



Pumped Hydro Energy Storage

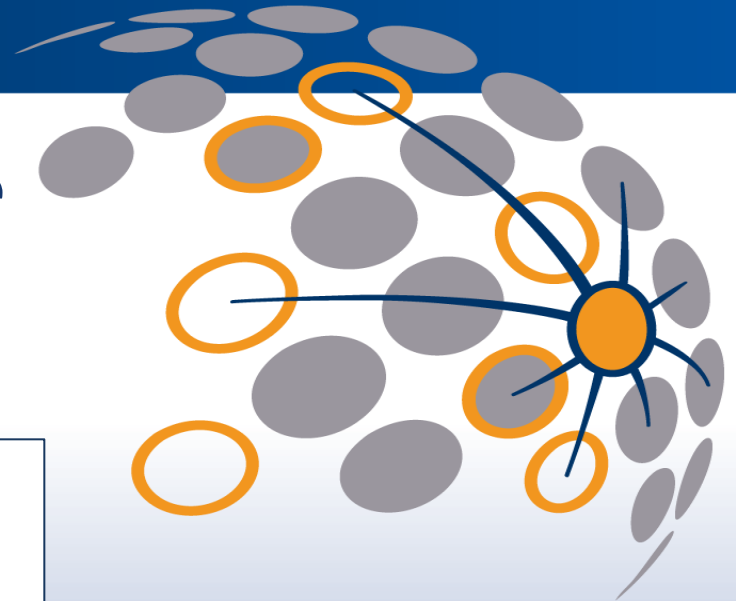
Tim Forcey – Energy Advisor

University of Melbourne Energy Institute

8 May 2014



AUSTRALIAN
ENERGY STORAGE
CONFERENCE & EXHIBITION



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



*Opportunities for
Pumped Hydro Energy
Storage in Australia
Arup-MEI Research
27 February 2014*



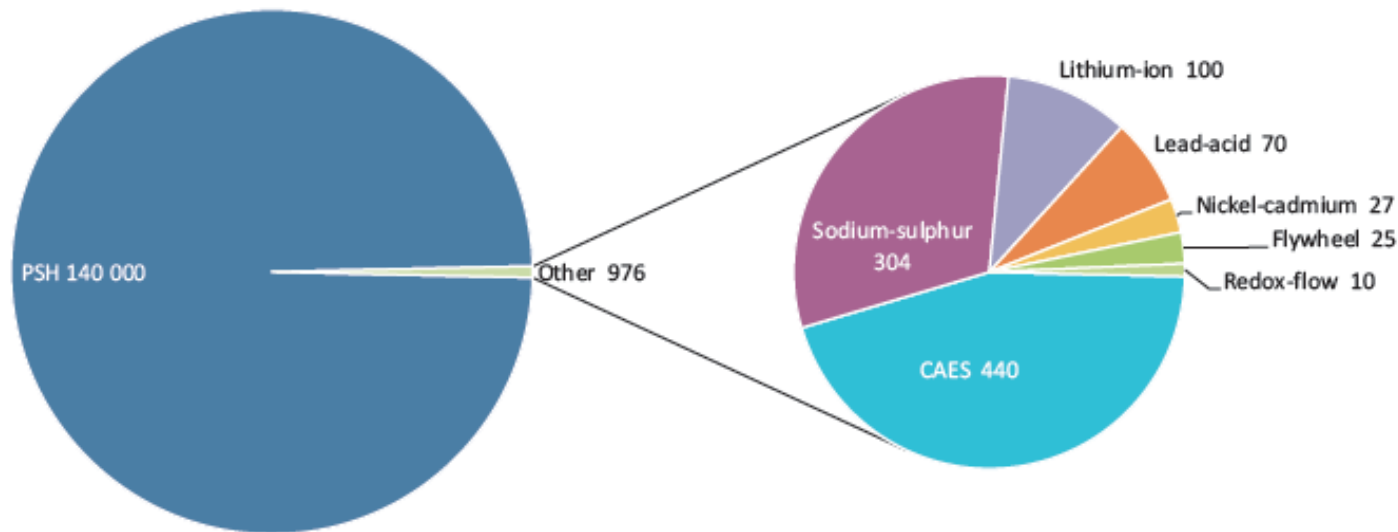
*Patrick Hearps, Roger Dargaville, Dylan McConnell
Mike Sandiford, Tim Forcey, Peter Seligman*



Tumut 3 Power Station - NSW

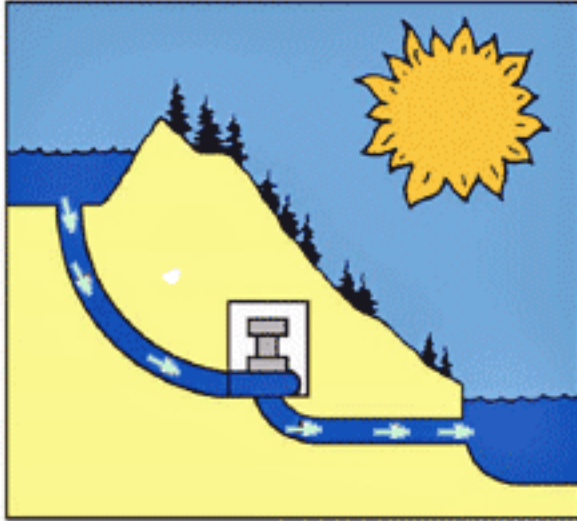
PHES: The world's *most-used* energy storage technology

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



Source: IEA analysis and EPRI (Electric Power Research Institute) (2010), "Electrical Energy Storage Technology Options", Report, EPRI, Palo Alto, California.

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

Tumut 3, 600 MW,
Snowy Mountains, 1973

Shoalhaven, 240 MW
southern NSW, 1977

Wivenhoe, 500 MW,
southern QLD, 1984

Total = 1.34 GW

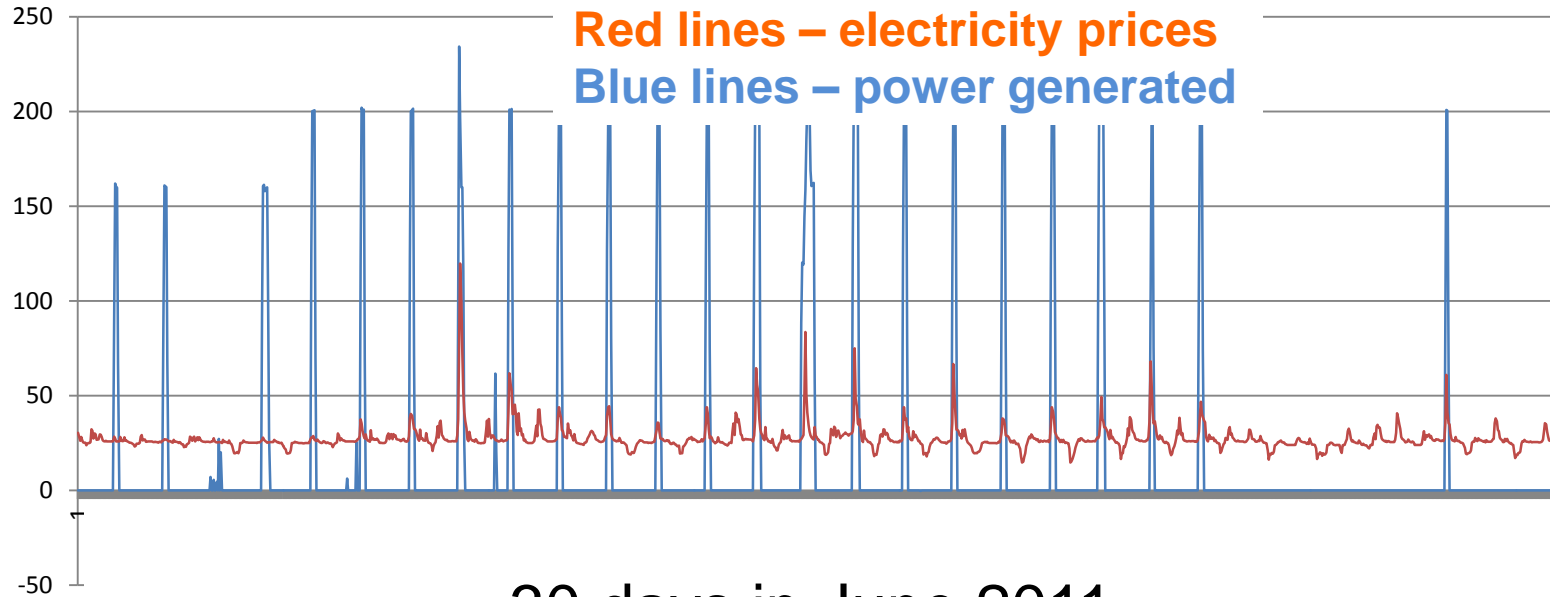
None built in the last 30 years.

Figure 3.3 – Shoalhaven Scheme



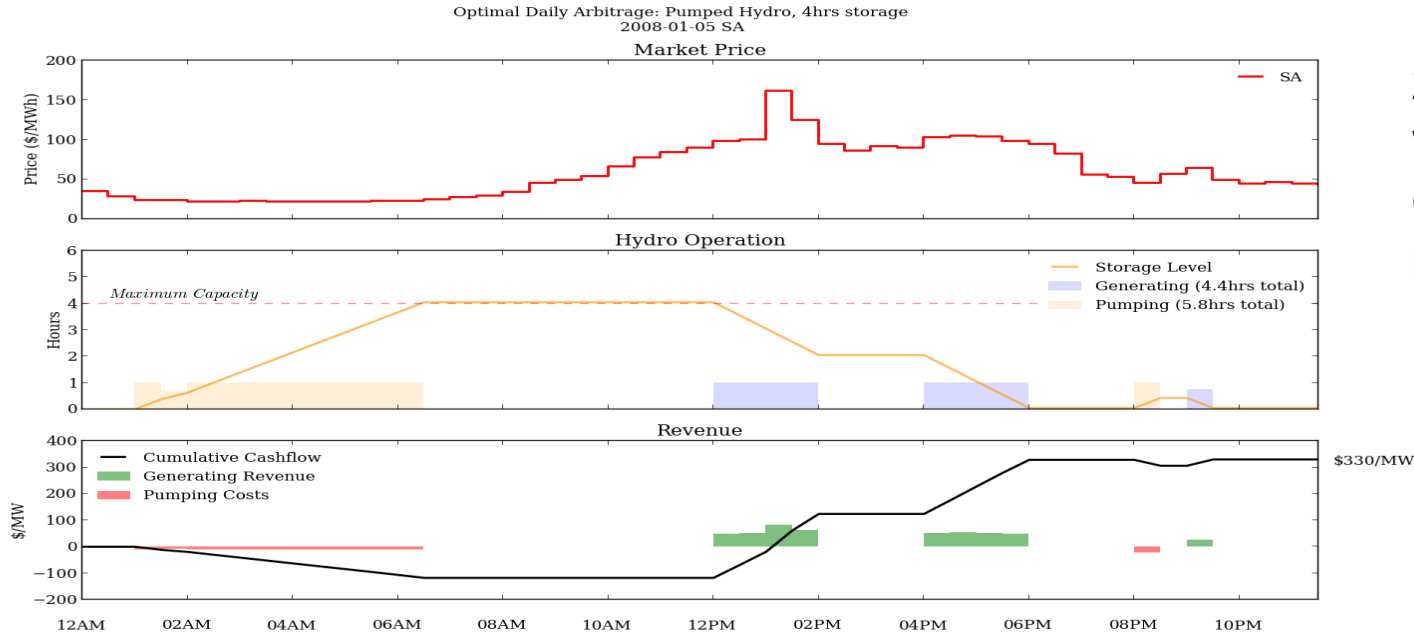
*Bendeela Pondage and
Bendeela Pumping and Power Station*

Shoalhaven NSW operation data, June 2011



30 days in June 2011

Pumped hydro arbitrage analysis



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



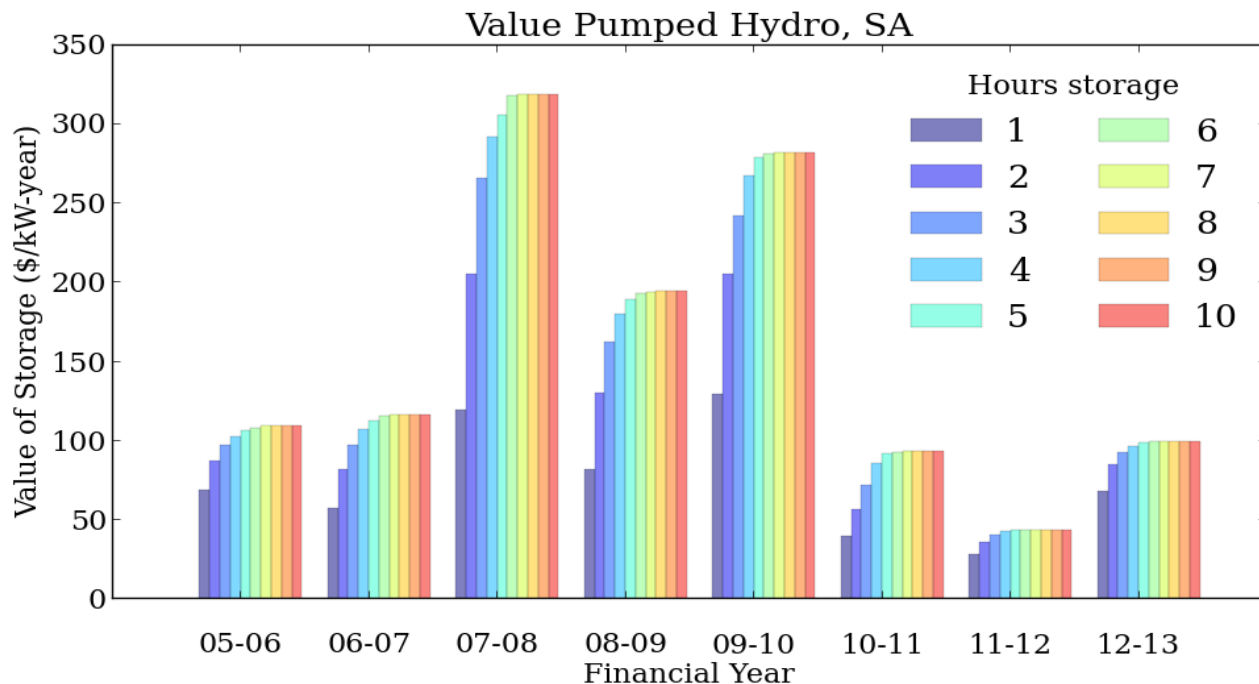
“The Price Of Electricity Is Astronomical In The Heatwave.”

Business Insider Australia, 15 January

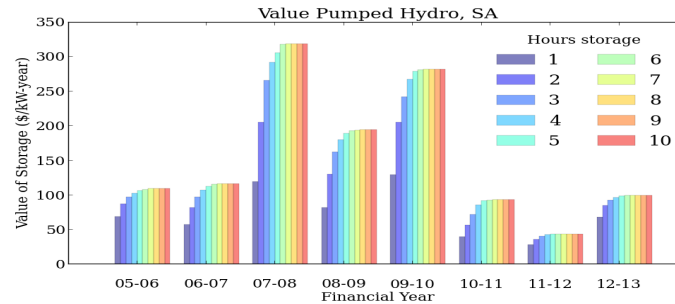
“Heatwave sends power prices soaring...”

Business Spectator, 16 January

“Pumped hydro arbitrage value index” – S. Australia

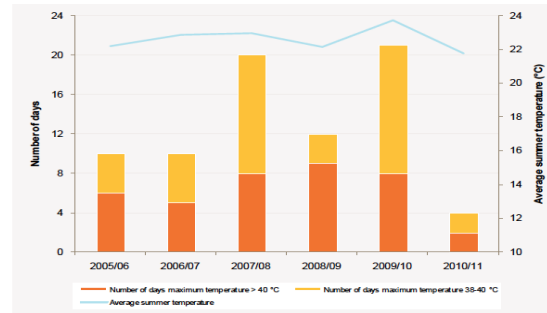


Arbitrage Value – depends on hot days



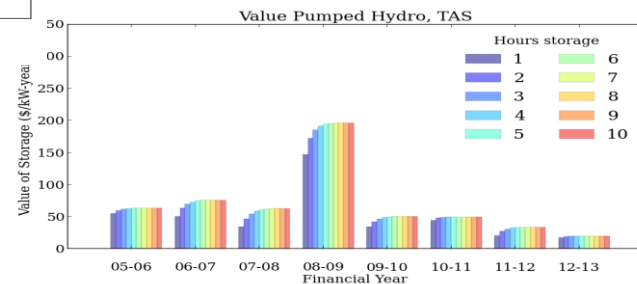
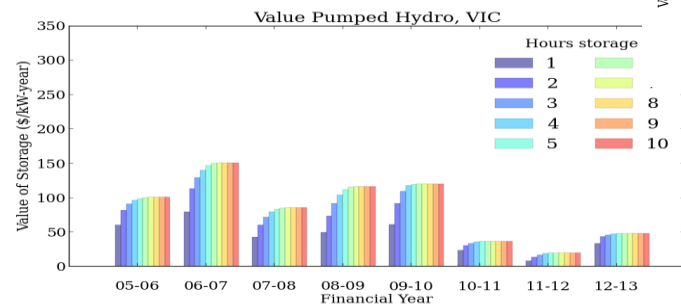
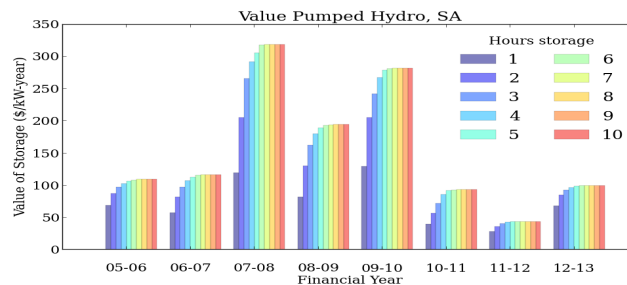
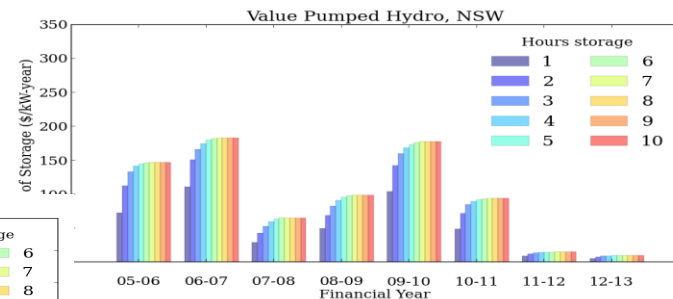
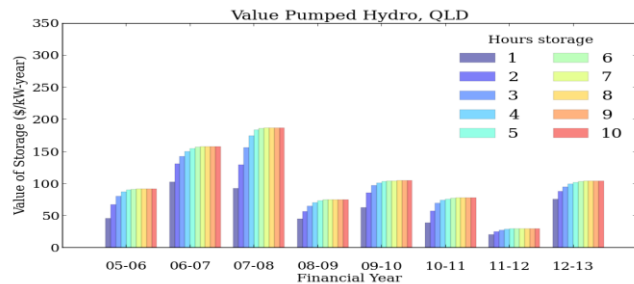
***Adelaide days
with max. temp.
over 38 C.***

Figure 2-5 — Number of hot days and average summer temperature

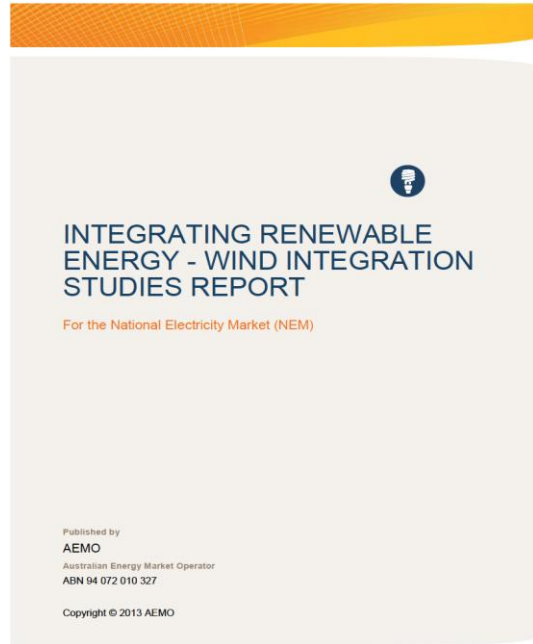


*Source: AEMO
South Australia Supply
and Demand Outlook*

“PHES arbitrage value index” – by state



AEMO – Integrating Renewable Energy



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



La Muela, Spain (completed in 2013)



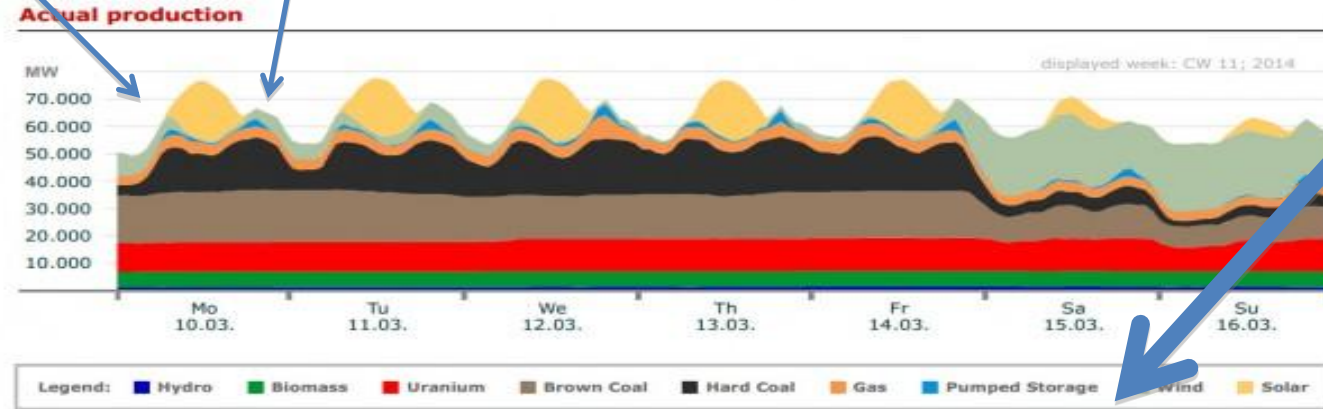
Tianhuangping, China

Europe: 11 GW under construction or in planning.

China: 10 GW under construction.

USA: New legislation to spur development.

Electricity Production in Germany: Calendar Week 11



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

Hyd	Bio	Uran	BC	HC	Gas	PSt	Wind	Solar
1.0		8.5	7.7	2.1	3.1	0	0.04	0
1.4		11.9	19.1	20.4	8.7	4.0	24.8	22.1
0.2	1.0	1.9	2.5	2.1	0.7	0.1	1.4	0.8

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

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Fraunhofer
ISE

But can we do pumped hydro in Aus?

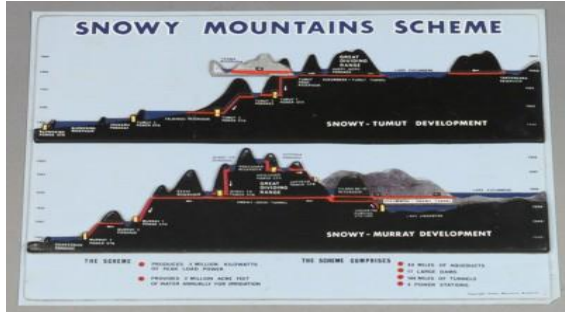
Where can it be built?



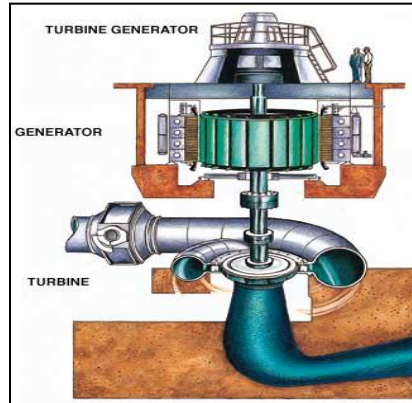
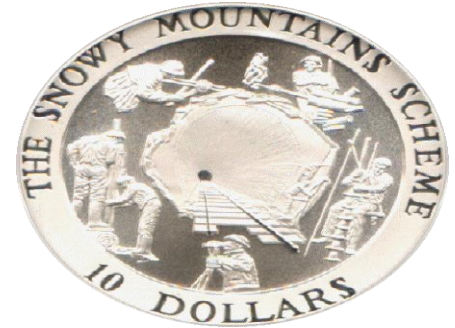
*Need to understand,
pumped hydro is not conventional hydro!*



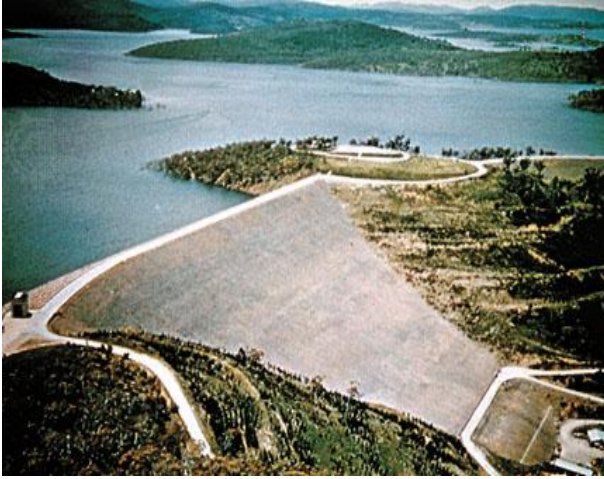
Conventional hydroelectricity generation



Snowy Mountains scheme



Conventional hydro – large dams & reservoirs required



Lake Eucumbene (NSW)
~ 15,000 hectares

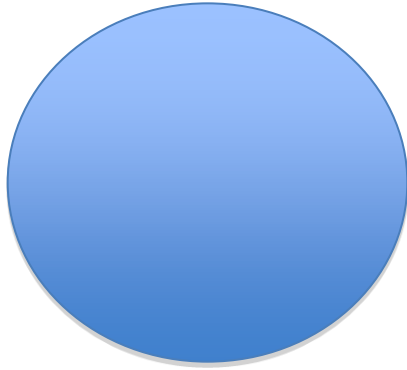
Gordon Dam
(Tasmania)
~ 27,000
hectares



Comparing:	Conventional Hydro	Pumped Hydro
Purpose	Energy generation, irrigation, flood control, recreation	Short-term energy storage and use
Electricity output	High	High
Water requirement	Once-through, no recycling	Recycled. Make-up required for evaporation minus rainfall
Water storage period	Months or years	Hours
Reservoir size	Can be > 10,000 hectares	5 to 50 hectares
Located on river?	Yes	Doesn't have to be. Can use "turkey-nest".
No. of possible Aus. sites	Limited	Thousands

ANU
and
MEI

Comparing reservoir size



Conventional hydro



Pumped hydro – upper and lower



“Turkey nest” pumped hydro (freshwater)



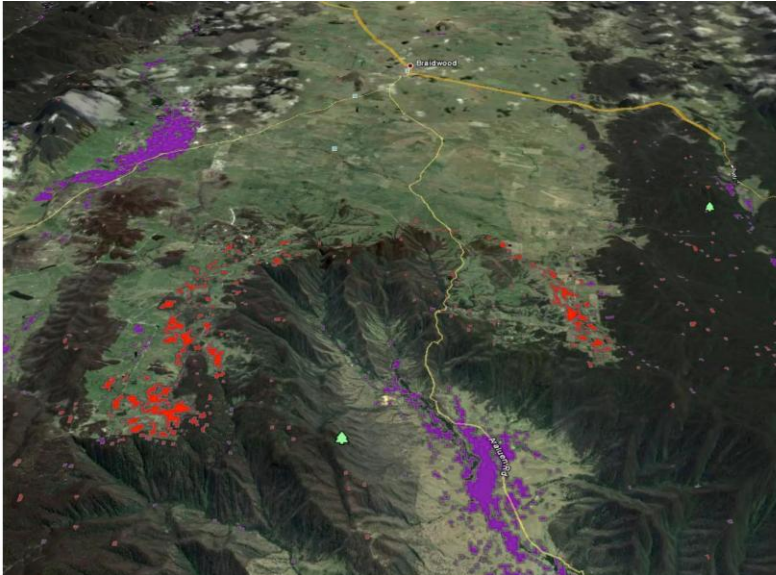
*If suitable valley
not available,
use a “turkey nest” dam.*



Rural Australia “turkey nest” water reservoir



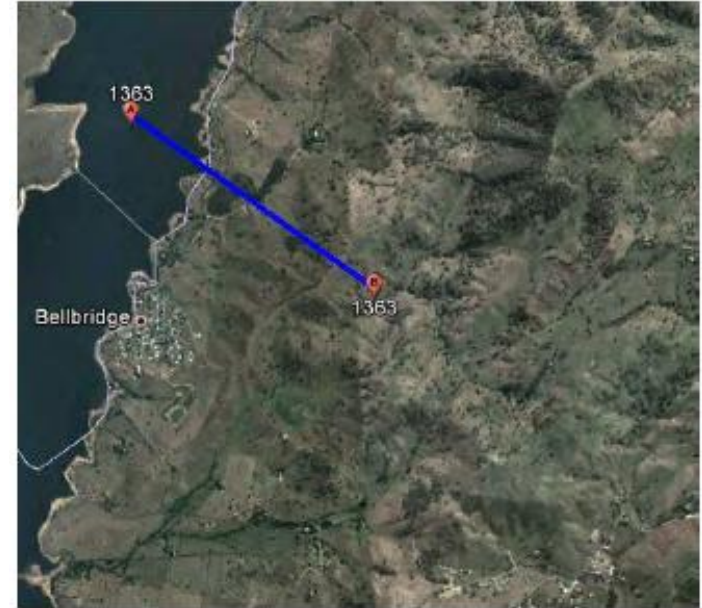
Australia – examples of inland pumped hydro site mapping



Australian
National
University
(ANU),

and

ROAM
Consulting



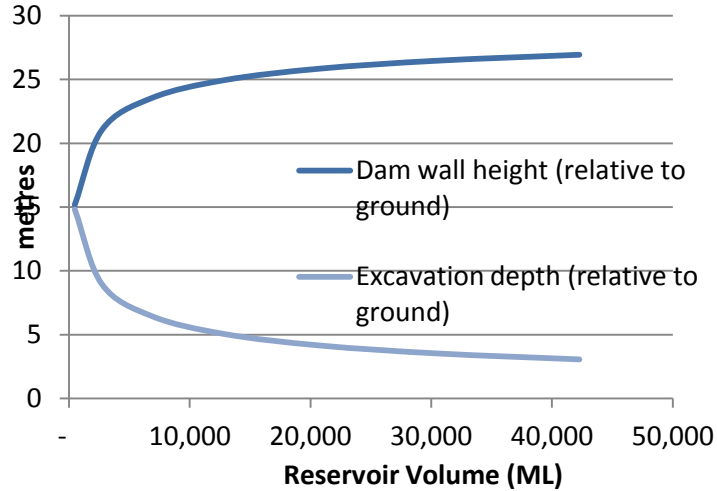
Seawater pumped hydro – Okinawa, Japan

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

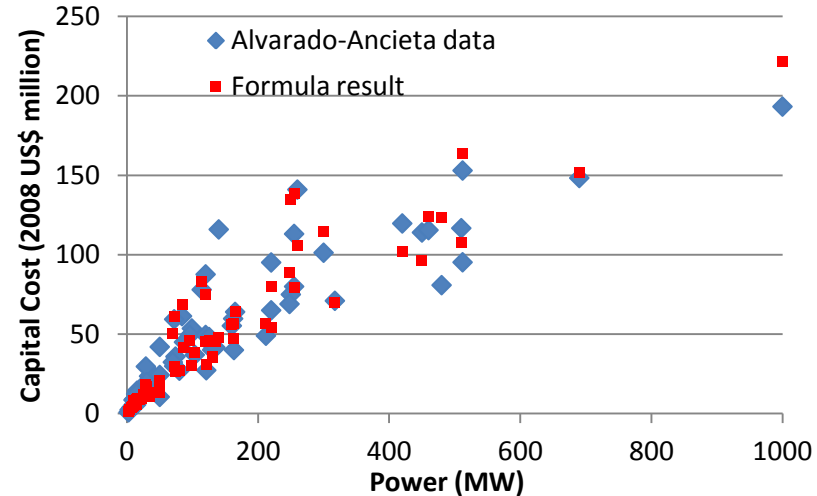
Upper pond covers
only 5 hectares.



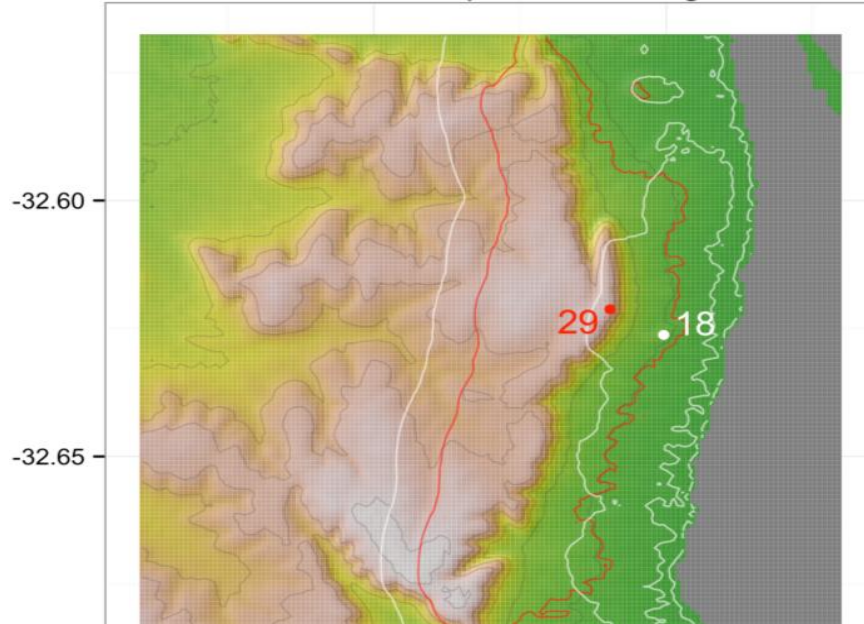
MEI cost model - components



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

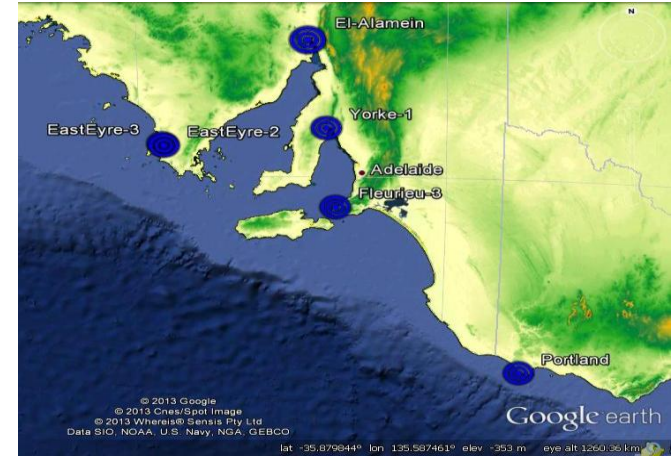
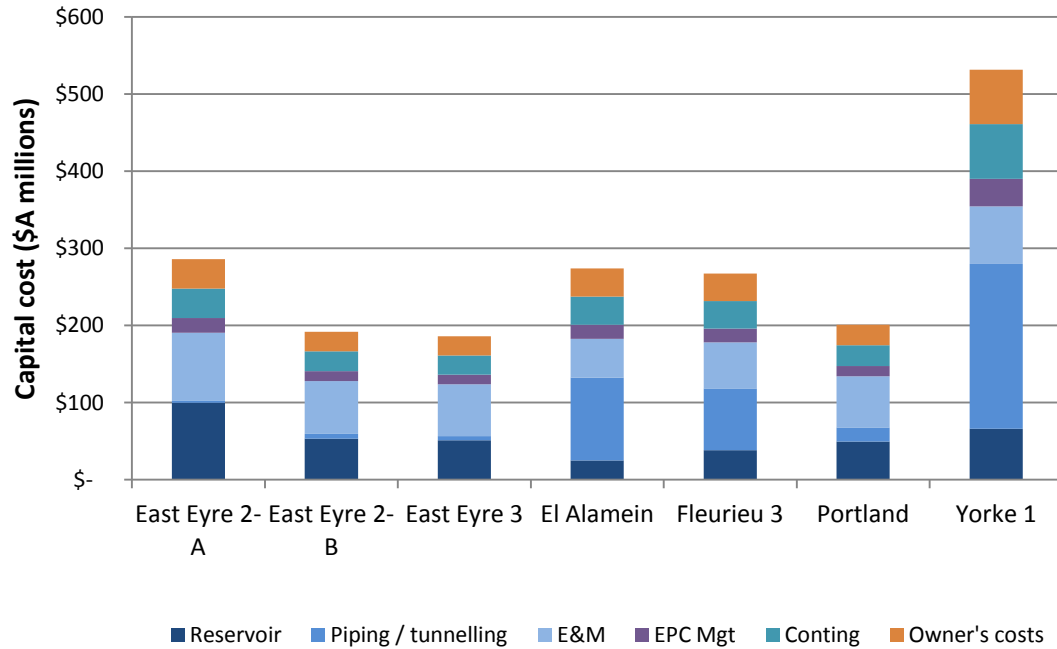
Google
Earth



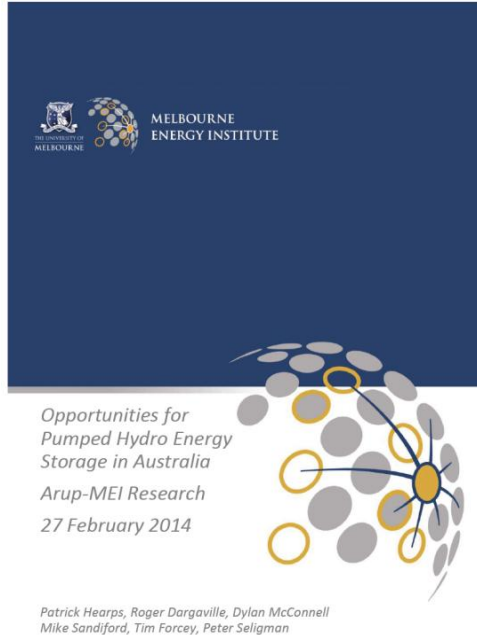
Existing
wind farm

Adequate
cliff-top
elevation
difference
for seawater
pumped
hydro.

PHES costs for 7 sites, 100 MW, 10 hrs storage, 1000 MWh



Arup-MEI pumped hydro energy storage paper



Available at

University of Melbourne

Energy Institute website:

<http://www.energy.unimelb.edu.au/library>