DOE Water Power Technologies Office

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

U.S. DOE Hydropower Grid Research Portfolio

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DOE Water Power Technologies Office

Hydropower

Upgrades for Existing Hydropower

Non-Powered Dams and Conduits

New Low-Impact Projects

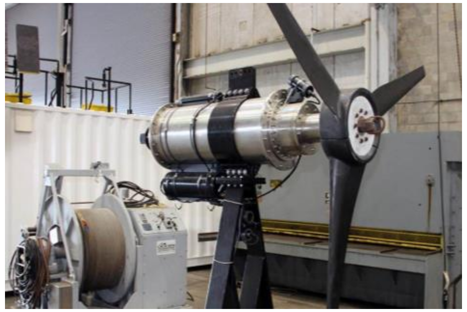
Pumped Storage Hydropower (PSH)

Marine Hydrokinetics

Wave

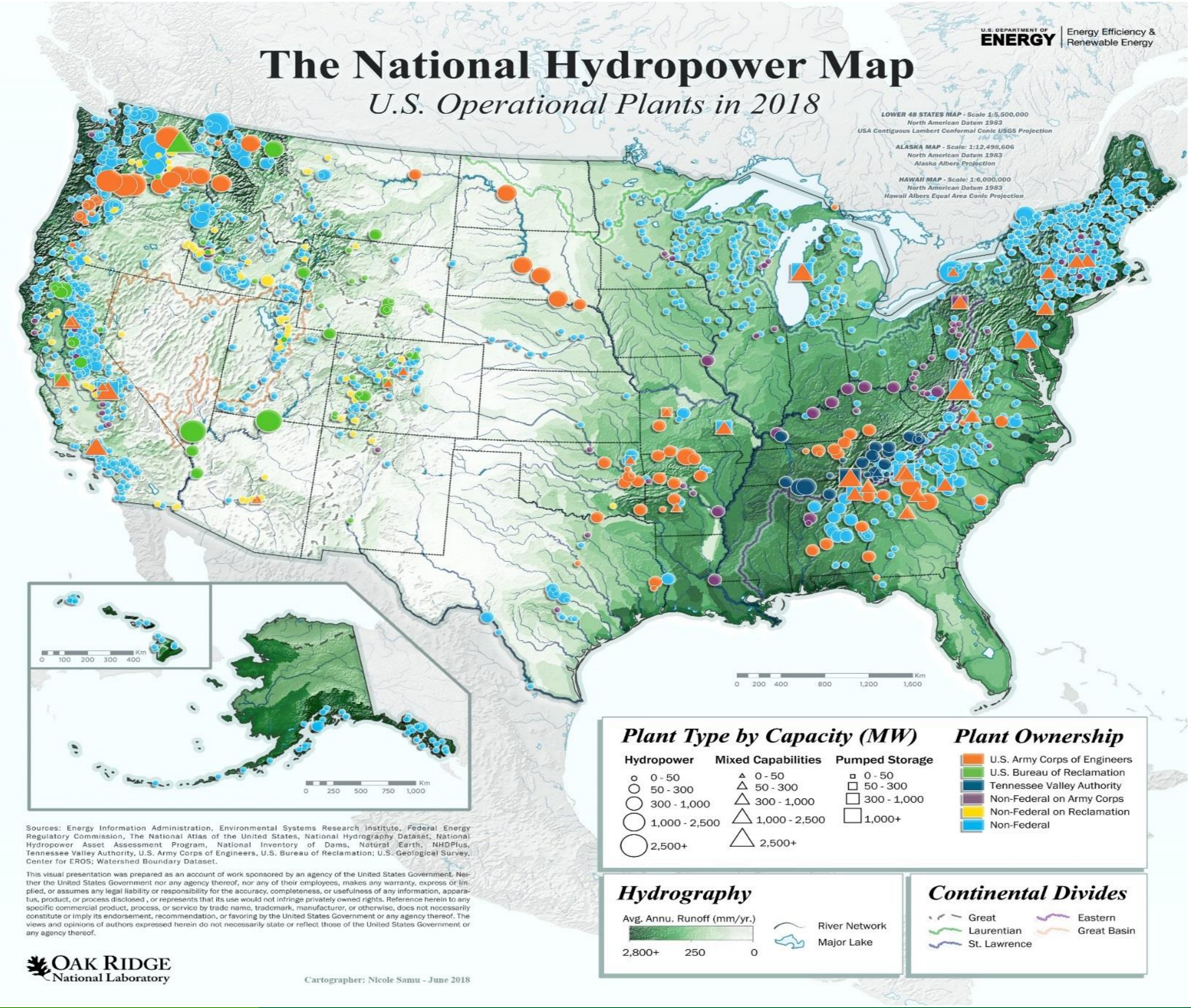
Tidal

River Current



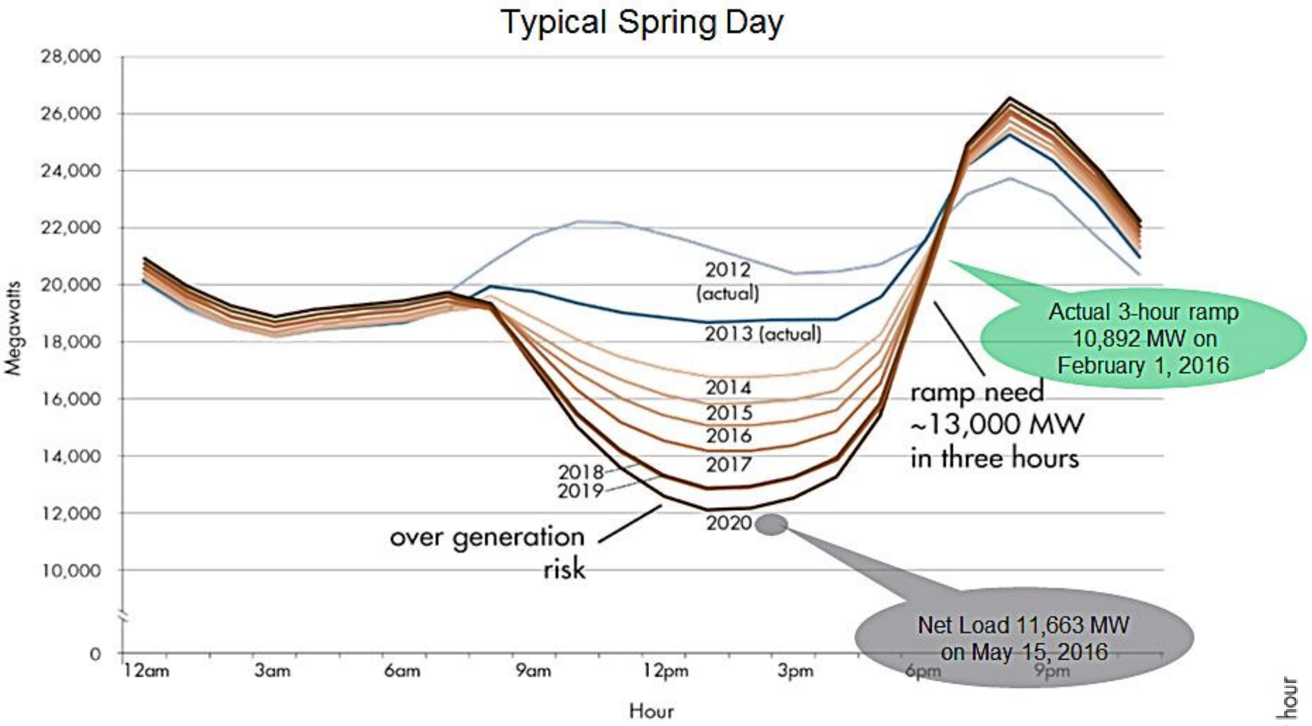
Ocean Currents

U.S. Hydropower and Pumped Storage Hydropower (PSH)



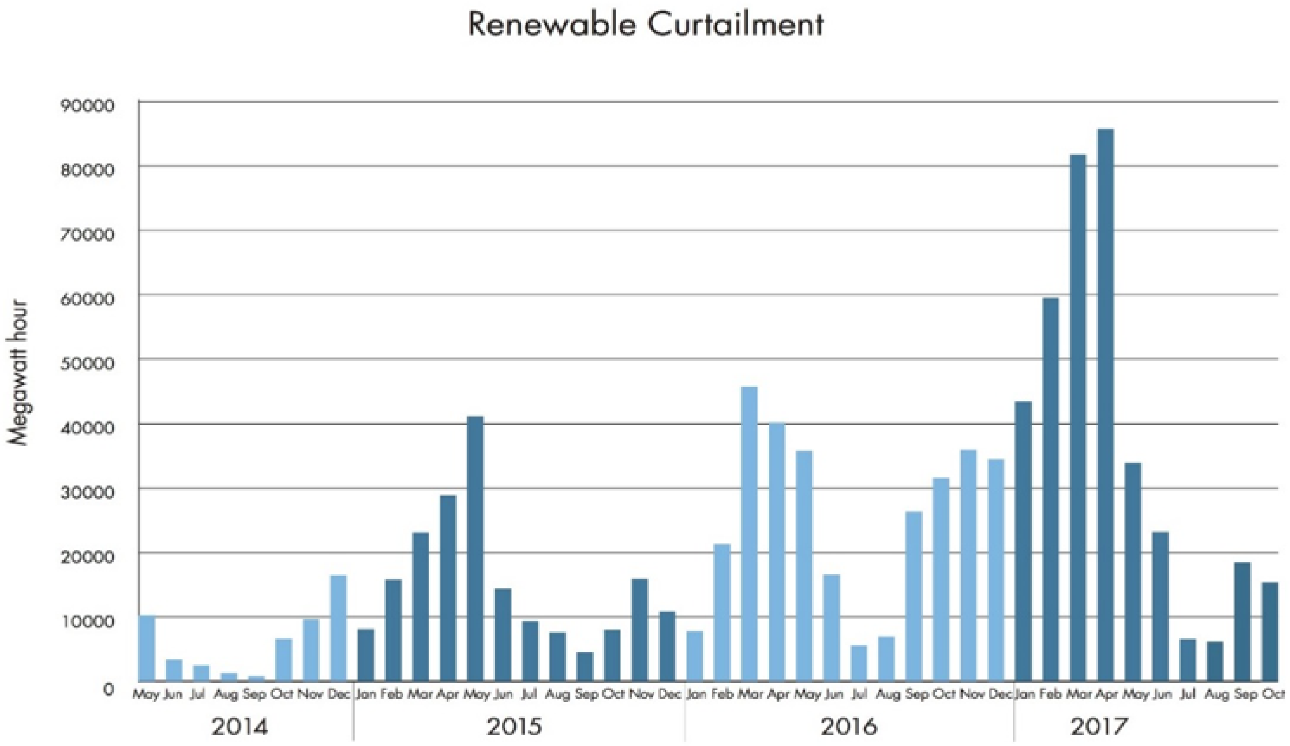
- **80 GW** of hydropower capacity – 7% of U.S. capacity
- **22 GW** of pumped storage capacity – greater than 95% of U.S. energy storage capacity
- Existing plants provide low-cost and reliable generation, **87,542 jobs** across 48 states
- **49%** of hydro capacity owned by the U.S. Government
- **Nearly 1.5 GW of capacity** added in the last decade but new opportunities often limited by regulations, high costs, and environmental concerns
- **$8.9 billion** in refurbishments and upgrades was invested across 158 hydropower dams in the U.S. between 2007-2017

The U.S. grid is changing rapidly



- High solar penetration (duck curve) requires fast ramps and sharp peaks in the evening hours.

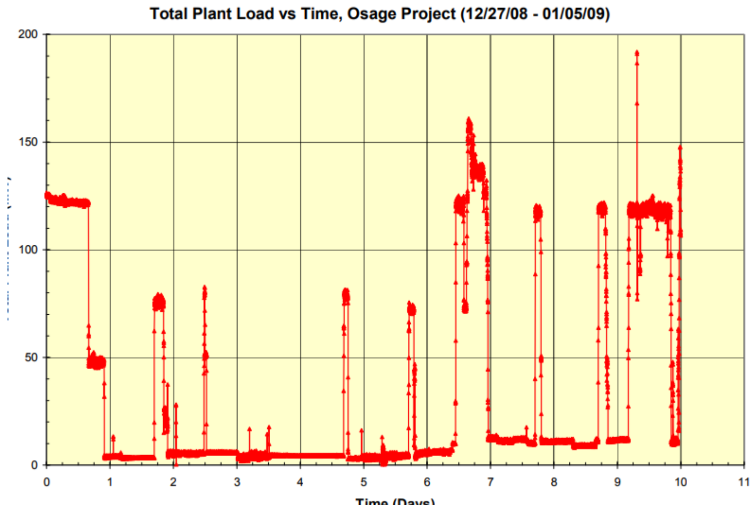
- Curtailment of renewables has increased markedly in recent years.



Source: California ISO, Production and Curtailments Data, May 1, 2014-May 31, 201.
http://www.caiso.com/informed/Pages/ManagingOversupply.aspx

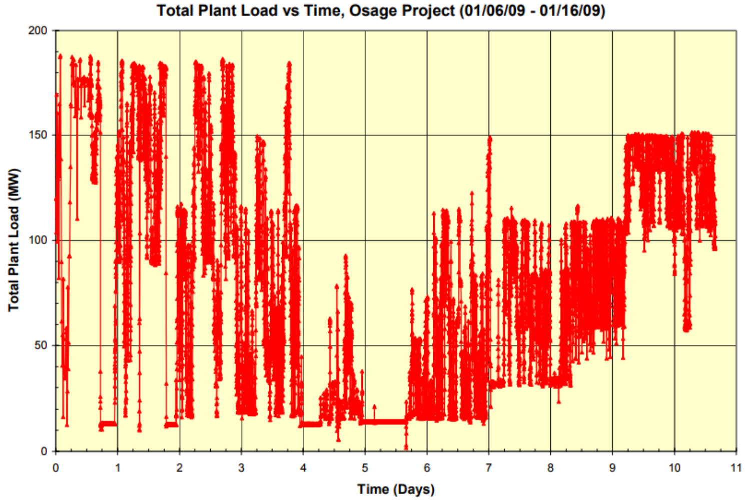
Operational Strategies for Hydropower and PSH are Already Changing…

Traditional Hydro: from steady or predictable patterns to fast and frequent ramping



Weekly generation:
(Osage Power Plant, MO)

Before participation in ancillary services market



After participation in ancillary services market

Pumped Storage: from day/night arbitrage to fast response

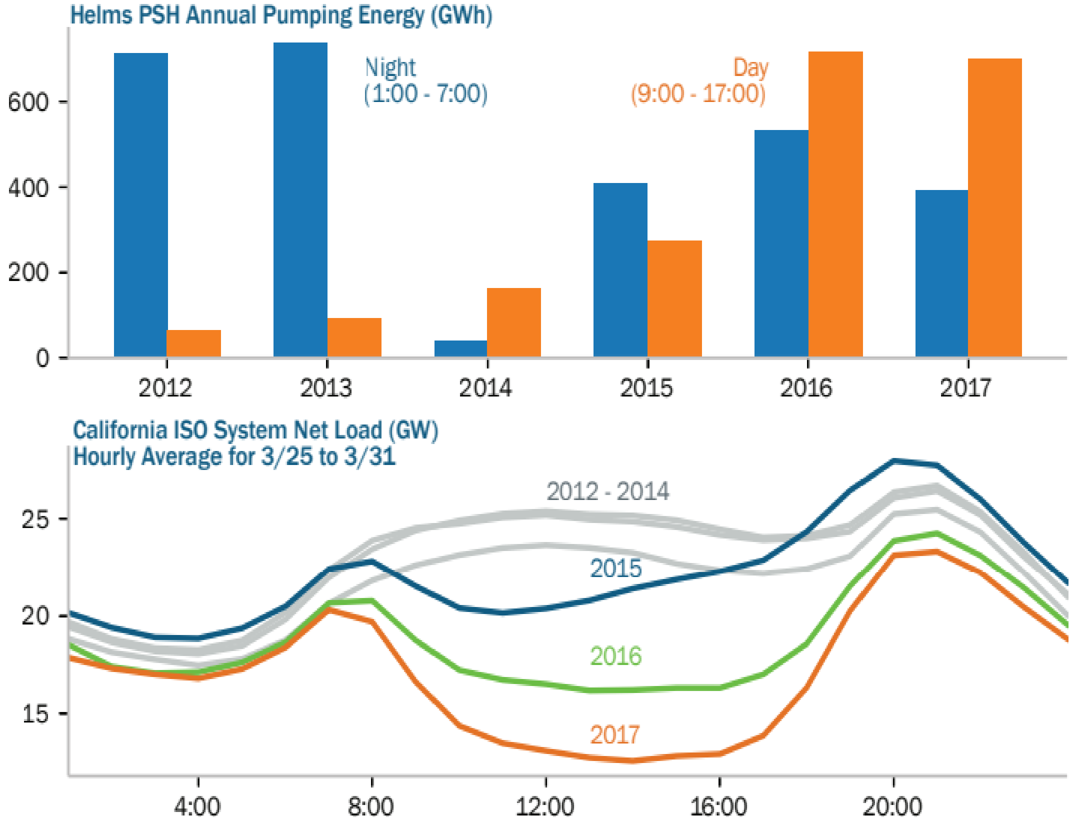


Figure 34. Annual pumping energy consumption by Helms PSH versus CAISO net load in the last week of March (2012-2017)

Pumped Storage Hydropower (PSH) can provide essentially all grid services

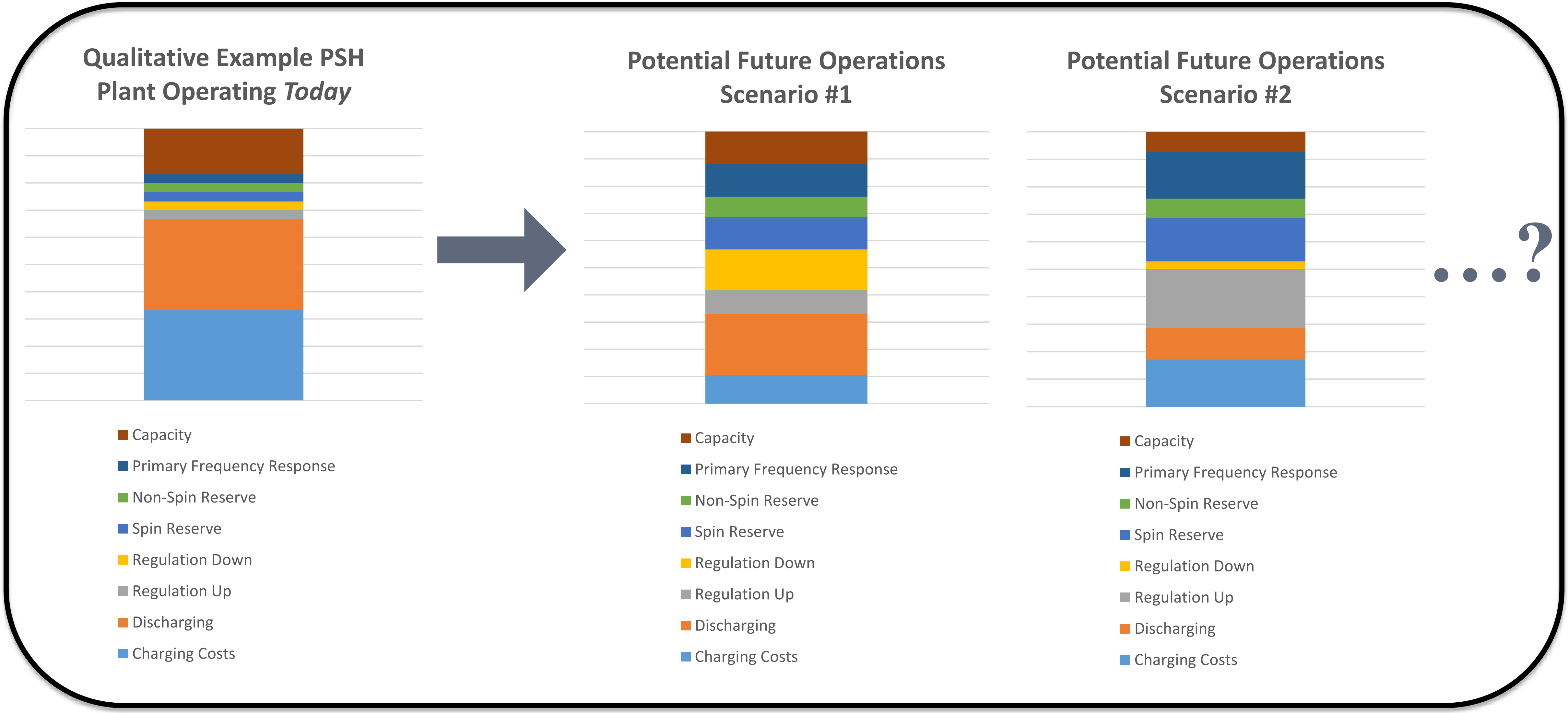
- Pumped storage hydropower characteristics:
  - ➢ Large (>100 MW), long duration
  - ➢ Historically built for daily swings in load and as a companion to large thermo-electric generators
  - ➢ Can provide nearly all possible grid services at low levelized cost
- ➢ 43 PSH plants with a total capacity of 22 GW provide 95% of utility-scale electrical energy storage in the United States

	PSH Contribution
1	Inertial response
2	Governor response, frequency response, or primary frequency control
3	Frequency regulation, regulation reserve, or secondary frequency control
4	Flexibility reserve
5	Contingency spinning reserve
6	Contingency non-spinning reserve
7	Replacement/Supplemental reserve
8	Load following
9	Load leveling/Energy arbitrage
10	Generating capacity
11	Reduced environmental emissions
12	Integration of variable energy resources (VERs)
13	Reduced cycling and ramping of thermal units
14	Other portfolio effects
15	Reduced transmission congestion
16	Transmission deferral
17	Voltage support
18	Improved dynamic stability
19	Black-start capability
20	Energy security

The Challenge: The Valuable Flexibility and Reliability Attributes of Hydropower and PSH are Poorly Understood

- Existing hydropower and pumped storage systems were originally optimized to operate under very different conditions, but the electricity system is changing rapidly.
- The value of hydropower's flexibility and quick response is likely to increase, but its precise future role is difficult to evaluate, resulting in sub-optimal designs and equipment, attrition of existing hydro resources, and stalled investments in new PSH.
- Utilities, ISOs, and markets are still evolving in their ability to value/monetize a range of flexibility & reliability services. There are significant gaps in information about the costs to hydro and PSH in providing these services and the system benefits/value.
- In addition, hydropower flexibility is constrained by a range of variables and competing water uses.
- Pumped storage technologies are considered mature, and there is little awareness of the opportunities that new PSH technologies can bring.

The Opportunity: New, More Valuable Roles Evolving for Hydropower and PSH?



Development of Hydropower Grid Research Portfolio

- Given these challenges, WPTO's has developed a hydropower grid research portfolio to understand and drive utilization of the full potential of hydroelectric resources (including PSH) to contribute to electricity system reliability and resiliency, now and into the future.

1) Value Under Varying System Conditions:
What Will the Grid Require?
OUTPUT: Drivers, Services, and Value

2) Capabilities and Constraints:
What Can the Hydropower Fleet Do, and Why, in Today's and the Emerging Grid?
OUTPUT: Technology Characterization

3) Operations and Planning:
How Can We Plan and Operate the Hydropower Fleet to Best Take Advantage of Capabilities?
OUTPUT: Competitive Position and Contribution to System Attributes

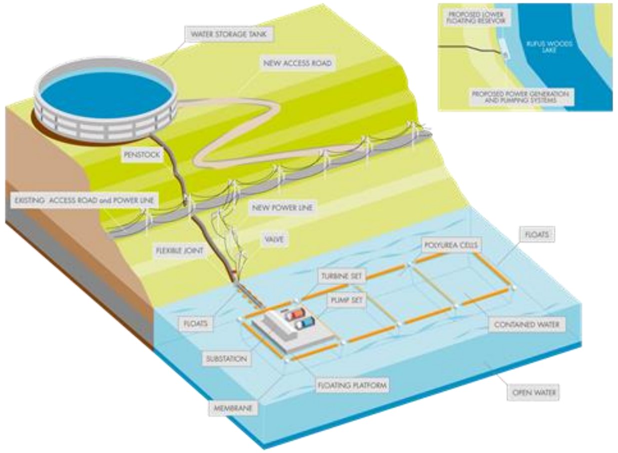
4) Technology Innovation:
What Achievable Innovations are Needed to Enable or Preserve Hydropower's Critical Contribution to the Electric System?
OUTPUT: New Technology Designs to Create New Capabilities or Remove Barriers

Relevant Efforts in the Hydropower Grid Research Portfolio

- Funding four innovative PSH technology concepts that reduce capital costs (since 2016)
- Valuation guidebook for PSH applied to two proposed PSH development sites (guidebook to be completed in 2020)
- Report on environmental effects of closed-loop PSH (summer 2019)
- Modeling Workshop to improve representation of hydropower and PSH in power system models (March 2019)
- “Beyond LCOE” cross-office effort to develop new metrics that capture system cost and value for all generation types (framework by end of 2019)

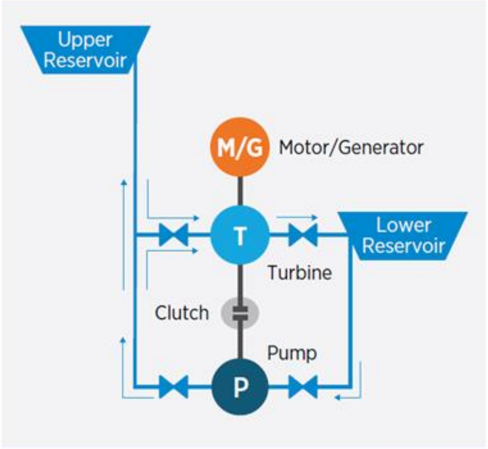
Current DOE-Funded PSH Technologies

Small Modular Hydro Battery (Shell)



Modular Compressed-Air PSH (ORNL)

Ternary PSH System (NREL)

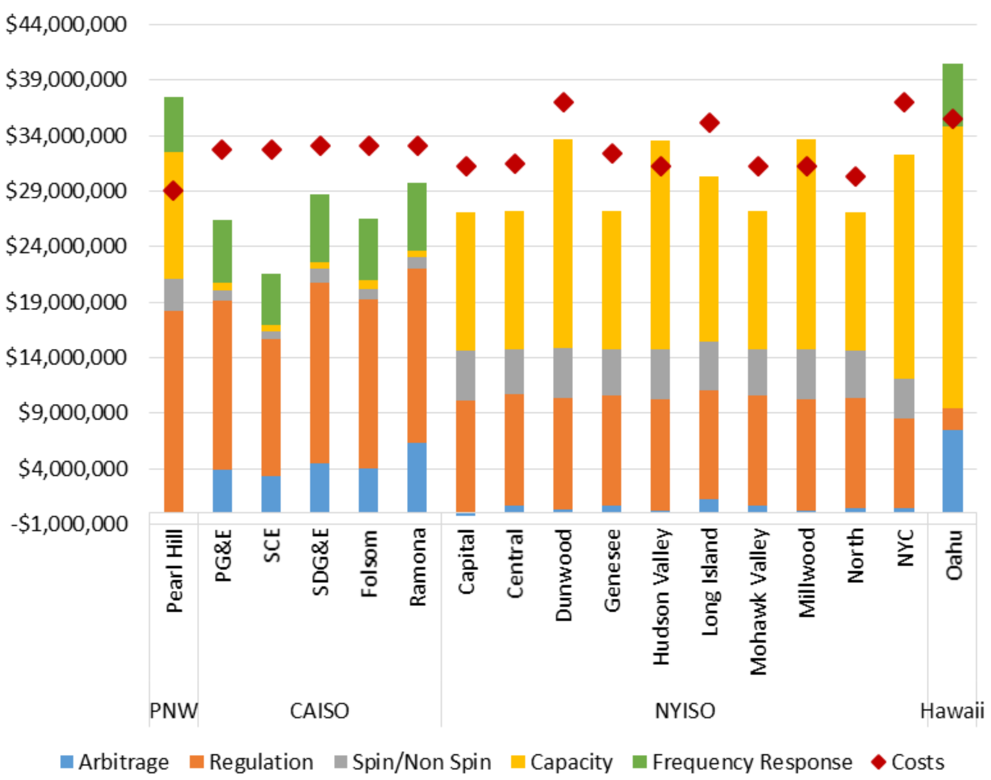


No-Powerhouse PSH (Obermeyer)

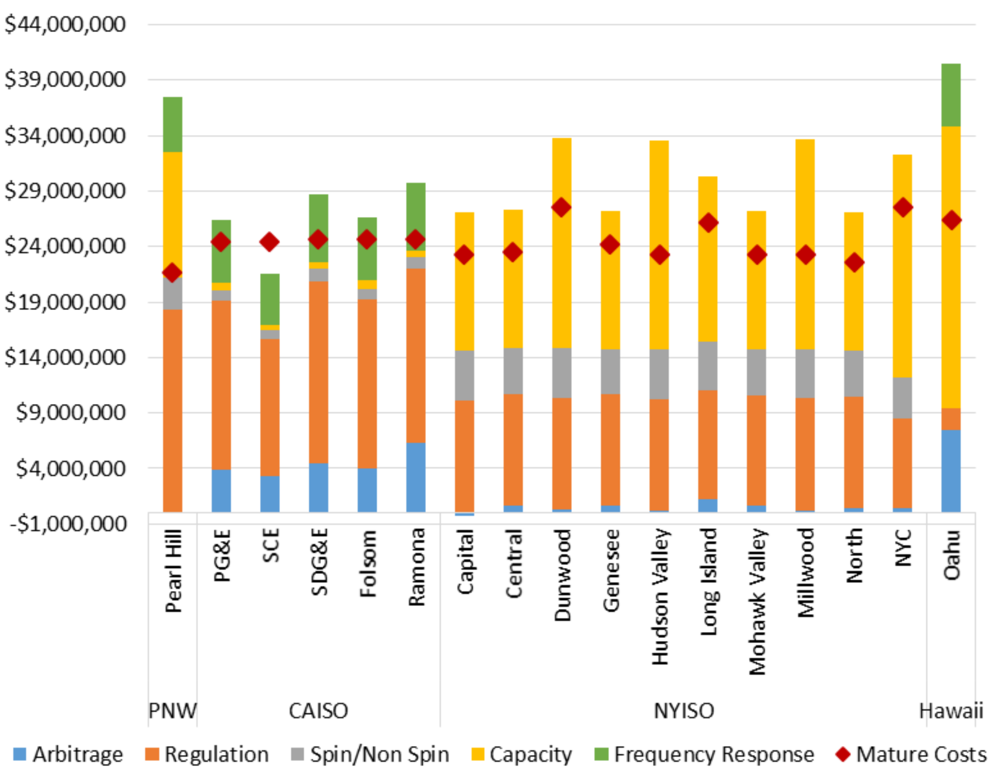
New tools to evaluate the value of PSH and hydropower grid services

Market Assessment for Small, Modular PSH (Shell Project)

Benefits vs. Base Costs



Benefits vs. Mature Costs

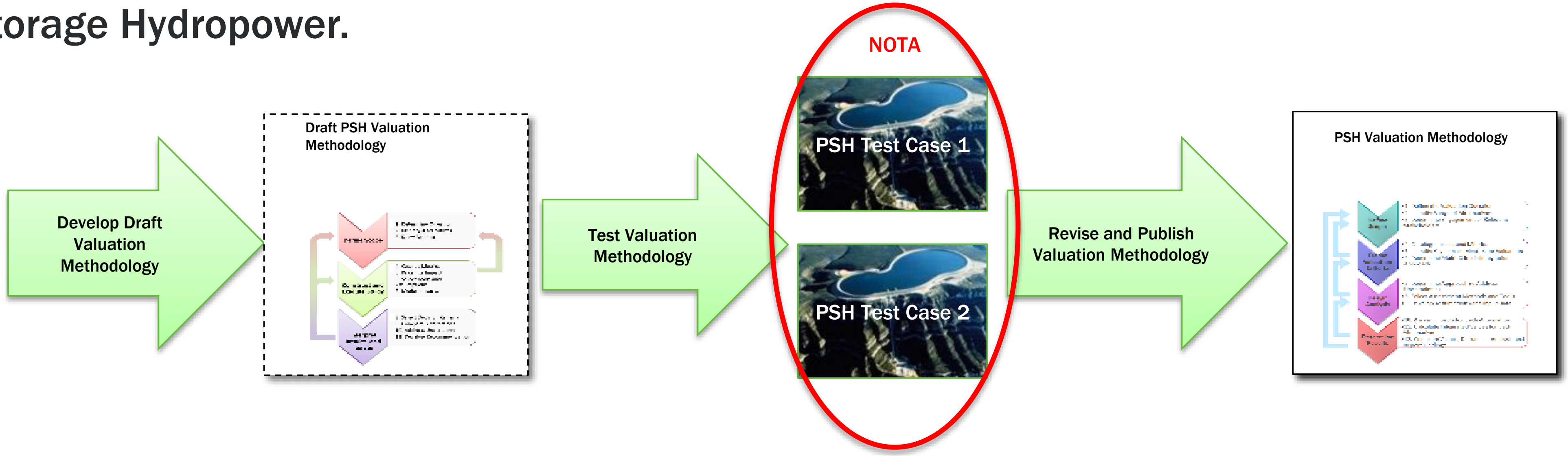


(The Base Costs case is set in terms of current market structures. The assumption is that economies of scale and lessons learned from the regulatory process can help realize the Mature Cost scenario, which includes 30% lower capital costs and only $1 million for licensing costs.)

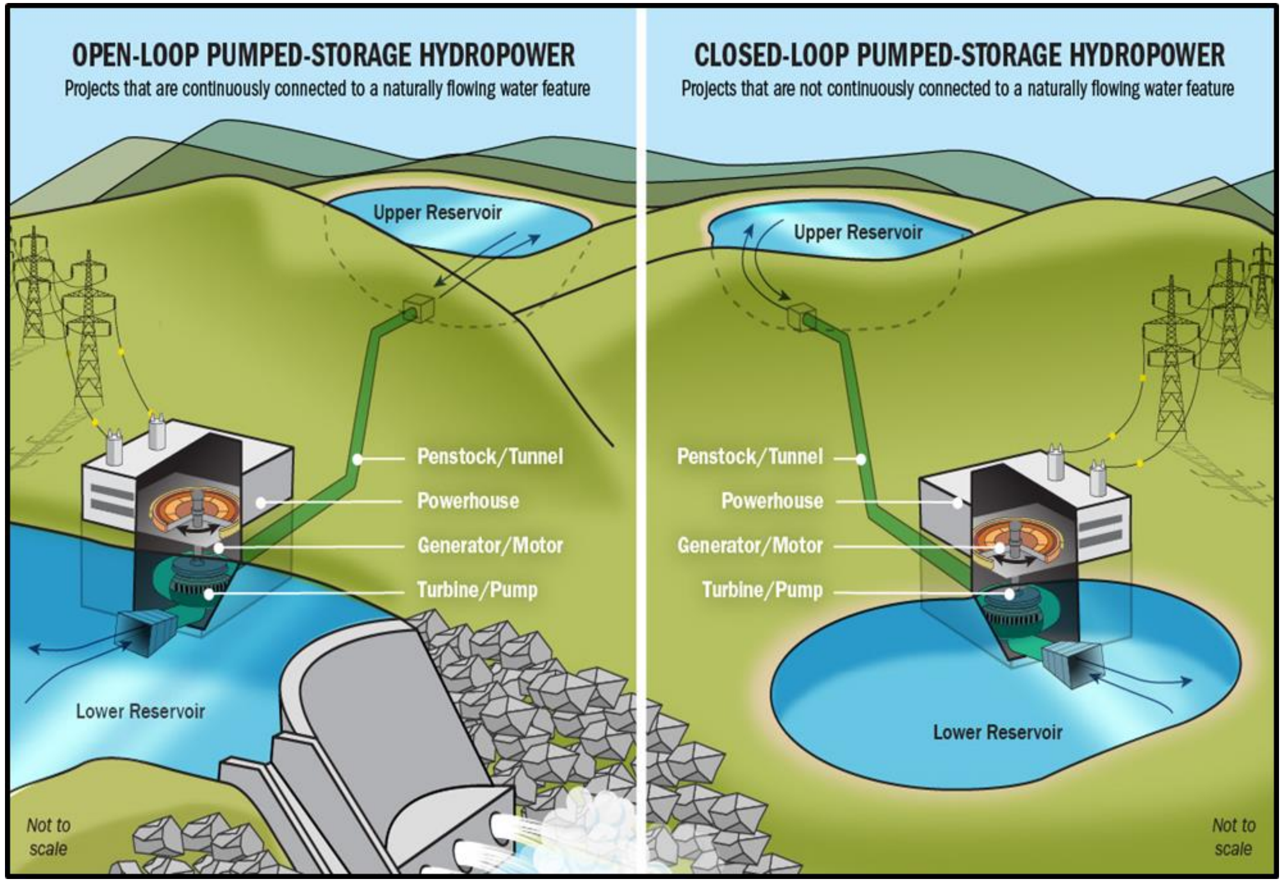
Courtesy of PNNL

Valuation guidebook for PSH

- Congress directed the Water Power Technologies Office (WPTO) to produce a thorough techno-economic analysis of the value of pumped-storage hydropower (PSH) at two sites with high-levels of intermittent renewable energy generation in the United States.
- In response, WPTO is developing an advanced valuation methodology for pumped storage hydropower that can be used by PSH developers, plant owners and operators, and other stakeholders to assess the economic value of existing or planned PSH projects.
- The draft valuation methodology will be tested at two proposed pumped storage project sites– **Banner Mountain (Absaroka Energy) and Goldendale (National Grid)**—selected through DOE's Notice of Opportunity for Technical Assistance (NOTA): Techno-Economic Studies of Pumped-Storage Hydropower.

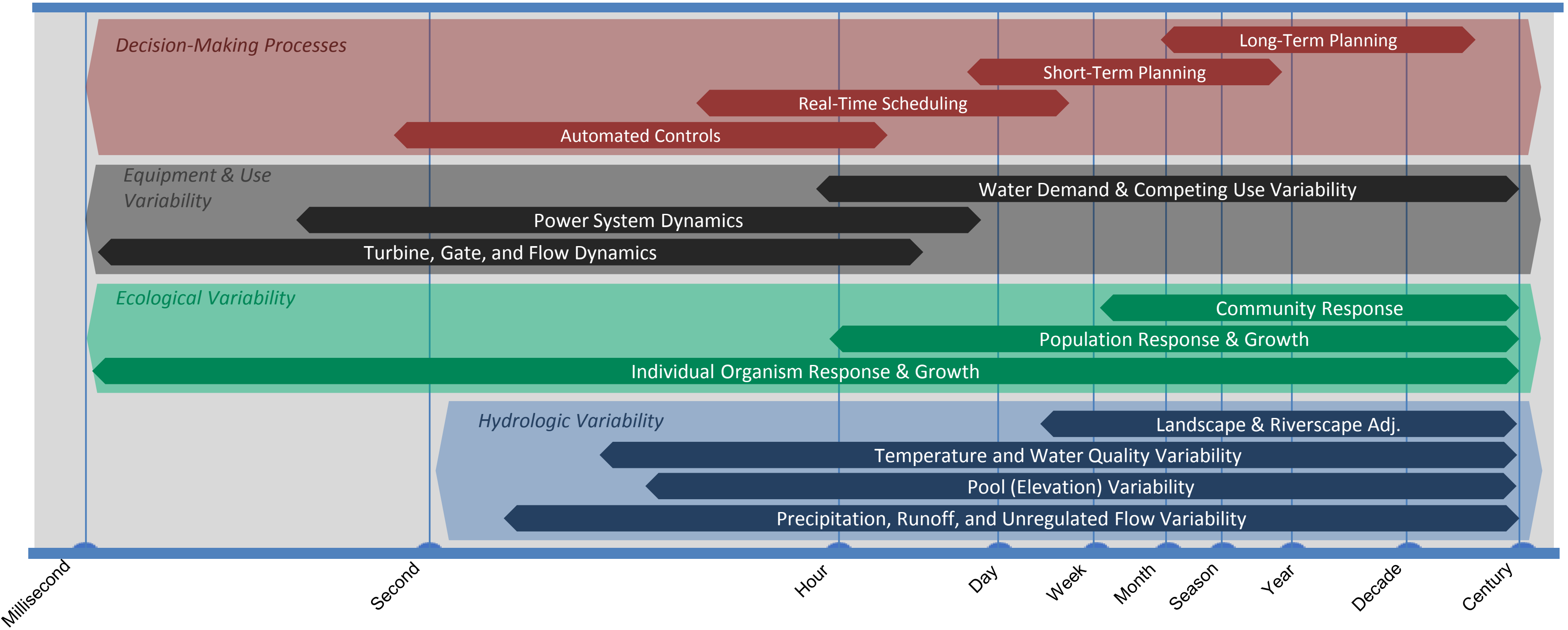


Environmental Effects of Closed-Loop Pumped-Storage Hydropower



- **All pumped storage hydropower (PSH) projects in U.S. are open-loop PSH**
- **There is increased interest in closed-loop PSH in U.S, especially with current effort to expedited licensing**
  - Environmental effects of closed-loop PSH not well understood
- **A DOE report (summer 2019) on the environmental effects of closed-loop PSH will include:**
  - A review of relevant U.S. and international literature
  - A review of U.S. FERC licensing records for proposed and existing PSH projects to identify effects and measures
- **Preliminary conclusions comparing closed-loop PSH to open-loop PSH:**
  - Generally, closed-loop PSH has smaller effects than open-loop PSH on fish and other aquatic ecological resources
  - Comparable <u>types</u> of effects on most other resources
  - There are much larger effects for closed-loop PSH using groundwater
  - Type and significance of effects depends on project location, size, configuration, and operation, but there are still notable differences between open- and closed-loop.

Challenges in representing hydropower and PSH in power system models

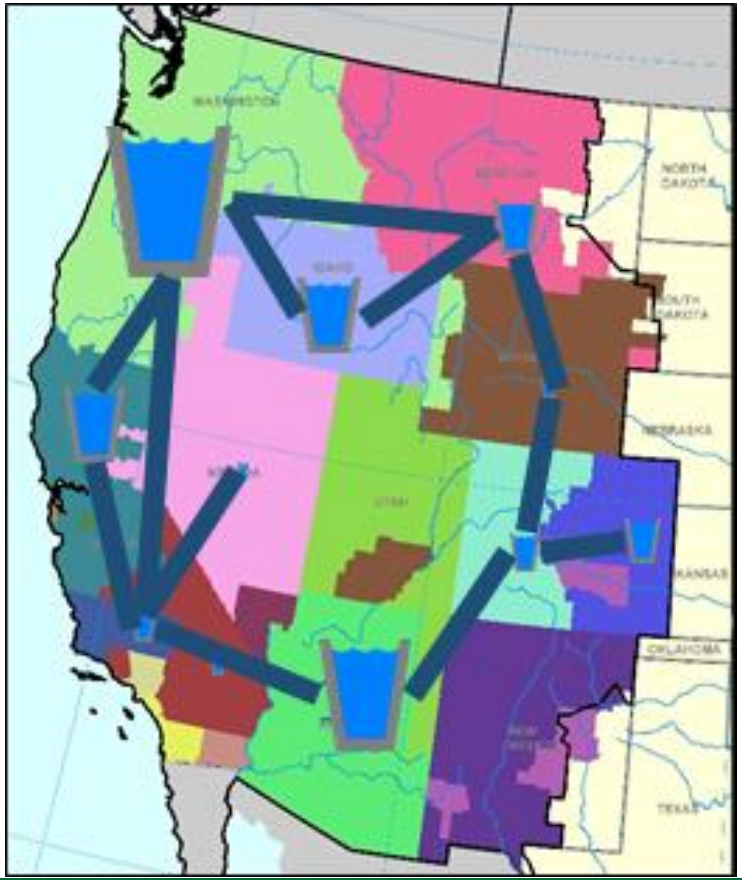


Comparison of Hydropower Operations Time Scales and Power System Time Scales (courtesy of ORNL)

Water Management Timescales

- Spatial, temporal, unit and computational complexity creates seams between water management and grid models
- Hydropower representation in current models does not capture complexity, diversity, and changed operational paradigm of the fleet
- An upcoming workshop with PNNL and NREL will explore these questions to improve modeling of hydropower and PSH

Hydropower in power system operations



Hydropower represented as a monthly potential at the balancing authority scale

(Voisin et al. 2017)

Beyond LCOE (Cross-Office Effort)

- **Problem:** Levelized Cost of Electricity (LCOE) fails to account for system costs and value, leading to inappropriate comparisons across technologies, impacting investment and R&D decisions.
- **Objective:** Develop and apply a framework that enables a more comprehensive understanding of costs and value of generation technologies to the power system.
  - **Costs:** LCOE plus transmission and other system costs
  - **Values:** Energy, capacity, transmission, ancillary & reliability services
- **Outcomes:**
  - **Conceptual framework** used to evaluate system value and enabling consistent technology comparisons, including the principles, methodologies, metrics, definitions, and scenarios
  - Application of framework to **develop quantitative metrics for current and potential future generating technologies** using existing models & tools

Thank You!

Questions?

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https://www.energy.gov/eere/water/

https://www.energy.gov/eere/water/pumped-storage-hydropower