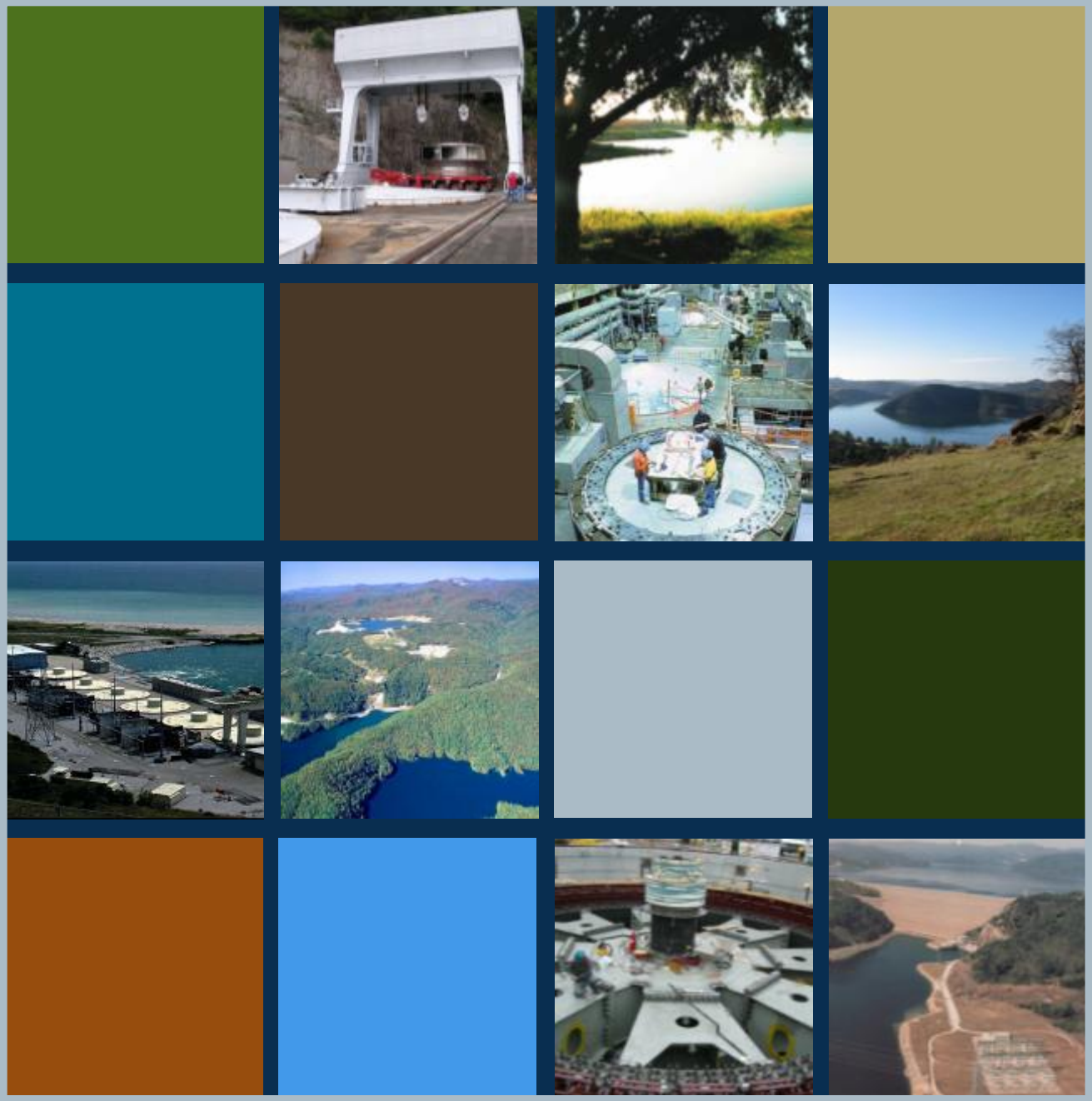


Pumped Storage - The Proven Grid Scale Storage Solution

Presented to:

NWPCC – GRAC Committee

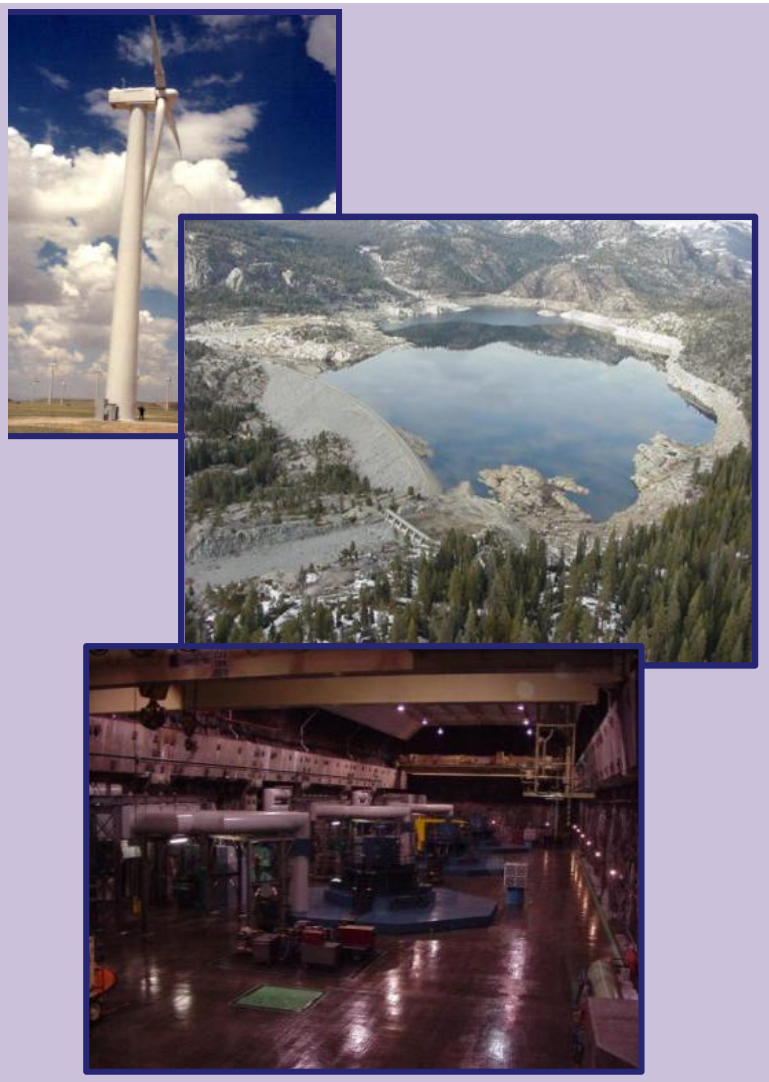
January 27, 2015

Presentation Agenda – Part 1

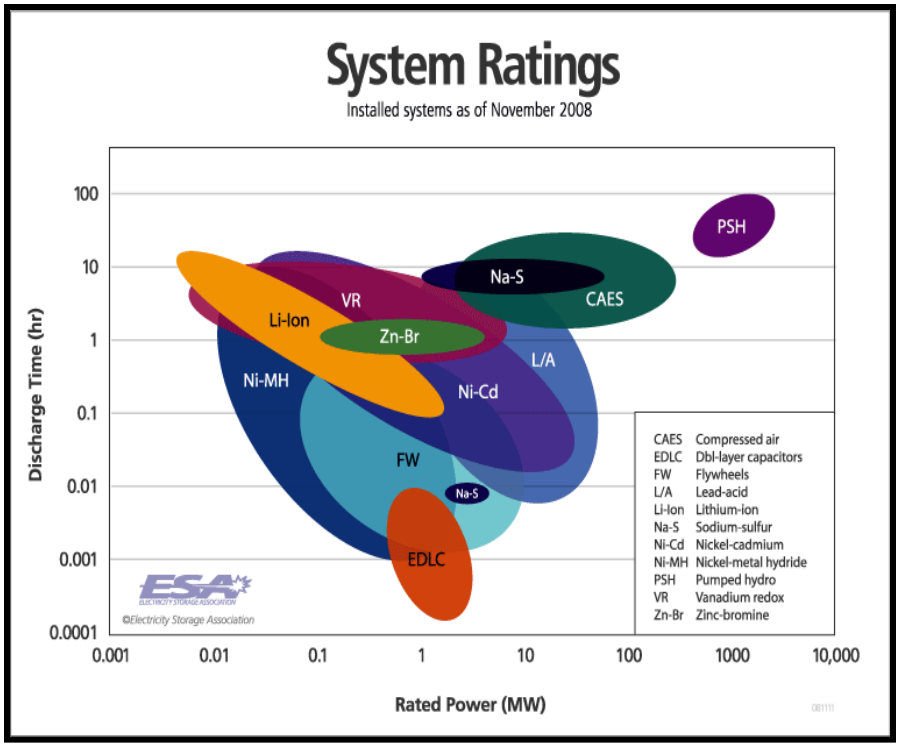
- Variable Energy Resources Integration Challenges
  - The Need for Grid Flexibility
- Pumped Storage Overview
  - Discussion of Technology
  - Capital and O&M cost elements
- Pacific NW potential sites

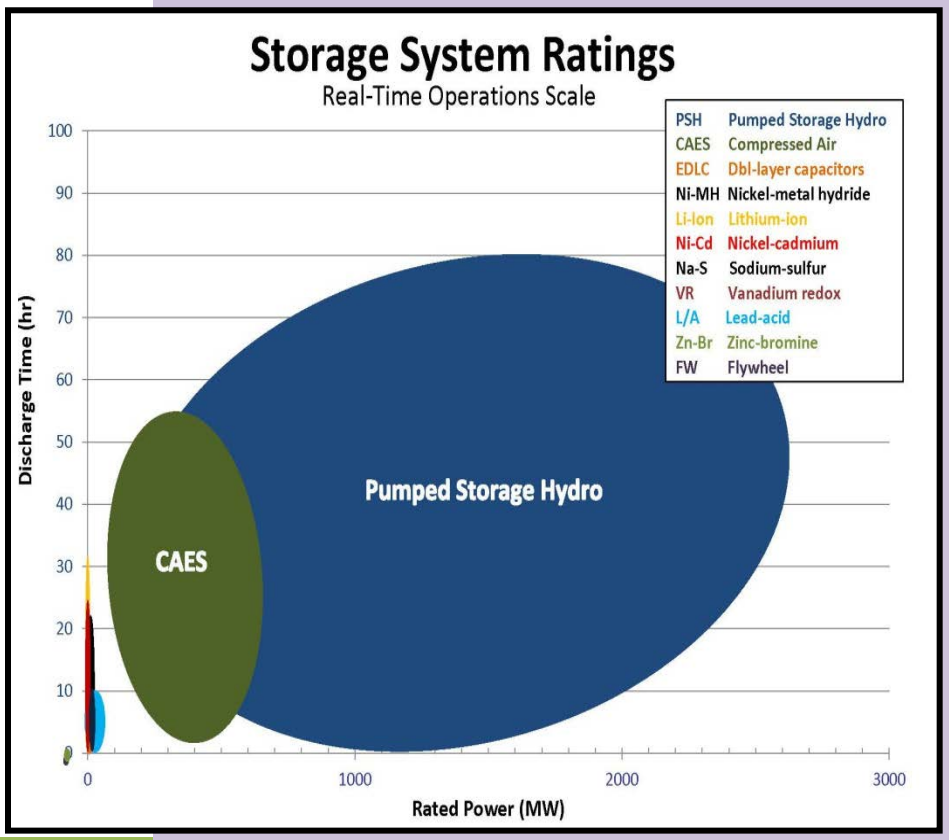
Three Interrelated Challenge

- Provision of Balancing Services
  - How can wind variability be managed in a reliable, efficient manner while recognizing the limits on the region's hydro flexibility and the need for dependable capacity?
- Oversupply
  - How can high hydro/high wind/limited load conditions be reliably and equitably managed?
- System Flexibility
  - How much is there now, how much will be needed?



Bulk and Distributed Energy Storage Technologies





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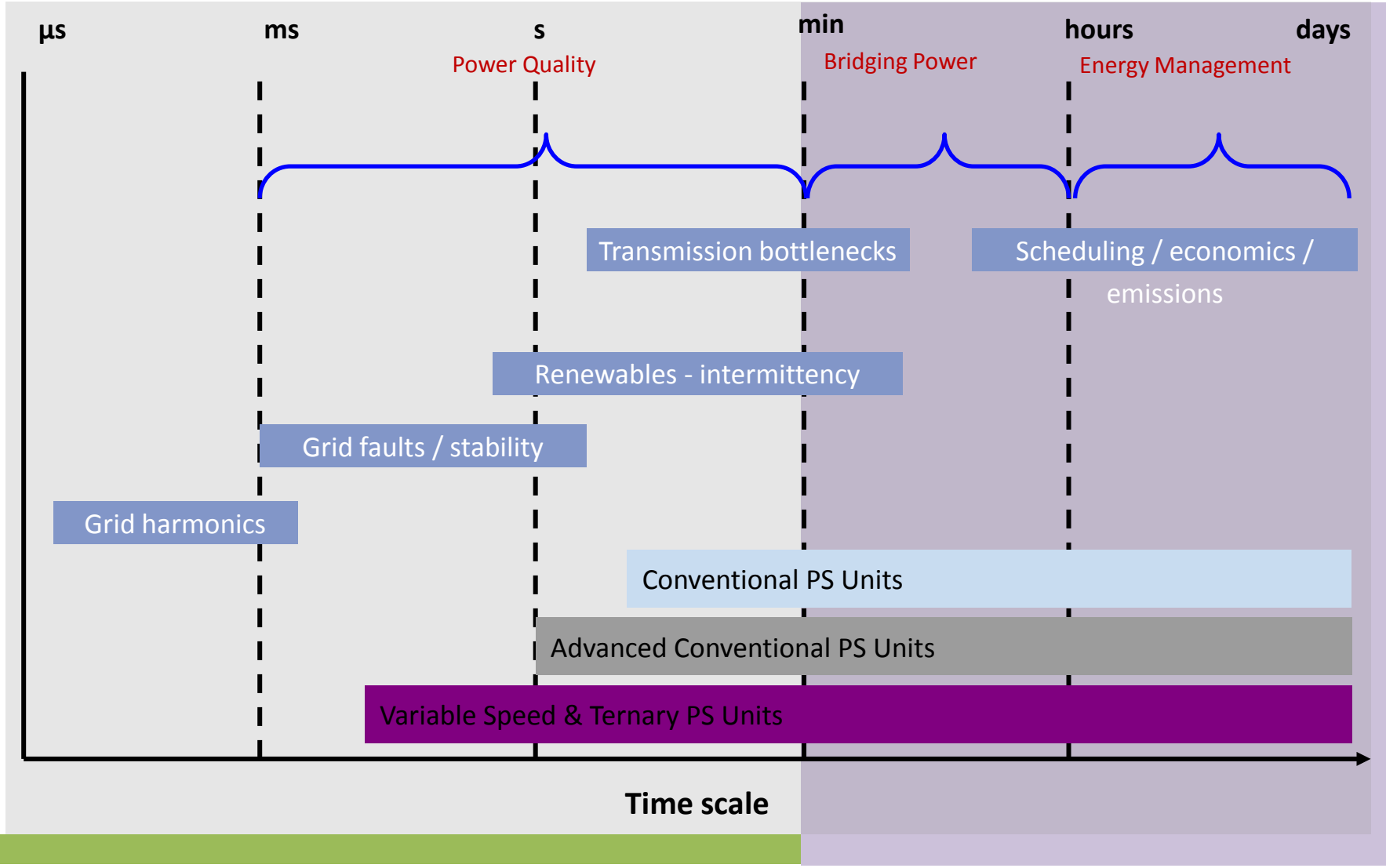
Pumped Storage Information & Characteristics



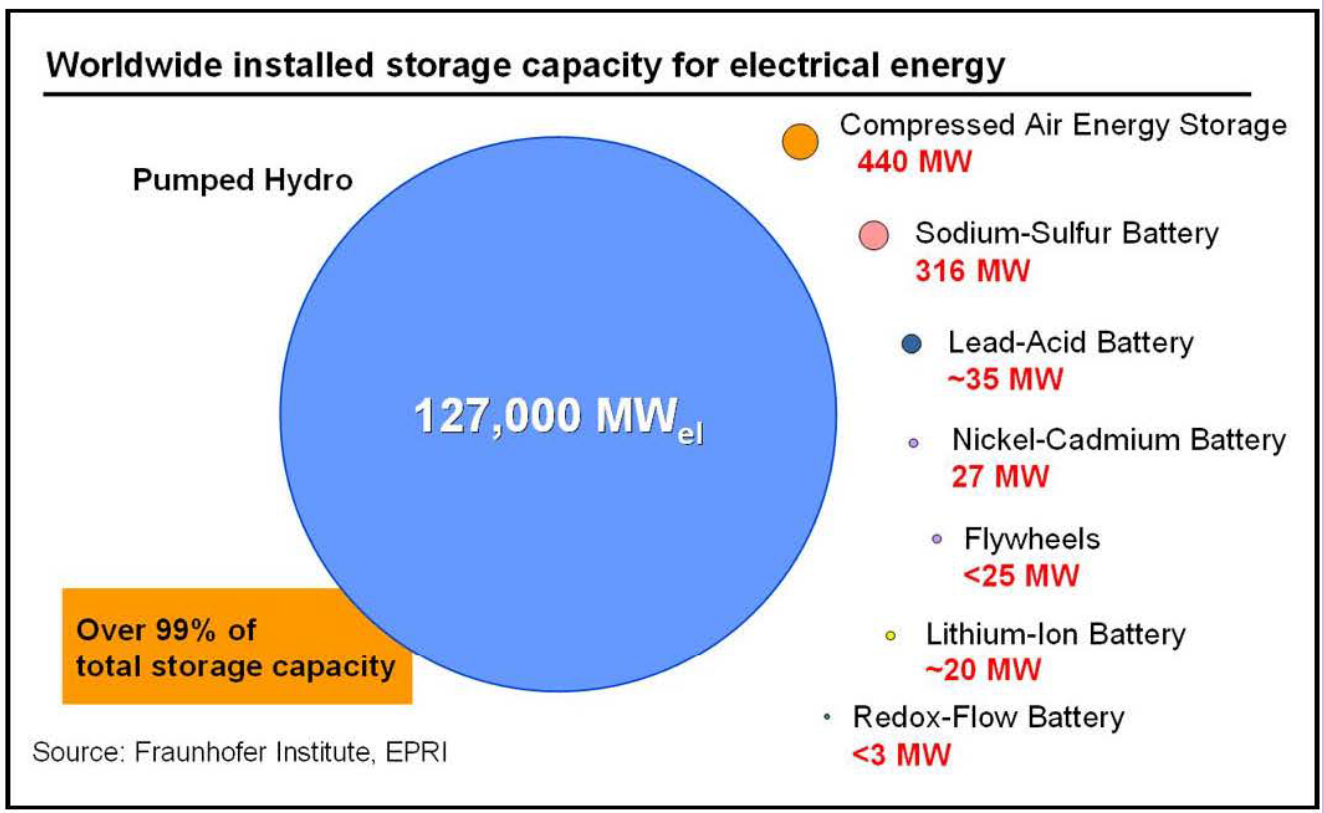
Equipment Response Time & Grid Benefits

Why Energy Storage?

- Attenuates generation volatility and physical availability risks
- Aligns peak generation to peak loads
- Reduces imbalance due to scheduling challenges
- Moderates transmission congestion and improves system reliability
- Enables further penetration of variable generating resources

Energy Storage Technologies

Current Landscape/Installed Capacity



EPRI Energy Storage Technology Options Report 1020676, 2010

Pumped Storage footprint in terms of batteries

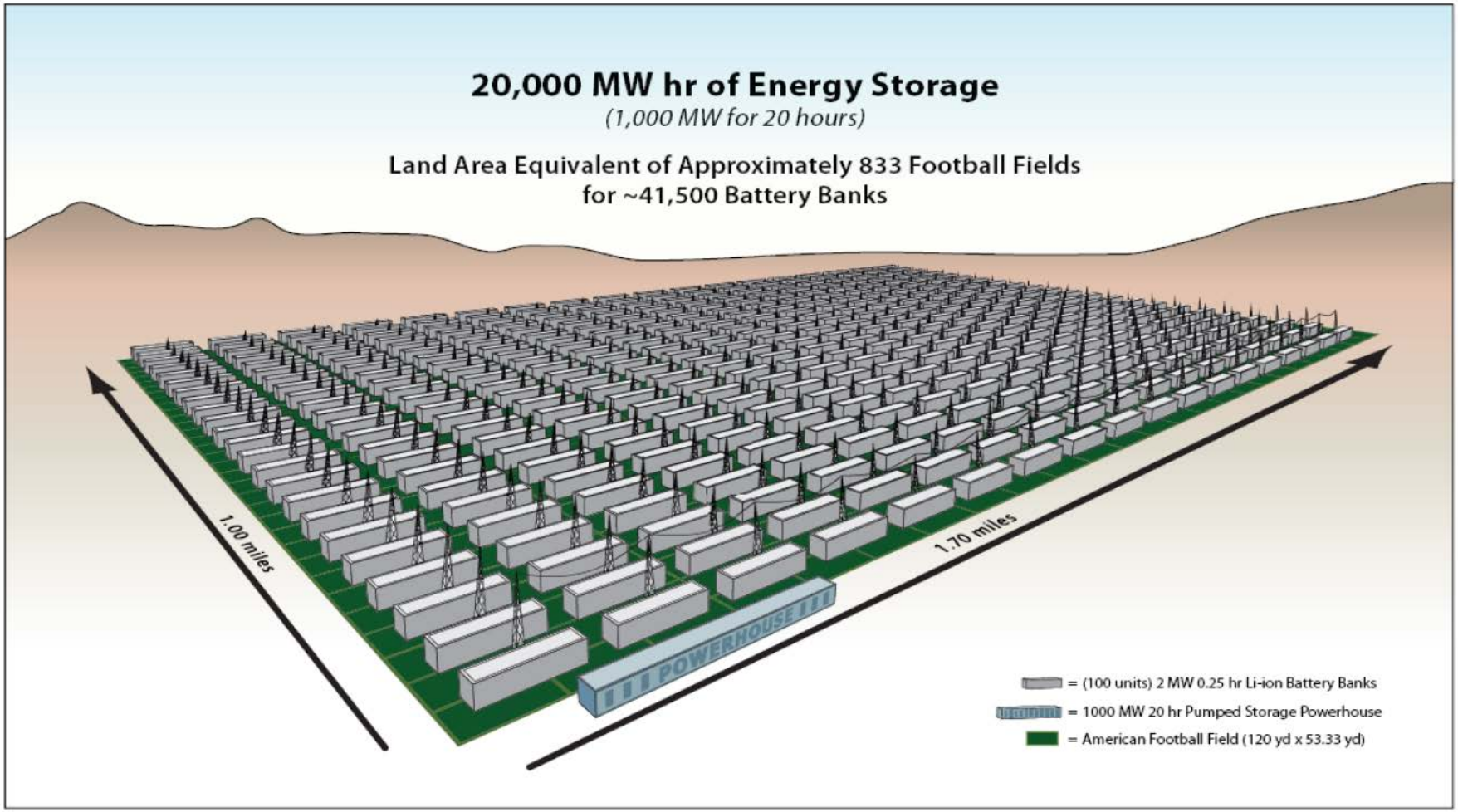
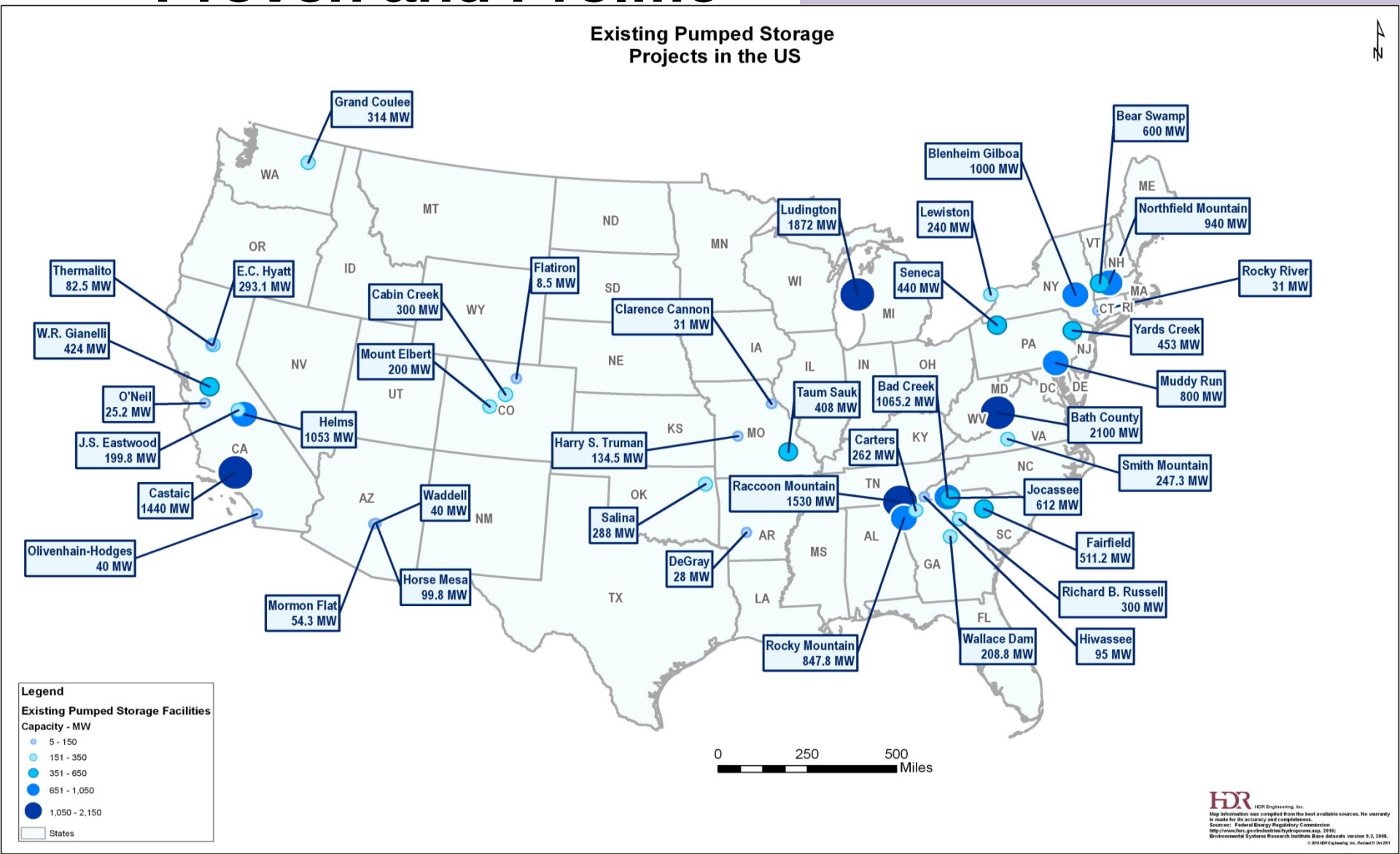


Figure 11. Li-ion Battery Field and a Hydroelectric P/S Plant for 20,000 MWh of Storage (Source: HDR|DTA)

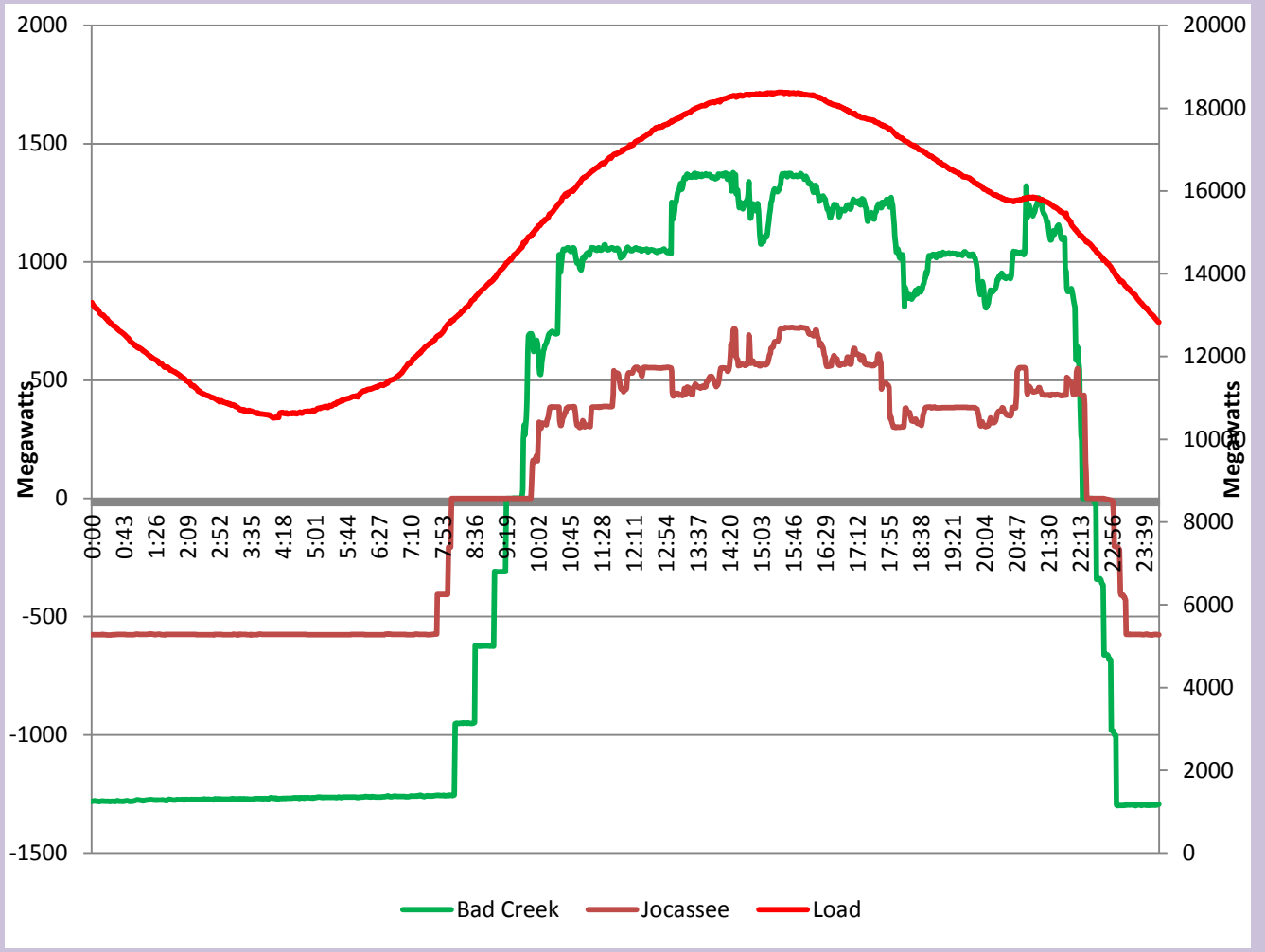
Existing U.S. Pumped Storage Projects

Proven and Prolific



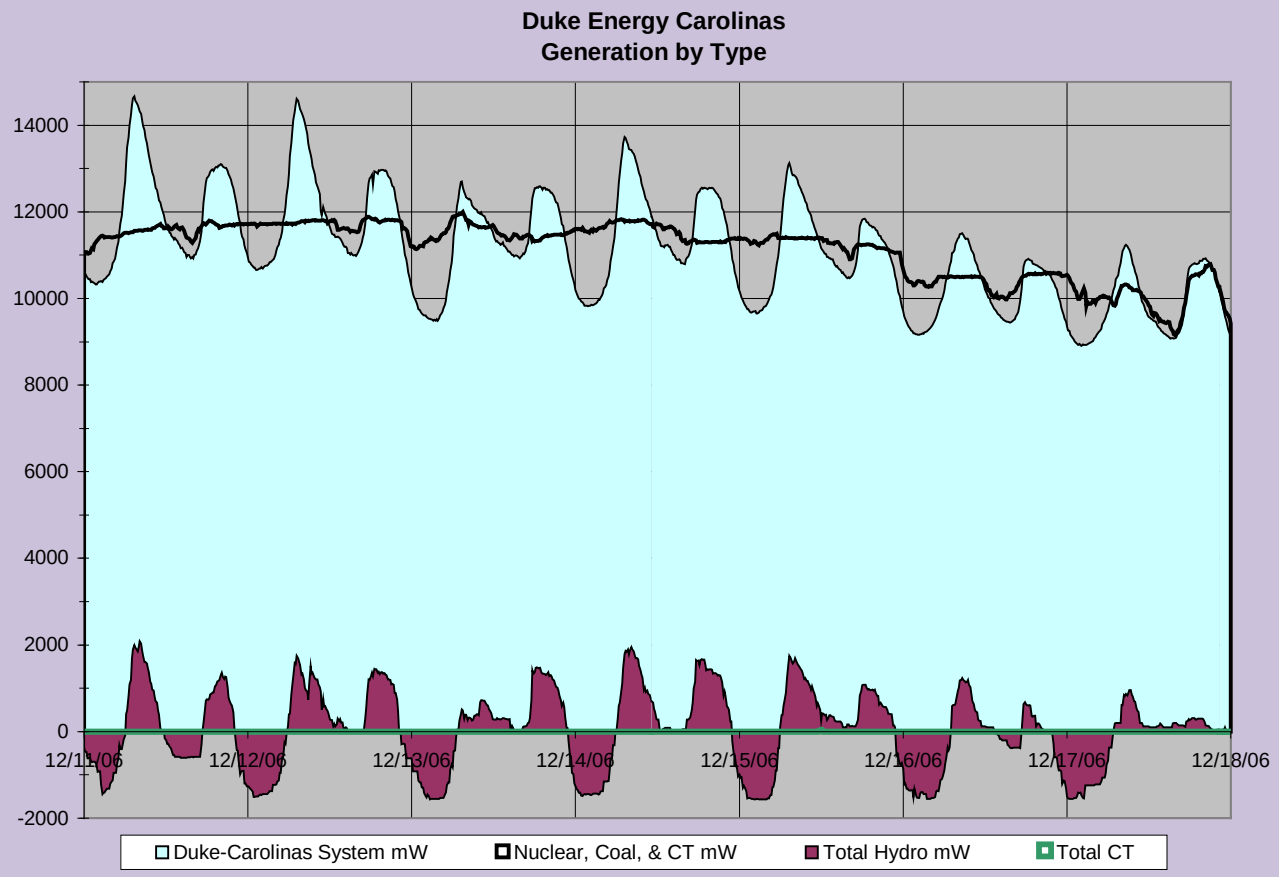
Pumped Storage Load Following, Balancing and Reserves

2000 MW of Inc and Dec Reserves



Pumped Storage Offsets Peak System Loads

Substantial Portfolio Optimization



Flattening the Intermittent Demand Curve with Pumped Storage and Hydro

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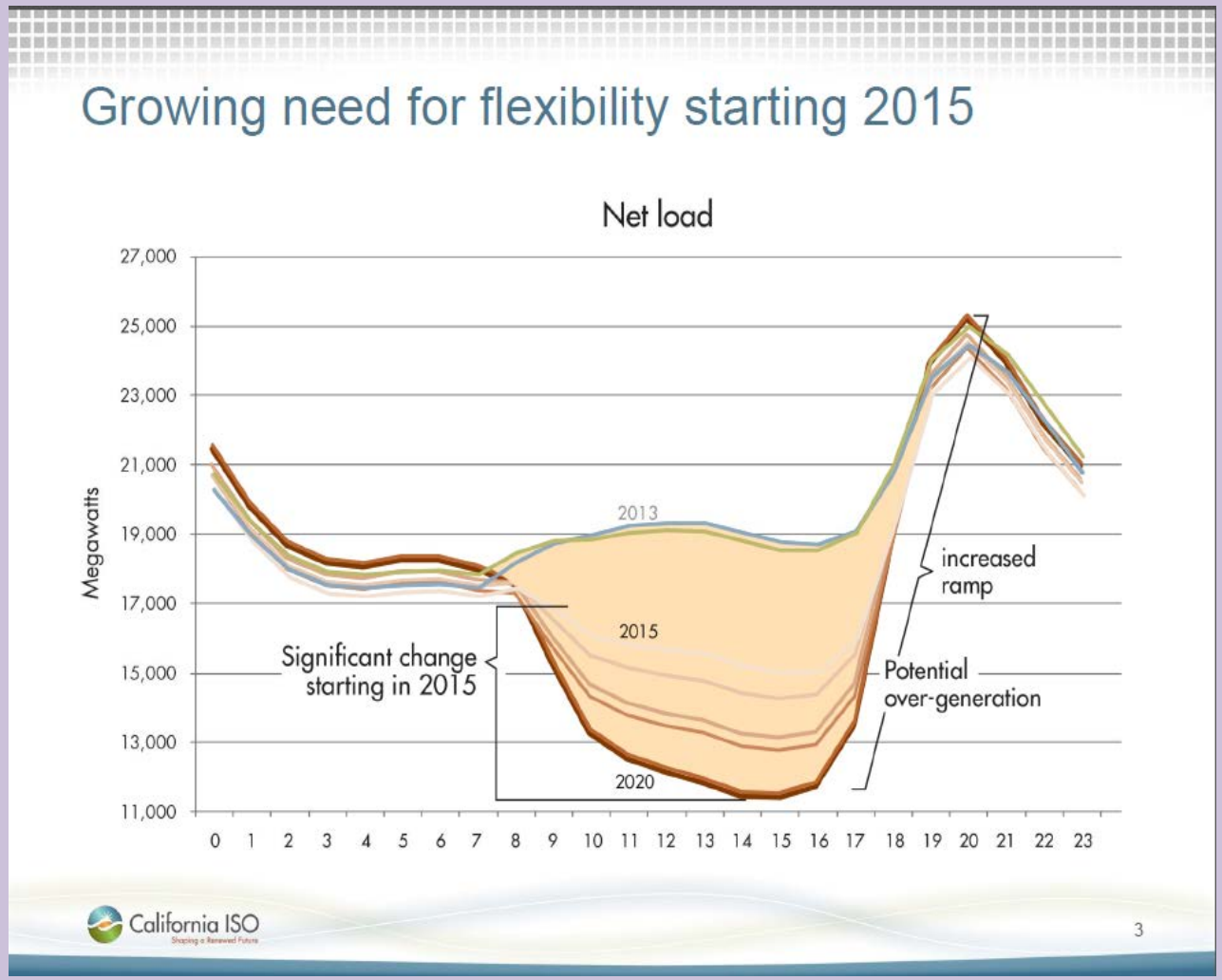
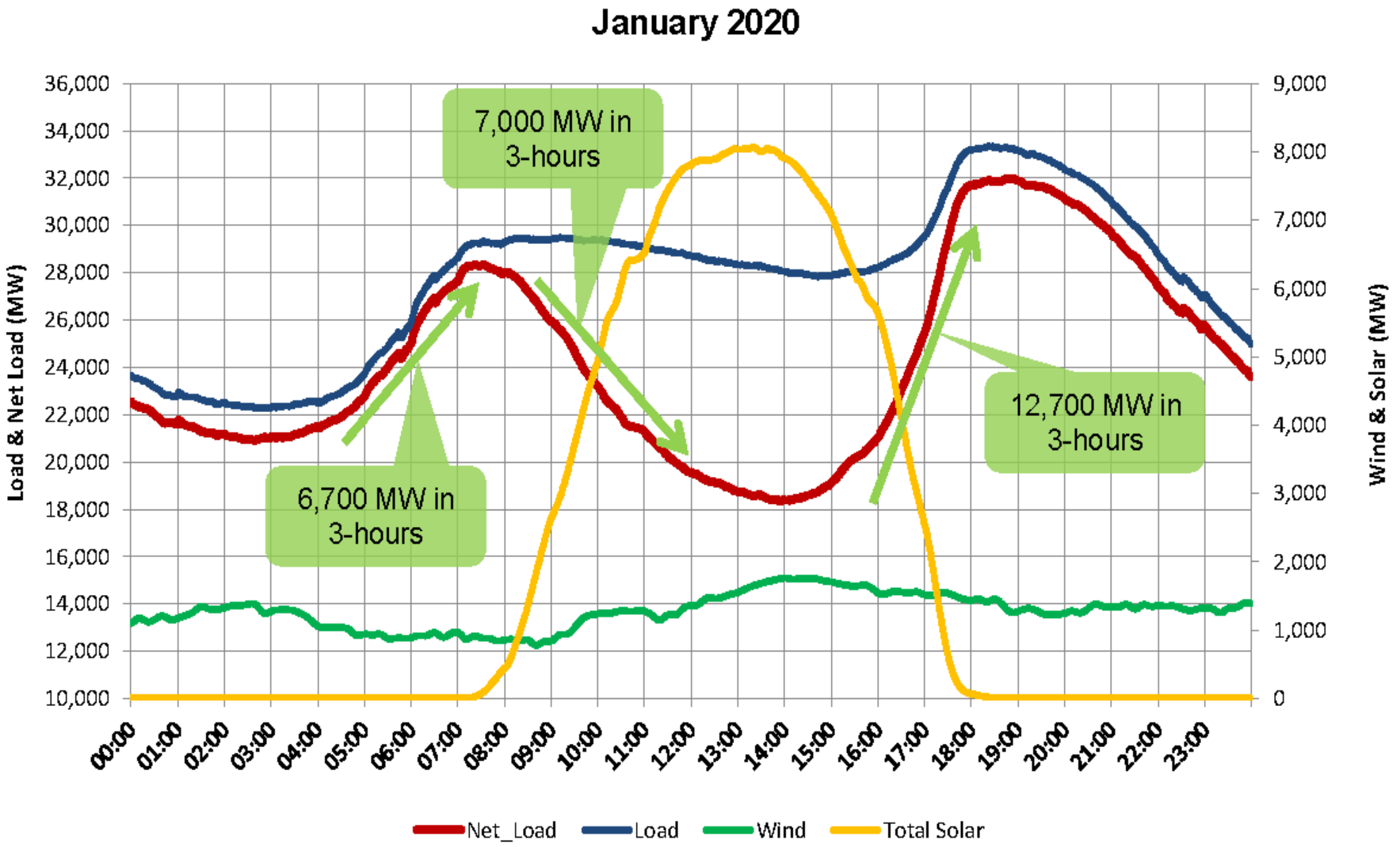
CAISO's – "Duck Curve"

- Most significant capacity/ramping impacts will likely be seen in Southern CA (largest loads plus daily solar ramp)
- CAISO's market structure designed to spread impacts across grid, but local constraints must be addressed (e.g., transmission, capacity, oversupply)



Load, Wind, and Solar Profiles – Base Scenario



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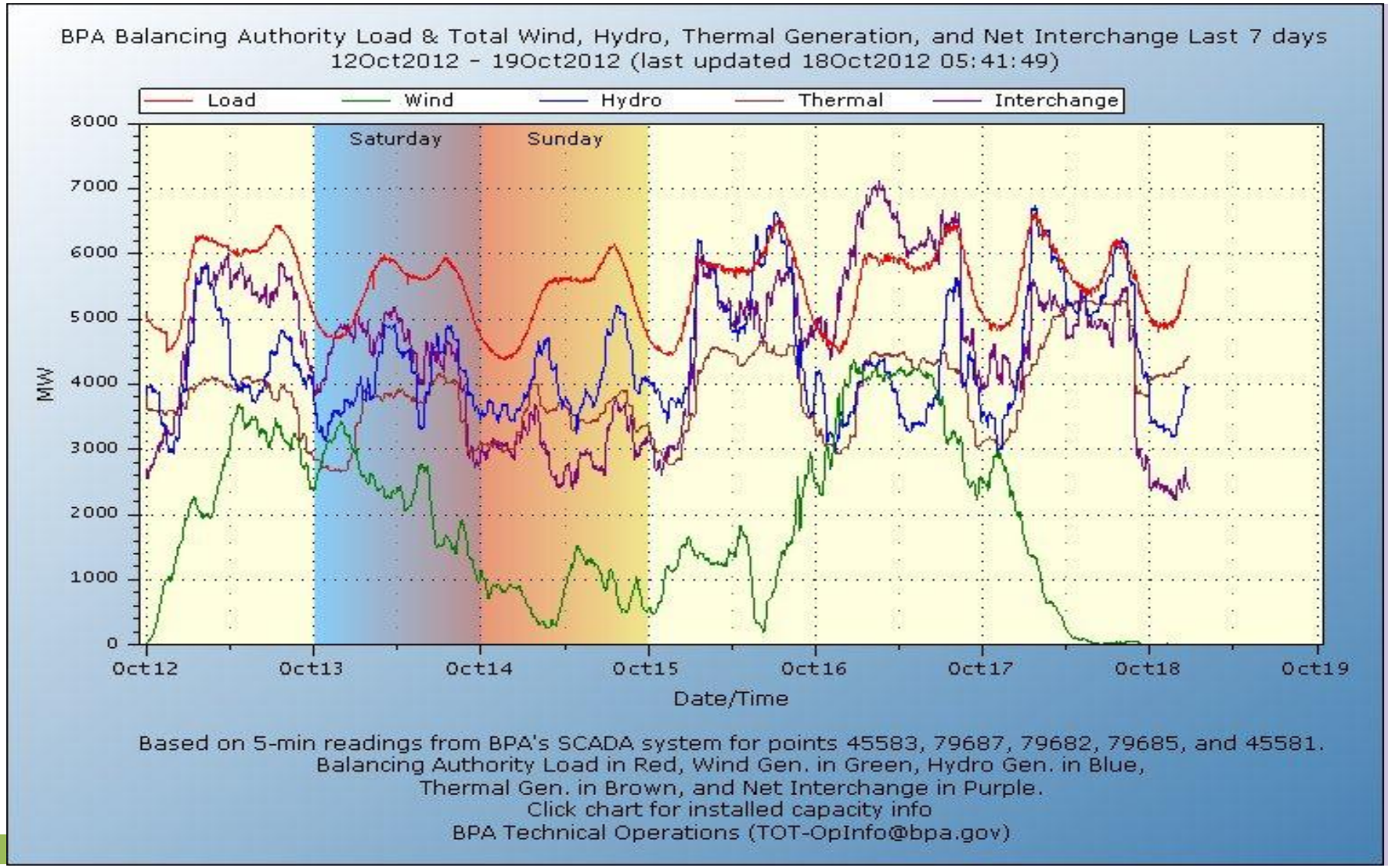
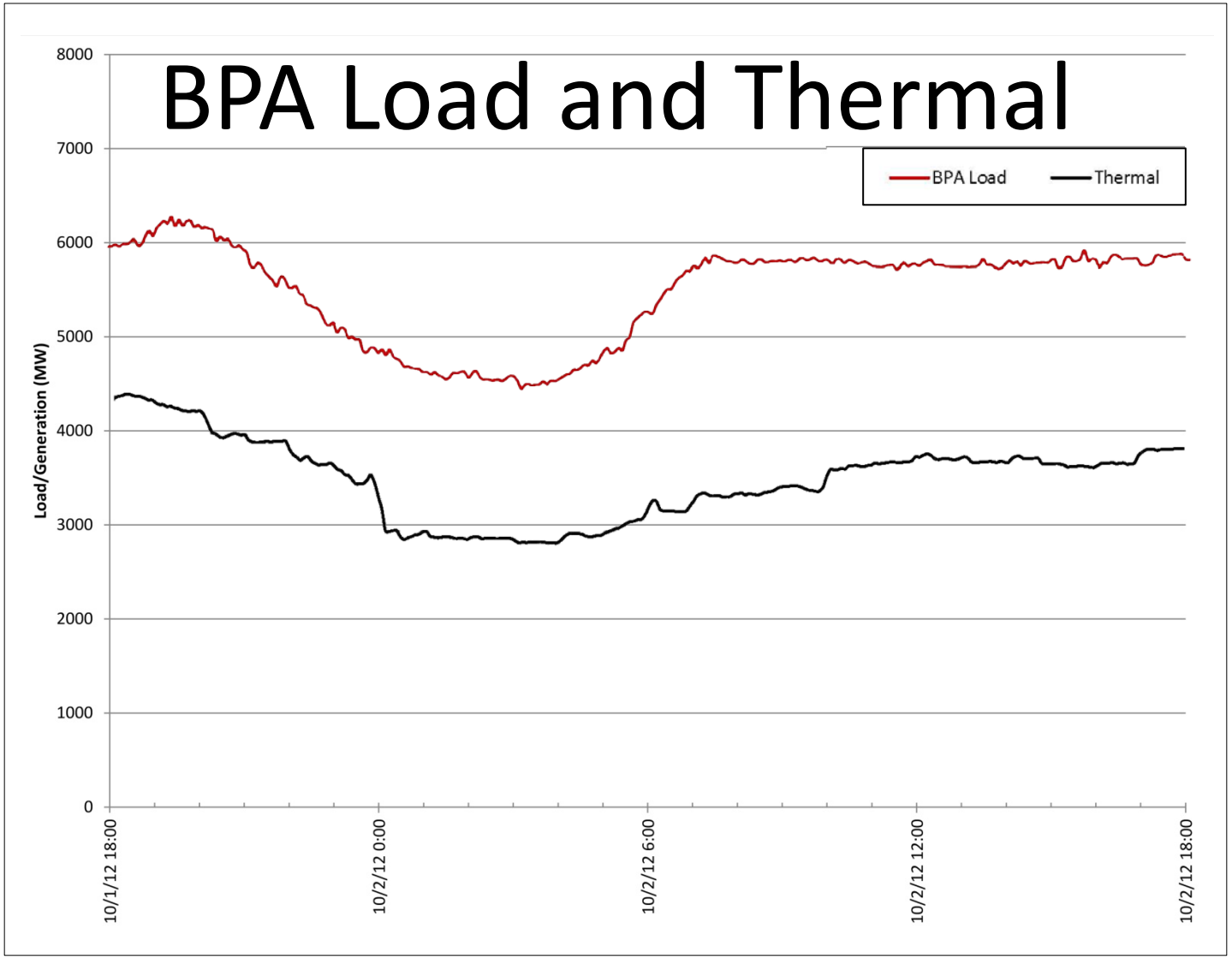
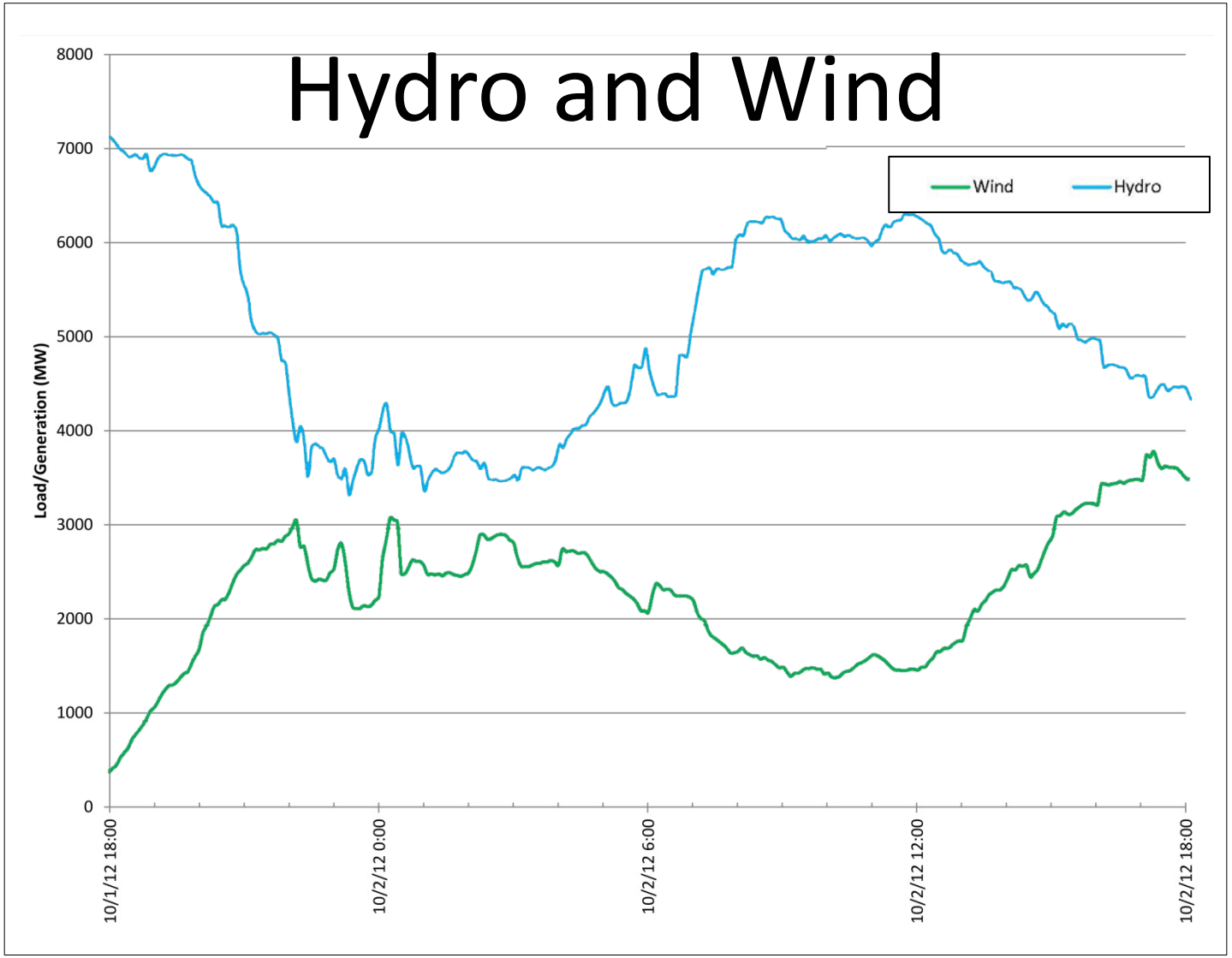
The Need for Flexibility

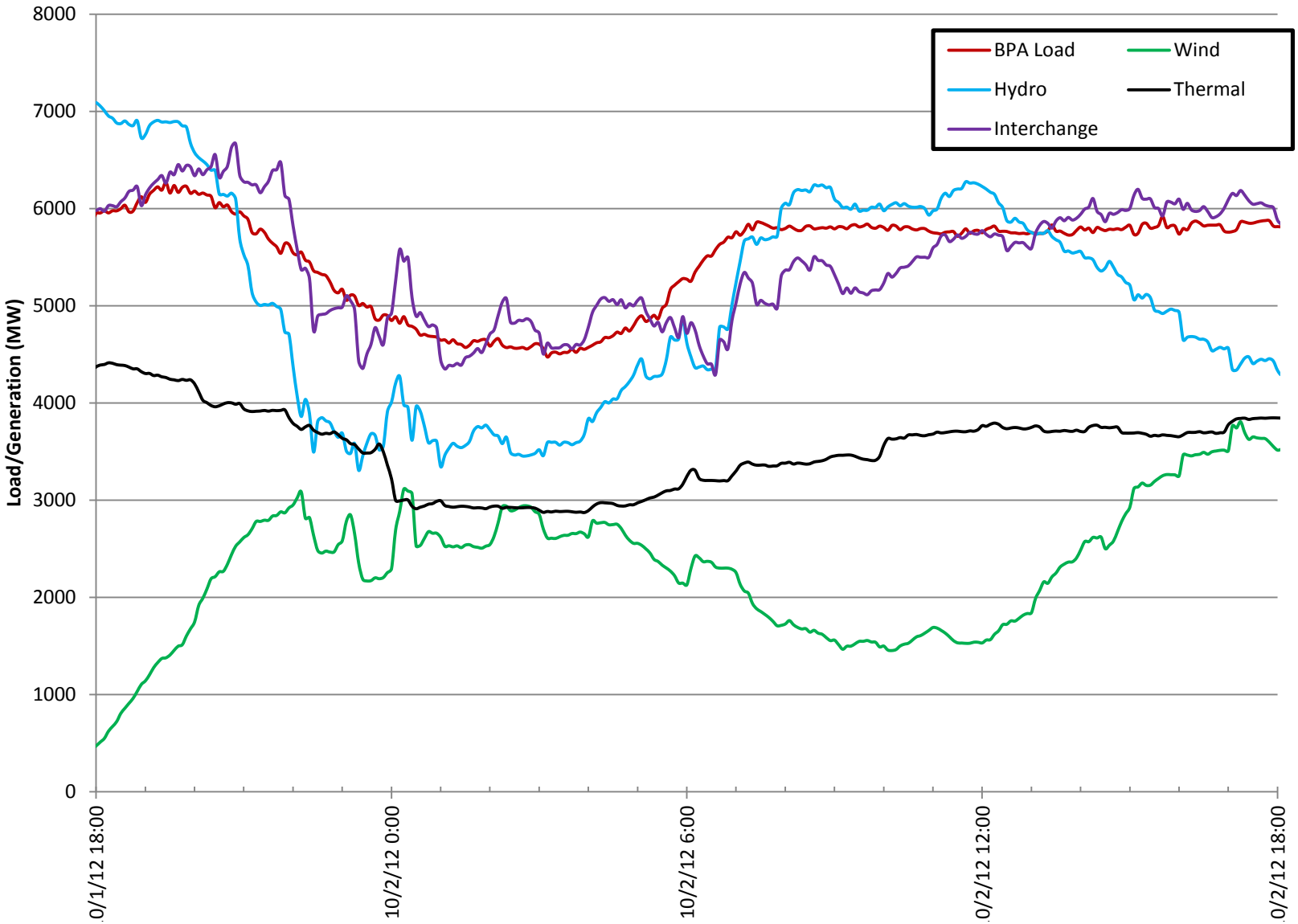


BPA Load and Thermal

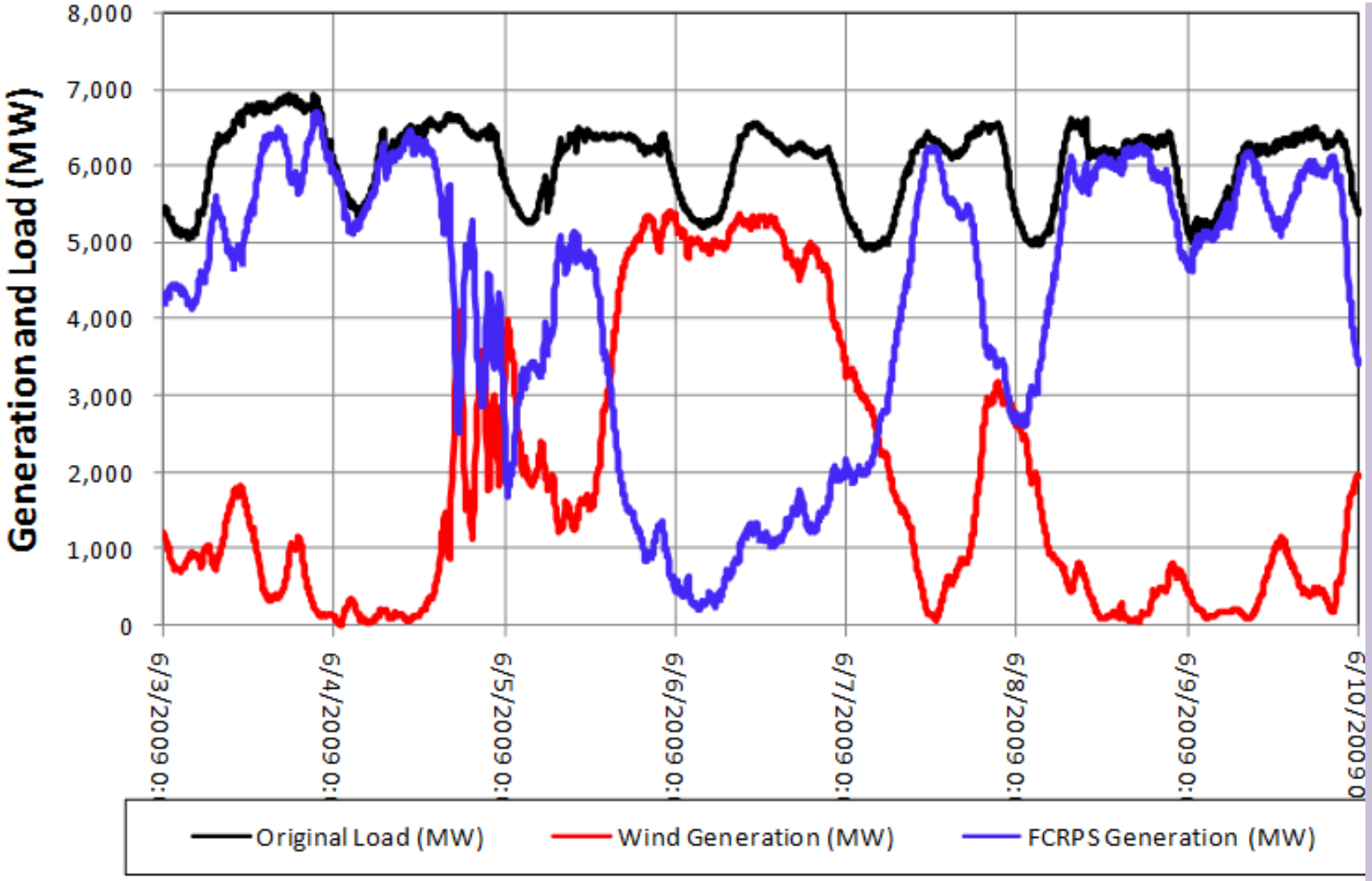


Hydro and Wind

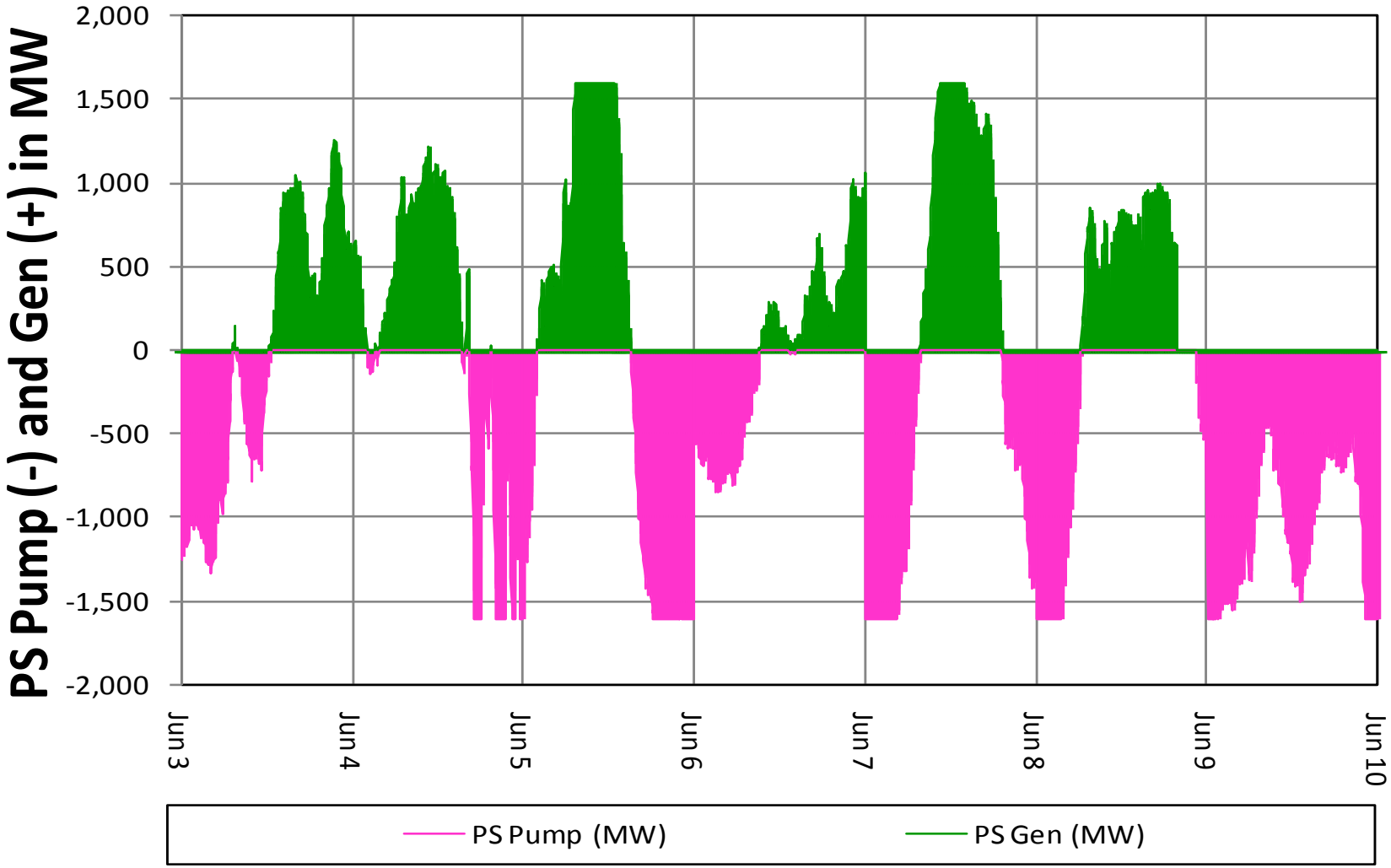



8000
7000
6000
5000
4000
3000
2000
1000
0
Load/Generation (MW)
BPA Load
Wind
Hydro
Thermal
Interchange
0/1/12 18:00
10/2/12 0:00
10/2/12 6:00
0/2/12 12:00
0/2/12 18:00

Historic BPA Demand Load and Wind Power
6,250 MW's Projected Wind Interconnection



Simulated 1,600 MW Project "X"
Pumped Storage Dispatch Schedule



Traditional Pumped Storage Dispatch with Rapid Response

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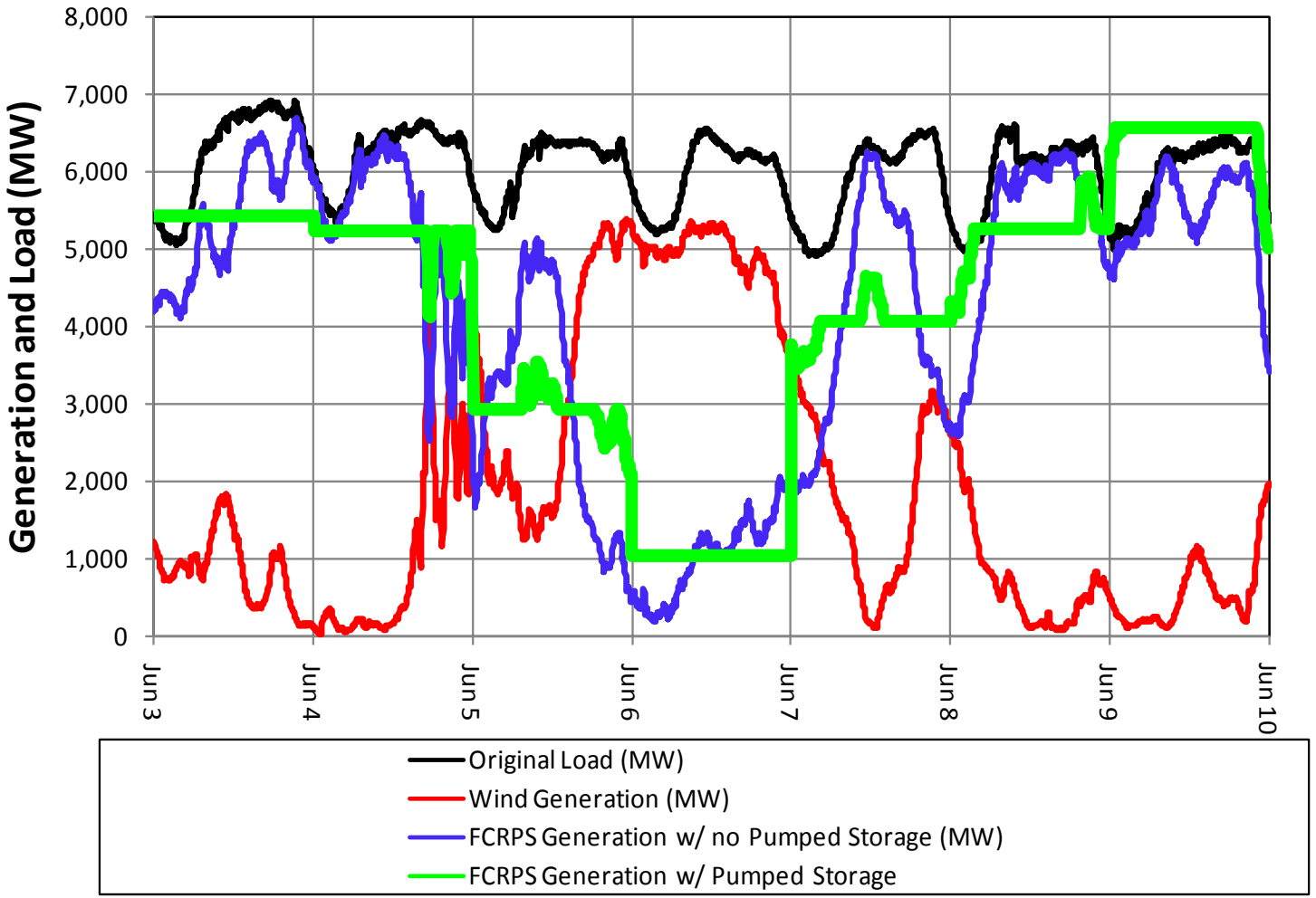
Historic BPA Load, Simulated Approximately 6,000 MW Projected Wind Interconnection and FCRPS Re-Dispatch due to Pumped Storage



A System Operator's Dream Come True!

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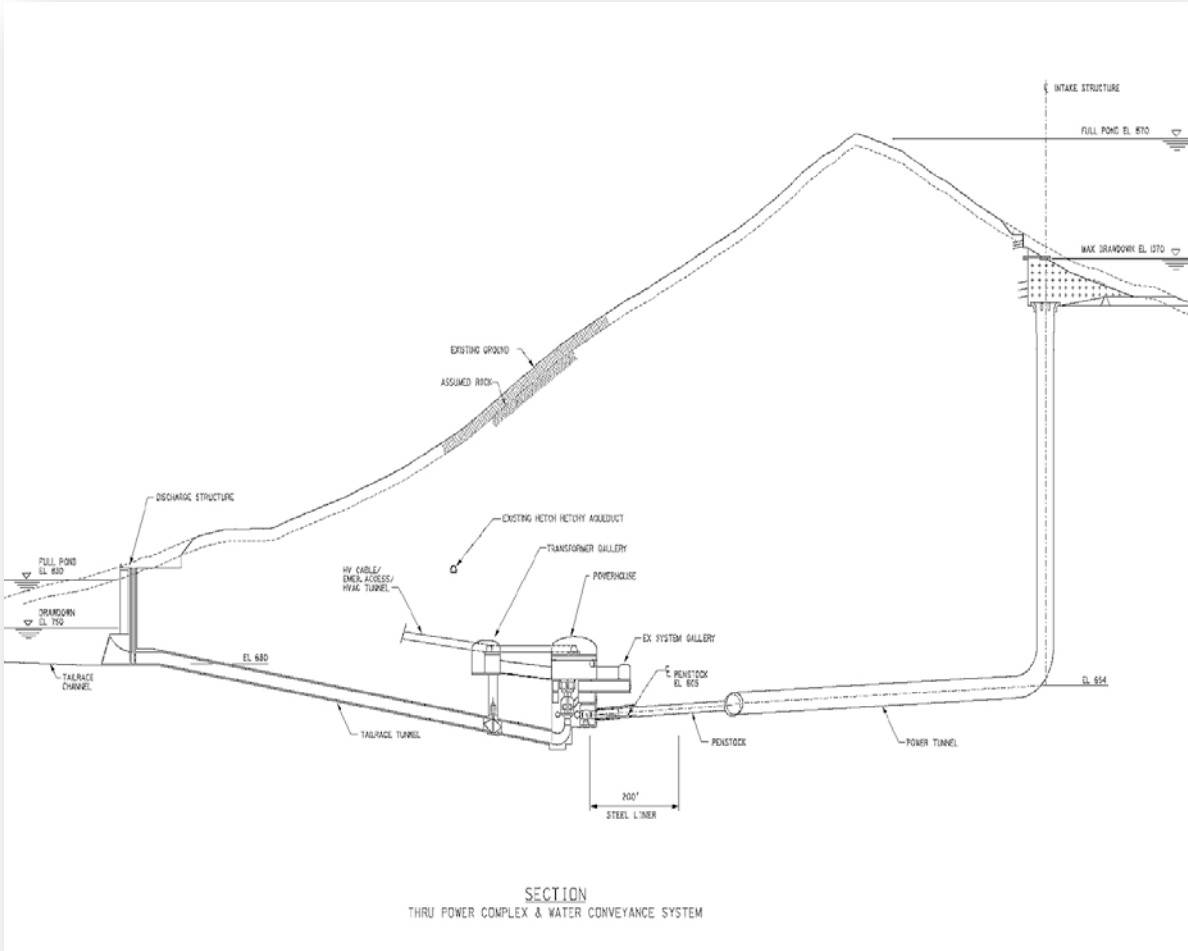
Hydroelectric Pumped Storage

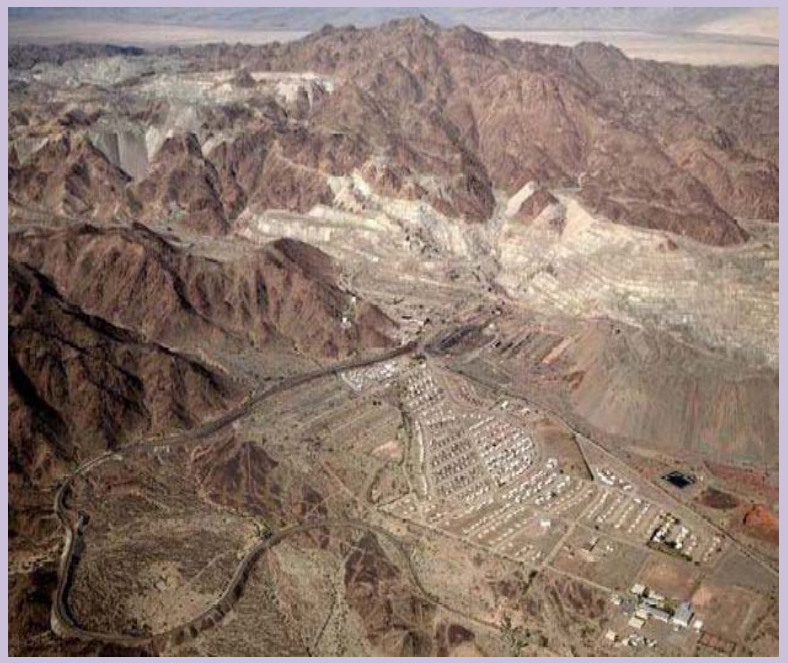
- What is it?
  - Efficient Energy Shifting
  - Strategic Flexibility
  - Grid Stability Services.
- How does it work?
  - During periods of low power demand, water is pumped from the lower lake to the upper lake.
  - During high demand periods, water from the upper reservoir is passed through turbines to generate power.
  - Power settings can be adjusted rapidly to provide “ancillary services”.



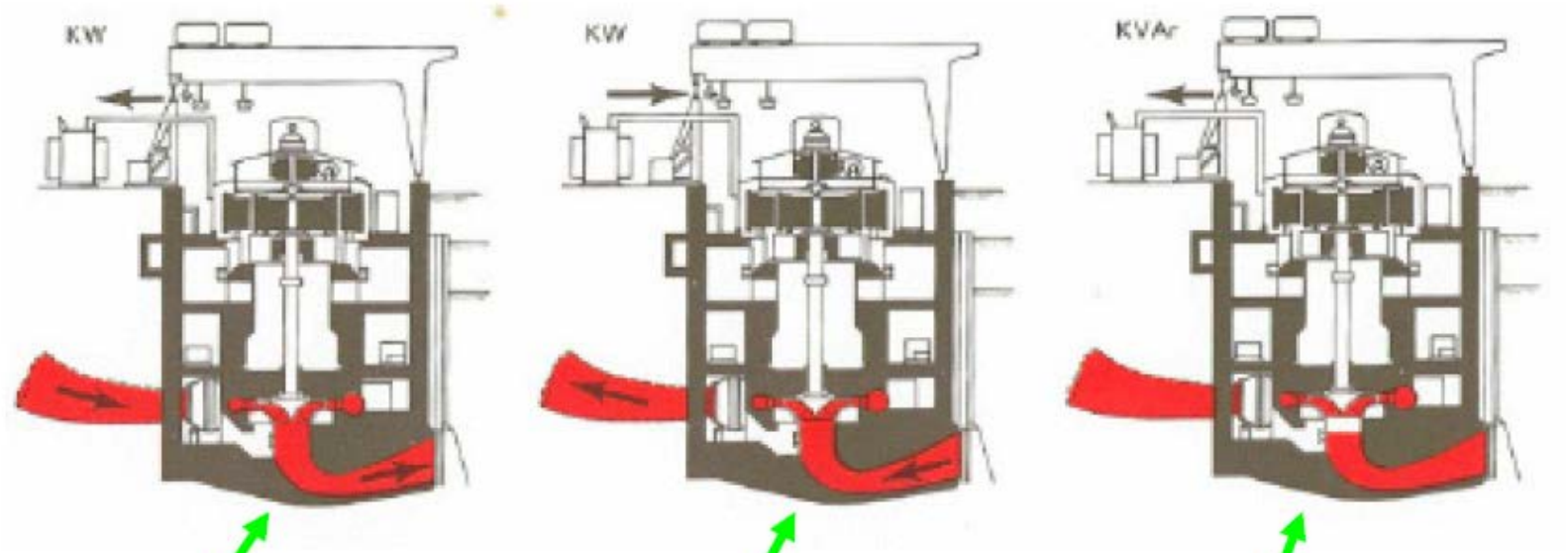
Key Differentiator: Pumped Storage is a System Operations/Transmission tool

Key Qualities of Modern Pumped Storage Facilities

- Closed Loop – No On Stream Reservoirs
- High Round-Trip Efficiency – 80% +
- Significant Ramping Rates – 10 MW/sec +
- High Capacity – 500 MW - 1,300 MW
- High Energy – 6- to 12-hour ponds = 10,000+MWh
- Fast Response – Seconds to Minutes
- Incremental and Decremental Reserves



Pump-Turbines – Three Modes of Operation



Normal Generation

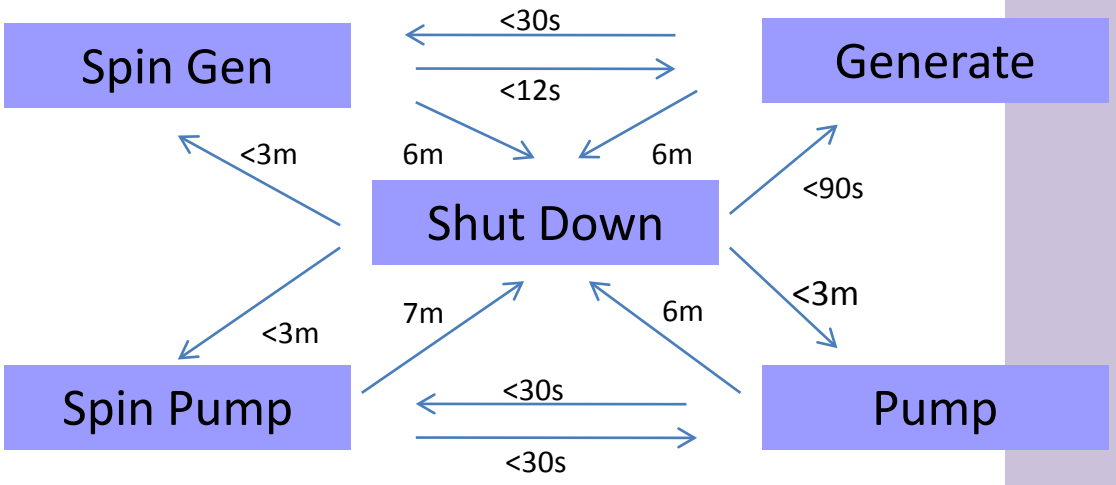
Pumping Operation

Synchronous Condensing

(Spinning in air)

Future Pumped Storage - Dinorwig Plant Capabilities

- Fast mode changes and start-up times
- High ramping rates – 15 MW/second per unit
- 40,000 mode changes per year (any combo below)
- 6 Hour reservoir capacity
- Recognized need for high reliability and availability

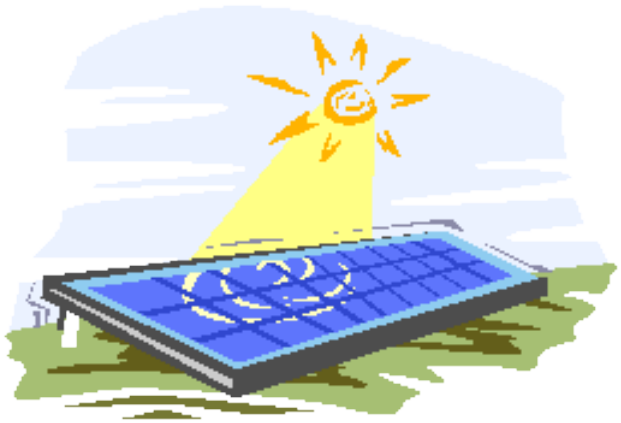


Dinorwig Mode Change Times

Advantages of Single and Variable Speed Pumped Storage Units

Single Speed Pump-Turbine

- Proven technology with multiple suppliers
- Lower equipment cost by ~30%
- Smaller powerhouse size
- Lower O&M costs
- Shorter project schedule



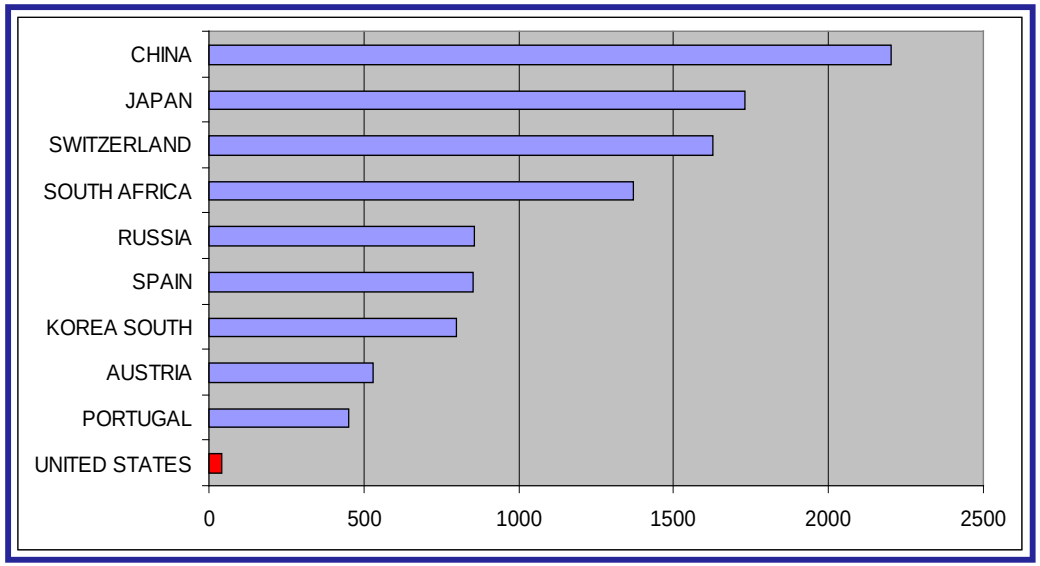
Variable Speed Pump-Turbine

- **Wide head range operation**
- **Flatter and higher generating performance curve**
- **Regulation in pumping cycle ±20% in power**
- **Wider generating operating range**

Snapshot of Pumped Storage Globally

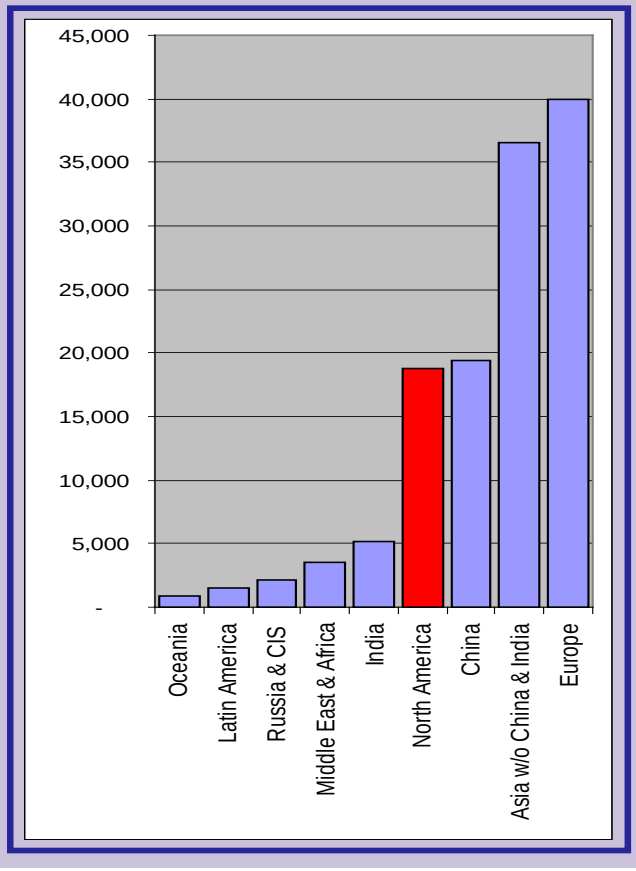
Pumped Storage Projects Under Construction (MW)

- 10,453 MW Worldwide
- Totaling 45 PS Units



Pump Storage Units in Operation (MW) by Country/Continent

- 127,961MW Worldwide
- Totaling 922 PS Units



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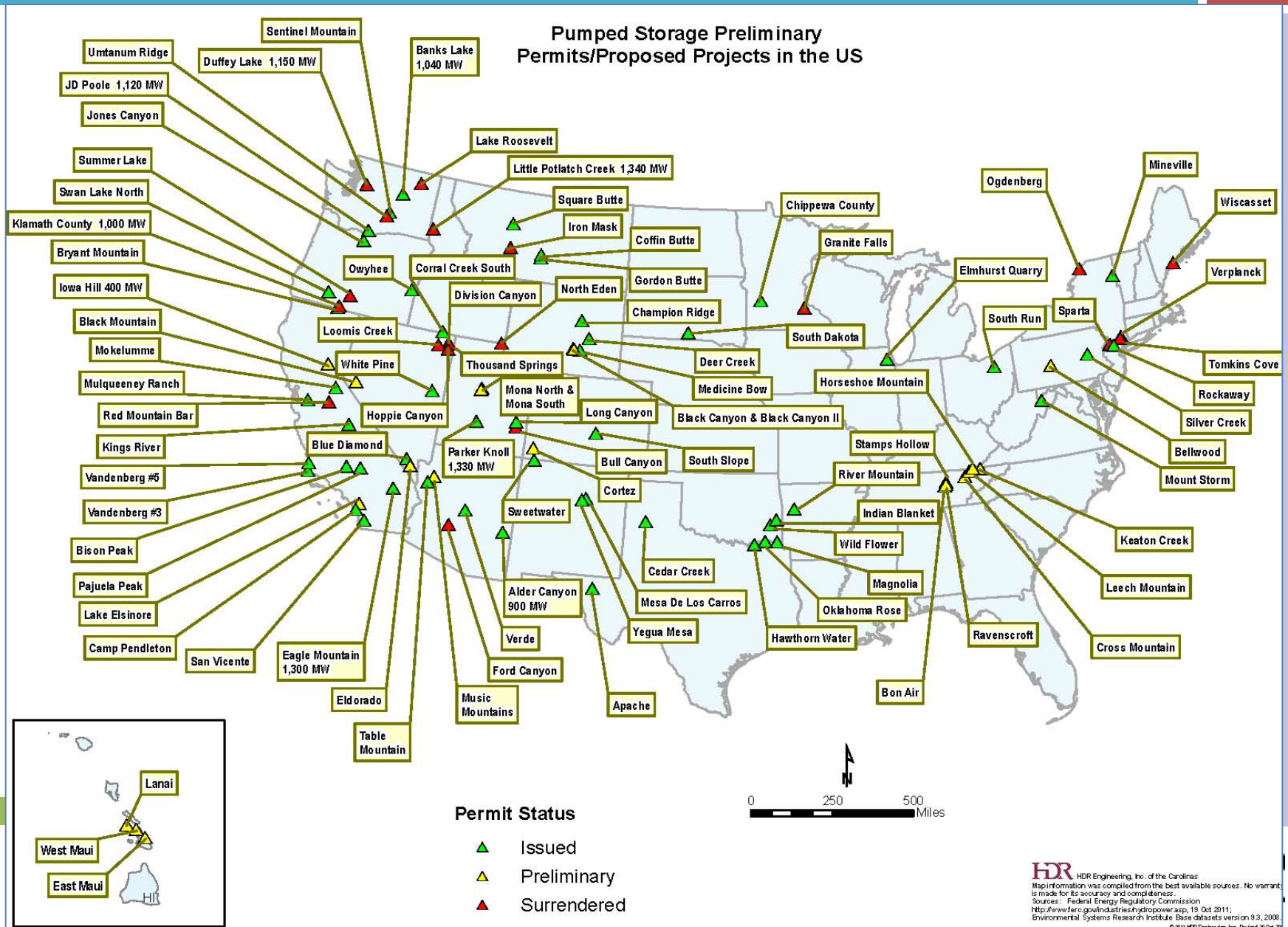
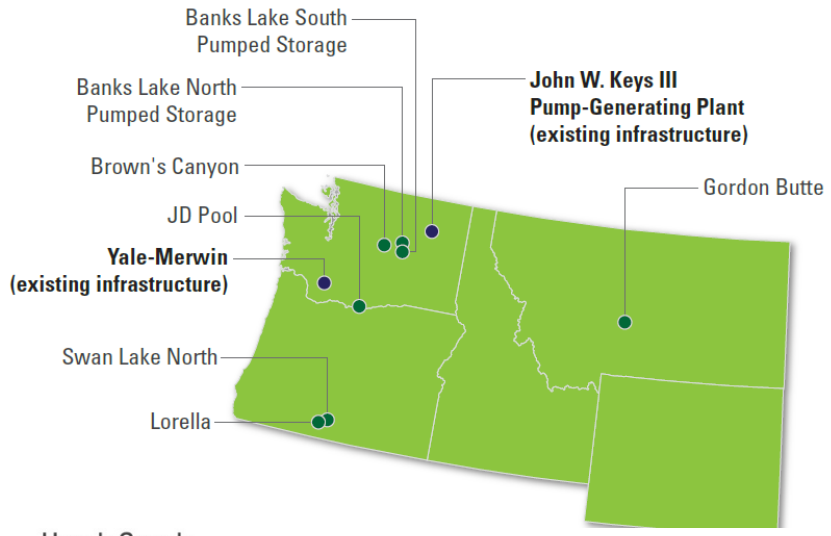
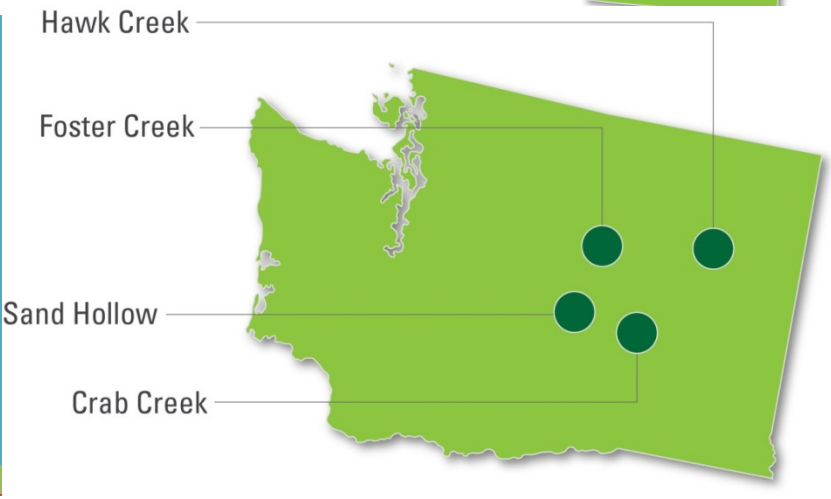
Proposed New Pumped Storage Projects



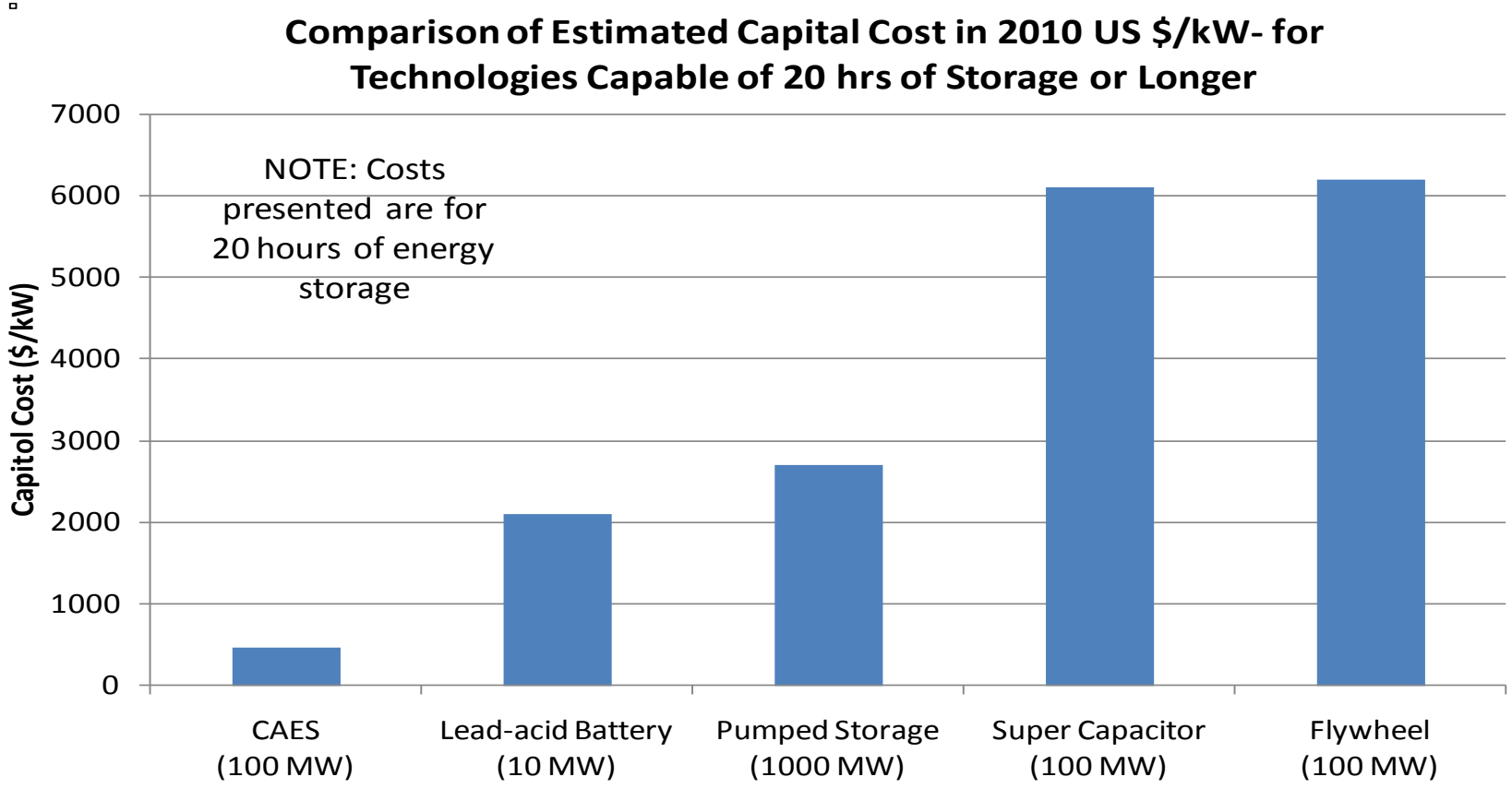
Summary of Capacity Identified in Studies C-1 through C-4





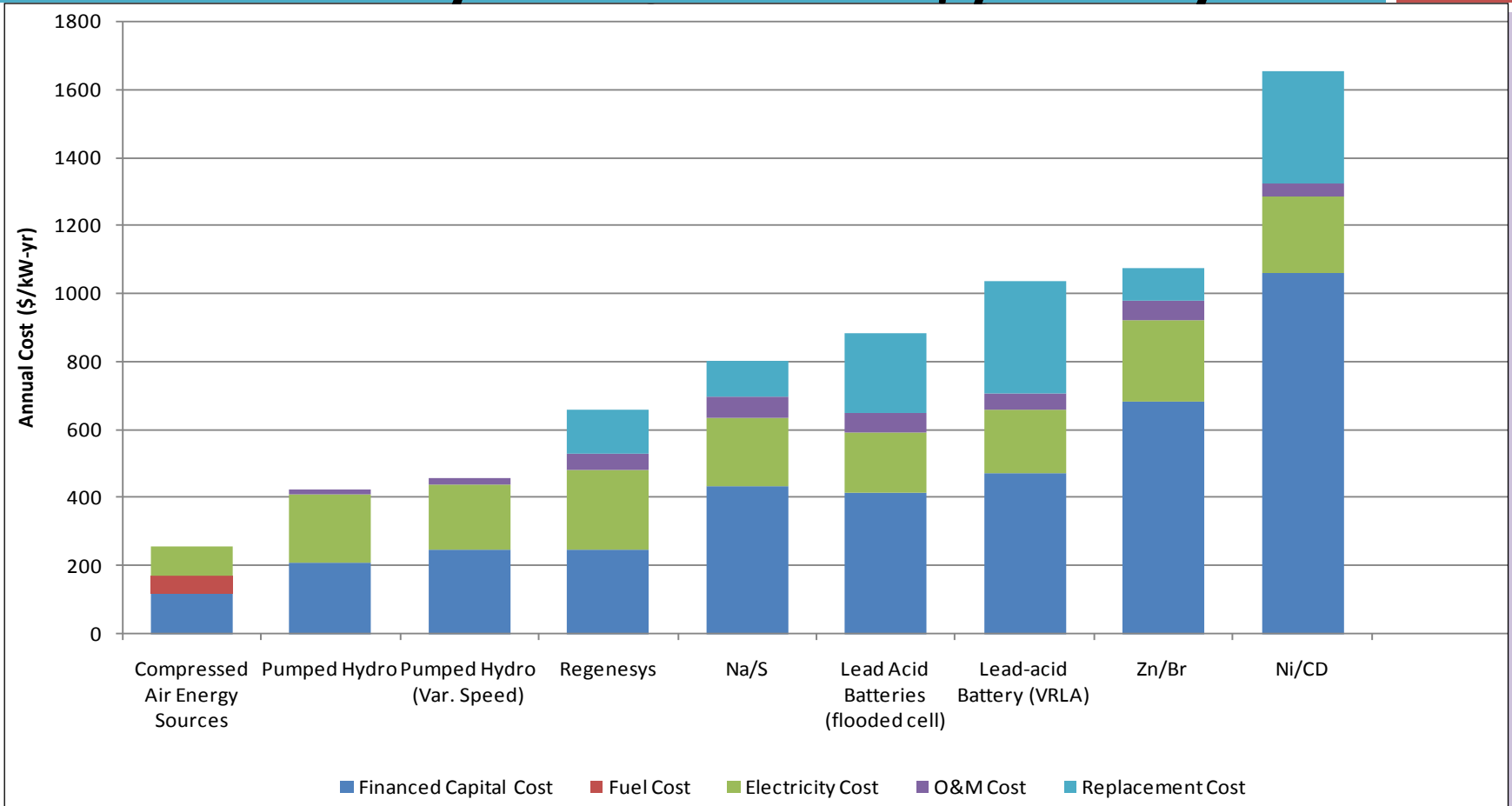
Study	Project Name	State	Capacity (MW)
C-1	See Report, Large Number of Studies Nationwide	N/A	-----
C-2	John Day Pool	WA	1300
C-2	Swan Lake	OR	600
C-3	Crab Creek (varies by size)	WA	69-392
C-3	Sand Hollow Creek	WA	285
C-3	Hawk Creek (varies by size)	WA	237-1136
C-3	Foster Creek	WA	300-1100
C-4	John Day Pool (duplicate, also cited in C-2)	WA	-----
C-4	Swan Lake North	OR	600
C-4	Brown's Canyon	WA	1000
C-4	Banks Lake Pumped Storage – North Banks Lake	WA	1000
C-4	Banks Lake Pumped Storage – South Banks Lake	WA	1040
C-4	Lorella (Klamath County)	OR	1000
C-4	Gordon Butte	MT	400
C-4	Yale-Merwin	WA	255

Capital Cost Comparison



Note: Pumped Hydro and Pumped Hydro (Var Speed: O&M and Financed Capitol Cost are estimated by HDR|DTA. All other options are derived from data from Makarov, Y. et al. "Wide-Area Energy Storage and Management System to Balance Intermittent Resources in the Bonneville Power Administration and California ISO Control Areas." Table 3.2 .Pacific Northwest National Laboratory, June 2008.

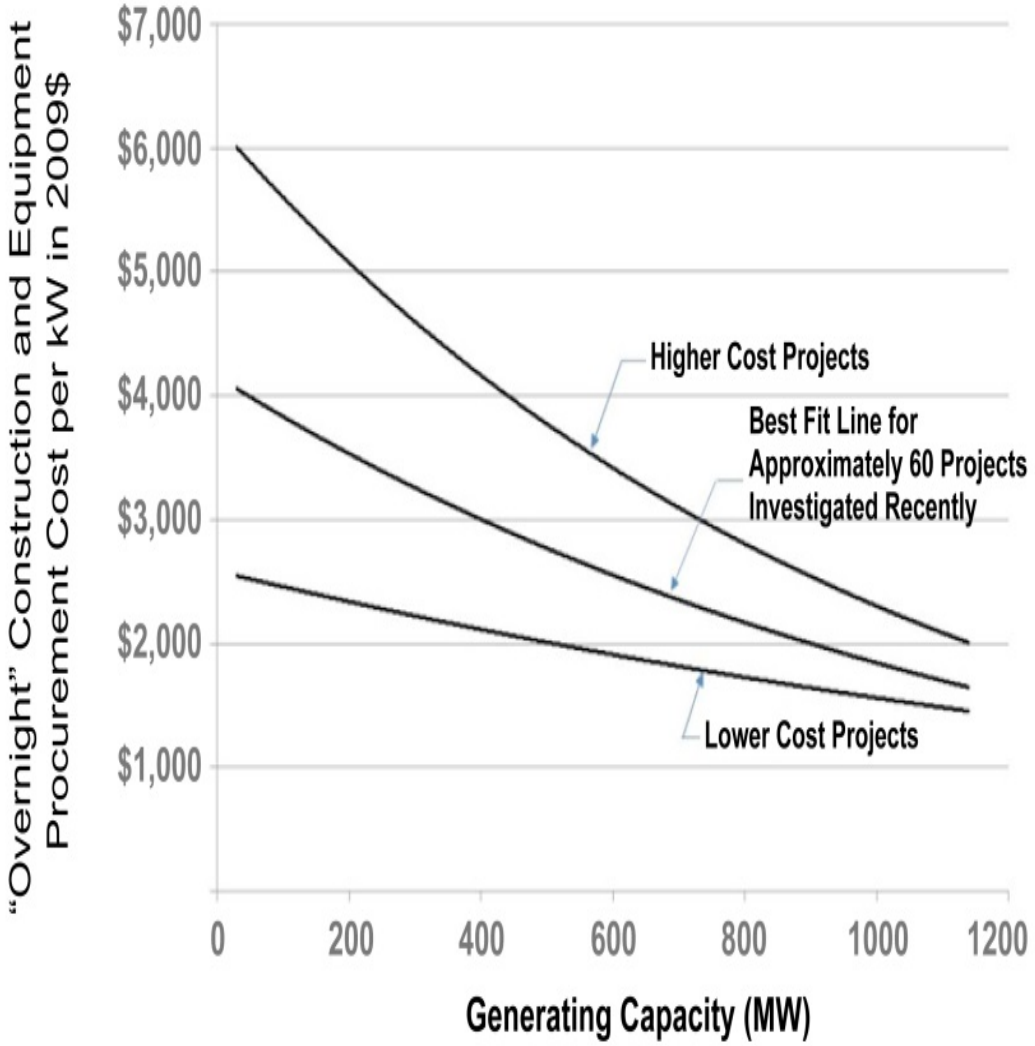
Life Cycle Costs - $/kW-yr



Note: Pumped Hydro and Pumped Hydro (Var Speed : O&M and Financed Capitol Cost are estimated by HDR|DTA. All other options are derived from Schoenung, S. and Hassenzahl, "Long vs.. Short Term Energy Storage Technologies Analysis- A Life Cycle Cost" Sandia National Laboratories, Sandia Report August 2003.

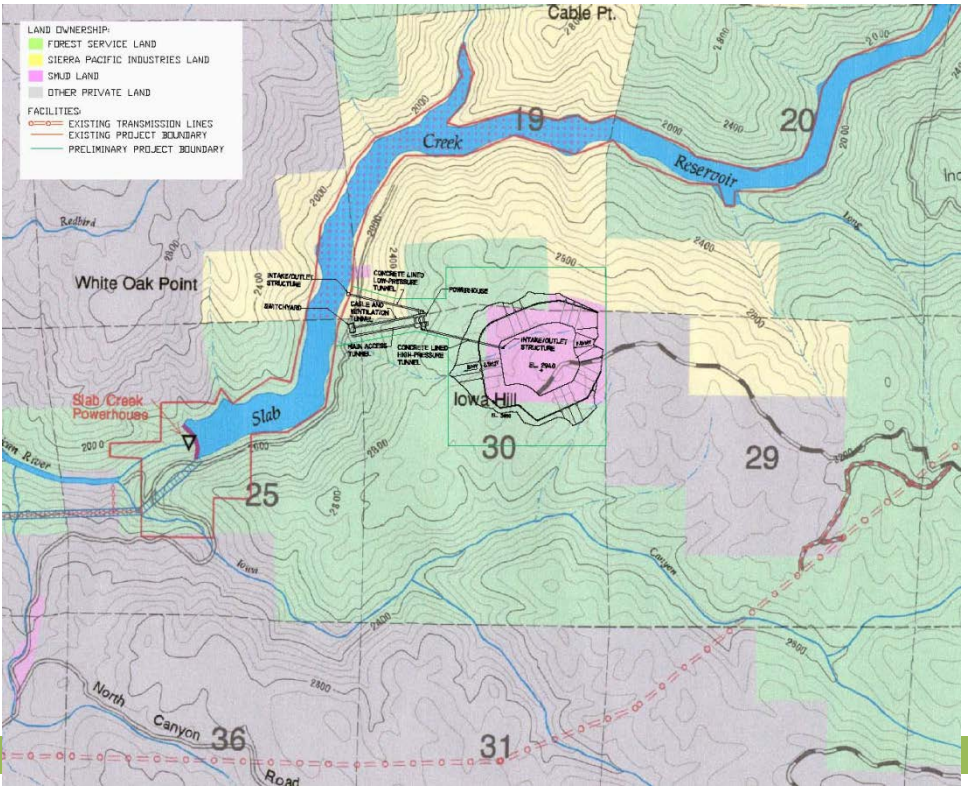
Pumped Storage Economics

- Licensing Cost Range
  - up to $15 to $20 million per license over the next 4 to 5 years
- Installed Cost Range:
  - $2,000 kW to $3,000 kW ($2 billion to $3 billion for a 1,000 MW facility)
- O&M Costs:
  - Fixed Costs Range: $10 million to $15 million/year
  - Variable Cost Range: ~$1.00/MWh



California Pumped Storage Update

Iowa Hill – 400 MW



Eagle Mountain – 1400 MW

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