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

HydroWIRES

U.S. DEPARTMENT OF ENERGY

# Overview of the HydroWIRES Initiative

## *Grid Reliability and Resilience Track*

**WPTO Hydropower Program**

Tuesday, October 8, 2019

**Samuel Bockenhauer, Ph.D.**

HydroWIRES Initiative Lead / Hydropower Technology Manager

(https://energy.gov/hydrowires)

# Alignment with the Program



## Hydropower Program Strategic Priorities

Environmental R&D and Hydrologic Systems Science

Big-Data Access and Management

Technology R&D for Low-Impact Hydropower Growth

R&D to Support Modernization, Upgrades and Security for Existing Hydropower Fleet

Understand, Enable, and Improve Hydropower's Contributions to Grid Reliability, Resilience, and Integration

# Hydropower in the U.S.

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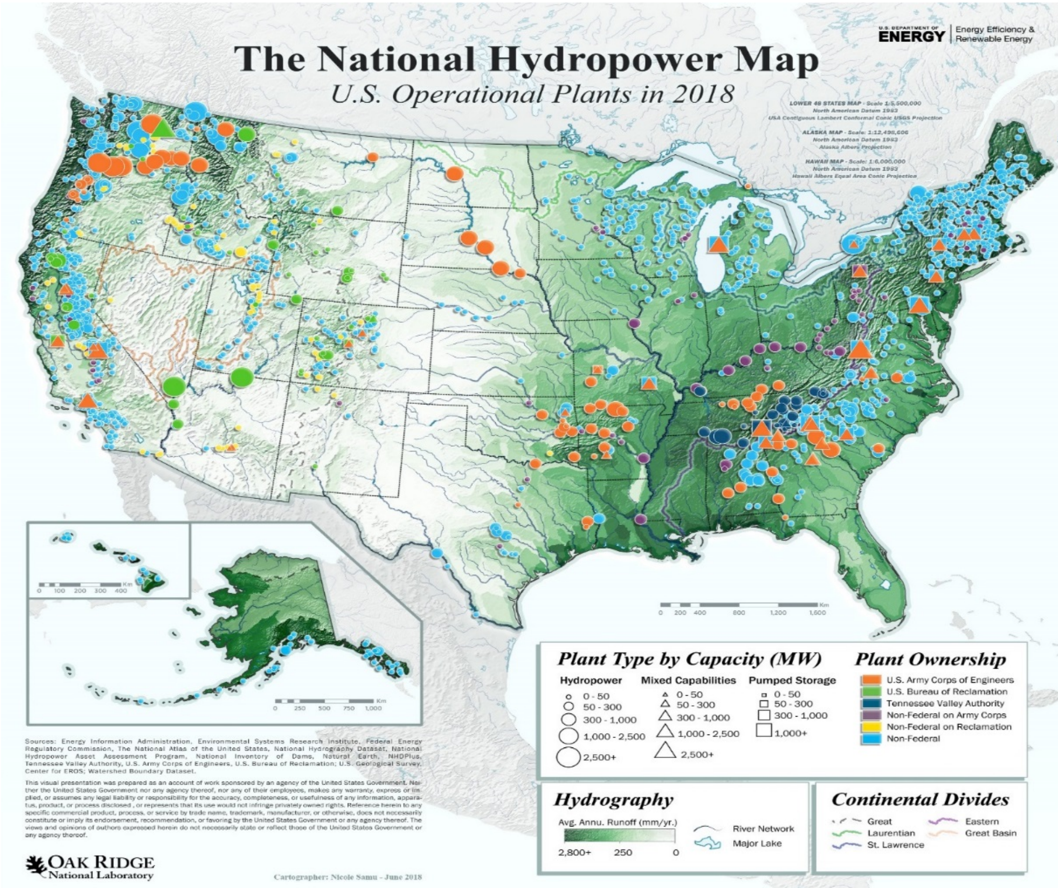


## HYDROPOWER HIGHLIGHTS

- **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)

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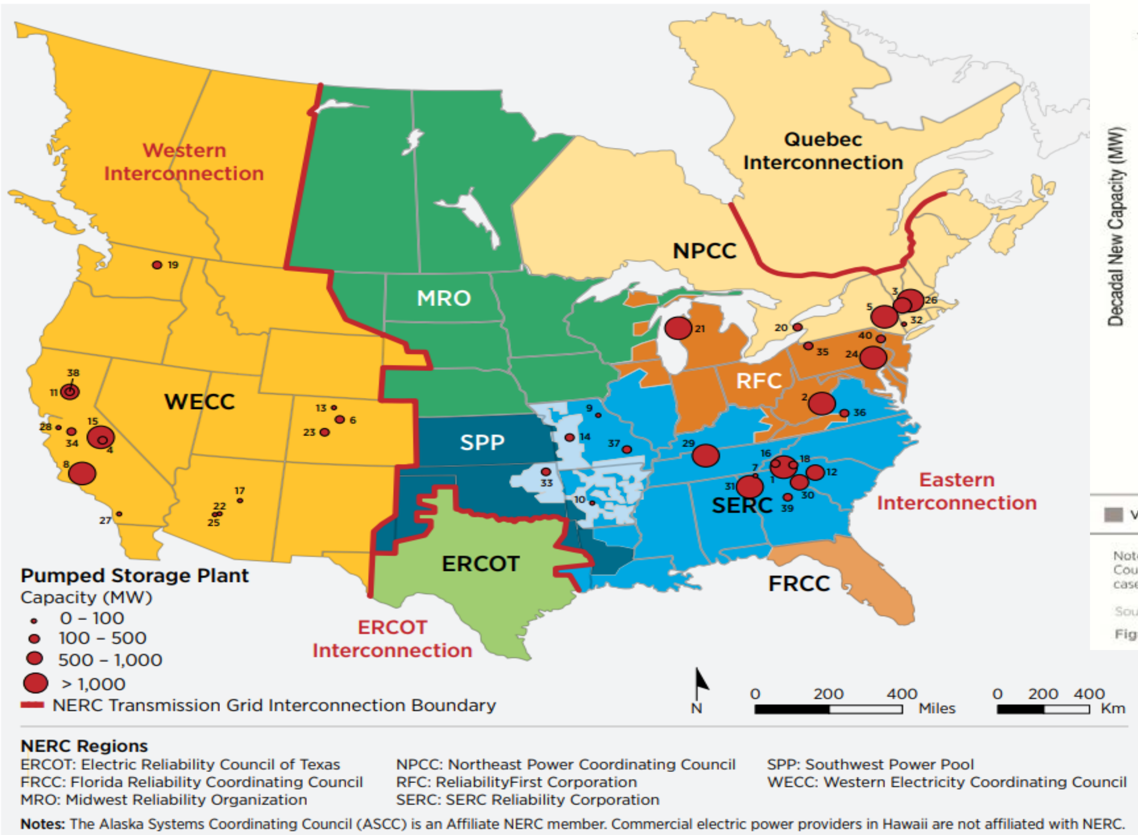
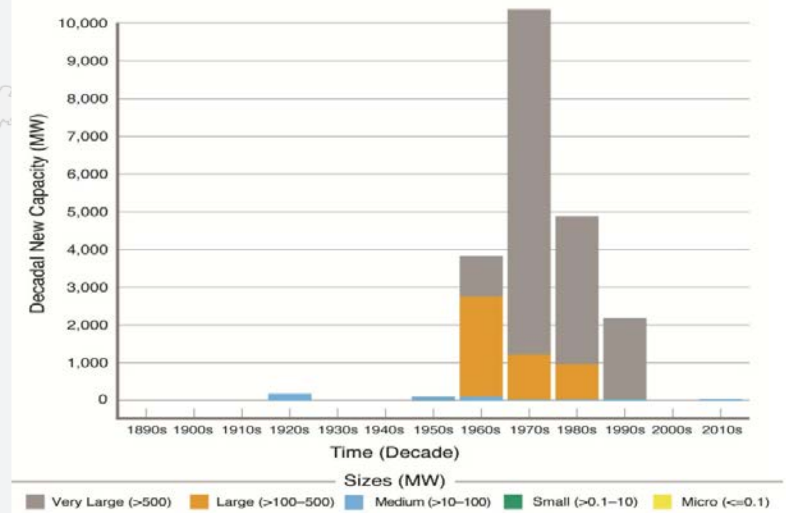



Source: Argonne National Laboratory

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




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

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

# Hydropower and PSH are Changing Rapidly

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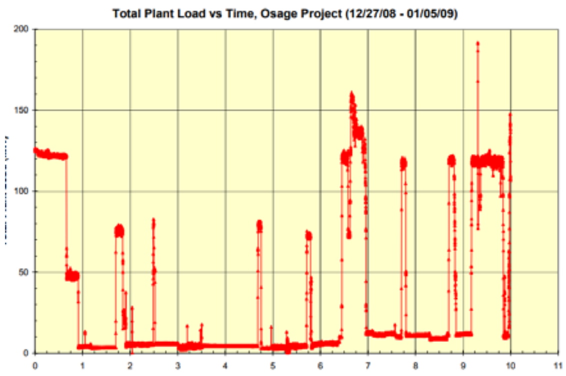
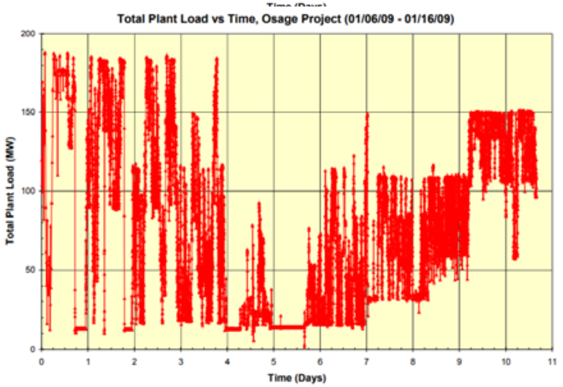
## Traditional Hydro: from steady or predictable patterns to fast and frequent ramping

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

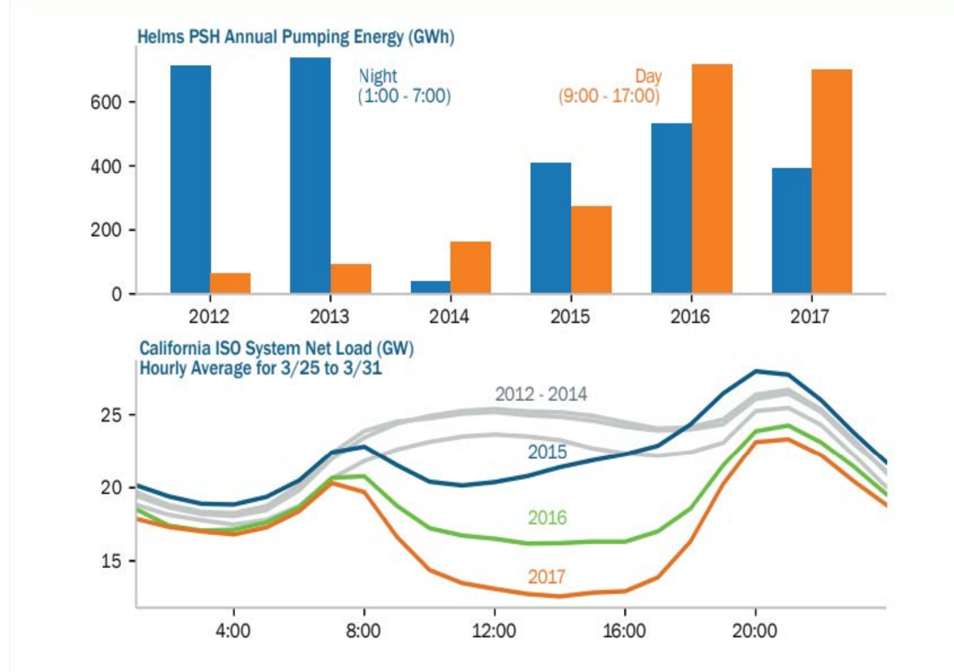



**Figure 34. Annual pumping energy consumption by Helms PSH versus CAISO net load in the last week of March (2012-2017)**

# Changing PSH operations worldwide

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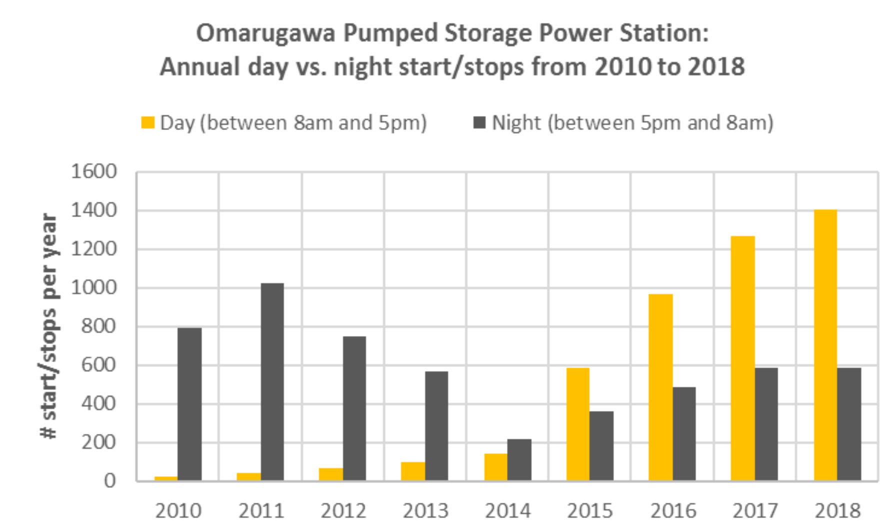


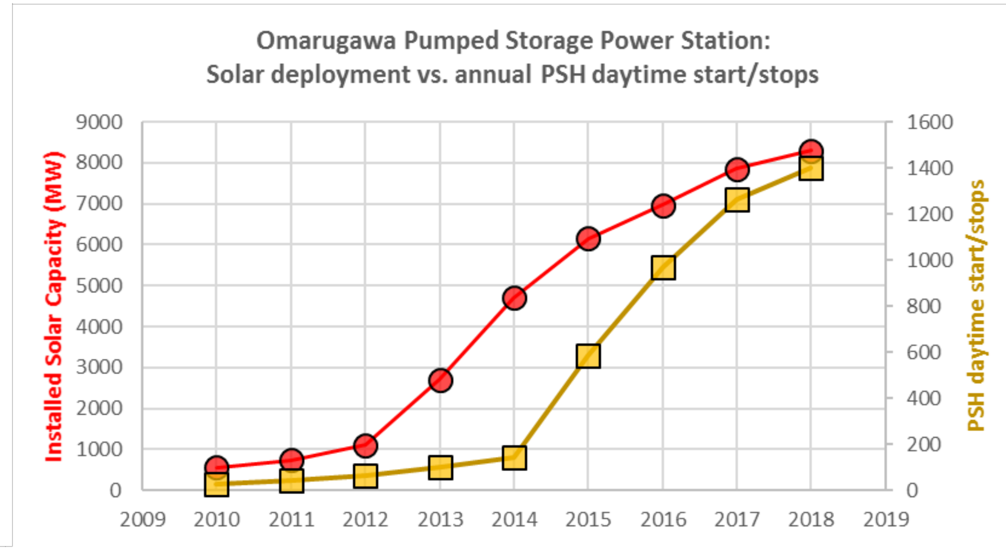


- The Omarugawa PSH plant in Kyushu, Japan now averages ~4 start-stops per day, increasing in close correlation with installed solar PV capacity
- Other countries are experiencing similar changes, suggesting opportunities for sharing knowledge

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

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- 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

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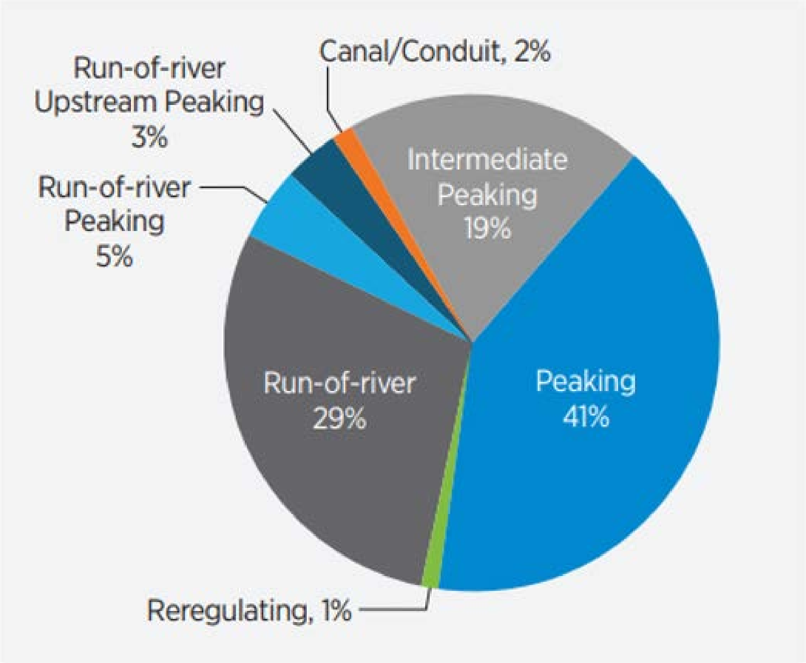
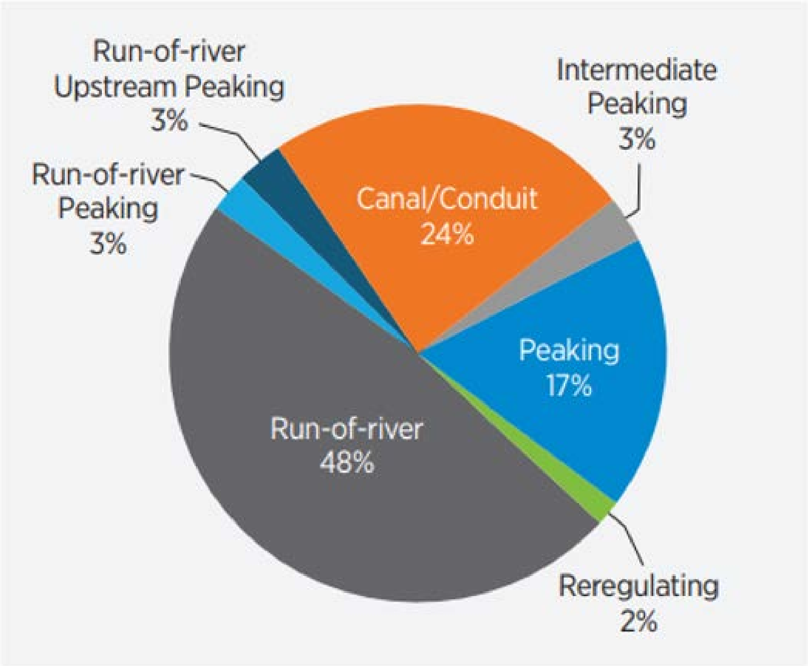
- About 70% of hydropower capacity has capabilities for flexible operation
- But operations vary by plant; flexibility is mostly concentrated in larger projects




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

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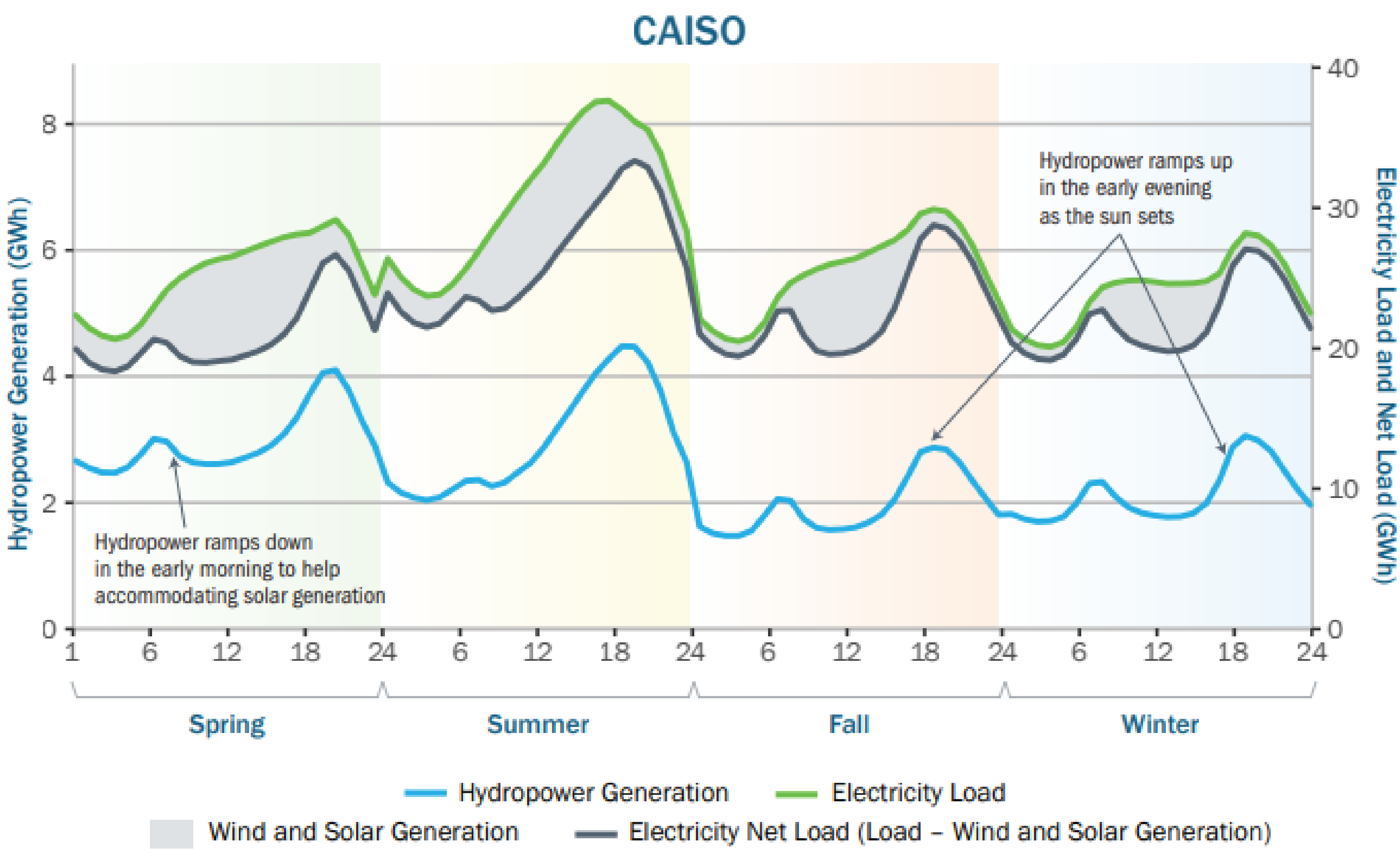


Average hourly hydropower and PSH generation, electricity load, and electricity net load by season in CAISO (2014-2017)

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

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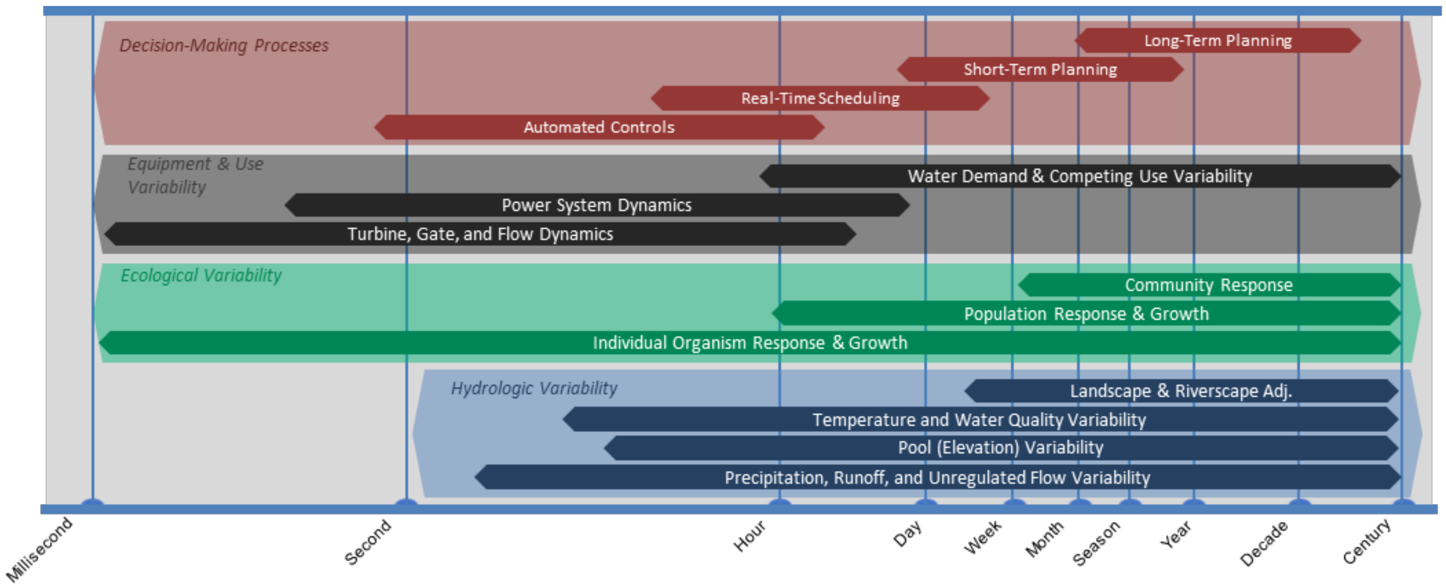
- Spatial, temporal, unit, and computational complexity can create a disconnect between water management and grid models
- Hydropower representation in current models does not capture complexity, diversity, and changed operational paradigm of the fleet




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

Workshop: Hydropower in Production Cost Models

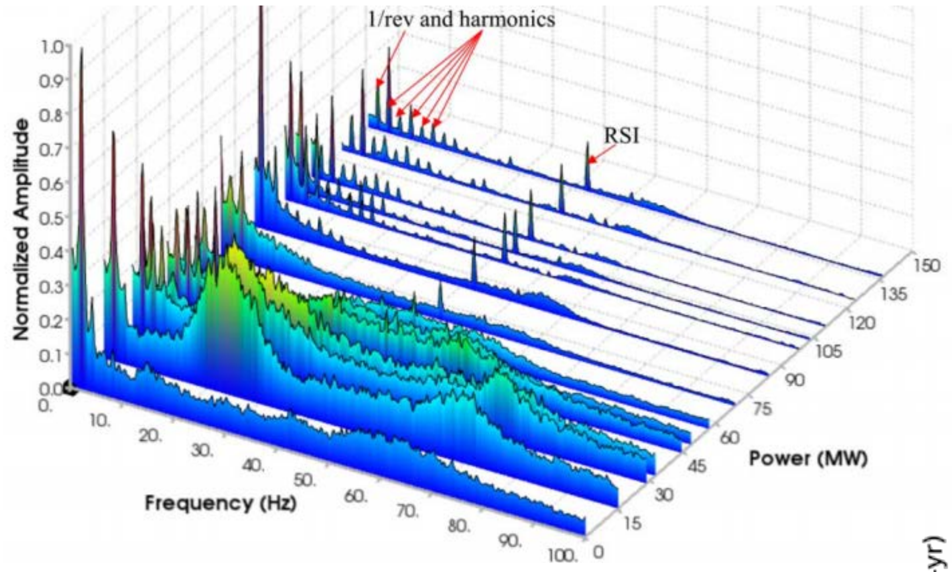
Salt Lake City, February 2019

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

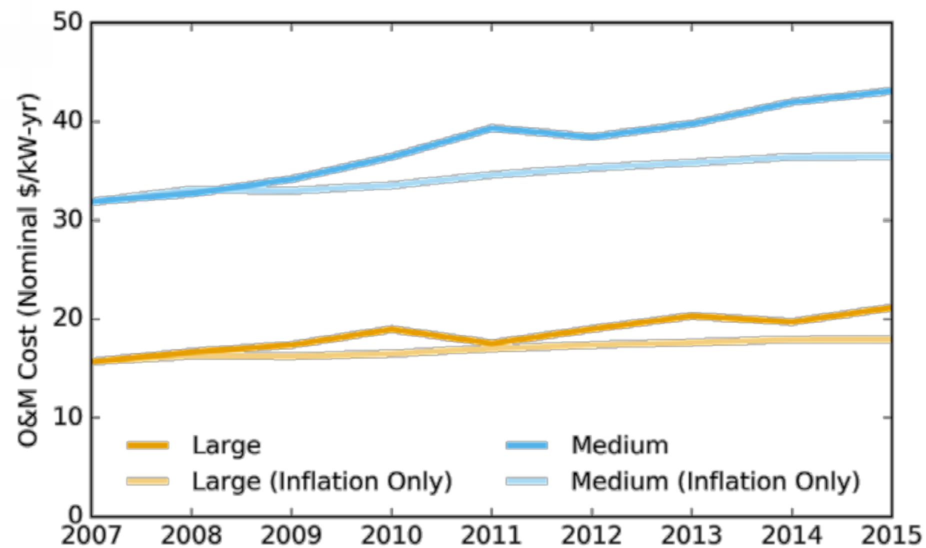
# More flexible operations have implications for equipment design and O&M






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

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




- 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

# The Challenge: Untapped Opportunities for Hydropower and PSH to Support a Rapidly Evolving Grid

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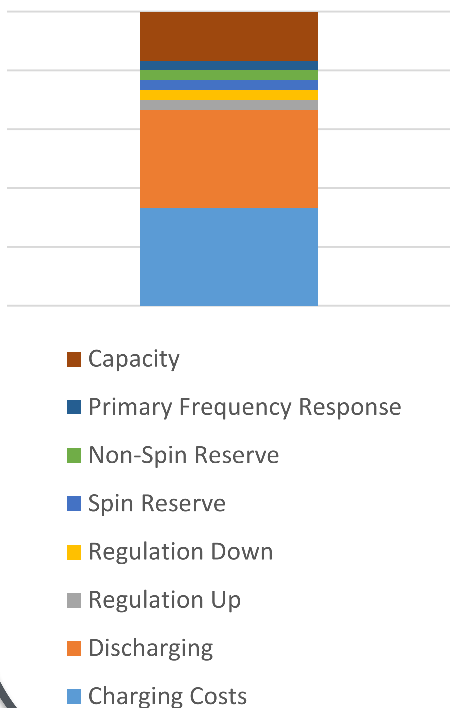
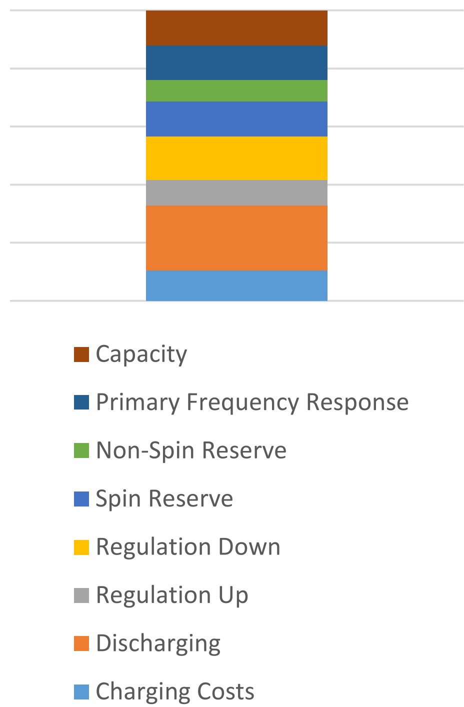
- As the electricity system is changing rapidly, there is limited understanding of which services will be needed, as well as limited ability to accurately value those services.
- Hydropower and PSH capabilities are bounded by the interaction of machines, water, and institutions, and some of these bounds 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?

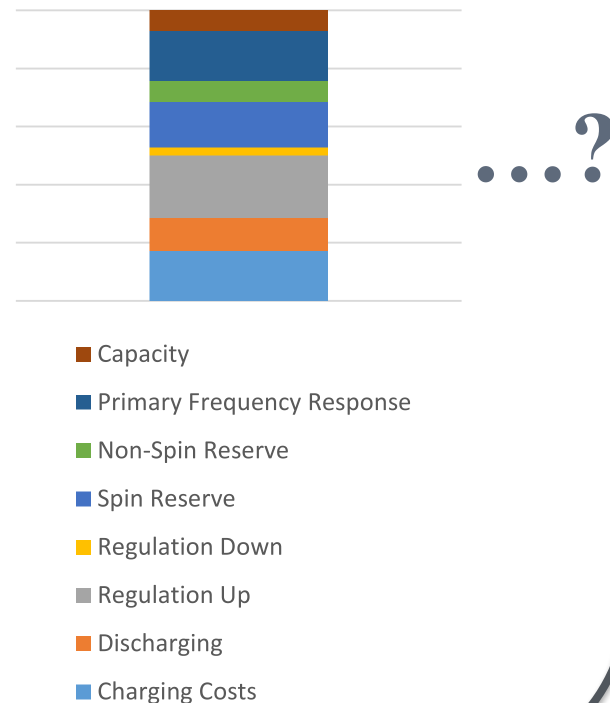
**Qualitative Example PSH Plant Operating *Today***




**Potential Future Operations Scenario #1**




**Potential Future Operations Scenario #2**



# HydroWIRES Initiative

- 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.

https://energy.gov/HydroWIRES

# Organization of Research Areas

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

HydroWIRES
U.S. DEPARTMENT OF ENERGY

## 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?"*

## 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?"*

# Congressional Support for HydroWIRES Activities

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- Strong focus on the value of flexibility/reliability services and PSH has been explicitly mandated by Congress in recent appropriations cycles

| FY16 Conference | FY17 Conference | FY18 Omnibus | FY19 Conference |
| --- | --- | --- | --- |
| "…not less than $5M to support competitive demonstrations to assess the commercial viability of new or advanced pumped storage technologies." | "Provides up to $3M within available funds for a techno-economic analysis of the value of pumped storage hydropower at two sites with high levels of intermittent renewable energy generation in the U.S." | "Within available funds, $10,000,000 is recommended for a competitive funding opportunity for multiple awardees to test the commercial viability of new use cases for pumped storage hydropower at locations to enhance grid reliability and manage variable generation." | "Within available funds, $35,000,000 is provided for conventional hydropower and pumped storage activities" |

# 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.

Argonne NATIONAL LABORATORY

**Lemont, Illinois**

INL Idaho National Laboratory

**Idaho Falls, Idaho**

NREL NATIONAL RENEWABLE ENERGY LABORATORY

**Golden, Colorado**

OAK RIDGE National Laboratory

**Oak Ridge, Tennessee**

Pacific Northwest NATIONAL LABORATORY

**Richland, Washington**

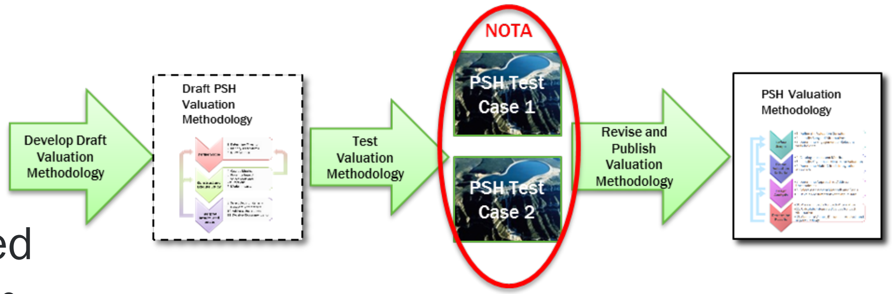
# Research Area 1: Value under Evolving System Conditions

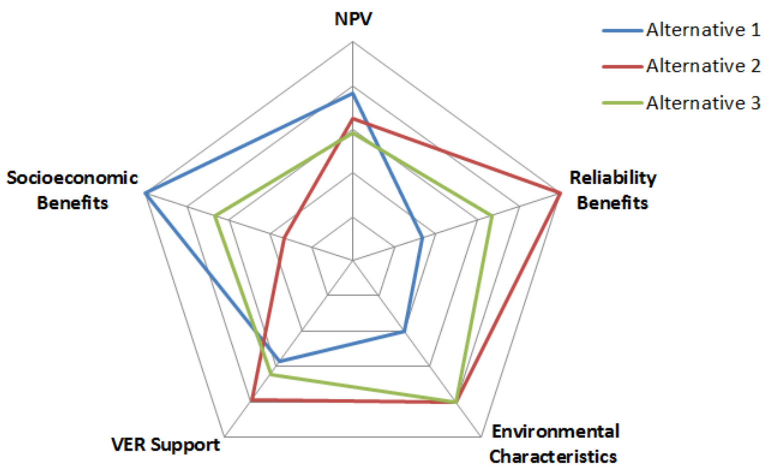
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

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

*"What will the grid need?"*

- **1.1 Grid Services Taxonomy.** Enable unified understanding of grid services and system benefits through consistent taxonomies.
- **1.2 Value Drivers.** Understand value drivers for hydropower in today's power system and investigate how this value might evolve under different future system scenarios.
- **1.3 Valuation Methodologies.** Develop rigorous, widely applicable methodologies that accurately value hydropower assets.




Pumped storage hydropower valuation guidance

** "Hydropower" includes both conventional hydropower and pumped storage hydropower (PSH) unless otherwise noted.*

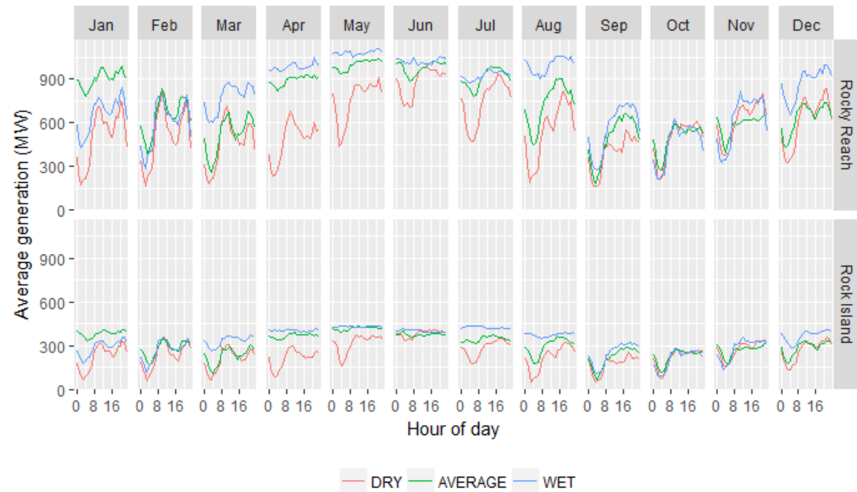
# Research Area 2: Capabilities and Constraints

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

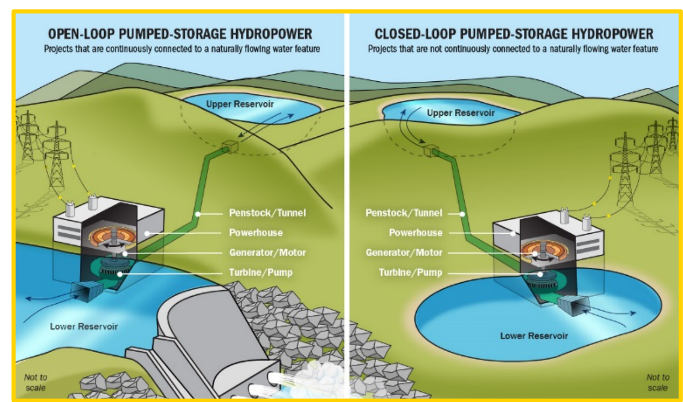
**Investigate the full range of hydropower's capabilities to provide grid services, as well as the machine, hydrologic, and institutional constraints to fully utilizing those capabilities.**

*"What can hydropower do?"*

- **2.1 Flexibility Framework.** Quantify the different types of flexibility available in hydropower plants as a first step to assessing the total flexibility available in the hydropower fleet.
- **2.2 Flexibility Tradeoffs.** Understand the tradeoffs between operating flexibly and meeting other objectives related to environmental performance, revenue opportunities, and machine wear and tear.
- **2.3 Hydrologic Forecasting.** Quantify and improve the accuracy and resolution of inflow forecasting tools to enable more flexible operation.
- **2.4 Modeling Representation.** Improve the representation of hydropower in power system models to more accurately capture its unique capabilities.




Hydropower Operational Flexibility FOA




Environmental Comparison of Closed- and Open-Loop PSH

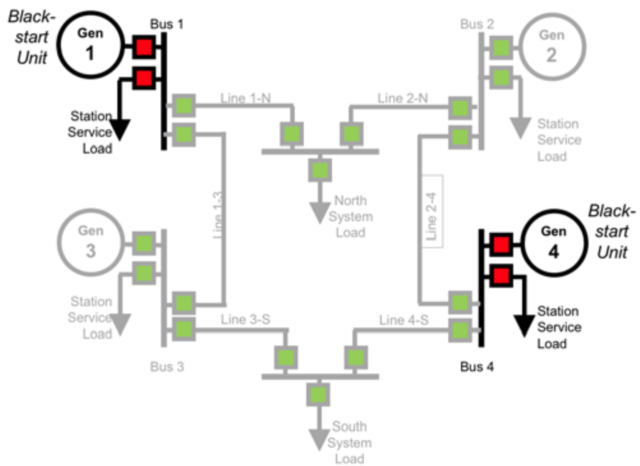
# Research Area 3: Operations and Planning

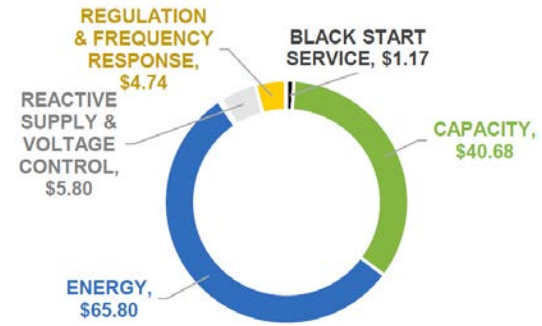
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

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

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

- **3.1 System Reliability and Resilience Contributions.** Quantify hydropower plant- and fleet-level contributions to system reliability and resilience requirements
- **3.2 Comparison with Other Resources.** Understand hydropower's unique benefits and costs—in comparison with other resources—to best inform planning decisions.
- **3.3 Operations Optimization.** Develop operational strategies and associated tools that enable hydropower to better optimize its operations to provide grid services.
- **3.4 System Effects of Operations.** Quantify effects of hydropower plant- and fleet-level operations on water availability, emissions, environment, and other system properties.




Hydropower as a Black Start Resource report

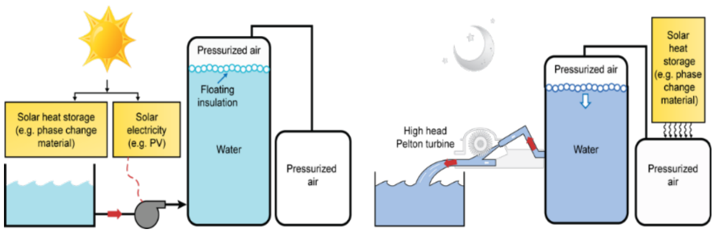
# Research Area 4: Technology Innovation

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

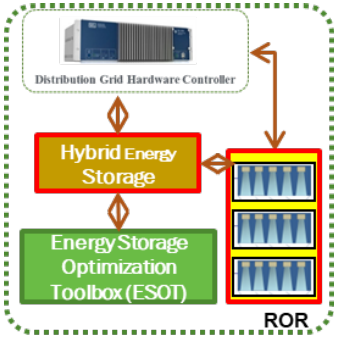
**Invest in innovative technologies that improve hydropower capabilities to provide grid services.**

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

- **4.1 Technology Gaps.** Identify and map out technology innovations that enable hydropower plants to improve provision of grid services.
- **4.2 Unit Flexibility Enhancement.** Develop technology solutions that enable enhanced flexibility at the unit level.
- **4.3 Plant Flexibility Enhancement.** Develop technology solutions that enable enhanced flexibility at the plant or cascading system level.
- **4.4 New PSH Approaches.** Develop new technology concepts and approaches that overcome barriers associated with PSH deployment.




GLIDES (Ground Level Integrated Diverse Energy Storage




Integrated Hydropower and Energy Storage Systems

# Organization of Research Areas

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

HydroWIRES
U.S. DEPARTMENT OF ENERGY

## 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?"*

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*What can hydropower do?"*

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

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# HydroWIRES Peer Review Projects (in order of appearance)

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

1) Hydropower Value Study

3) PSH Valuation Guidance

2) NARIS

**Value under Evolving System Conditions**

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4) Integrated Hydro and Storage Systems

5) Networked Small Hydropower

**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?"*

6) Ternary PSH

7) GLIDES PSH

8) Shell Hydro Battery

9) No-Powerhouse PSH

# Other HydroWIRES Lab Call and External Projects

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

**Value under Evolving System Conditions**

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

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**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?"*

- A) Environmental-Flexibility Tradeoffs
- B1) Dynamic Hydro Classification for PCMs
- B2) Water Model/PCM Integration
- D1) Hydro Improvements in ReEDS
- D3) Value of Inflow Forecasting

**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?"*

- D2) Transmission-Storage Equivalence
- C) Hydro Contributions to Resilience
- FY18 FOA: PSH Optimization

**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?"*

- FY18 FOA: PSH Technology Concepts
- FY19 FOA: Hydro Flexibility Framework
- FAST Prize
- FY19 FOA: Hydro Flexibility Enhancements

# HydroWIRES Reports (more coming soon!)

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

**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 representation in production cost modeling (workshop report)

**Work in Progress:**

- 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
  - Review of Market Rules for Hydropower
  - The Value of Water
  - Value Drivers for Hydropower Operations
  - Power Systems vs. Hydropower Operational Timeframes
  - Hydropower Capabilities & Technology Gap + Cost Analysis
- North American Renewable Integration Study (technical report)
- Ground-Level Integrated Diverse Energy Storage (technical report)
- …

# Stakeholder Engagement, Outreach, and Dissemination



- 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)


About 40 respondents to initial RFI

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

# HydroWIRES Partners and Awardees

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

## Internal Collaboration

- Argonne National Laboratory
- INL Idaho National Laboratory
- NREL National Renewable Energy Laboratory
- Pacific Northwest National Laboratory
- Oak Ridge National Laboratory
- GRID Modernization Initiative, U.S. Department of Energy

DOE Executive Board:

- GMI
- OE
- EERE-SPIA

## International Collaborators

- iea
- Hydro Tasmania
- HydroCen Norwegian Research Centre for Hydropower Technology

## Awardees

- nationalgrid
- Quidnet Energy
- EPRI Electric Power Research Institute
- Rye Development
- RTI International
- CADS WES
- Absaroka Energy LLC
- Obermeyer Hydro, Inc. – Ideas that hold water™
- GE
- Missouri S&T University of Science & Technology
- Shell

# Questions?

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https://energy.gov/HydroWIRES