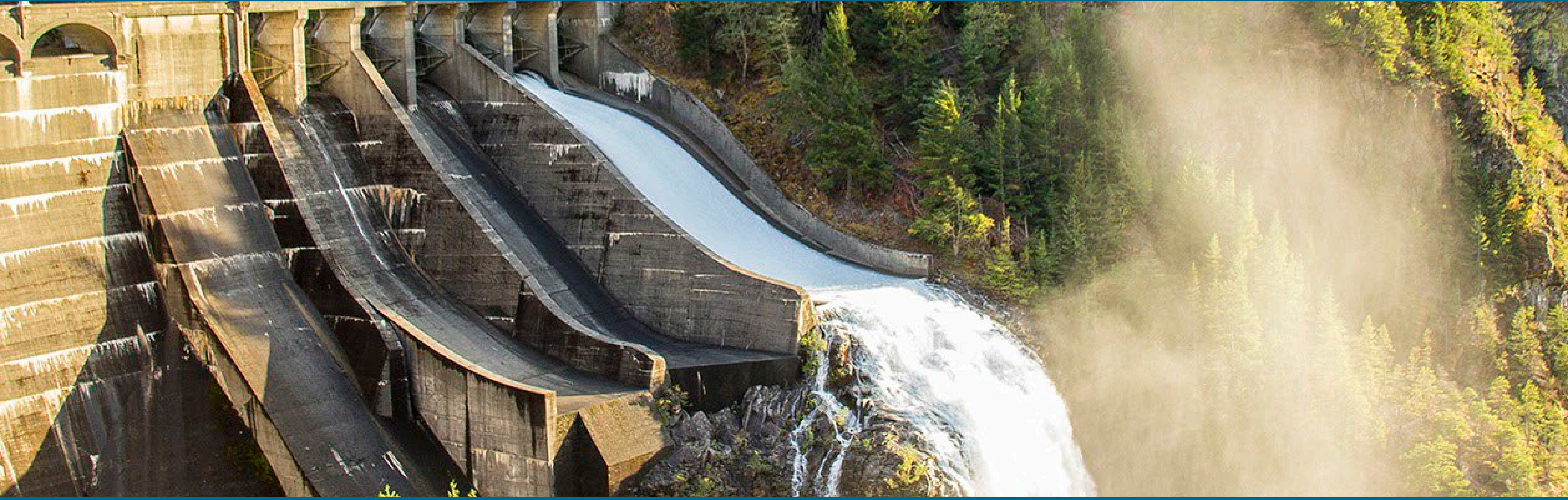
The Role of Hydropower in a Decarbonized Power System



Samuel Bockenhauer, Ph.D.
HydroWIRES Initiative Lead, DOE Water Power Technologies Office

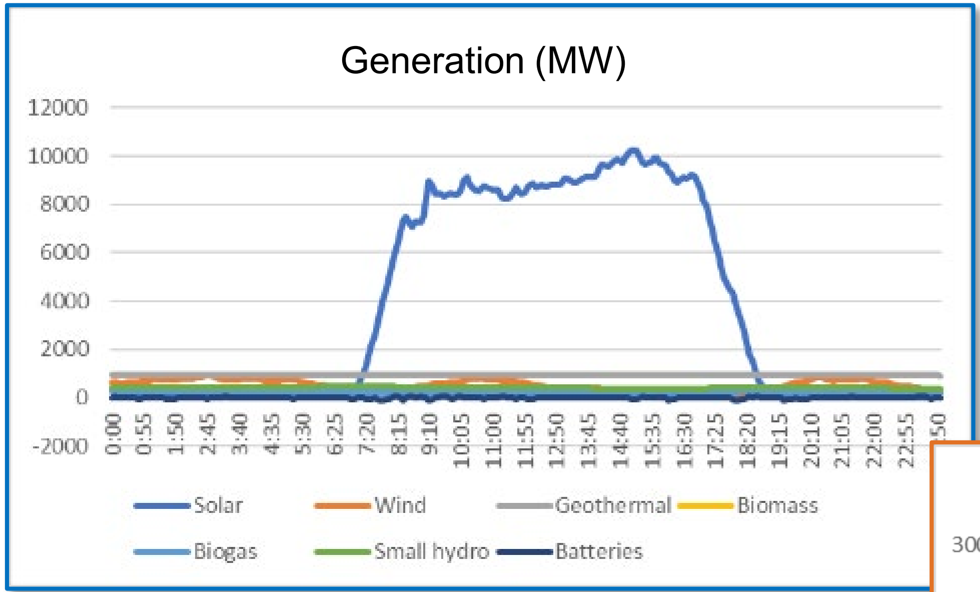
US Decarbonization Goals

2030	2035	2050
50% reduction in greenhouse gas pollution from 2005 levels	100% carbon pollution-free electricity	Net zero emissions economy-wide





The power system is changing...



California Example

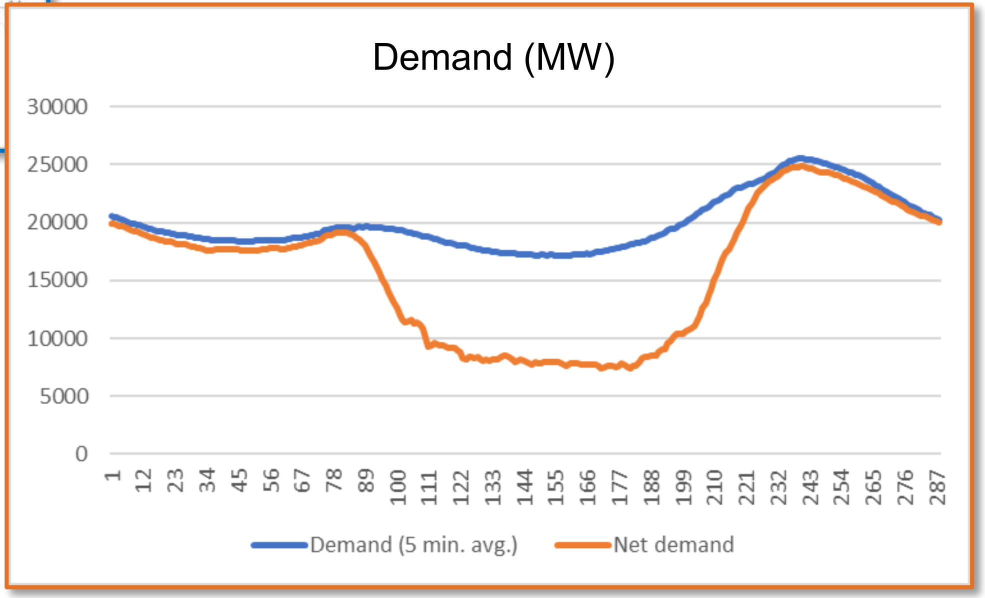
March 31, 2019

Total Generation from Renewable Resources

California Example

March 31, 2019

Demand and Net Demand



And hydropower has an important role to play

- Existing pumped storage hydropower (PSH) operations are changing due to more variable renewable energy
- The ability of hydropower and PSH to store energy and operate flexibly could enable additional variable renewables to come online

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

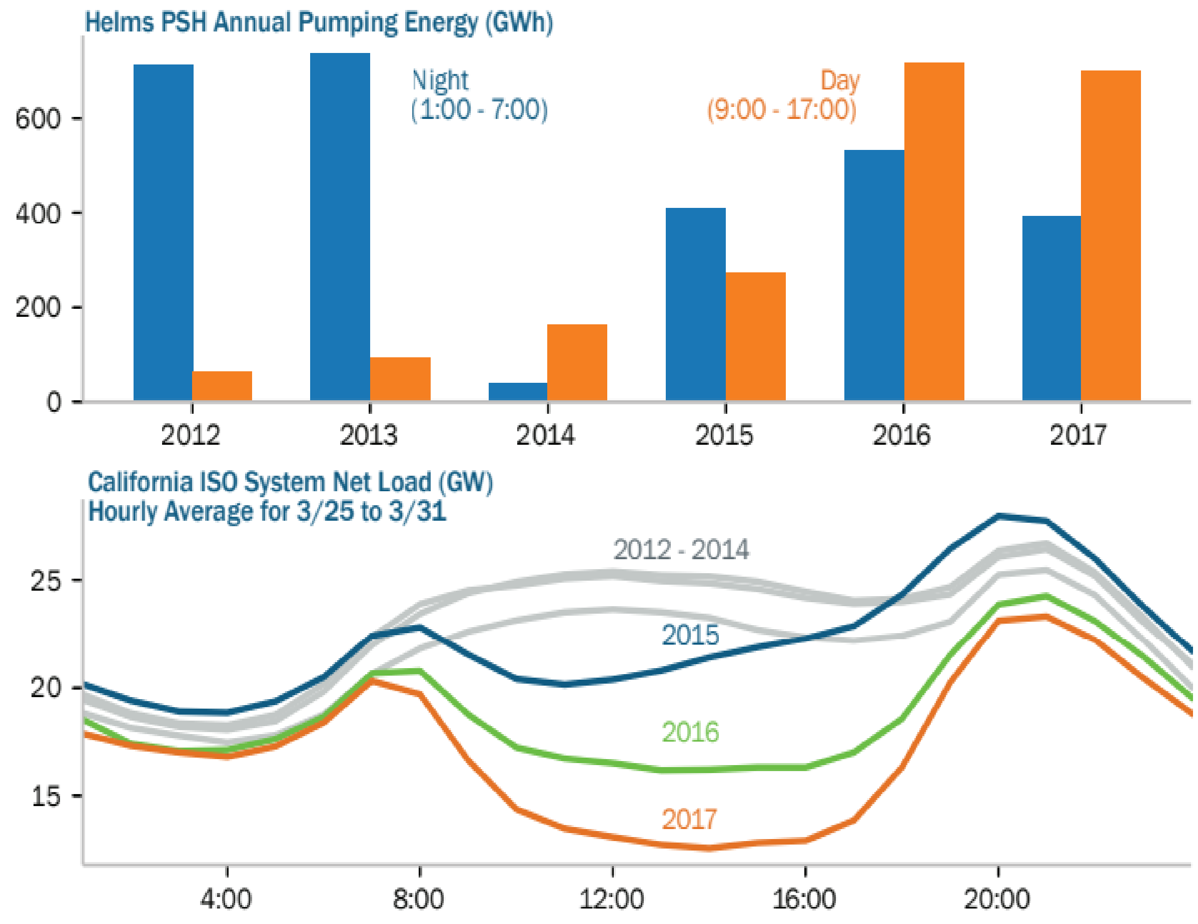
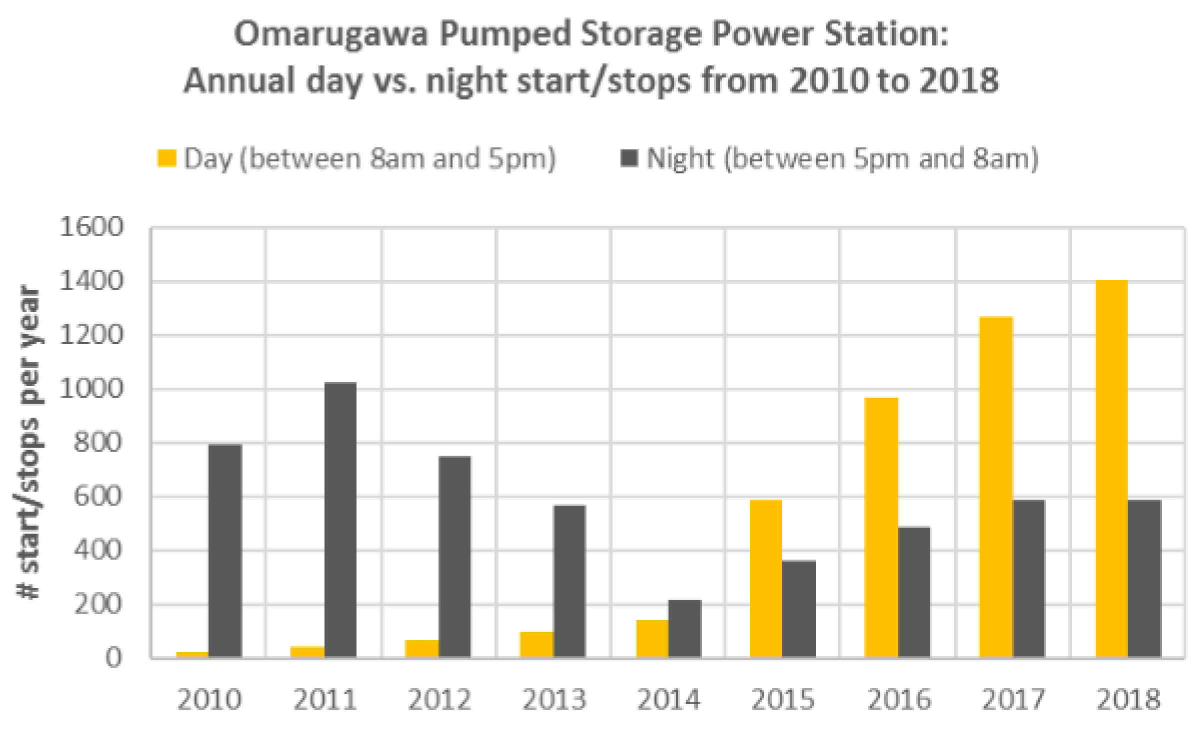
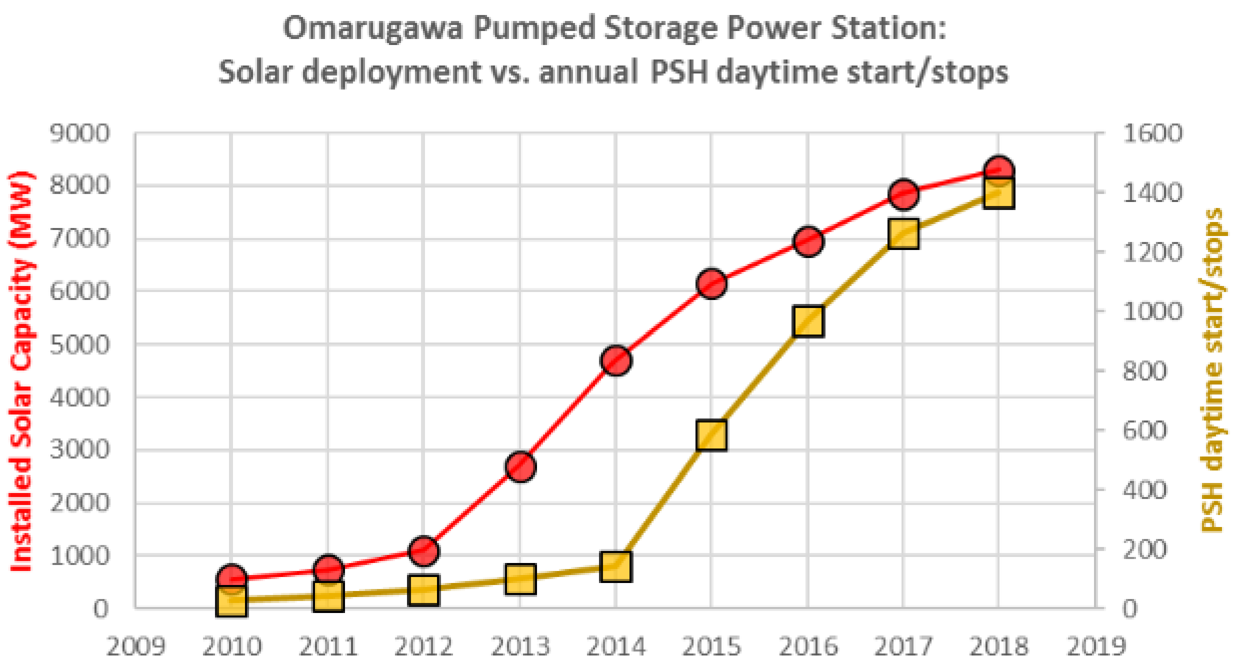


Figure 34. Annual pumping energy consumption by Helms PSH versus CAISO net load in the last week of March (2012-2017)

We see similar operational changes worldwide

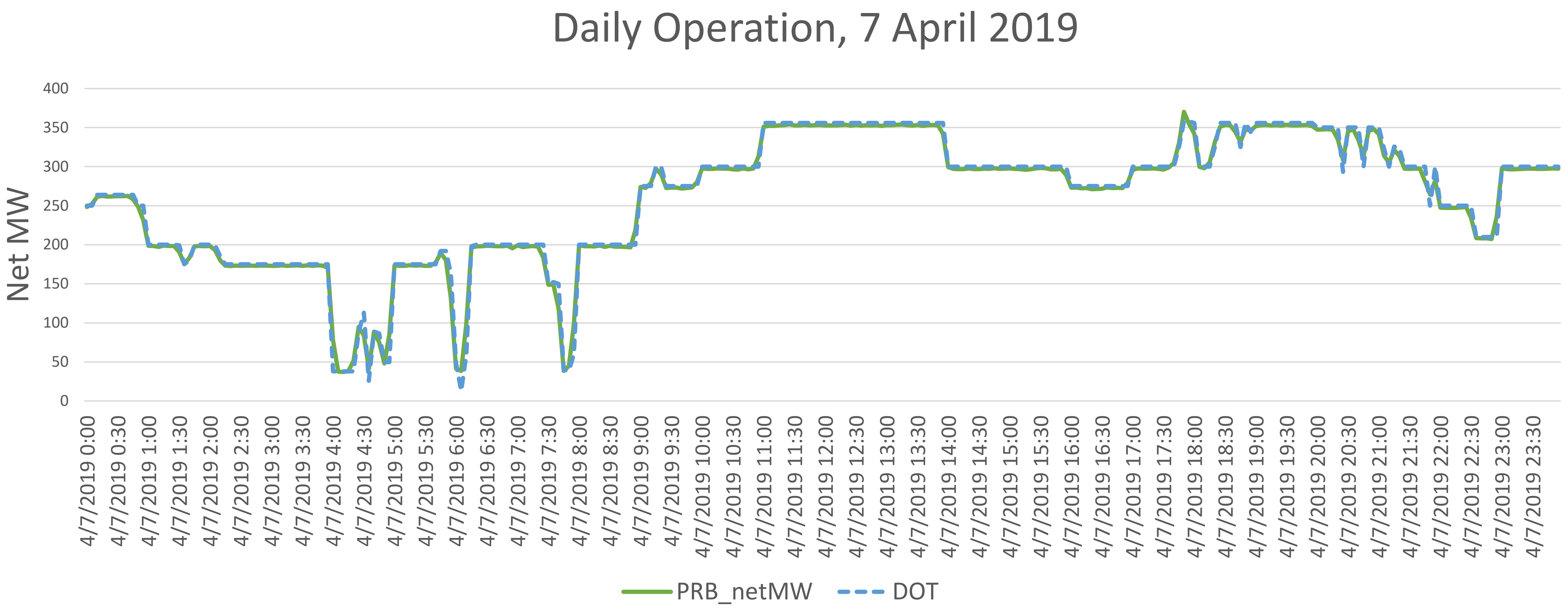


We see this pattern in the US and around the world, e.g. in Japan



New market structures encourage hydropower flexibility

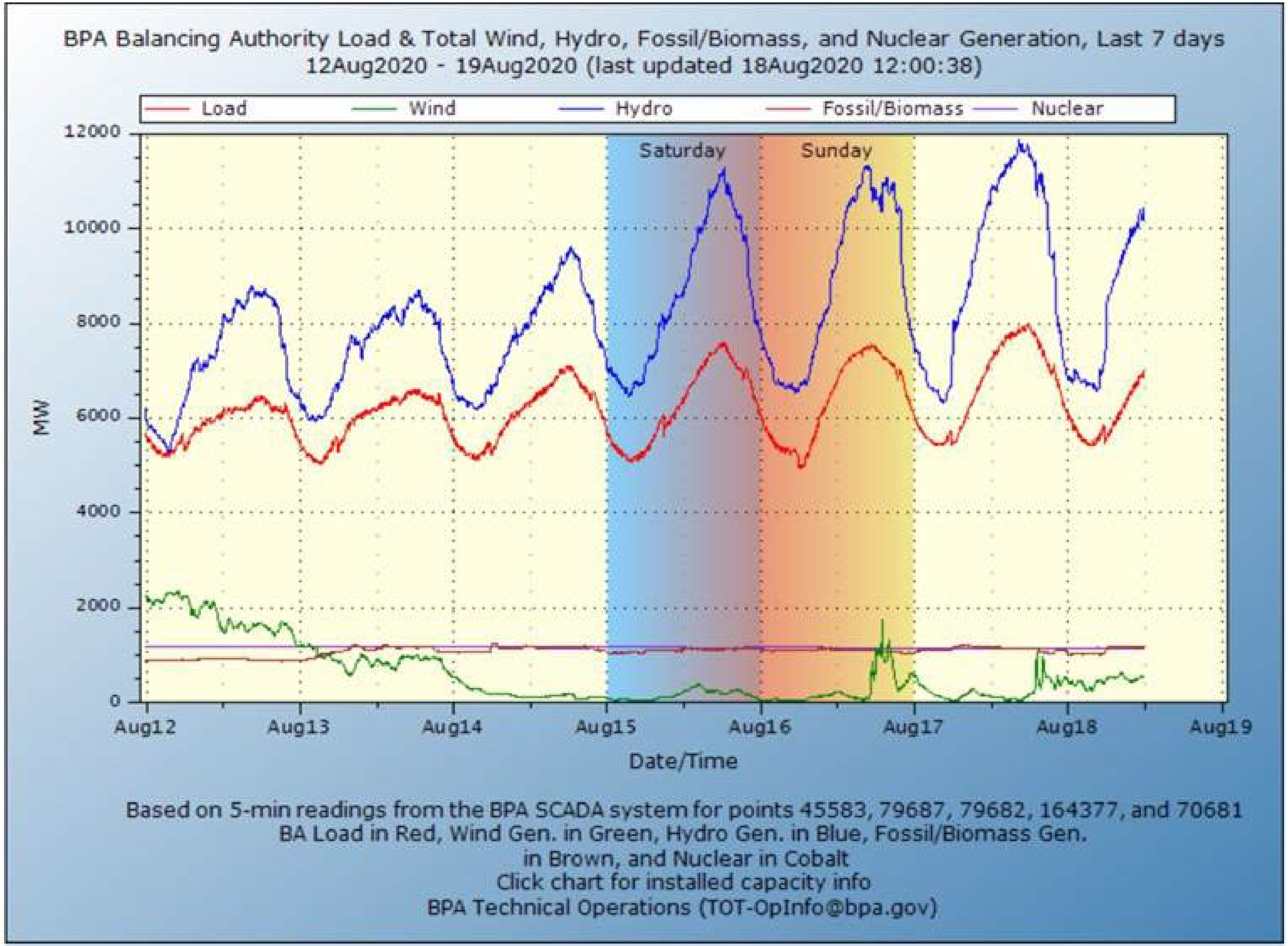
New market opportunities such as the Western EIM are causing owners to operate their plants much more flexibly



Pelton Round Butte, Portland General Electric, Oregon USA

Hydropower can play a critical role during extreme events

During heat waves and other extreme events, hydropower can ramp up its generation to meet demand and prevent outages



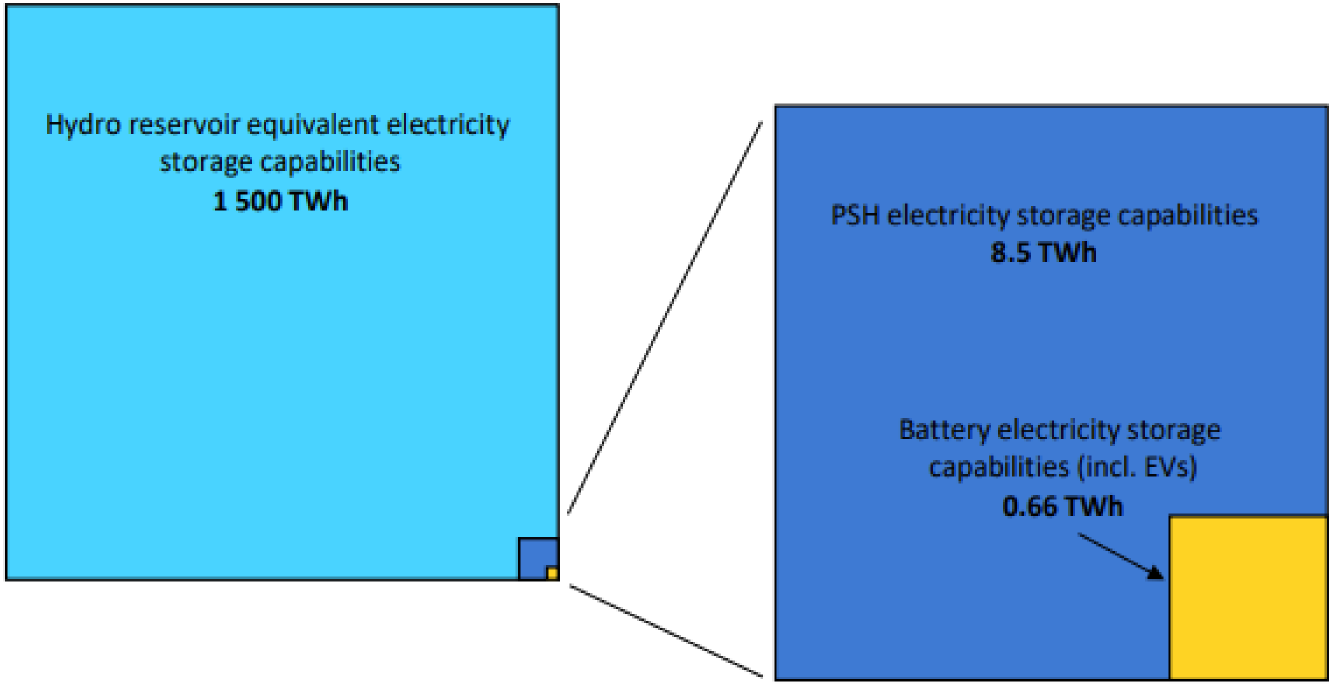
Hydropower and PSH provide the majority of energy storage

- IEA estimated **nominal energy storage capacity** on a global scale

$$E = \frac{\rho \times g \times V \times H}{3.6 \times 10^9}$$

- Modeling studies show large need for long-duration storage
- We can start thinking more about hydro and PSH in terms of MWh and not just MW

Figure 4.7 Global energy and electricity storage capabilities by technology, 2020



Notes: PSH = pumped-storage hydropower. EV = electric vehicle.
Source: Based on International Commission on Large Dams, ENTSO-E and national transmission system operator data.

Figure from IEA Hydropower Special Market Report
https://iea.blob.core.windows.net/assets/83ff8935-62dd-4150-80a8-c5001b740e21/HydropowerSpecialMarketReport.pdf
Ongoing work by ORNL on reservoir storage capacity dataset

But there are challenges…

1. 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.

2. 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.

3. There are gaps in information regarding how to optimize hydropower and PSH operations and planning in coordination with other resources.

4. Current hydropower and PSH technology may not be designed for flexible operation.

...and opportunities

Hydropower and Water Innovation for a Resilient Electricity System

HydroWIRES

U.S. DEPARTMENT OF ENERGY

A research initiative by DOE's Water Power Technologies Office **to understand, enable, and improve hydropower's contributions to reliability, resilience, and integration** in a rapidly evolving electricity system.

HydroWIRES Research Areas

Value under Evolving System Conditions
- Quantify value of hydro/PSH
- Understand market and policy implications

Capabilities and Constraints
- Improve model capabilities
- Quantify operational tradeoffs

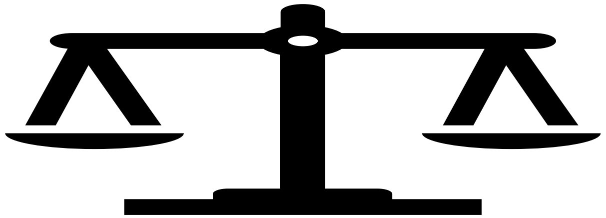
Operations and Planning
- Increase flexibility through operational strategies
- Distinguish hydro from other resources

Technology Innovation
- Increase flexibility through technology innovation
- Develop PSH and hydropower hybrids

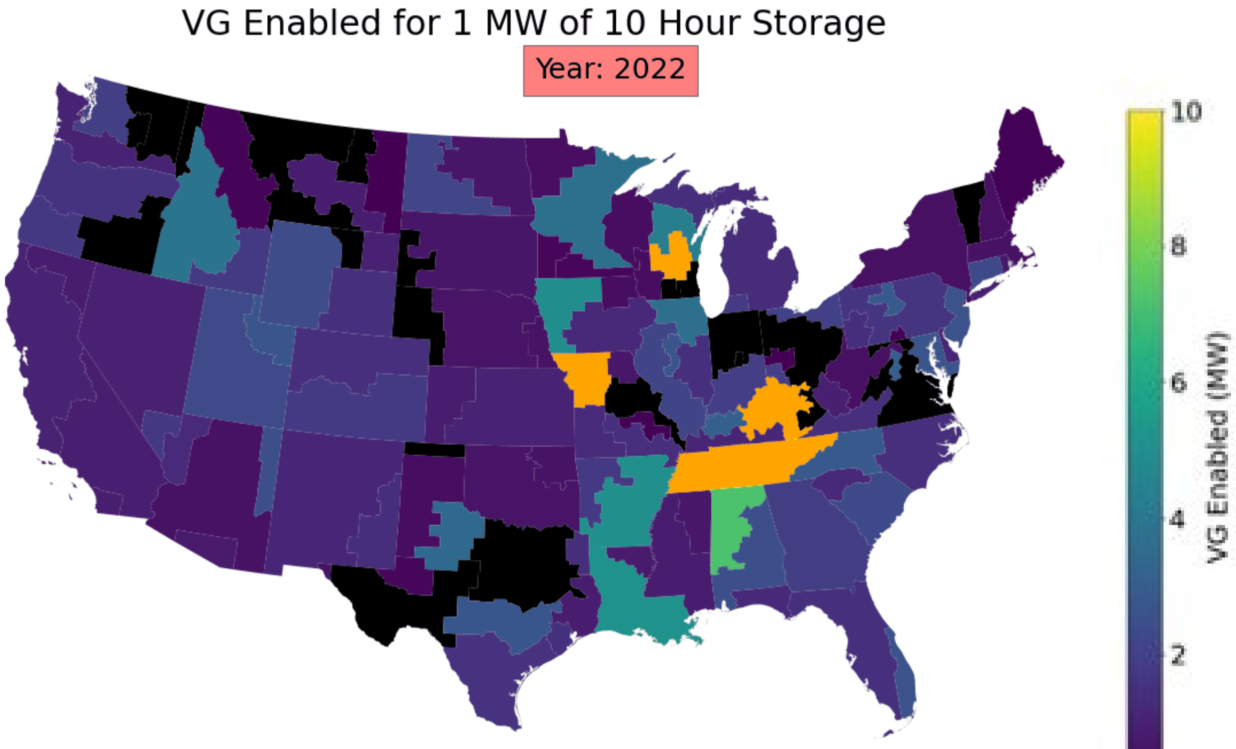
"Hydropower can enable more MW of VRE" – so how much?

Balance additional storage, solar, and wind with removed fossil for both **energy** and firm **capacity**

Storage + Solar + Wind



Fossil-fueled generators



*Locations in Orange are Above 10 MW, Black are 0 MW

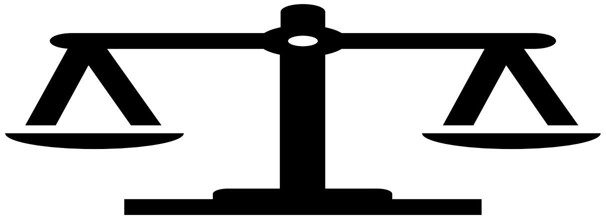
- Impact of storage by region varies significantly by region
- Impact of storage reduces in later years, as grid becomes closer to zero-carbon (these scenarios were 95% carbon-free in 2035)

VRE Integration white paper (NREL)

"Hydropower can enable more MW of VRE" – so how much?

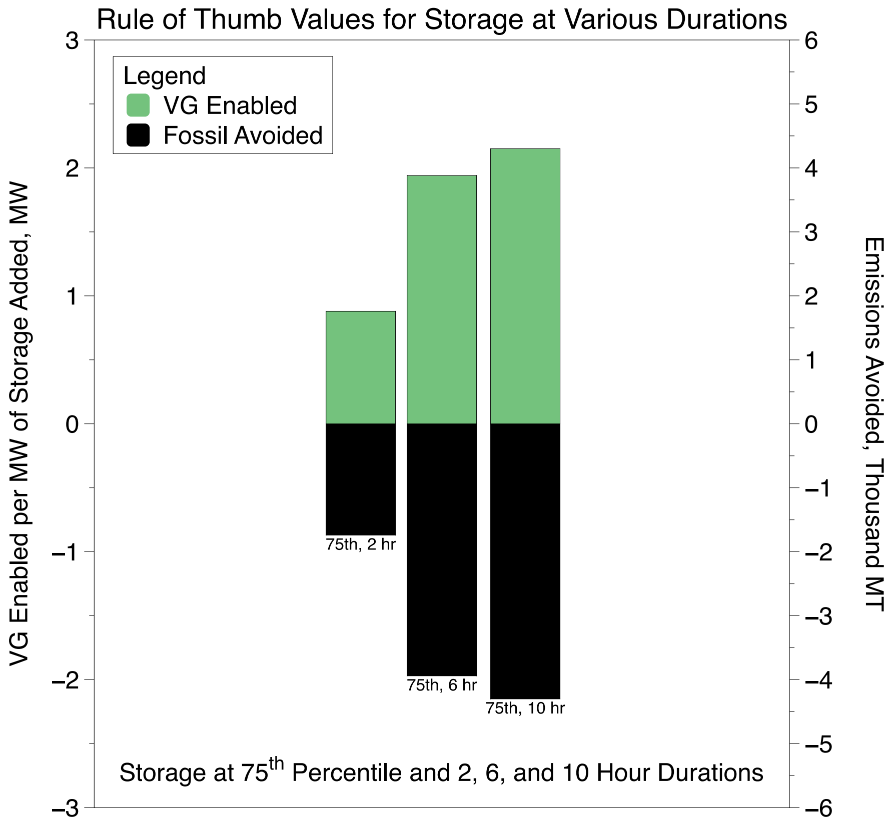
Balance additional storage, solar, and wind with removed fossil for both **energy** and firm **capacity**

Storage + Solar + Wind



Fossil-fueled generators

- Storage can enable approximately 1-2 MW of wind and solar per MW.
- 10-hr storage is more effective in enabling wind and solar (VG) deployment and emission reduction than 2-hr storage.



Flow requirements are complex, but win-wins are possible

Hydropower Functions and Ancillary Services	Temporal Scale	Effect of Flow Requirement on Function or Service			
		Min	Max	Prescribed	Ramp
Load-following or energy-balancing units	Hourly plan with 5-10 min resolution				
Reactive supply and voltage control	Continuous with response in seconds				
Frequency regulation	Every few minutes, minute-to-minute resolution				
Spinning operating reserve	Begin within 10 seconds, full power within 10 minutes				
Non-spinning operating reserves	Respond within 10 minutes				
Replacement reserves	Respond within 60 minutes, run up to 2 hours				
System black start	As required				
Firm capacity	As required				

Environment-flexibility tradeoffs (ORNL, PNNL, NREL, ANL, INL)

Pumped Storage Hydropower Research

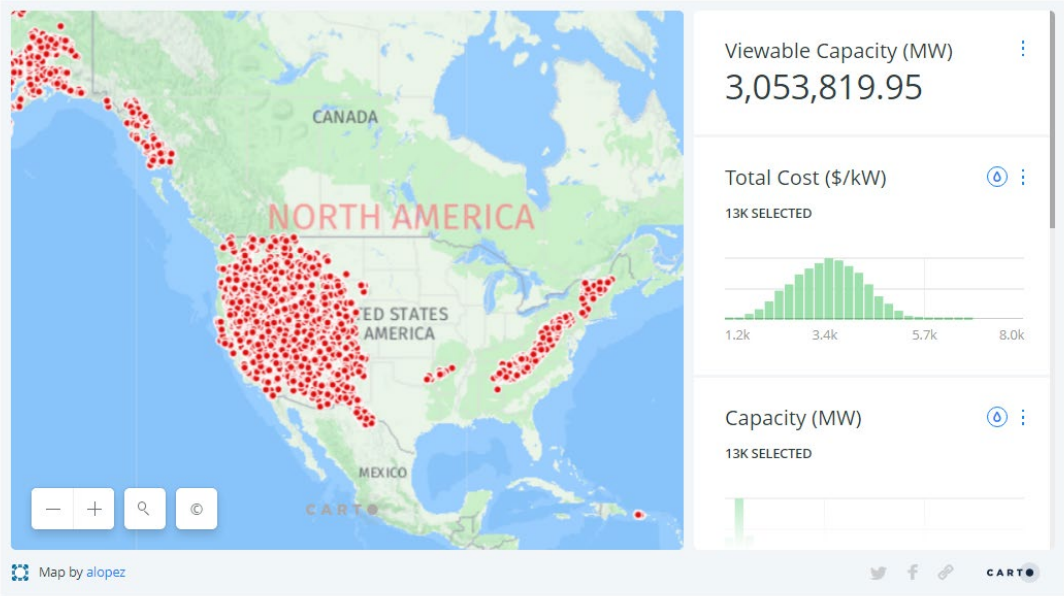
Pumped Storage Hydropower Resource Assessment (published by NREL)

- Using spatial mapping, identified nearly 15,000 sites in the United States where closed-loop PSH technology could be deployed in the future.

Innovative Pumped Storage Hydropower Report (published by Argonne)

- Highlights 12 promising PSH technologies that could significantly reduce cost, time, and risk, including:
  - Submersible pump-turbine and motor-generators
  - Geomechanical PSH
  - Open pit mine PSH

Interactive Map



[Closed-Loop Pumped Storage Hydropower Resource Assessment for the United States]

[A Review of Technology Innovations for Pumped Storage Hydropower]

Hydro Hybrids Demonstration Report and Market White Papers

Report: Small hydropower hybrid demonstration with Idaho Falls Power

- Small hydropower with energy storage can provide distribution grid black start.
- Use of the ultracapacitor system increased operational stability.

White paper: Long-duration energy storage compensation mechanisms

- New PPA structures include multi-part payment schemes.
- These help off-takers hedge against market and generation risks, while providing revenue guarantees to developers.

White paper: Zero-carbon market designs and hydropower

- Ongoing market design initiatives include replacing fixed operating reserve requirements with demand curves, accommodating state policies, and implementing new market products.
- Hydropower can support system flexibility and take advantage of new price dynamics.

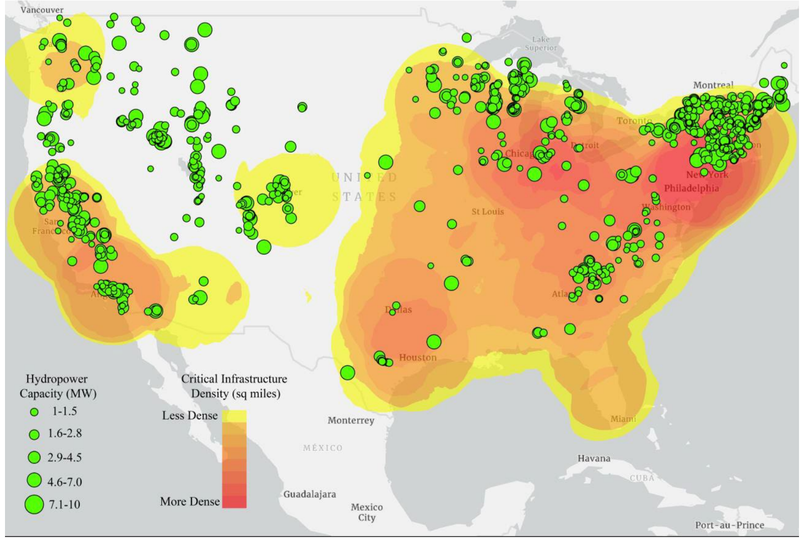


Figure: small hydropower overlaid with density of critical infrastructure

https://www.energy.gov/eere/water/hydrowires-publications

International Collaboration on Hydropower

- Chair of the IEA Hydropower Technology Collaboration Programme (TCP)
  - Annex IX: Hydropower services
  - Annex XIII: Hydropower and fish
  - Annex XVI: Hidden Hydro
- US-Norway MOU on Hydropower R&D
  - Optimization and Modeling
  - Digitalization and Modernization
  - Environmental Performance
- International Forum on Pumped Storage Hydropower (completed)

Office of Energy Efficiency & Renewable Energy

Energy Department Renews Commitment to Collaboration on Hydropower Research and Development with Norway

iea

HydroCen
NORWEGIAN RESEARCH CENTRE FOR HYDROPOWER TECHNOLOGY

Pumped Storage Hydropower International Forum

Questions?

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EERE Water Power Technologies Office

U.S. Department of Energy

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https://energy.gov/hydrowires

https://ieahydro.org

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