Pumped Hydroelectric Storage Systems

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Current Status

• Pumped hydroelectric storage (PHS) — the only long duration energy storage in the market
• PHS — over 90% of the world’s grid-scale energy storage applications
• Current global installed capacity of PHS — 165 GW\(^1\)
• Capacity added in 2021 — 4.7 GW, mostly in China
• U.S. — 43 plants with total installed capacity of 22 GW\(^2\)

• Support thermal, nuclear
• Time-shift energy
• Economic growth

Environmental Impacts
Geographic Barriers
Capital intensive

Figure 1. Existing PHS facilities in the U.S\(^3\).
Figure 2. Rocky River pumped storage plant on the Housatonic river in Connecticut, operation started in 1929\(^4\)

Largest PHS facility in the world — Fengning Pumped Storage Power Station (3.6 GW) in China

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3. Hydroelectric Pumped Storage for Enabling Variable Energy Resources within the Federal Columbia River Power System — Bonneville Power Administration
4. Rocky River Pumped Storage Hydraulic Plant | ASCE
Deployment

Fixed-speed PHS — Traditional

- Used in the U.S.
- Operates almost at a **fixed speed**
- Cannot perform frequency regulation

Adjustable-speed PHS — Flexible

- Used in Japan, China, Europe
- Uses **power electronic converters**
- Operates across greater generating and pumping power ranges
- Rapidly exchange energy with the bulk power system — fast frequency response services

FS can be upgraded to AS units

Yagisawa PHS plant (Japan) — 87 MW unit was converted from FS to AS in 1990

Figure 1. Ludington Pumped Storage facility in Michigan

Figure 2. Nant de Drance pumped storage facility in Switzerland

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1. Pumped Storage Hydro Electricity | Consumers Energy
2. This giant ‘water battery’ under the Alps could be a game-changer for renewable energy in Europe | CNN
**U.S. PHS — Pipeline (FERC)**

- **40 GW** issued preliminary permits by FERC
- **36 GW** pending preliminary permits

- No new projects online since 2012 (Lake Hodges in San Diego, CA)
- No new project under construction
  - Eagle Mountain Hydroelectric Storage Project licensed since June 2014
  - Gordon Butte Pumped Storage Project licensed since December 2016

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Challenges

Why aren’t there any new PHS projects in the U.S.?

- Cost — Large engineering projects, capital intensive, long construction duration
- Environmental impacts — Building dams, disruption of aquatic life, flooding
- Geographic barrier — Reservoirs separated by elevation, massive water requirement
- Regulatory issues — multiple licenses required, no investment tax credit
- Valuation — markets lack revenue streams for PHS
Recent Projects — Non-traditional Configurations

- Underground Reservoir PHS — Can use old mine shafts, depleted natural gas formations
- Can be installed in flat areas — eliminating typical geographical challenges
- Lower capital cost

**Geomechanical Pumped Storage**¹

- Being developed by Quidnet Energy and funded by the U.S. DOE
- 1 – 10 MW modules with 10+ hours of storage each

**Gravity Power Plant**²

- Being developed by Gravity Power
- Estimated Levelized Cost of Energy lowest among PHS, Hydrogen, Flow, and Li-ion³: $0.14/kWh for some long duration categories

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¹. [Quidnet Energy – Technology](#)
². [Home - Gravity Power](#)
³. [Energy Storage Cost and Performance Database | PNNL](#)
Recent Projects — Non-traditional Configurations

- Aquifer pumped hydro (APH) — uses aquifers as lower reservoirs
  
  - California Energy Commission (CEC) funded project\(^1\)
  - Over 100,000 wells in Central Valley, CA
  - Existing wells retrofitted to generate power
  - Discharge duration depends on upper reservoir size
  - \textit{Goal}: 10 hour discharge at 200 kW
  - Backup hospitals, nursing homes, charging centers
  - Estimated installed cost: $380/kWh

1. Home (aquiferpumpedhydro.com)
Recent Projects — Non-traditional Configurations

- Ground-Level Integrated Diverse Energy Storage¹ (GLIDES)

- Modular design
- Combination of PHS and CAES technologies
- Stores energy by compression-expansion of air
- Cost depends on the material used: steel, carbon fiber vessel, pipe segments
- Round-trip efficiency (RTE) of prototypes low²
- Potential to reach RTE³ of 70 – 82%
- Estimated installed cost: $180 – 400/kWh

¹ Energy – High-efficiency storage | ORNL
² Experimental and analytical evaluation of a hydro-pneumatic compressed-air Ground-Level Integrated Diverse Energy Storage (GLIDES) system | Elsevier Enhanced Reader
³ Pub148157.pdf (ornl.gov)
Summary

• Traditional PHS — well-suited to provide long duration energy storage (LDES)

• Challenges: cost, geographic barriers, environmental concerns

• No projects under construction in the U.S.

• Non-traditional configurations: underground reservoir, aquifers, GLIDES

• Alternate configurations — currently in development, potential to serve as LDES
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BACKUP SLIDES
Working Principle

- PHS converts electrical energy to potential energy
- Two reservoirs connected with a head difference through a water conductor
- Two modes of operation: **pumping** and **generation**
  - **Pumping**: Motor/pump system moves water from lower to the upper reservoir
  - **Generation**: Generator/turbine system generates electricity from the stored water

**Figure.** Working principle of a PHS