Pumped Hydro Energy Storage

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Energy storage questions

What technology?

What scale? What impact?

What benefits? What costs?

What risks?

Who wins… and who loses?
Arup-MEI pumped hydro energy storage research

Tumut 3 Power Station - NSW
PHES: The world’s most-used energy storage technology

Figure 4: Current global installed grid-connected electricity storage capacity (MW)

Pumped hydro operation

Daytime: Water flows downhill through turbines, producing electricity

Nighttime: Water pumped uphill to reservoir for tomorrow's use

www.water.usgs.gov
Forms of pumped hydro energy storage (PHES)

Raccoon Mountain, USA
1,652 MW

Bath County Virginia, USA
3,030 MW pumped storage
“world’s biggest battery”
### Existing large-scale pumped hydro in Australia

<table>
<thead>
<tr>
<th>Project</th>
<th>Capacity (MW)</th>
<th>Location</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tumut 3</td>
<td>600</td>
<td>Snowy Mountains</td>
<td>1973</td>
</tr>
<tr>
<td>Shoalhaven</td>
<td>240</td>
<td>southern NSW</td>
<td>1977</td>
</tr>
<tr>
<td>Wivenhoe</td>
<td>500</td>
<td>southern QLD</td>
<td>1984</td>
</tr>
</tbody>
</table>

Total = 1.34 GW

None built in the last 30 years.
Shoalhaven NSW operation data, June 2011

Red lines – electricity prices
Blue lines – power generated

30 days in June 2011
Pumped hydro arbitrage analysis

Optimal Daily Arbitrage: Pumped Hydro, 4hrs storage
2008-01-05 SA

Market Price

Hydro Operation

Maximum Capacity

Revenue

Cumulative Cash Flow
Generating Revenue
Pumping Costs

24 hours of wholesale electricity prices
PHES operation
Cumulative cash flow
Heat waves / wholesale electricity price spikes

“South Australian electricity wholesale prices spike to $10,515 / MWh due to heatwave”

Adelaide Advertiser, 14 January

“The Price Of Electricity Is Astronomical In The Heatwave.”

Business Insider Australia, 15 January

“Heatwave sends power prices soaring…”

Business Spectator, 16 January
“Pumped hydro arbitrage value index” – S. Australia
Arbitrage Value – depends on hot days

Adelaide days with max. temp. over 38 C.

Source: AEMO
South Australia Supply and Demand Outlook
“PHES arbitrage value index” – by state
Identified potential grid issues with:

- system inertia
- frequency control
- Interconnector limits

...potentially resulting in curtailment of future wind energy.
Reasons the world is looking at pumped hydro again, 30 years later

• For energy consumers:
  • a moderating effect on wholesale electricity prices.
• For renewable energy project owners and developers,
  • and other low-cost generators that receive lower than average value.
• For grid operators:
  • provides stability.
Global pumped hydro growth spurt, using “turkey-nest” dams

Europe: 11 GW under construction or in planning.
China: 10 GW under construction.
USA: New legislation to spur development.

La Muela, Spain (completed in 2013)
Tianhuangping, China
Electricity Production in Germany: Calendar Week 11

Actual production

Legend:
- Hydro
- Biomass
- Uranium
- Brown Coal
- Hard Coal
- Gas
- Pumped Storage
- Wind
- Solar

min. power (GW)
max. power (GW)
weekly energy (TWh)

Graph: Bruno Burger, Fraunhofer ISE; Data: EEX Transparency Platform

© Fraunhofer ISE
But can we do pumped hydro in Aus?
Where can it be built?

Need to understand,
*pumped hydro is not conventional hydro!*
Conventional hydroelectricity generation

Snowy Mountains scheme
Conventional hydro – large dams & reservoirs required

Lake Eucumbene (NSW)  
~ 15,000 hectares

Gordon Dam (Tasmania)  
~ 27,000 hectares
<table>
<thead>
<tr>
<th>Comparing:</th>
<th>Conventional Hydro</th>
<th>Pumped Hydro</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purpose</td>
<td>Energy generation, irrigation, flood control, recreation</td>
<td>Short-term energy storage and use</td>
</tr>
<tr>
<td>Electricity output</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Water requirement</td>
<td>Once-through, no recycling</td>
<td>Recycled. Make-up required for evaporation minus rainfall</td>
</tr>
<tr>
<td>Water storage period</td>
<td>Months or years</td>
<td>Hours</td>
</tr>
<tr>
<td>Reservoir size</td>
<td>Can be &gt; 10,000 hectares</td>
<td>5 to 50 hectares</td>
</tr>
<tr>
<td>Located on river?</td>
<td>Yes</td>
<td>Doesn’t have to be. Can use “turkey-nest”.</td>
</tr>
<tr>
<td>No. of possible Aus. sites</td>
<td>Limited</td>
<td>Thousands</td>
</tr>
</tbody>
</table>
Comparing reservoir size

Conventional hydro

Pumped hydro – upper and lower
“Turkey nest” pumped hydro (freshwater)

If suitable valley not available, use a “turkey nest” dam.
Rural Australia “turkey nest” water reservoir
Australia – examples of inland pumped hydro site mapping

Australian National University (ANU),
and
ROAM Consulting
Seawater pumped hydro – Okinawa, Japan

1 seawater PHES facility in the world: Yanbaru, Okinawa (1999). Cliff-top “turkey nest” style. 30 MW.

Upper pond covers only 5 hectares.
MEI cost model - components

Costs for PHES components converted to mathematical formulas, to aid site mapping.
Cost-based seawater PHES site identification (MEI)

White contours – locations of PHES earthen dams with cost less than a specified threshold.

White dot (18) – cheapest location for earthen dam.

Red contours and dot (29) - results for roller-compacted-concrete dams.
Site identification, Fleurieu Peninsula SA

Google Earth

Existing wind farm

Adequate cliff-top elevation difference for seawater pumped hydro.
PHES costs for 7 sites, 100 MW, 10 hrs storage, 1000 MWh

<table>
<thead>
<tr>
<th>Site</th>
<th>Capital cost ($A millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>East Eyre 2-A</td>
<td>$150</td>
</tr>
<tr>
<td>East Eyre 2-B</td>
<td>$200</td>
</tr>
<tr>
<td>East Eyre 3</td>
<td>$300</td>
</tr>
<tr>
<td>El Alamein</td>
<td>$400</td>
</tr>
<tr>
<td>Fleurieu 3</td>
<td>$500</td>
</tr>
<tr>
<td>Portland</td>
<td>$600</td>
</tr>
<tr>
<td>Yorke 1</td>
<td>$700</td>
</tr>
</tbody>
</table>

- Reservoir
- Piping / tunnelling
- E&M
- EPC Mgt
- Conting
- Owner's costs
Arup-MEI pumped hydro energy storage paper

Available at
University of Melbourne Energy Institute website:
http://www.energy.unimelb.edu.au/library