Strengthening the grid's 'backbone' with hydropower

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Argonne-led studies investigate how hydropower could help Alaska add more clean energy to its grid, how it generates value as grids add more renewable energy, and how liner technology can improve hydropower efficiency.

Three recent studies by the U.S. Department of Energy's (DOE) Argonne National Laboratory advance the role of hydropower in driving the clean energy transition. The research explored hydropower's potential in Alaska, its value to grid operations and its optimal design. DOE's Water Power Technologies Office (WPTO) recognized this work in its 2022–2023 Accomplishments Report—a compilation of some of the most impactful WPTO-funded hydropower research. The three studies were supported by WPTO's HydroWIRES Initiative.

Why hydropower matters

Rapid deployment of wind and solar energy often makes headlines in news coverage of the clean energy transition—and rightly so. These low-cost, zero-carbon renewable energy sources are helping the U.S. meet its ambitious goal to build a clean power system by 2035.

While less often in the headlines, hydropower—the world's largest source of renewable energy—is equally important for transitioning electric grids to clean energy. It can support the integration of wind and solar generation in several ways. When the output of these variable energy resources is not enough to meet demand, conventional hydropower reservoirs can release more water to increase energy generation. This helps balance the grid when the wind doesn't blow or the sun doesn't shine.

Another type of hydropower facility known as pumped storage hydropower (PSH) is the most mature grid-scale storage technology. During low-demand periods, these facilities use excess solar and wind electricity to pump water from a lower to an upper reservoir.

This process stores the energy. Later, when demand is greater, water released by the upper reservoir flows through a turbine to the lower reservoir, generating electricity. According to the DOE, these giant "water batteries" accounted for 96% of utility-scale energy storage capacity in the U.S. in 2022.

PSH's proven ability to provide long-duration energy storage—more than eight hours—supports grid reliability and resilience. This becomes particularly important during extreme weather when the grid may need days or even weeks of backup energy.

"We need a huge amount of energy storage to reliably operate grids with a high penetration of wind and solar," said Vladimir Koritarov, director of DOE's Argonne National Laboratory's Center for Energy, Environmental and Economic Systems Analysis. "A mix of various storage technologies, including hydropower and batteries, will be necessary to perform diverse functions."

Enormous PSH potential in Alaska

While most states in the U.S. are connected in regional grids, Alaska has two standalone grids (the Railbelt and Southeast Alaska) that serve most of the state's population. It also has more than 150 small, isolated power systems serving remote communities. According to the U.S. Energy Information Administration, fossil fuels generated 68% of the state's electricity in 2022.

Argonne worked with DOE's National Renewable Energy Laboratory (NREL) to evaluate the potential for PSH deployment to enable integration of solar and wind energy in Alaska. Using geographic information systems, the team identified more than 1,800 sites with geography suitable for PSH. This demonstrates the great potential for PSH to help make Alaska's power systems cleaner and more resilient.

Next, researchers examined how PSH could support Alaska's largest power system, the Railbelt. They created a model to simulate a future Railbelt system with a high penetration of wind and solar and assessed storage needs for reliability. They found that by 2046 the system will need up to 600 megawatts of PSH capacity for long-duration energy storage as well as batteries for short-term storage.

The team modeled the economic viability of small PSH facilities—less than 1 megawatt—in Alaska's remote communities and found that batteries would generally be more cost-effective in these locations.

The study can inform the state's storage and renewable energy policies and investments. The results also have broader applicability in other states.

"Across the U.S., pumped storage is going to be needed to support a clean energy grid in combination with other storage technologies," said Koritarov, who was the study's lead author. "It is cost-competitive for providing very large amounts of storage. And it is particularly helpful for providing backup power during outages."

Rethinking how hydropower can benefit the grid

In grids dominated by wind and solar, hydropower facilities will need to be operated in different ways to maintain reliable, affordable electricity networks. Because of this, the value of the different services that hydropower can provide to the grid will change. Argonne worked with NREL and DOE's Pacific Northwest National Laboratory to quantify these changes. The Hydropower Value Drivers study involved simulating the operation of different grids and optimizing hydropower operations, with an aim of minimizing grid costs.

Today, conventional hydropower plants yield the majority of their value for the grid by providing energy. The team found that these plants can provide additional value in the future by flexibly ramping generation up and down to balance solar and wind. Hydropower's ability to provide a grid service known as capacity will also increase in value.

"Capacity is like a long-term insurance mechanism for the grid," said Todd Levin, Argonne's Electricity Markets Team lead and the study's lead author. "When a hydropower plant provides capacity, it gets paid for promising to provide energy when it's needed—even if it's never called upon. If wind and solar generation are lower than expected, a hydropower plant will have water in its reservoir ready to be released."

Another finding was that PSH facilities will become increasingly valuable in a grid reliant on wind and solar. That's because PSH can absorb excess solar and wind generation and discharge the power during a future energy shortfall.

The study suggests that grid and hydropower operators need to rethink how they use hydropower plants to meet clean-energy goals. Facilities may also require certain mechanical upgrades to enable new operating modes.

"We hope our findings encourage regulators and electricity market operators to revisit how they value hydropower's capabilities," Levin said. "There may even be a need to pay hydropower plants for new services that aren't compensated today."

Innovating PSH reservoir liners to improve hydropower efficiency

To operate PSH facilities, it's necessary to frequently raise and lower the reservoirs' water levels. Reservoirs are typically lined with special materials to help retain water during this process and ensure reliable operations. Traditionally, these liners have been made of clay, concrete or asphalt.

The U.S. hydropower industry wanted to know whether a class of materials known as geomembrane liners would be a viable option for PSH facilities. These materials are less permeable than traditional liners, potentially reducing leakage and improving plant efficiency. They have been used in PSH facilities in other countries, but the U.S. has limited experience with them.

In collaboration with DOE's Oak Ridge National Laboratory and the engineering firm Stantec, Argonne assessed the characteristics, potential uses and benefits of geomembrane liners. The team concluded that these materials are a good option for PSH facilities. But there is a caveat: PSH developers need to carefully consider numerous site characteristics to inform a decision on the best lining system.

"The developer should work closely with geomembrane manufacturers to determine the optimal material for their sites," Koritarov said. "The manufacturer can also help identify the most appropriate design and installation methods."

The team found that there is a lack of readily available information on the costs of geomembrane liners. As a follow-up effort, Argonne researchers are developing a tool that will enable PSH developers to estimate the lining costs for their particular facilities.

"Hydropower is a tried-and-true electricity generation technology dating back to the late 1800s," Koritarov said. "Argonne's recent research points to hydropower's great potential to complement the variability of wind and solar—and ultimately serve as the backbone for a clean grid."

More information: WPTO's full Accomplishment Report: www.energy.gov/eere/water/arti … -report-highlighting

Provided by Argonne National Laboratory

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