values can be impacted by clearing (or inundation) of vegetation communities and fauna habitat for new off-stream reservoirs and dams, the power station and associated infrastructure, water conveyances and the transmission lines. Aquatic environmental values can be impacted by changes in reservoir and cascade operation impacting aquatic habitat and water quality (e.g. through increasing shoreline erosion).

Utilising existing reservoirs has the potential to significantly reduce potential environmental impacts when compared to the new on-stream pumped hydro or traditional hydro-electric projects. For this reason, new on-stream sites were excluded in Stage 1 of this study.

Potential environmental and social impacts will be further assessed and siting and design mitigations identified in the next stages of studies.

5.3.4 High cost of development activities

The long lead times and high development costs of pumped hydro projects can be major deterrents to developers. Projects generally take more than four to five years from the point of conception to 'power on', and require millions of dollars of capital for development and hundreds of millions for construction. In other words, when funding is first committed, it may not see a return for five years or more.

5.4 Ability to provide network services

Around the world, pumped hydro projects make up the vast majority of grid energy storage and have traditionally been used by energy utilities to supply additional power to a grid during times of highest demand. Pumped hydro projects also provide network support in various forms including inertia, fault level, voltage and frequency control.

5.4.1 System Security and Reliability

Inertia

The typical inertia constant of a hydro power plant is in the range of 3s – 7s. Pumped hydro project inertia would lie in the range of say, 150MW x 3s = 450MWs to 300MW x 7s = 2100MWs. This assumes pump turbine capacity is in the range of 150MW and 300MW.

Frequency Control Ancillary Services (FCAS)

Pumped hydro projects can provide FCAS. A pumped storage could provide its entire installed capacity plus an incremental amount of power above rated output for FCAS.

Voltage Control

Being a synchronous generator fitted with an AVR, a pump-turbine generating unit is ideally suited to the provision of voltage control ancillary services. The quantum of voltage control is proportional to the installed capacity, so might be in the range of 150MVA in Tasmania.

Fault Level

The pump – turbine generating unit is a synchronous generator and therefore provides reactive power input for fault level control in proportion to its installed capacity.

5.4.2 Controllability

The response of a pumped hydro to a command to increase or decrease output is a function of the layout of the project. Specifically, this means the arrangement of the waterways linking the upstream and downstream storages – and the type of pump turbine units (fixed speed, variable speed etc).

Inertia

Inertia varies with the output of a generator. In generator mode, inertia can be controlled by varying the load on the pump-turbine generator unit anywhere from 0% load to 100% load.

FCAS

Regulation FCAS

All pumped hydro projects can provide regulation FCAS in generating mode. Only variable speed turbines can vary their load in pumping mode. Fixed speed machines are either at full load or no load in pumping mode.

Contingency FCAS

The ability of the pumped hydro project to meet the fast raise/fast lower contingency is dependent on the length of the waterways and can only be depended upon if the project is operating at the time of the event.

Similarly, the slow raise/slow lower contingency can be met if the project is operating in generating mode. Some pumped hydro projects may be able to meet the slow raise contingency from standstill if the upper reservoir is not empty and the generating sets are primed for generating.

Most pumped hydro projects could meet the requirements of a delayed raise/delayed lower contingency event while generating and from standstill in generating mode unless there is a very long distance between storages.

Variable speed pump turbines can also be regulated in pumping mode, so FCAS services can also be provided while pumping.

Voltage Control

Voltage control ancillary services are always available while the generator is operating.

Fault Level

Fault level control is always available while the generator is operating.

5.4.3 Volatility

The ability of a pumped hydro project to provide support to the power system is dependent on the mode of operation at the time of an event and the relative volume of water in each storage.

Power output varies as water is transferred between storages such that there is less capacity available with less volume of water in the upper storage.

The variability of generating capacity is dependent on the volume of the storages and the fluctuation in water levels in each storage.

6.0 Cost calculations (capital and operational cost)

Estimating the capital or operation costs of a pumped hydro project, prior to the completion of a site specific concept study, is not recommended as there are numerous factors that have potentially substantial impacts on project costing.

In particular, the following key risks cannot be identified or quantified at a GIS-based screening level:

- *Geological conditions of both dams / reservoirs, and their intakes*

  For any type of dam / reservoir, geological conditions of the dam foundation and reservoir rim are important in the design of the dam. The type and shape of the dam is directly related to the geological conditions.

  For pump storage projects in particular, the stability of the reservoir rim is important where daily water level fluctuations are expected.

  Without an appropriate geological review and site-specific geotechnical investigation, the assumed design and associated cost is very approximate and could be misleading.

- *Geological conditions of water conveyances and power station*

  In most cases, new pumped hydro projects are more likely to involve underground stations with water conveyances being in forms of shafts and tunnels. This is a key risk that requires sub-surface geotechnical investigations in the feasibility stage.

  However, a site visit associated with a desktop review, mapping and analysis could provide a high level idea of the quantum of this risk and therefore be included in the initial costing.

- *Environmental and social*

  Failure to adequately identify potential environmental and social impacts of pumped hydro projects can lead to significant cost escalations and operating constraints. This concept study used GIS based screening together with subject matter experts within Hydro Tasmania to identify potential risks at a desktop level.

  Further assessment through subsequent project stages will continue to identify and, where necessary, mitigate (e.g. through project siting and/or design) potential environmental and social impacts reducing the risk of unidentified environmental or social constraints leading to increased capital or operational costs.

- *Flood risks and water loss*

  An attempt has been made in the screening stage to estimate the water gain/loss of the reservoirs at a high level so that it could be factored in the costing.

  However, flood risks will have direct impact on the dam’s consequence categories which will ultimately result in additional costs for the dam and its related structures.

6.1 Capital costs

In the absence of such data, high level cost estimation was undertaken for all identified sites based on previous experience and available international data. A summary of assumptions relating to this high level cost estimation is as follows:

- **Upper and lower reservoirs**
  - *Existing dams/reservoirs and natural lakes*

    An intake would most likely need to be constructed on the existing reservoir. Based on Entura's experience, it can be assumed with certainty that the typical dam intake is not suitable for a pumped hydro project. The to-be-built intake has construction complexities given that the existing dam is in operation and most likely the reservoir cannot be lowered (below the current MOL).

    Site specific temporary works such as a cofferdam would be required to construct the intake. At this stage, it is assumed that the intake is a horizontal diffuser shape that is permanently submerged under water with adequate depth at the inlet. Data for a similar design is scaled according to the design discharge to obtain costs.

    Although it is a more complicated relationship, it could be assumed that the cost increases/decreases with the square root of the discharge for such a structure. This is based on keeping the design average velocity of the water at the intake more or less the same based on current engineering practice.

    Most likely, some stabilisation works would be required on the existing dam itself and/or the reservoir rim. This is a major unknown factor in the cost estimation as it is very site specific and depends on the local topography and geological and geotechnical conditions. A judgement on the need and extent of such works can realistically be made only after initial site investigations.

  - *Off-stream (e.g. Turkey's nest) dams*

    Off-stream dams were assumed to be constructed using homogenous rock fill with durable and economic liners on the water side. It is acknowledged that this generic arrangement might not be the optimal type and arrangement for some sites.

    However, given that these dams are to be constructed either on top of a ridge or at the bottom of hilly areas with rock fill sources available on site, a balanced earthmoving activity (cut and fill with compaction) is potentially the most economical solution.

    Given an assumed water level fluctuation of 15 m, a nominal freeboard of 2m, and a maximum unusable storage depth of 3m close to the intake area, the total height of the dam would be approximately 20m on the water side. On the external side this height varies depending on the topographical conditions. GIS modelling provided the average elevation over the area of identified dam site, together with the area and perimeter.

    It is assumed that an average 15m dam with 2(H):1(V) internal slope and 1.5(H):1(V) external slope needs to be constructed around the perimeter of the off-stream reservoir. This is a cross sectional area of 300m^2 for the entire length of the reservoir perimeter.

    Also, it is assumed that the liner (including sandy layer underneath) is required over the entire internal slope of the reservoir and the reservoir floor area.

    The cost of the intake is assumed to be similar to that described above for existing reservoirs.

- **Water conveyances**

  For a pumped storage project, it is normally optimal to have a layout with the shortest water conveyance route connecting the two reservoirs. This not only reduces the head losses in the system (thus increasing the cyclic efficiency) but also reduces the project costs.

  Based on this, and taking into consideration that the fixed speed reversible units (generally the optimal / economic arrangement) require substantial submergence in relation to the minimum operating level of the lower reservoir; underground power station and water conveyances are the most economic solutions. There are some occasions that surface water conveyances and power station or a combination of both could be more favourable.

  As such, a fully underground arrangement has been assumed with about 25% of the average gross head being steel lined (including the branches) and the remainder concrete lined. It has also been assumed that the average velocity in the largest section of the water conveyances is approximately 4 m/s and that at least two units are involved.

  It has also been assumed that for active storages under 6Mm³, one main conveyance with approximately 333 m^3/s average discharge (about 10m diameter) is suitable with two units (i.e. two branching). For active storages higher than this it is assumed more than one main conveyance (each with two branches) is required incrementally.

  It should be noted that though this cost estimation is very approximate and high level application of it to long tunnel arrangements with TBM is not considered as the maximum horizontal distance between two reservoirs is assumed to be 3.5 km for most projects.

- **Power Station (including switchyard)**

  – *Electrical and mechanical (E&M)*

    Estimation of E&M costs relates significantly to the head and discharge of the station as well as type of technology adopted. It appears that for large scale pumped storage projects, fixed speed reversible units are the most economic choice most of the time. Variable speed units and ternary sets are at least 30% and 50% more expensive based on recent experience and liaison with top tier E&M suppliers, including Andritz, GE, Toshiba and Voith Fuji.

    The cost of E&M equipment can be estimated based on a relationship between head and flow.

  – *Civil*

    Civil costs of the power station, switchyard and associated miscellaneous elements such as cable/exhaust shaft/tunnels or routes can be estimated based on a relationship between head and flow.

- **Access tunnel and construction adits**

  Both permanent and temporary access tunnels are very site specific as the shortest access route to the station is defined by the topographic conditions of the site. An appropriate allowance must be made for access tunnels.

- **Access road to site**

  At concept study stage, it is assumed that access to site is available for both construction and operation. This should be assessed in subsequent stages of project development.

- **Transmission line**

  It is typical to calculate the cost of transmission to the nearest substation of sufficient capacity. Wider power system upgrades may or may not be the responsibility of the developer.

- **Miscellaneous**

  Items such as hydraulic instrumentation, hydro-mechanical works such as gates, valves, etc. that is not included in the power station E&M, water balancing pumps and pipework, etc. An estimation of 2% of total cost of the works excluding access roads/tunnels is considered suitable for this.

- **Other development costs**
  - The direct cost estimations above include contractor's indirect costs and profit;
  - Preliminary and general costs;
  - Design and approvals;
  - Owner's costs; and
  - Contingency.

6.2 International benchmarking

Table 6.1 provides examples of recent pumped-storage projects built or being studied worldwide together with unverified published cost information.

Table 6.1: Unit cost for various international pumped storage projects

Installed Capacity (MW)	Country	Notes	~2016 million USD/MW	Converted million AUD/MW at 0.75 rate, 2016
2000	India	1 new reservoir	0.7	0.9
1800	China	2 new reservoirs	1.0	1.4
1560	Russia	-	2.2	2.9
1333	South Africa	2 new dams	3.2	4.3
1040	Indonesia	1 new dam	1.1	1.5
1000	Spain	Existing reservoirs	1.2	1.6
1000	Romania	-	2.1	2.8
1000	USA	2 new reservoirs	2.4	3.2
1000	USA	2 new reservoirs	2.8	3.7
1000	India	-	0.5	0.6
1000	India	Existing dams?	0.4	0.5
600	UK	-	2.8	3.7
500	USA	New small reservoir	2.2	2.9
360	Ireland	An existing open cut mine	2.0	2.7
340	Israel	Together with Chinese	1.3	1.8
300	Chile	Sea water, ocean lower reservoir	1.4	1.9
251	Portugal	-	1.8	2.4
100	UK	Existing slate quarries	2.6	3.4
74	Germany	Extension to existing PSP	1.4	1.8

6.3 Operation and maintenance costs (OPEX)

Operation and maintenance costs are an important part of a business case for a pumped hydro project. Annual average operation and maintenance is estimated to cost around 1% to 3% of the capital cost of the project depending on the project characterises, logistics, and owner/operator's expectations.

In the case of Hydro Tasmania, all projects are within existing power station operational regions which already have in place the necessary infrastructure, resources and support arrangements, which will minimise ongoing operating costs.

6.3.1 Operations costs

Modern pumped hydro projects are typically remotely operated. To manage plant operations, there would be rostered duty operators available on-call 24 hours a day and 7 days a week, in case there are urgent plant alarms or other issues to respond to at any time, or in case local machine operation or electrical switching is required. Remote operation can be achieved via web based or other means of SCADA interface on a computer in a remote office, or even via a tablet or smart phone application.

As well as operations staff, there would need to be personnel responsible for roles such as:

- A site manager;
- Administration;
- Station operators who can respond to operational issues, perform electrical switching, make isolations, etc;
- Mechanical and electrical fitters;
- Condition monitoring and maintenance planning;
- Civil maintenance, for dam safety, roads, underground, structures;
- Maintenance assistants; and
- Cleaners.

6.3.2 Life cycle costs

Hydropower plant total lifecycle can cover many decades of reliable operation. The nature of the construction of these assets results in some components such as civil asset like dams having an expected service life exceeding 50 – 100 years while at the same time control and protection systems may have an expected component life more in the order of 10 – 15 years. A major factor in achieving the financial and performance expectations as set out in the original business case is the successful implementation of an appropriate asset management plan.

Generally speaking, the majority of key electrical and mechanical (E&M) assets can be managed within an outage strategy that revolves around a 30 year cycle. This cycle is made up of general yearly minor maintenance interventions for attending issues such as filter cleaning and minor electrical maintenance, larger outages are generally scheduled at indicative periods of 6 yearly, 12 yearly and 30 yearly with the intensity of maintenance and refurbishment work compounding respectively.

Dams associated with pumped storage projects are managed in accordance with the Australian Commission on Large Dams (ANCOLD) guidelines that schedules dam safety work at indicative periods of 2 yearly, 5 yearly and 20 yearly.

A typical asset management strategy revolving around a 30 year cycle can be repeated to account for a 60 year scheme life. A hydro power plant or a pump storage plant, if adequately maintained and rehabilitated, can run for 60 years or longer.

A major factor that affects the total lifecycle costs of an asset are the performance requirements “service factor” of the plant with direct correlation between performance and cost of maintenance being evident. Generally speaking, the greater the reliability required, the higher cost of maintenance.

6.3.3 Refurbishment/replacement

Major refurbishment of a pumped hydro storage project should not be required for a period of up to 30 years, depending on the operating environment. A 30 year maintenance schedule would involve major work, considering the age of the plant and equipment which is now nearing its end of life.

It may be necessary to conduct major mechanical and electrical refurbishment to the generator and turbine and switchyard.

Refurbishment activities may include:

- Generator rewinds;
- Runner repair or change out;
- Governor replacement;
- Switch yard upgrade;
- Replacement of pipes valves and filter systems;
- Penstock and tailrace repairs;
- Draft tube repairs;
- Overhead crane repairs;
- Cooling water system repairs; and
- Hydraulic gates repairs.

7.0 Land access and development approval

7.1 Land access

The siting of infrastructure including reservoirs, water conveyances, access roads and transmission associated with the selected options will include a mix of different land tenures. The majority of the selected options are located on Crown land and land managed by Sustainable Timber Tasmania. Engaging with land owners and land managers (both public and private) early will be key to identifying land access needs and risks.

7.2 Development approvals

The development of a pumped hydro project in Tasmania will require consideration of the following key State and Commonwealth Acts:

- *Hydro-electric Corporation Act 1995*
- *Environment Protection and Biodiversity Conservation Act 1999 (Cwlth)*
- *Land Use Planning and Approvals Act 1993*
- *Water Management Act 1999*
- *Environmental Management and Pollution Control Act 1994*
- *State Policies and Projects Act 1993*
- *Threatened Species Protection Act 1995*
- *Forest Practices Act 1995*
- *Historic Cultural Heritage Act 1995*
- *Aboriginal Heritage Act 1975*
- *Crown Land Act 1979*
- *Mineral Resources Development Act 1995*

The proposed siting and design of the project together with an assessment of potential impacts to environmental and heritage values (determined through the results of desktop and, where required, field assessments) will be key to determining the requirement for obtaining approvals/permits under relevant Acts.

An initial desktop environmental and social assessment was completed as part of this concept study to identify known key environmental risks and opportunities associated with the selected options and to assist site ranking. Further environmental assessment and targeted stakeholder engagement will be completed during pre-feasibility to better understand these risks and siting and design mitigation options.

This approach is consistent with the IHA Hydropower Sustainability Assessment Protocol - Early Stage Tool, in particular ES – 7 and ES – 8.

8.0 Conclusion and next steps

The *Battery of the Nation* – Tasmanian Pumped Hydro Concept Study has identified a group of high potential pumped hydro energy storage options in Tasmania that warrant further investigation through pre-feasibility studies.

The selected options include redevelopment of existing power stations, new links between existing Hydro Tasmania storages and existing Hydro Tasmania storages linked to new off-stream storages. The sites have been selected from an initial list of about 2000 potential sites using a four step screening process.

The sites have a combined installed capacity of approximately 4800 MW, with a total of approximately 140,000 MWh of storage capacity and an average unit cost of installed capacity of approximately $1.5 million per MW (range of $1.1m/MW to $2.3m/MW).

While it is not expected that all selected sites will be developed, the study has demonstrated the substantial potential for large scale pumped hydro projects in Tasmania to support the NEM transition to low emission sources.

Each of the selected sites will be further investigated in pre-feasibility studies. Pre-feasibility typically comprise preliminary analysis of engineering, economic, environmental and social impacts of the selected sites.

A key focus of the pre-feasibility studies will be the siting and preliminary design of each project to address risks and opportunities identified during pre-feasibility studies. Pre-feasibility will also involve limited non-intrusive on site assessments to validate existing conditions.

With 14 studies to complete, the programme is expected to run over a 12-month period. If there are market signals suggesting implementation of a pumped hydro project in the near term, such as if approval is given for development of a second interconnector, the full feasibility study of a selected project could begin prior to completion of the programme of pre-feasibility studies.

Critical inputs to pre-feasibility studies include:

- Survey to the highest available accuracy (field surveys may or may not be conducted during the pre-feasibility study stage);
- Detailed hydrological data;
- Geological maps and commentary;
- High level cost data; and
- Economic and financial parameters.

Environmental heritage and social inputs into the pre-feasibility studies will include:

- Mapping of known environmental and heritage values (with potential on-site validation);
- Assessment of environmental and potential social impacts and benefits to inform site selection and design mitigations;

- Identification of known stakeholder values and opportunities for local and regional community benefit based on Hydro Tasmania's knowledge of project locations (to be validated in subsequent project phases); and
- Preliminary development approval pathway.

A key aspect in proving a pumped hydro project is viable is an assessment of how the project will operate. This requires both market modelling and modelling of the hydrological resource. Market modelling will be performed during pre-feasibility studies based on assumed future market conditions. Water resource modelling to understand reliability and operational profile of water levels will also be carried out. This will assist with understanding both direct and indirect impacts on environmental and social values.

The output of the pre-feasibility studies will be a series of reports summarising the findings of the studies. Reports will include a recommendation on whether to proceed with further investigations on the projects (feasibility studies).

9.0 References

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Appendices

Appendix A – Project data sheets

ARENA only
(Recipient confidential information)