



U.S. DEPARTMENT OF ENERGY

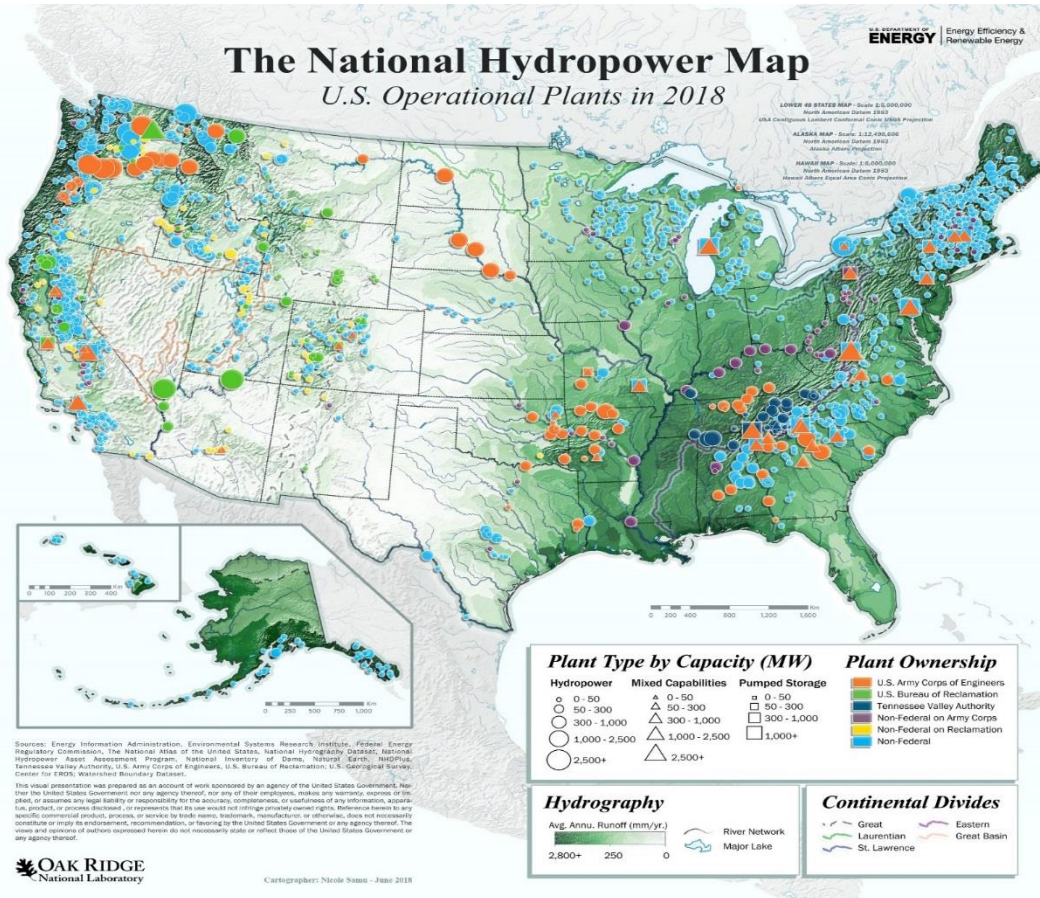
## HydroWIRE Initiative Overview: A New Role for Hydropower

Hydro Power Summit  
Trondheim, Norway  
February 5, 2020

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HydroWIRE Initiative Lead  
Water Power Technologies Office  
(<https://energy.gov/hydrowires>)

- Motivation and Background: Changing roles for hydropower in a changing power system
- DOE-WPTO's HydroWIRES research initiative
- Examples of HydroWIRES projects you'll hear about today
- Forthcoming reports and next steps

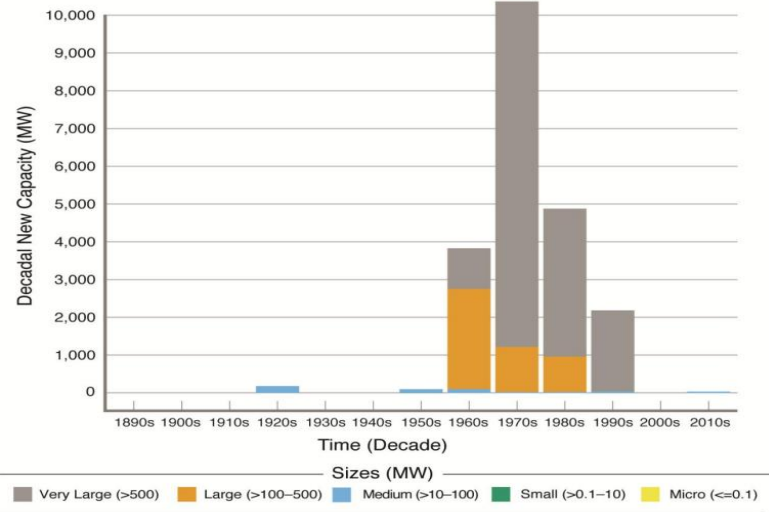
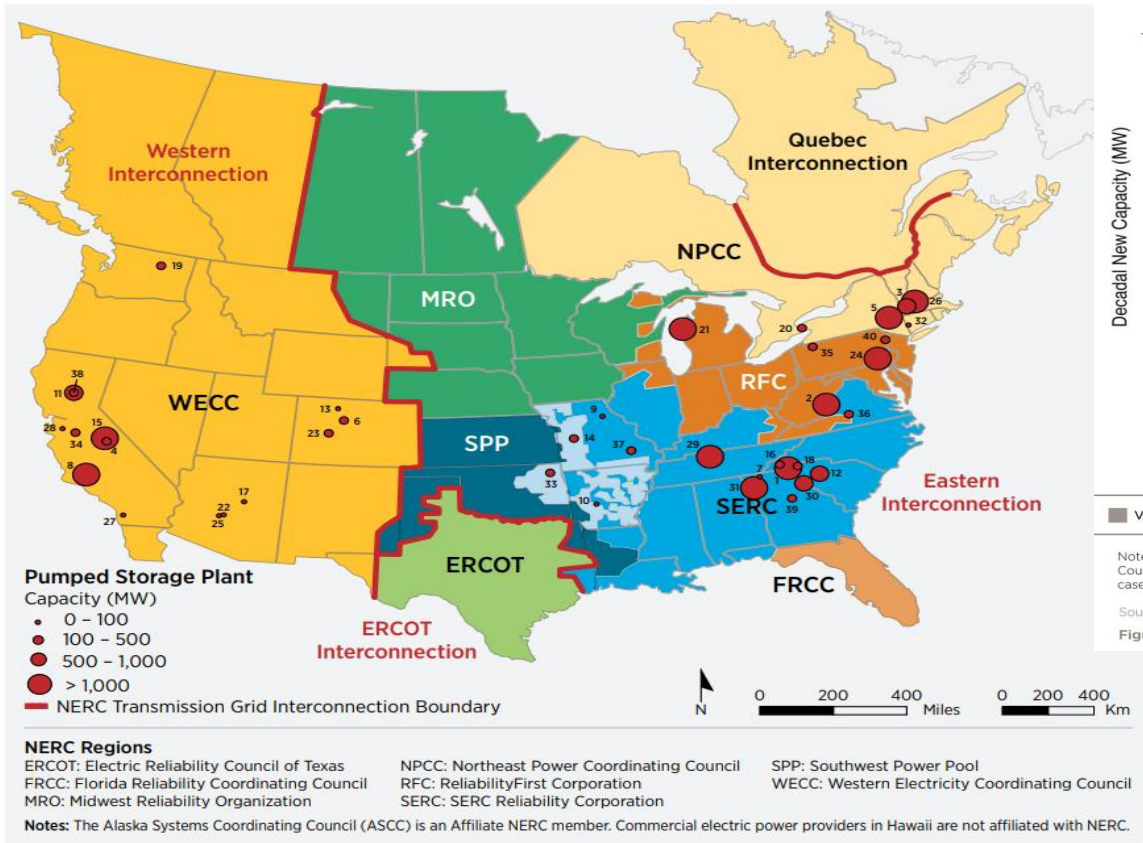


## HYDROPOWER HIGHLIGHTS

- **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

- **Large existing resource, including the vast majority of grid-scale storage**
- **Significant complexity and variety in the fleet**

# Pumped storage hydropower (PSH)



Note: This figure displays the initial year of operation for each project except in two cases (Hiwassee and Grand Coulee) in which no pumped storage units were installed when they first became operational. In those two cases, the capacity was assigned to the decade in which the pumped storage units were added.

Source: NHAAP

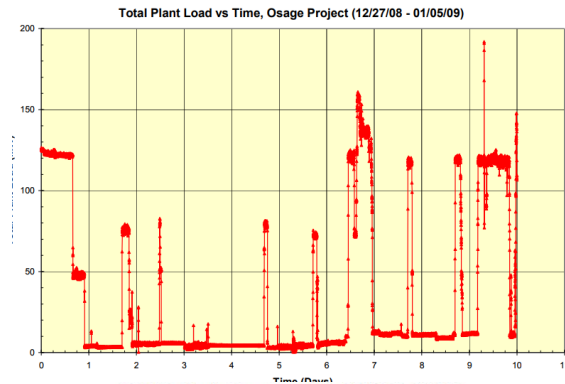
Figure 18. Pumped storage hydropower installation timeline by plant size

Source: Argonne National Laboratory

Figure 2-41. Existing pumped storage hydropower plants in the United States

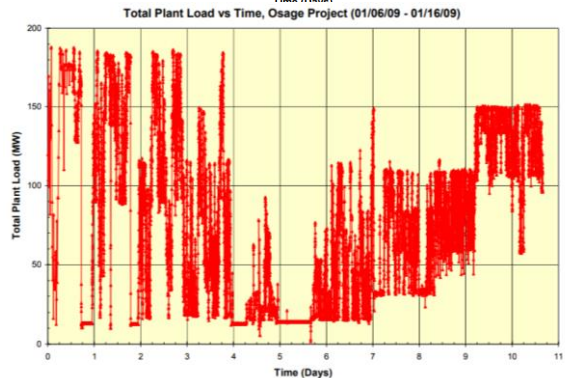
- About 22 GW of PSH capacity deployed in the US, but no new large projects in the last 20 years

## 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

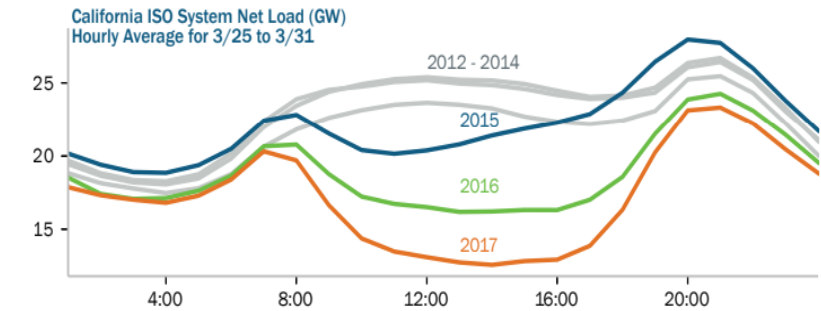
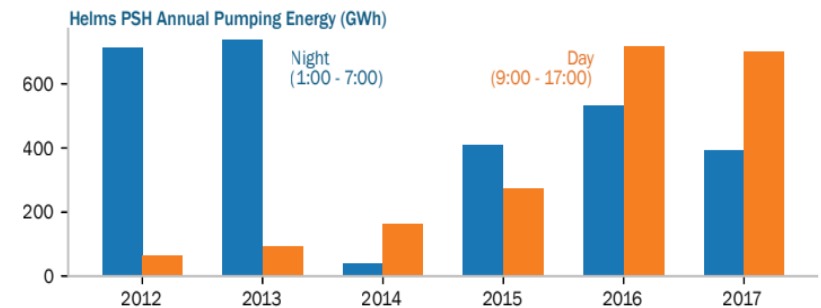
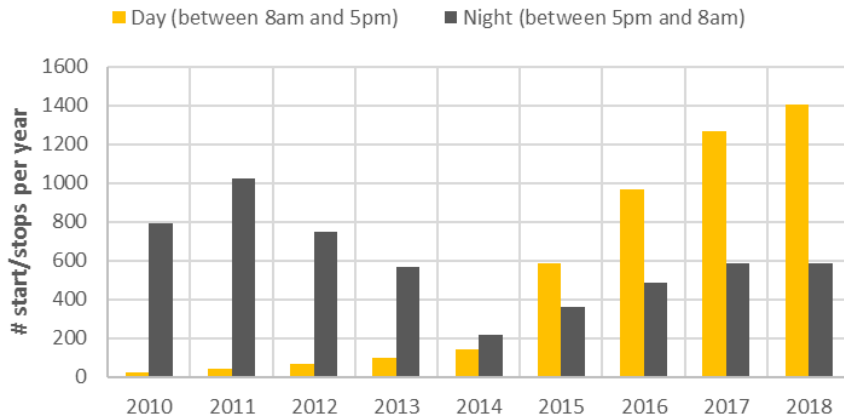


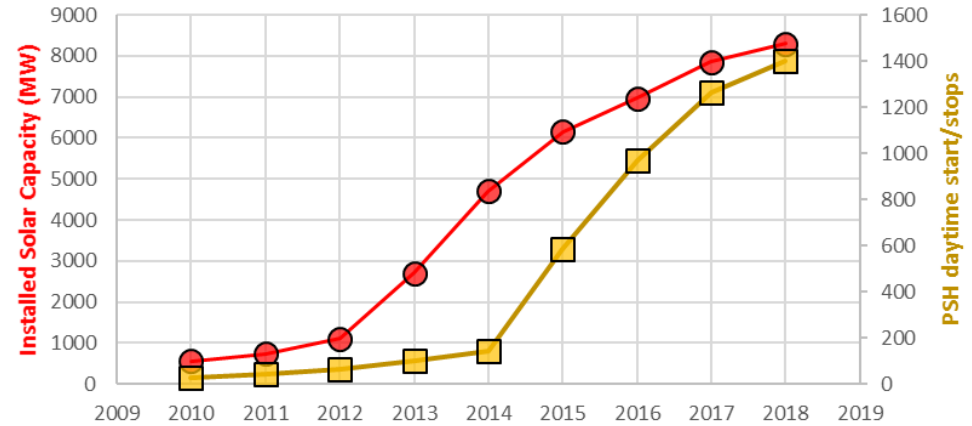
Figure 34. Annual pumping energy consumption by Helms PSH versus CAISO net load in the last week of March (2012-2017)

# Changing PSH operations worldwide

Omarugawa Pumped Storage Power Station:  
Annual day vs. night start/stops from 2010 to 2018



Omarugawa Pumped Storage Power Station:  
Solar deployment vs. annual PSH daytime start/stops



- The Omarugawa PSH plant in Kyushu, Japan now averages ~4 start-stops per day, increasing in close correlation with installed solar PV capacity
- Other countries are experiencing similar changes, suggesting opportunities for sharing knowledge

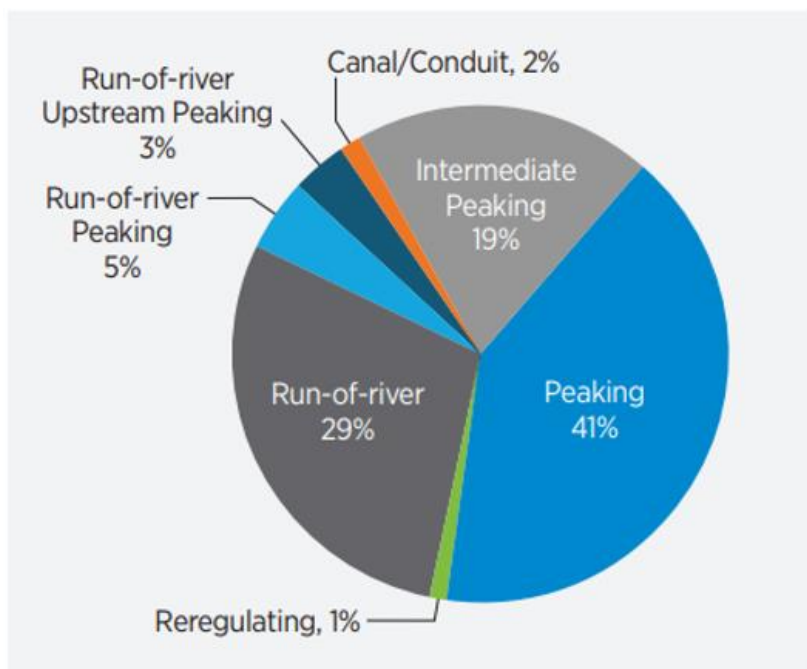
# Pumped Storage Hydropower (PSH) can provide essentially all grid services

- Large (>100 MW), long-duration storage
- 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
- Not all of these services are compensated in organized markets, but all have value in some situations
- Accurate valuation of these services (for PSH as well as hydropower and other resources) is a fundamental challenge

	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

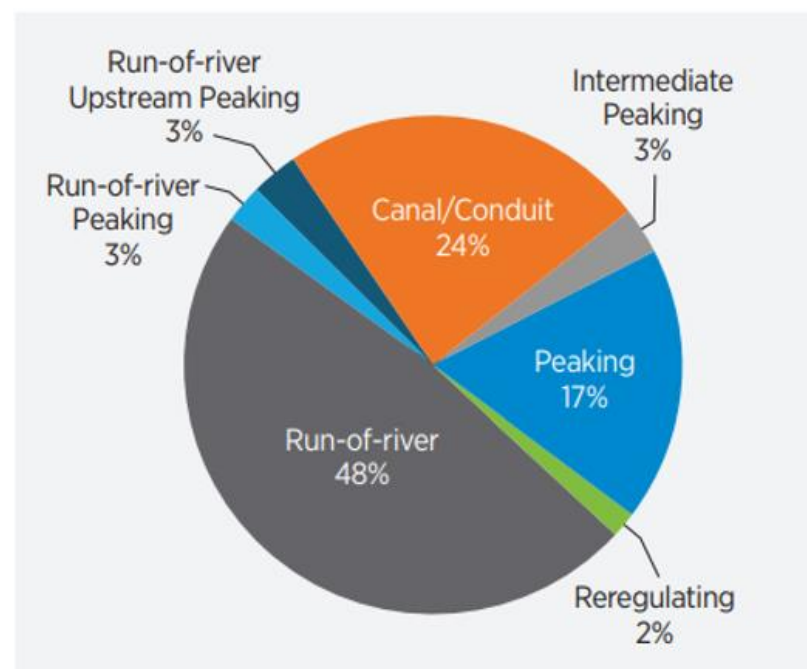
# The US conventional hydropower fleet can also provide significant flexibility

- About 70% of hydropower capacity has capabilities for flexible operation
- But operations vary by plant; flexibility is mostly concentrated in larger projects



Source: National Hydropower Asset Assessment Program FY15 Plant Database [15]

**Figure 2-9.** Distribution of operating modes for hydropower facilities, by capacity

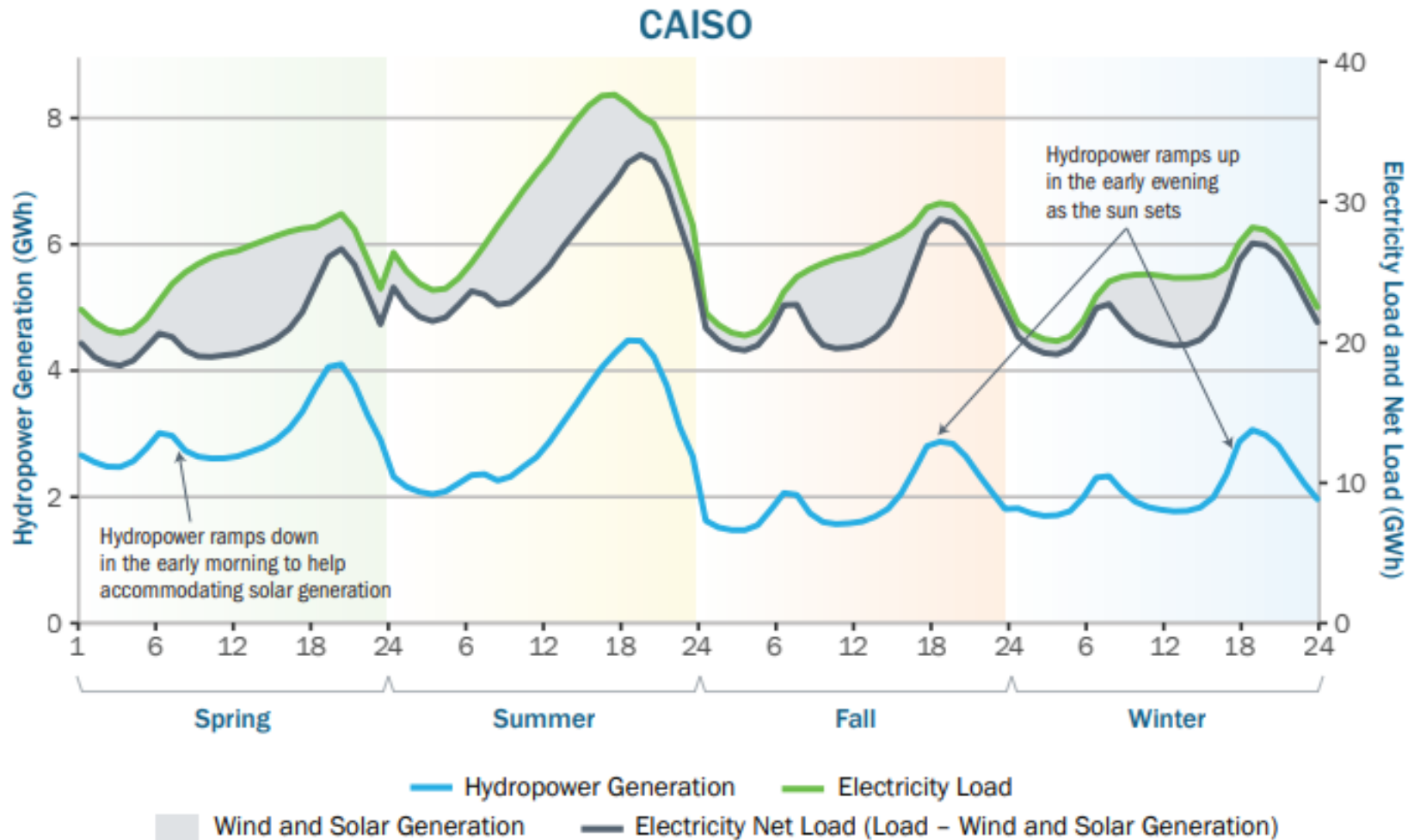


Source: National Hydropower Asset Assessment Program FY15 Plant Database [15]

**Figure 2-8.** Distribution of operating modes for hydropower facilities, by number of projects



# Hydropower provides load following in all ISO/RTO markets

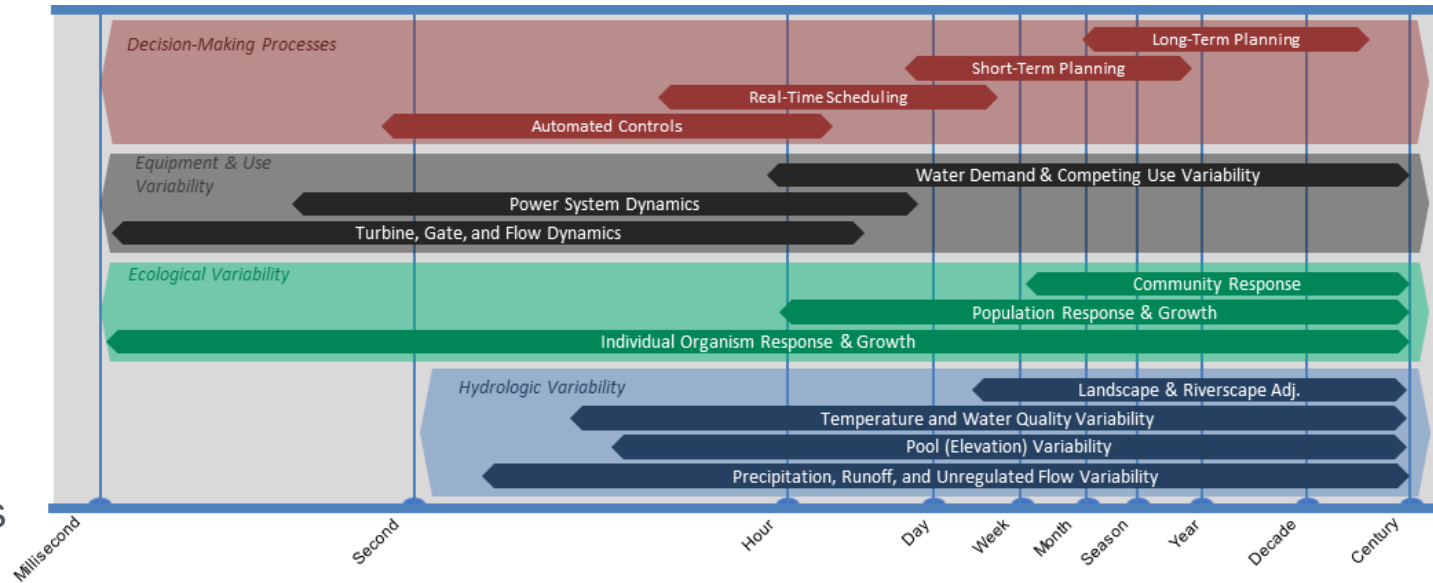


Average hourly hydropower and PSH generation, electricity load, and electricity net load by season in CAISO (2014-2017)

Oak Ridge National Laboratory, 2017 Hydropower Market Report, 2017  
<https://www.energy.gov/sites/prod/files/2018/04/f51/Hydropower%20Market%20Report.pdf>

# Challenges in representing hydropower in power system models

- Spatial, temporal, unit, and computational complexity can create a disconnect between water management and grid models
- Hydropower representation in current models does not capture complexity, diversity, and changed operational paradigm of the fleet



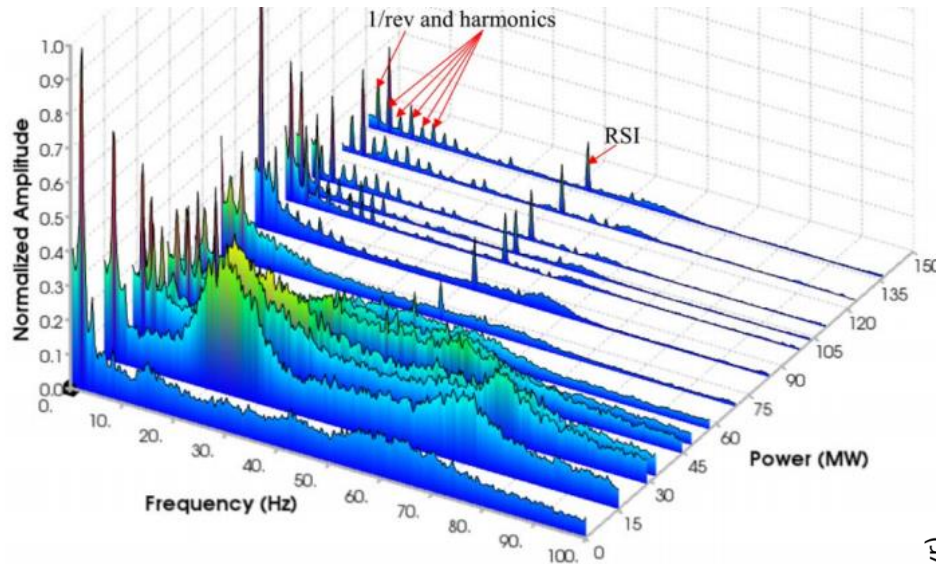
Comparison of Hydropower Operations Time Scales and Power System Time Scales (courtesy of ORNL)

Workshop: Hydropower in  
Production Cost Models  
Salt Lake City, March 2019

## Consensus on the need for:

- Improvements in the organization of publicly available data;
- Improved approaches for validation and characterizing uncertainty;
- New modeling frameworks that can address multiple competing objectives, and;
- Increased collaboration among the hydropower and power grid modeling communities

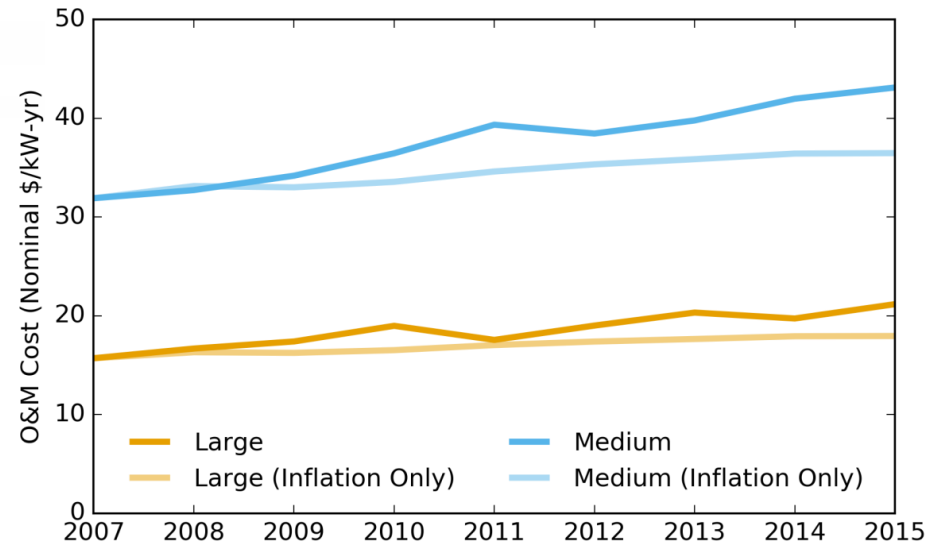
# More flexible operations have implications for equipment design and O&M



Strain gauge amplitude spectrum from tests at Vattenfall's Stornorrfors hydro plant [2016]

- More flexible operations required by the changing power system may be challenging for turbines designed for baseload operation
- Major OEMs have already seen changes in performance specifications that customers ask for

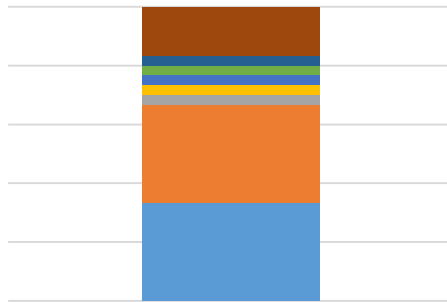
Since 2007, growth in O&M cost has outstripped inflation.



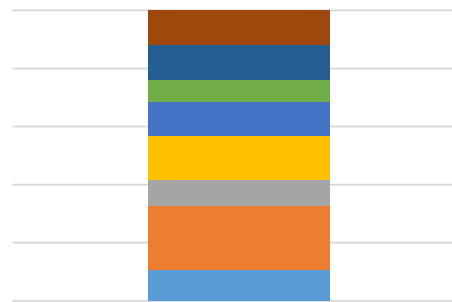
- As the electricity system is changing rapidly, there is limited understanding of which services will be needed, as well as limited ability to accurately value those services.
- Hydropower and PSH capabilities are bounded by the interaction of machines, water, and institutions, and some of these bounds may result from legacy decisions that did not consider evolving grid needs.
- There are gaps in information regarding how to optimize hydropower and PSH operations and planning in coordination with other resources.
- Current hydropower and PSH technology may not be designed for flexible operation.

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

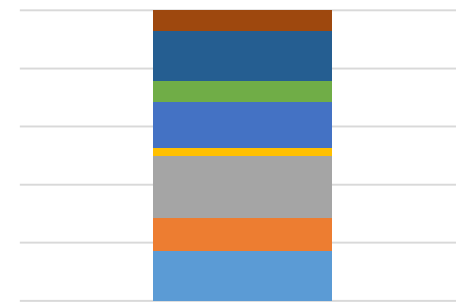
**Qualitative Example  
PSH Plant Operating  
Today**



**Potential Future  
Operations Scenario  
#1**



**Potential Future  
Operations Scenario  
#2**



- Capacity
- Primary Frequency Response
- Non-Spin Reserve
- Spin Reserve
- Regulation Down
- Regulation Up
- Discharging
- Charging Costs

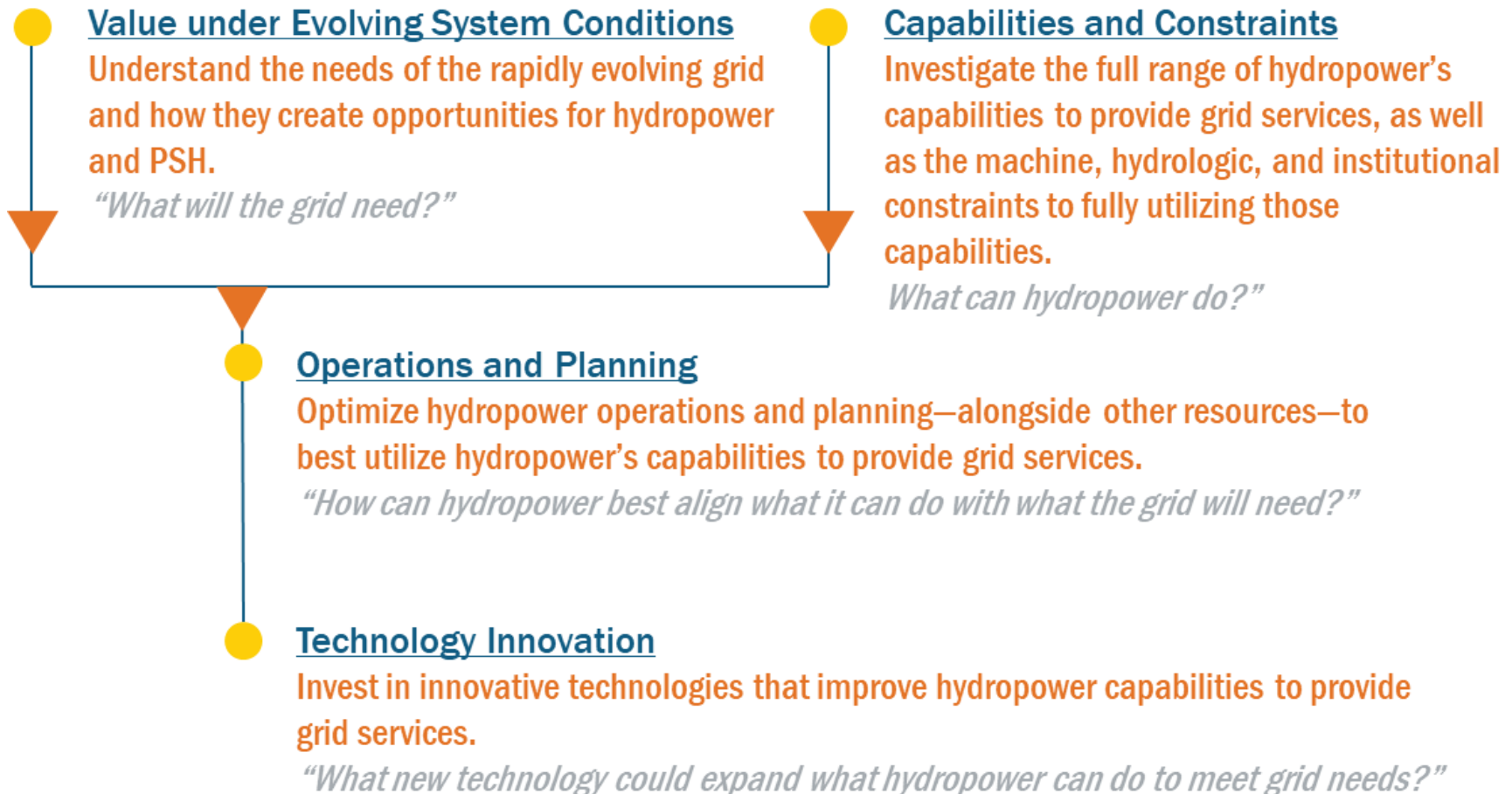
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- Given the rapid changes occurring in the U.S. electric system—and associated challenges and opportunities—WPTO has launched a new hydropower-grid research initiative titled **HydroWIRES: Water Innovation for a Resilient Electricity System**.
- The mission of HydroWIRES is to understand, enable, and improve hydropower's contributions to reliability, resilience, and integration in a rapidly evolving electricity system.
- HydroWIRES includes ~\$15M annual funding for modeling, analysis, technical assistance, and technology R&D to inform decisionmakers and improve their capabilities.



<https://energy.gov/HydroWIRES>



# HydroWIRES Initiative Organization

- To support HydroWIRES research efforts and sharing of ideas, we have convened a collaborative group of national lab researchers to support the research areas.
- These lab researchers provide leadership and strategic direction to inform the research portfolio and build connections within WPTO and to broader DOE efforts.



**Lemont, Illinois**



**Idaho Falls, Idaho**



**Golden, Colorado**

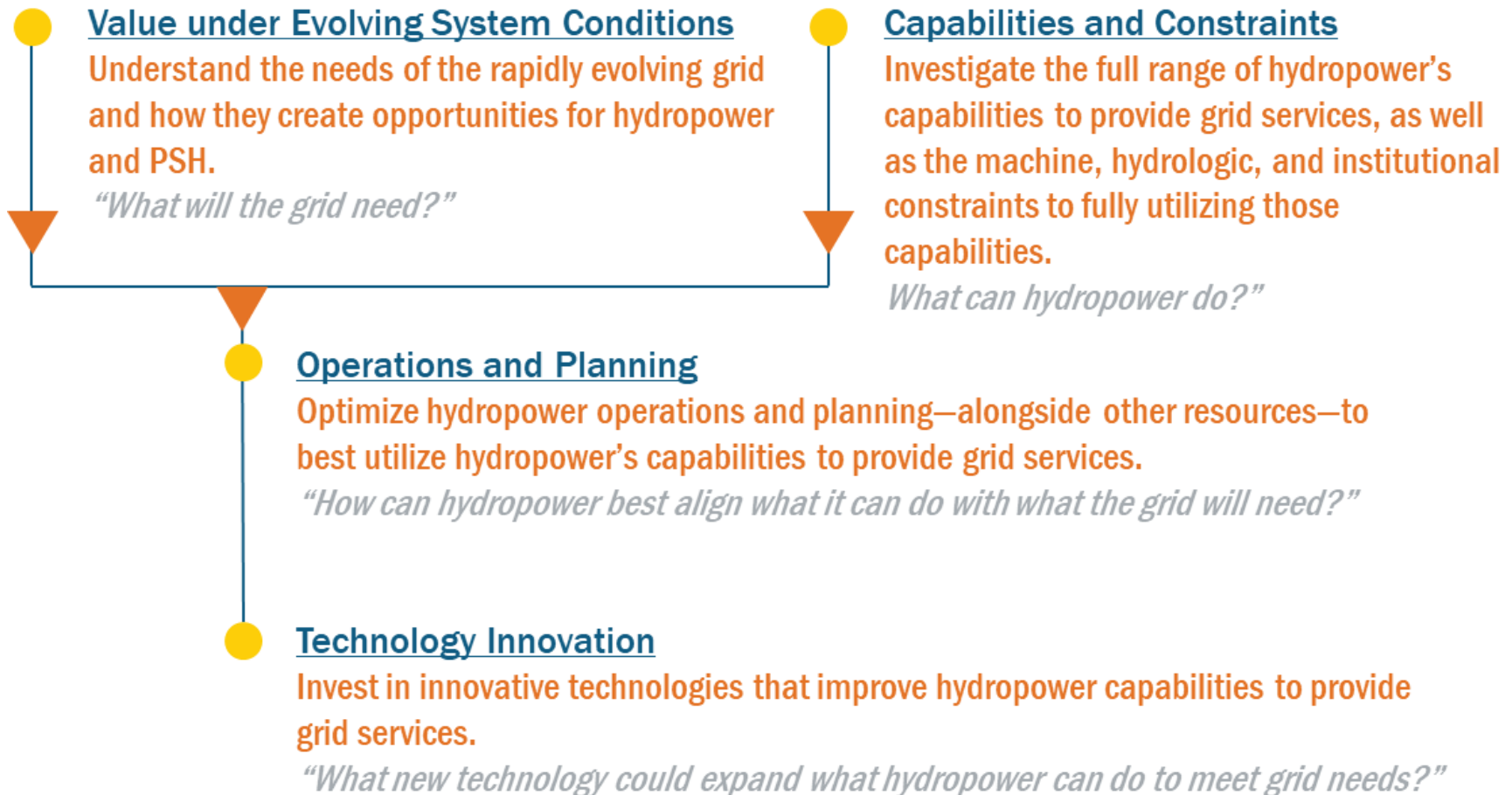


**Oak Ridge, Tennessee**



**Richland, Washington**





# HydroWIRES Projects in Today's Sessions

Hydropower Value Study

PSH Valuation

## Session 1

B1) Dynamic Hydro  
Classification for PCMs

### Value under Evolving System Conditions

Understand the needs of the rapidly evolving grid and how they create opportunities for hydropower and PSH.

*"What will the grid need?"*

### Capabilities and Constraints

Investigate the full range of hydropower's capabilities to provide grid services, as well as the machine, hydrologic, and institutional constraints to fully utilizing those capabilities.

*"What can hydropower do?"*

B2) Water  
Model/PCM  
Integration

A) Environmental-  
Flexibility Tradeoffs

## Session 3

### Operations and Planning

Optimize hydropower operations and planning—alongside other resources—to best utilize hydropower's capabilities to provide grid services.

*"How can hydropower best align what it can do with what the grid will need?"*

### Technology Innovation

Invest in innovative technologies that improve hydropower capabilities to provide grid services.

*"What new technology could expand what hydropower can do to meet grid needs?"*

FAST Prize

Geomechanical Storage

Ternary PSH

GLIDES PSH

Shell Hydro  
Battery PSH

No-Powerhouse  
PSH

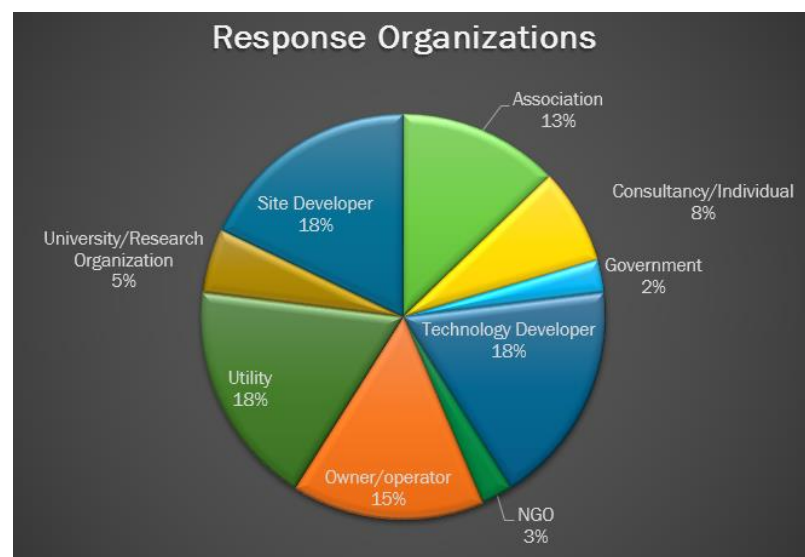
## Session 2

- RFI to solicit feedback on priorities and direction, issued February 2018
- HydroWIRES announced by Assistant Secretary Simmons in April 2019
- Engagement with hydropower and broader power system communities

- Waterpower Week
- HydroVision International
- NHA Regional Meetings
- Northwest Hydropower Association
- Energy Storage Integration Group
- CEATI working groups
- EPRI technical workshops
- IHA World Hydropower Congress
- IEA Hydropower Technical Collaboration

Programme (Annex IX)

- New RFI on the HydroWIRES Research Roadmap to be released March 2020
- “Quick Wins” mechanism to enable flexibility to stakeholder needs
- Also planning targeted technical workshops with external experts



About 40 respondents to initial RFI

# HydroWIRES Reports (more coming soon!)

## Published:

- [Hydropower Plants as Black Start Resources](#)
- [Energy Storage Technology and Cost Characterization Report](#)

## Near-Final Drafts:

- A review of storage in transmission planning (white paper)
- A review of pumped storage market participation and FERC Order 841 (white paper)
- Closed-loop pumped storage environmental effects (technical report)
- Hydropower-battery hybrids (technical report)
- NREL ternary pumped storage (technical report)
- Fast commissioning challenge baseline report (technical report)

- Hydropower Value Study (HVS) series of reports:
  - Hydropower Value Study Executive Summary
  - Historical Analysis of Hydropower Operations in MISO
  - Historical Analysis of Hydropower Operations in WECC
  - Historical Analysis of Hydropower Operations in ISONE
  - Case Study – Chelan Public Utility District
  - Case Study – Tennessee Valley Authority
  - Value of Non-monetized Services by Hydropower
  - The Value of Water
  - Power Systems vs. Hydropower Operational Timeframes
  - Hydropower Capabilities & Technology Gap + Cost Analysis

• ...

<https://energy.gov/HydroWIRES>

# HydroWIRES Partners and Awardees

## Internal Collaboration



DOE Executive Board:

- GMI
- OE
- EERE-SPIA

## International Collaborators



## Awardees



ELECTRIC POWER RESEARCH INSTITUTE



# Thank you!

## Questions?

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<https://energy.gov/HydroWIRES>