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Development of a Cost Model for Pumped Hydro Energy Storage

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Pumped hydro energy storage (PHES) constitutes 99% of energy storage worldwide (>160 GW) because it is the cheapest source of energy storage. Conventional on-river PHES with large reservoirs for long term storage are largely exploited and new proposals will encounter public resistance. In contrast, PHES located away from rivers ("off-river") is well suited to low cost short term storage, avoids community conflict, reduces transmission costs, increases PPA value, and has hundreds of potential sites and large potential.

ANU has recently completed the initial phase of the ARENA funded STORES project. This work investigated off-river pumped hydro energy storage to support high penetration of variable wind and solar power generation in electricity markets. The goals that were delivered were to:

a) Find all the good PHES sites (thousands of them). Exclude national parks and other sensitive areas. Produce an Atlas of PHES. Add in solar data, wind data, transmission lines and constraints. Find renewable energy precincts with PHES + transmission line + good wind and sun.
b) Develop a reliable costing tool. Project developers can screen sites before detailed (and expensive) investigation.
c) Analysis integration of PHES at a national, state and precinct level.

The ANU identified more than 22,000 potential sites across Australia as has been reported elsewhere. A costing tool enables the best sites to be identified. A tool has been developed in collaboration with two established hydro consultancies, B&V and GHD. The cost model was initially trialled on five reservoir pairs in Far North Queensland near Townsville as seen in Figure 1. These sites were chosen due to their size; all sites were capable of 20h or more storage for a large system power (800MW). The sites also represented a range of different water volume to dam volume ratios in the reservoirs.

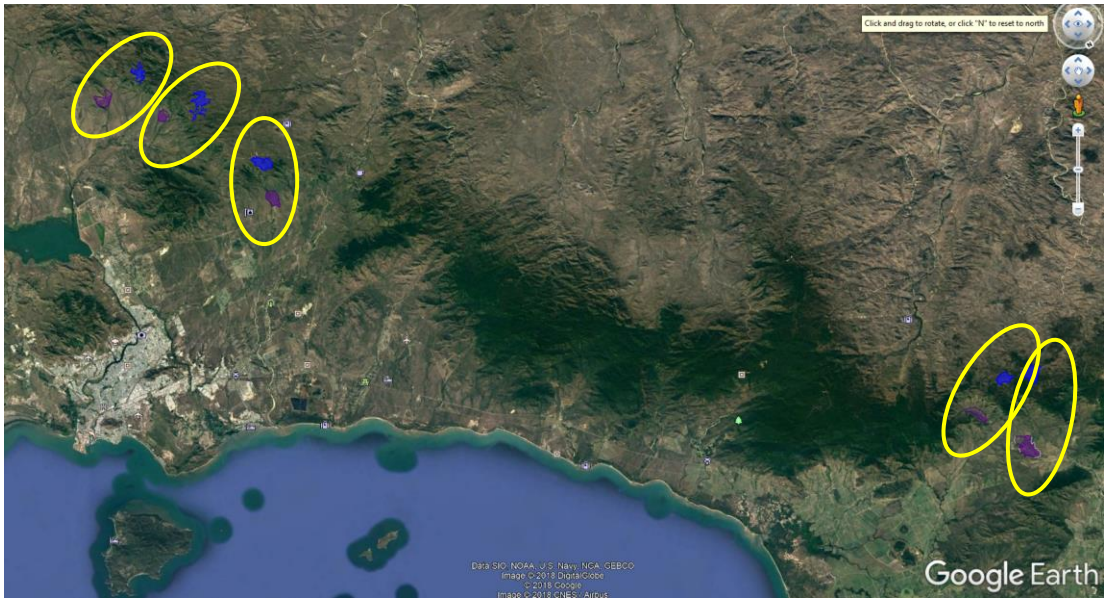

Figure 1. Reservoir pair locations for Beta model trials

A GIS-based spatial model was used to determine the information required for the costing including the optimal tunnel and penstock routing options and distance to the nearest transmission line, roadhead and water access point. The sites have high power (800 MW) and long storage (23-64 hours), and costs for these very large sites vary significantly from $3,500m to $7,800M.

Table 1 looks at these costs scaled to the amount of power and energy storage. Power costs include the powerhouse (which includes the pump/turbines), the tunnel and transmission infrastructure. Relative values for these components are reported as $/kW. Energy storage costs are related to the upper and lower water reservoirs. Relative values for these costs are shown in $/kWh. The lowest relative cost for each column is highlighted in green and the highest is highlighted in orange. The cost of the reservoirs was the largest source of variation for the system costs highlighting the importance of good site selection.

Site	Total $/kW	Total $/kWh	Powerhouse $/kW	Tunnel/Penstock $/kW	Transmission $/kW	Lower $/kWh	Upper $/kWh
1	**$1,141**	**$78**	$694	$313	$133	$15	$64
3	**$1,247**	**$112**	$647	$467	$134	$63	$49
17	**$1,210**	**$140**	$745	$339	$125	$10	$40
96	**$1,165**	**$311**	$761	$283	$120	$203	$108
189	**$1,339**	**$148**	$892	$315	$132	$116	$32
Max/min	**117%**	**397%**	**138%**	**165%**	**111%**	**1361%**	**338%**

Table 1. Relative total and component costs of power ($/kW) and energy storage ($/kWh).

The costs for the better sites compare favourably with recent publically announced schemes around Australia. These comparisons can be seen in Table 2 below. The costs of most schemes are reasonable predicted (+/-25%) with the exception of Cultana (sea-water) and Snowy 2.0 (very long tunnel).

Project	Owner	MW	MWh	Cost $M (proponents)	Head (m)	New reservoirs	Cost model $M	ratio
Goat Hill	Altura	250	2000	$410	200	2	$456	111%
Highbury	Tilt	300	1350	$400	120	1	$440	110%
Baroota	Rise	215	1570	$406	200	1	$313	77%
Iron Duchess	GFG Alliance	90	390	$170	100	1	$136	80%
Cultana	EA	225	1755	$477	260	1	$315	66%
Kidston	Genex	250	2000	$330	240	0	$288	87%
Snowy 2.0	Snowy	2000	350,000	$4,000	660	0	$2,300	57%

Table 2. Parameters for proposed pumped hydro sites and comparison to model costings

The ANU is seeking further funding from ARENA to automate the cost model to rank all of the 22,000 sites found in the site searching, allowing government and developers to identify the best potential PHES locations to support high penetration of renewables.