OAK RIDGE National Laboratory

An Introduction to Pumped Storage Hydropower
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Overview of U.S. PSH fleet and development pipeline

Rocío Uría-Martínez (uriamartiner@ornl.gov)
Megan Johnson (johnsonmm@ornl.gov)
Oak Ridge National Laboratory

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Outline

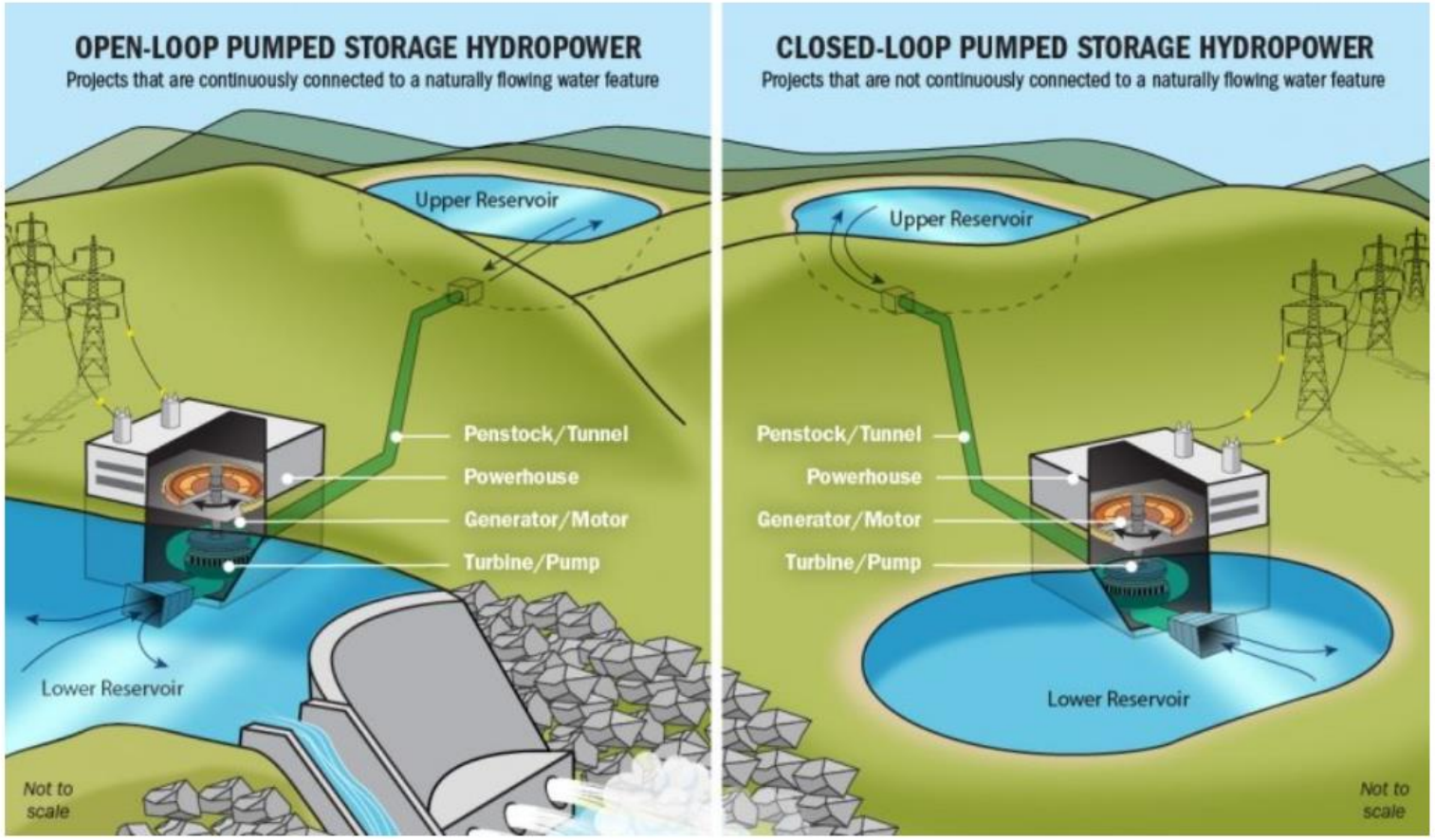
a) Existing PSH fleet
   1. Global capacity by region
   2. U.S. PSH fleet
      1. Summary metrics
      2. Regional distribution
      3. Construction timeline

b) U.S. PSH development pipeline
   1. PSH development pipeline map (location, sizes, development stage)
   2. Trends in new PSH project development (project configurations, developer types)
   3. Status of licensed projects

c) Recent federal legislation supporting new PSH development

Most of the information and plots in these slides comes from one of DOE's Hydropower Market Report publications (full report or slide decks)

What is pumped storage hydropower?



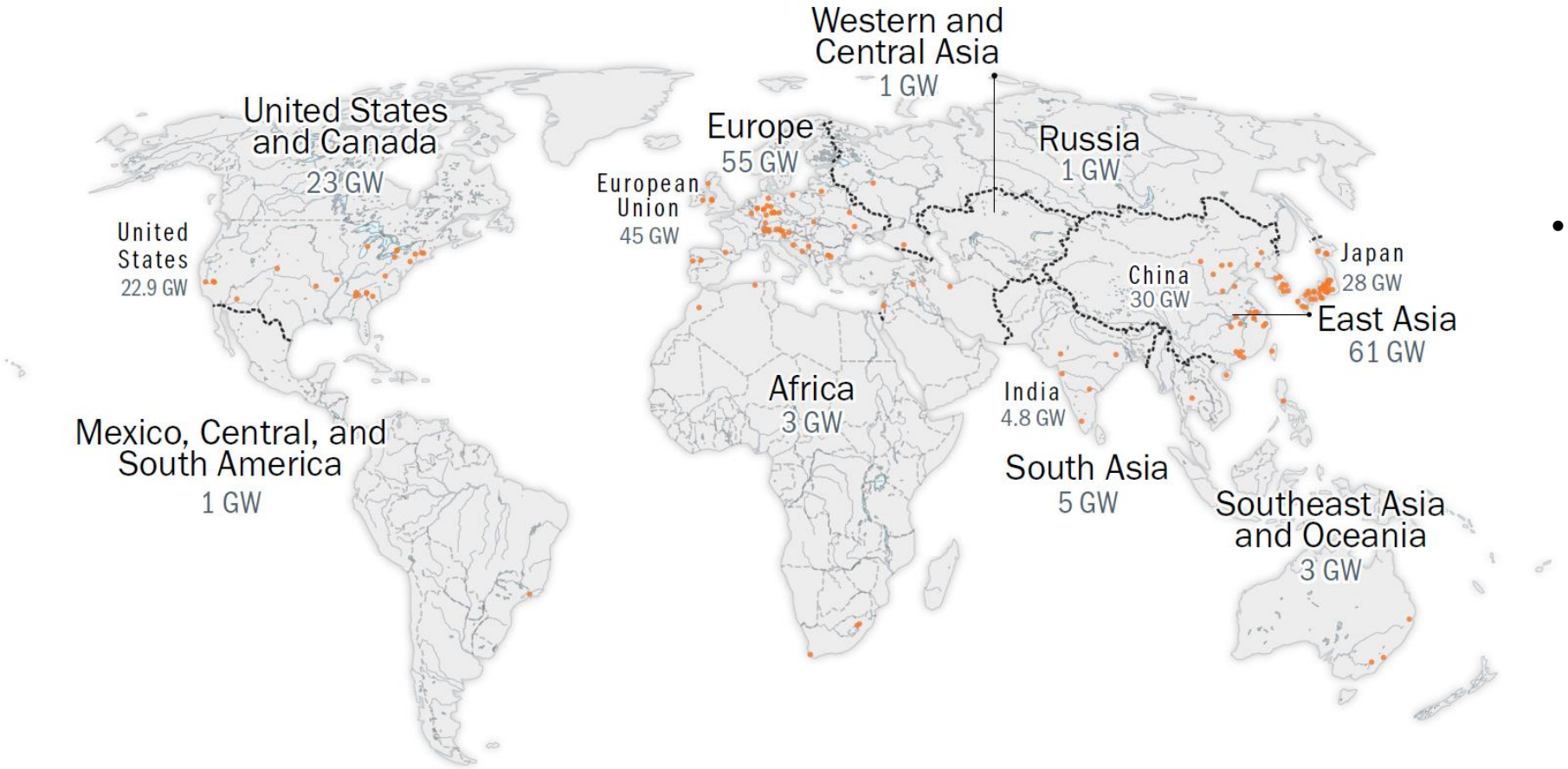
Source: DOE

- It is a type of hydroelectric energy storage; a giant "water battery".
- It requires two reservoirs at different elevations connected by a penstock.
  - At times of low electricity prices, water is pumped from the lower reservoir to the upper reservoir.
  - At times of high electricity prices, water is released from the upper reservoir and passed through the turbine to generate power.
- Round-trip efficiency: 70%–87% (Mongird et al., 2020)

Source: Mongird, K. et al. (2020). "2020 Grid Energy Storage Technology Cost and Performance Assessment". Publication No. DOE/PA-0204.

Global PSH capacity was 165 GW at the end of 2021; the U.S. fleet accounts for 13% of global hydropower capacity.

Map of operational PSH plants by world region (2019)



- The U.S. has the third largest PSH fleet in the world (after China and Japan).
- Twenty new PSH plants started operation in 2010–2019.
  - Eleven of them are in China and other four in European countries; the rest were distributed between United States, South Africa, Israel, South Korea and Japan.

Note: Geolocated points only include plants with a capacity ≥ 10 MW but capacity labels include plants of all sizes.

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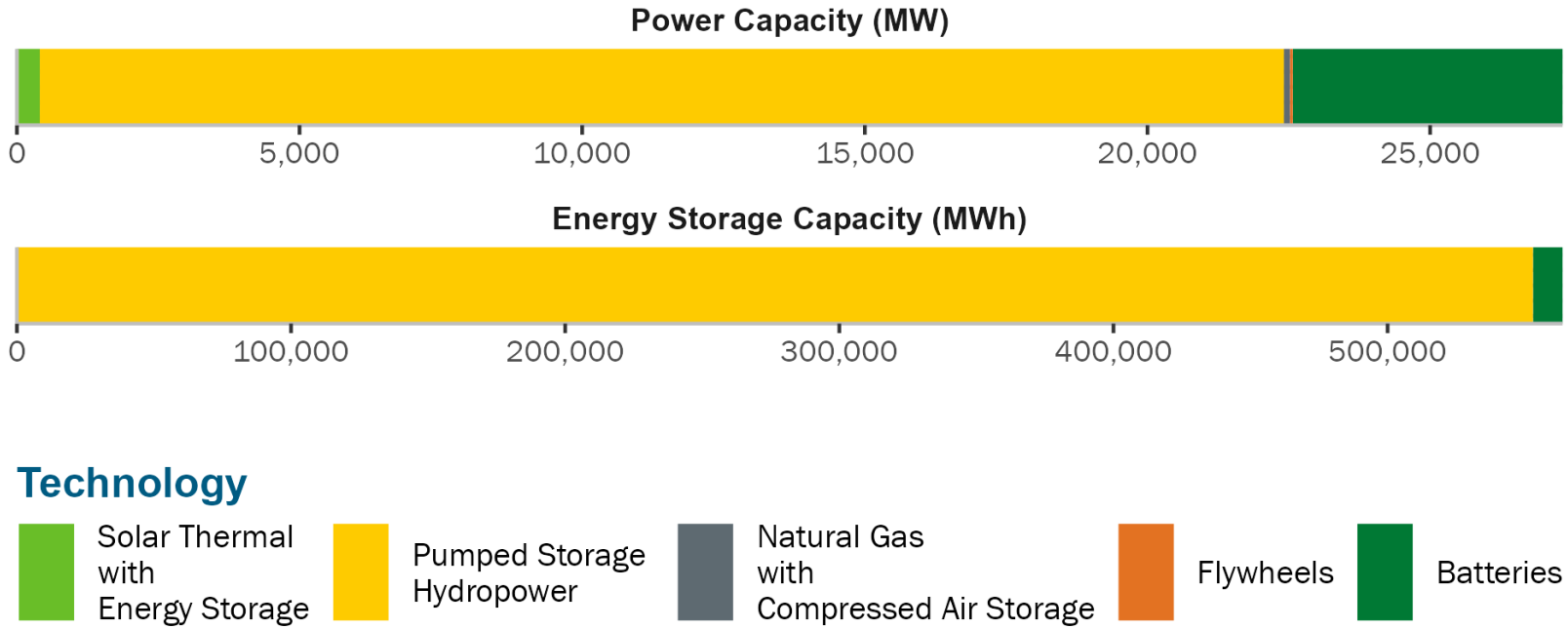
Sources: International Hydropower Association, IIR

Note: The capacities shown in the map are net summary capacity instead of nameplate capacity.

PSH is the technology providing the bulk of utility-scale electrical energy storage capacity in the United States.

- 43 PSH plants with total power capacity of **22 GW** and estimated energy storage capacity of **553 GWh** accounted for 80% of utility-scale storage power capacity (GW) and 98% of electrical energy storage (GWh) in 2021.
  - All other utility-scale energy storage projects (mostly batteries) deployed by the end of 2021 had a combined power capacity of 5.3 GW and energy storage capacity of 10.8 GWh.

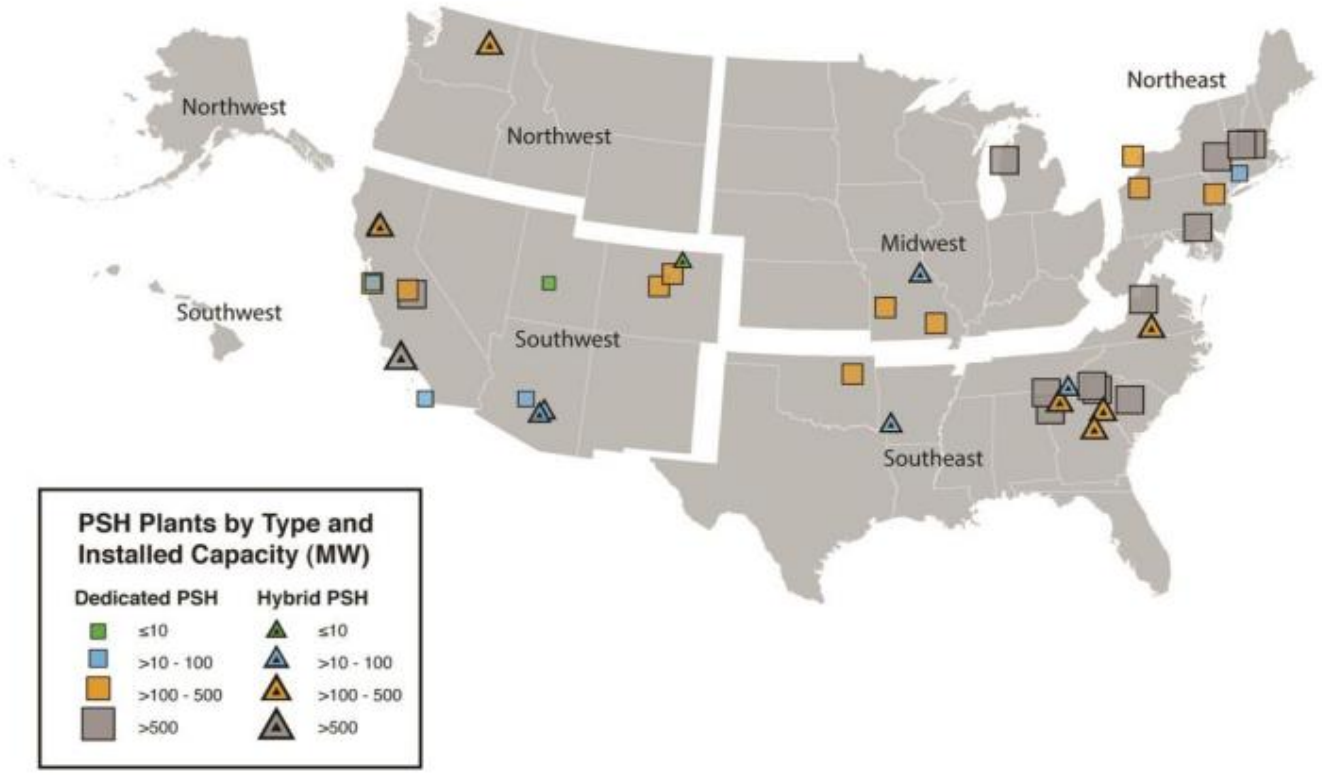
U.S. utility-scale electrical energy storage capacity by technology type (2021)



Source: EIA Form 860 (2021)

Eighteen (42%) of U.S. PSH plants are in the West; they account for 22% of U.S. installed capacity.

U.S. Pumped Storage Hydropower Fleet

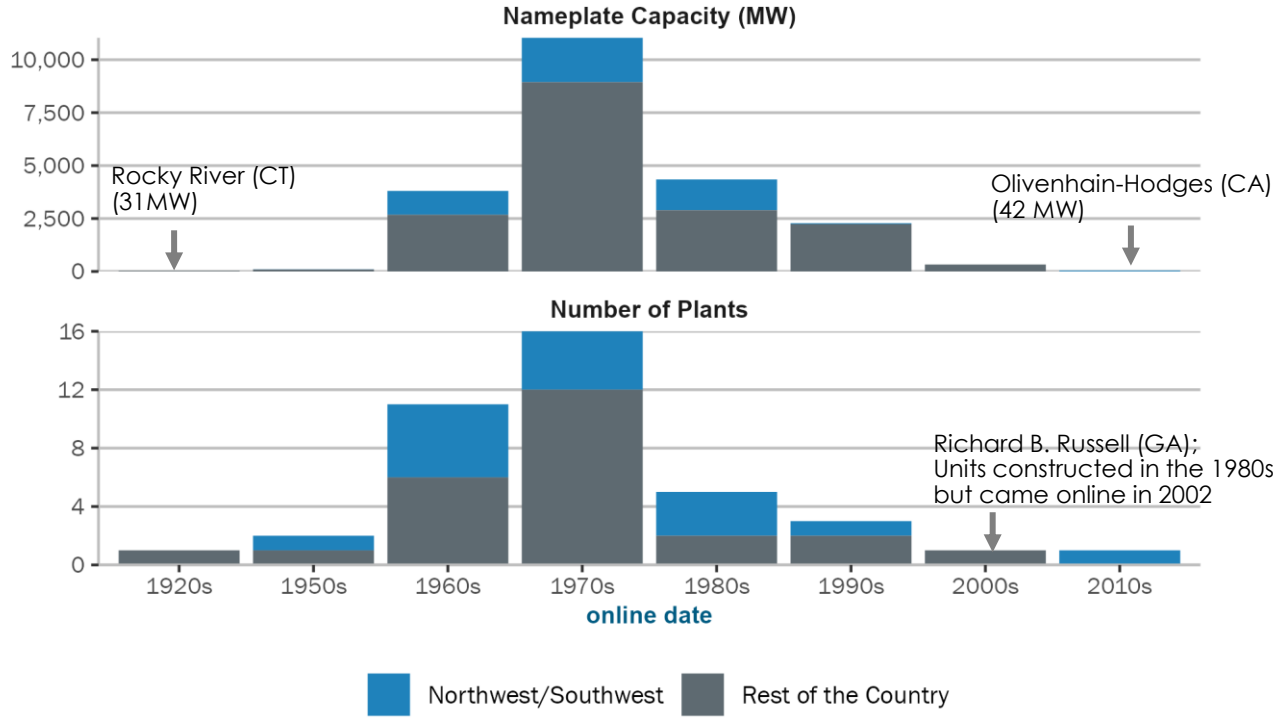


Note: This map displays the location and capacity of existing pumped storage hydropower (PSH) plants in the United States by region. Different symbols are used for PSH plants depending on whether all their units are pumped storage units (dedicated PSH) or they contain a mixture of regular and pumped storage units (hybrid PSH). For plants that contain both types of units, only the capacity of the pumped storage units is shown in the map.

Source: ORNL NHAAP Existing Hydropower Assets Data Set, 2000 Census-State Boundaries.

- The median size of PSH plants in the West (91 MW) is smaller than in the rest of the country (453 MW).
- All but three of the PSH plants in the West are owned by federal, state, or municipal agencies managing water and power.
  - For many of these, water-related functions (irrigation, water supply) are higher priority purposes than power storage/production.

No new large-scale PSH plant has been built in the United States since the 1990s; increases in installed PSH capacity since then have been almost exclusively upgrades to existing plants.

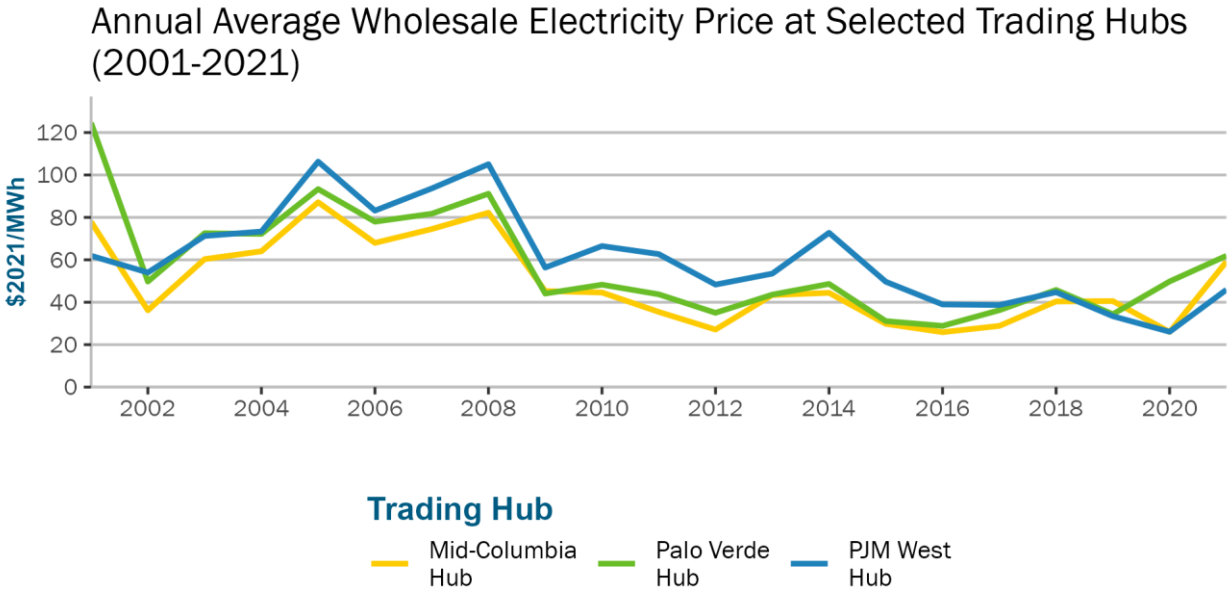


Source: Existing Hydropower Assets (EHA), 2022

- Most U.S. PSH plants came online between 1960 and 1990.
  - PSH complemented nuclear and thermal baseload plants that provided cheap power for pumping and were not well suited to follow demand peaks.
- Since 1995, except for a 42-MW plant (Olivenhain-Hodges in California), all additional PSH capacity has come from modernization and upgrades to the existing fleet.

Renewed interest in PSH development started in the late 2000s and resulted in an increased number of preliminary permit applications to FERC.

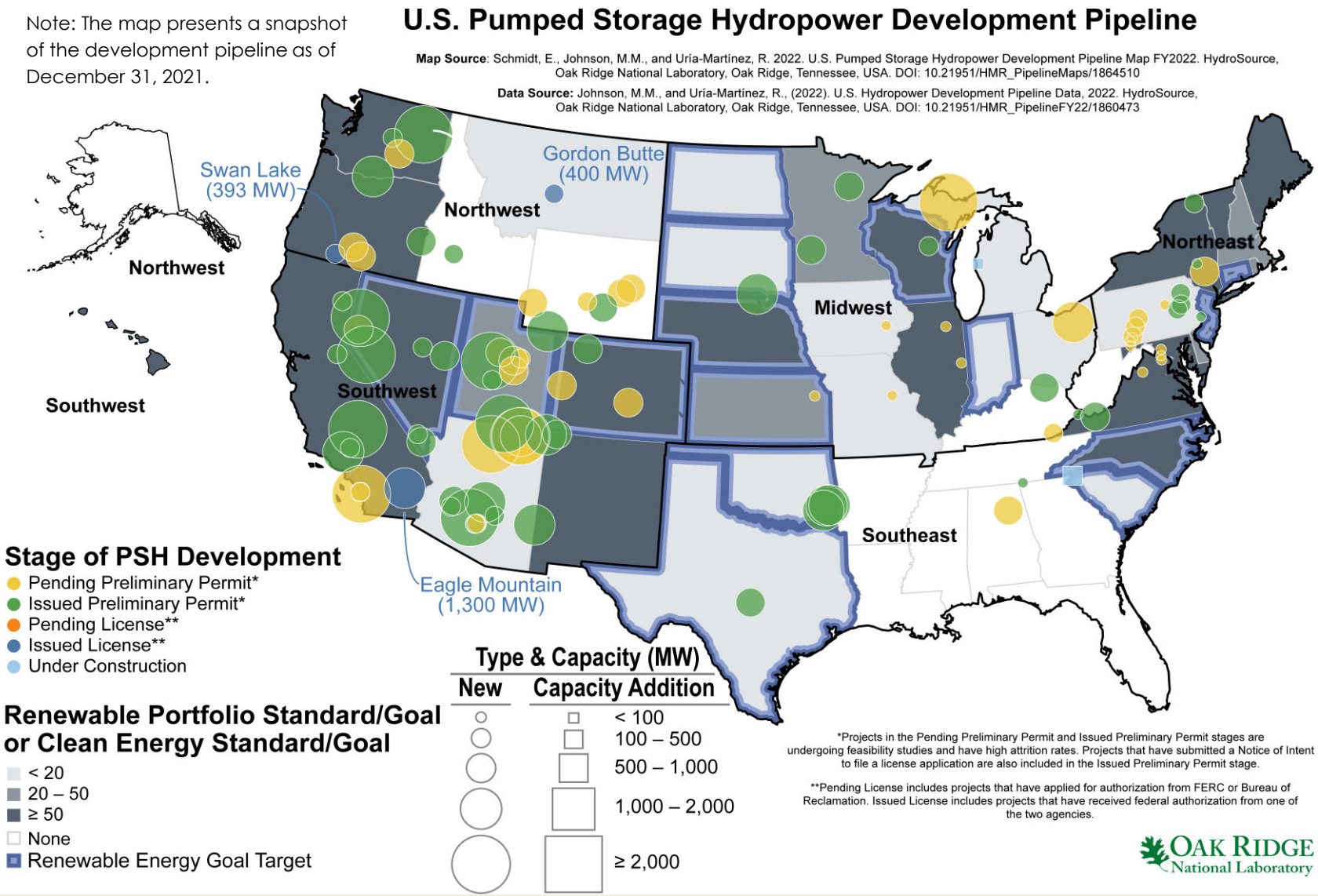
- FERC Order 890 (2007) directed ISO/RTOs to modify their market rules so that storage resources could participate in ancillary services and capacity markets.
  - PSH can access new revenue streams
- Growth in installation of variable renewables; states pass renewable portfolio standards requiring additional renewable generation capacity.
  - PSH is a well-suited, mature technology to integrate variable renewables into the grid.
- But the low electricity prices of the 2010s challenged the business case for new PSH.



Source: Energy Information Administration

At the end of 2021, 96 new PSH projects were in the U.S. development pipeline and three of them (all in the West) already had a FERC license.

Note: The map presents a snapshot of the development pipeline as of December 31, 2021.



- Most projects are in (or close to) states with policies requiring increased penetration of renewable generation.
- Almost 60% of the projects are in the West.
  - The median size of projects in the West (500 MW) is larger than in the rest of the country (179 MW).
- Projects with preliminary permits are at the feasibility evaluation stage and have a large attrition rate.
  - Preliminary permits grant their holder exclusive rights to file a license application at a specific site for a three-year period.

Notable 2022–2023 development pipeline updates:

- FERC accepted the license application for the Goldendale Energy Storage Project (WA, 1,200 MW) in 2022.
- In January 2023, private developer submitted a license application for the Seminoe Pumped Storage Project (WY, 972 MW)

Developers are increasingly focusing on closed-loop PSH projects; investor-owned utilities have started submitting preliminary permit applications.

Project configurations:

- More than 80% projects in the development pipeline are closed-loop (i.e., not continuously connected to a naturally flowing water feature).
  - The environmental effects of closed-loop PSH projects are generally lower than for open-loop projects (Saulsbury, 2020)

Developer types:

- Several investor-owned utilities (IOUs) brought projects into the FERC development pipeline in 2021. In the previous decade, IOUs had focused on capacity upgrades at existing projects.
  - Three IOUs submitted preliminary permit applications for 12 PSH projects in 2021; 11 of them in the West.
    - Public Service Company of Colorado (Unaweep Pumped Storage 800 MW in Colorado), Pacificorp submitted 10 permit applications for PSH projects across the Northwest (OR, WY, WA, UT).
  - This uptick in PSH studies by IOUs is an indication that the need for long-duration energy storage is arising in long-term planning for these utilities.
  - The ability of IOUs to finance PSH development through their rate base and integrate PSH within the portfolio of assets that serves their customers removes some of the post-licensing steps presenting challenges for private non-utility developers.

Source: Saulsbury, B. (2020). A Comparison of the Environmental Effects of Open-Loop and Closed-Loop Pumped Storage Hydropower. PNNL-29157.

All licensed projects have requested to FERC one or more construction deadline extensions.

- Substantial variability in licensing process duration across recently licensed project

	Project Configuration	Date of Submission of Notice of Intent to File License	Final License Application Submission Date	Final License Issuance Date	Time elapsed from NOI to License Issuance
P-13123 (Eagle Mountain)	Closed-loop	01/10/2008	06/22/2009	06/19/2014	6.4 years
P-13642 (Gordon Butte)	Closed-loop	04/30/2013	10/01/2015	12/14/2016	3.6 years
P-13318 (Swan Lake)	Closed-loop	06/09/2010	10/28/2015	04/30/2019	8.9 years

- Post-licensing challenges include securing additional permits, financing, and power purchase agreements.

- FERC docket filings indicate that the three licensed PSH projects are continuing their pre-construction activities.
  - FERC has granted extensions of time to start construction to all three projects (beyond the standard two-year deadline from license issuance date).

Federal legislation has introduced incentives and innovation in the permitting process to encourage new PSH development.

- The *Inflation Reduction Act* (2022) includes tax credits for new energy storage facilities.

Credit	Qualified facilities/projects	Credit amount	Adders	Eligibility period
Clean Electricity Investment Credit (Section 48E)	New generation facilities with a GHG emissions rate <=0 or ***any energy storage technology with a storage capacity >= 5 kWh***	Full amount: 30% of eligible investment costs (if wage and apprenticeship requirements are met) Base amount: 6%	Additional 10 percentage points of credit if project meets domestic content requirements or is located in an "energy community"	2025–2032

- The *American Water Infrastructure Act* (2018) directed FERC to introduce an expedited licensing process for qualifying closed-loop PSH projects.
  - The new process is available since 2019 and requires FERC to make a final decision on the license application within two years of its submission date.
  - For a closed-loop PSH project to qualify it must neither affect endangered species nor cause significant change to pre-existing surface or groundwater flow.

Summary

- The United States has 13% of global PSH capacity (third largest fleet behind China and Japan).
- The U.S. PSH fleet contains 43 plants with a combined capacity of 22 GW.
  - Twenty-two percent of the capacity is in the Northwest and Southwest regions.
- No new large-scale PSH plant has been built in the United States since the 1990s; however, there has been an increased interest in studying and holding the option to develop sites since the late 2000s.
  - Existing fleet was built as a peaking complement to nuclear and thermal baseload generating facilities; business case centered around energy price arbitrage.
  - New projects seek to complement variable renewables and provide not only peaking energy but also capacity and grid services (e.g., frequency regulation).
- At the end of 2021, there were ~100 PSH projects in the FERC development pipeline; most of them are requesting or holding preliminary permits to conduct feasibility evaluation studies.
  - Almost 60% of the projects are in the West
- Three projects (all in the West) already have a FERC license.