Pumped hydro storage and 100% renewable electricity

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New generation capacity worldwide in 2016

Net new capacity
1st place: PV
2nd place: wind
3rd place: coal
PV learning curve

Average module sales price (USD 2015/Wp) vs. cumulative PV module shipments (MW).

- Historic price data
- LR 21.5%

- Late 2017
- 380 GW
100% renewable electricity

- Technical diversity
  - 90% wind & photovoltaics (+ existing hydro & biomass)
- Demand management
  - Shift loads from night to day, interruptible loads
- Wide geographical dispersion
  - Supported by high voltage interconnectors
- Mass storage
  - Pumped hydro: 97% of all storage
  - Advanced batteries
High voltage DC transmission (HVDC)

**Storage & HVDC** belong together

HVDC: Transmit Gigawatts at Megavolts over thousands of km

- Basslink: 400kV, 290km, 0.5GW
- ABB (China): **1100kV, 3000km, 12GW**
Sunlight in Australia

Supply all of Australia’s and the world’s electricity
Excellent wind

HVDC backbone
World wide energy storage
- 160 Gigawatts (2GW in Australia)
- Lowest cost storage

Source: [www.energystorageexchange.org/projects/data_visualization](http://www.energystorageexchange.org/projects/data_visualization)
On-river pumped hydro
Talbingo reservoir (Tumut 3)
Snowy 2.0
Off-river closed-loop pumped hydro
Off-river PHES

- No expensive flood control
- Daily (not seasonal) storage
  - 25 hectare reservoirs, 25m deep, 500m head
  → 500 MW for 12 hours
- Triple the head
  - Tripled power
  - Tripled energy storage
  → Less than tripled cost
Automated GIS pumped hydro site search

- Minimum head: 300m (200m in WA, NT)
- Minimum stored energy: 1 GWh
- Minimum pipe/tunnel slope: 1:15
- Exclude national parks and urban areas
- 99% of sites are off-river (closed loop)
- Research program
  - Found 22,000 upper reservoirs for 40m wall height
  - Find lower reservoirs and pair them
  - Model 10m, 20m, 40m, 80m wall heights
  - Develop public cost model
Found in our survey: 22000 sites, 67 TWh
Requirement for 100% renewables: 20 sites, $\frac{1}{2}$ TWh

We can be very choosy in site selection
Off-river pumped hydro site search

<table>
<thead>
<tr>
<th>Region</th>
<th>Sites found</th>
<th>Energy (GWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SA</td>
<td>185</td>
<td>500</td>
</tr>
<tr>
<td>NT</td>
<td>1500</td>
<td>5000</td>
</tr>
<tr>
<td>Tas</td>
<td>2100</td>
<td>6000</td>
</tr>
<tr>
<td>Qld</td>
<td>1800</td>
<td>7000</td>
</tr>
<tr>
<td>WA</td>
<td>3800</td>
<td>9000</td>
</tr>
<tr>
<td>Vic</td>
<td>4400</td>
<td>11000</td>
</tr>
<tr>
<td>NSW/ACT</td>
<td>8600</td>
<td>29000</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>22000</strong></td>
<td><strong>67000</strong></td>
</tr>
<tr>
<td>Requirement for 100%</td>
<td>About 20</td>
<td>450 GWh</td>
</tr>
</tbody>
</table>

- Only the best 0.1% of the sites needed → be choosy
- Cost model under development: beta version late this year
Selected pumped hydro capacities (GWh)

100% renewable electricity requirement
- 450 GWh of energy storage
- 20 GW of power capacity

Largest off-river PHES in each state
Araluen (near Canberra)
Townsville - pairing

Upper reservoirs

Lower reservoirs

Choose one pair for the whole of north Qld
Qld energy

- Unlimited PV & wind potential
- Several GW of PV & wind under development
- Excellent potential sites for pumped hydro
- New jobs in regional Qld
  - PV
  - Wind
  - Pumped hydro
  - HVDC powerline
- Galilee coal prospect

Map: Margaret Blakers
PHES: water and environment - 100% renewables scenario

• Environment
  – Exclude national parks
  – Australia: 36 km² total reservoirs (5 ppm)
  – USA: 500 km² total reservoirs (60 ppm)

• Water
  – Water recycled; evaporation suppressors
  – PV/wind/PHES system uses ¼ of the water used by a coal-dominated system
Modelling 100% renewable electricity

• No heroic assumptions: only use technologies with >100 GW deployment
  – PV, wind, pumped hydro, HVDC/AC
• Hourly demand, wind, sun data for 2006-10
• 90% PV + wind
  – 10% existing hydro and biomass
• Very widely distributed over 1 million km²
  – Wide range of weather, climate, demand
• Pumped hydro energy storage (PHES)
  – Plus batteries and demand management
Balancing 50-100% renewables

• Storage requirements
  – 450 GWh of energy storage
  – 20 GW of storage power capacity
  – Spread across about 20 sites

• Balancing cost
  – Storage + HVDC + spillage
  – $5/MWh for 50% renewables
  – $25/MWh for 100% renewables
All-in cost of electricity

- Meets the Australian Paris target
- 35% reduction in emissions from 2016
- 48% reduction in emissions from 2016

50% renewables: 50
100% renewables: 80
100% renewables + electrified transport: 100
Current wholesale price range: 120

35% reduction in emissions from 2016
48% reduction in emissions from 2016
100% renewables: cost including balancing

Storage requirements
- 450 GWh of energy storage
- 20 GW of storage power capacity
- Spread across about 20 sites

Wholesale prices

Balancing cost
- Storage
- HVDC
- Spillage
100% renewables: **energy** storage needs (GWh)

- 450 GWh of energy storage
- 20 GW of storage power capacity
- Spread across about 20 sites for robustness

Only the best few sites needed in each state (from 22,000 candidates)
100% renewables: storage **power** needs (GW)

50% renewables: meets the Paris target
- 45 GWh of energy storage
- 6 GW of storage power capacity
- $9B spread over 50 year lifetime costing about $5/MWh

Gigawatts (GW)

Snowy 3.0

Snowy 4.0
Path to 100% renewable electricity in Australia

Enormous learnings during 2017-19 lead to large further cost reductions in Australia

Renewable Electricity in 2030

- Rate in 2015
- Current rate (2017-19)

Meets Paris target

Annual installation rate of PV + wind (Gigawatts)
Eliminating emissions, sector by sector

- Electricity: 35%
- Land sector & other: 18%
- Fugitive emissions: 8%
- Industrial processes: 4%
- Aviation & shipping: 4%
- High temperature heat: 11%
- Low temperature heat: 7%
- Land transport: 13%

55% of emissions:
- PV + wind
- Electric vehicles
- Electric heat pumps
Conclusions

• PV + wind enables rapid decarbonisation
• PHES and HVDC supports a secure grid (+ batteries & demand management)
• Effectively unlimited number of PHES sites in Australia
• On-track for >50% renewables by 2030 at zero net cost (compared with fossil fuels)
• Electrify most things for deep (>75%) cuts
Path to 100% renewables by 2040

World Electricity supply and demand

- Annual demand
- Wind + PV
- PV (15% growth rate)
- Wind (10% growth rate)
Thank you!

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