



2017 Hydropower Market Report Executive Summary

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The U.S. hydropower fleet represents 7% of total electricity generation installed capacity (as of the end of 2016) and produces 6.3% of electricity (2014-2016 average). In addition, 43 pumped storage hydropower (PSH) plants with a total capacity of 21.6 GW provide 95% of utility-scale electrical energy storage in the United States. The U.S. fleet is the third largest in the world for both hydropower and PSH. The U.S. hydropower fleet also provides considerable load-following flexibility and a host of ancillary services—from frequency regulation to black start—that contribute to grid stability and reliability. The 2017 Hydropower Market Report is compiled from many different publicly available datasets and from information collected to support ongoing Department of Energy R&D projects. First published in 2015, this second edition of the report provides industry, policy makers, and other interested stakeholders with important data and information on the distribution, characteristics, and trends of the hydropower industry in the United States. Download a copy of the full report by visiting energy.gov/hydropowerreport.

U.S. hydropower capacity has increased by 2,030 MW from 2006 to 2016 bringing installed capacity to 79.99 GW across 2,241 separate plants.

Of this net increase, 70% (1,435 MW) resulted from refurbishments and upgrades (R&U) to the existing fleet. Most of the 118 new hydropower plants that have started operation since 2006 involved additions of hydropower generation equipment to non-powered dams (40) or conduits (73), but five new stream-reach development (NSD) projects also started operation from 2006 to 2016—all of them in the Northwest. The median size of new plants is small (≤ 10 MW); the largest new hydropower plants coming on line over the last decade were the NPD projects developed by American Municipal Power along the Ohio River: Meldahl (105 MW), Cannelton (88 MW), and Willow Island (44 MW). The range of capital costs for recently completed projects is very wide (\$2,000 to \$8,000 per kilowatt installed) which reveals a high degree of site-specificity in the project economics of new hydropower.

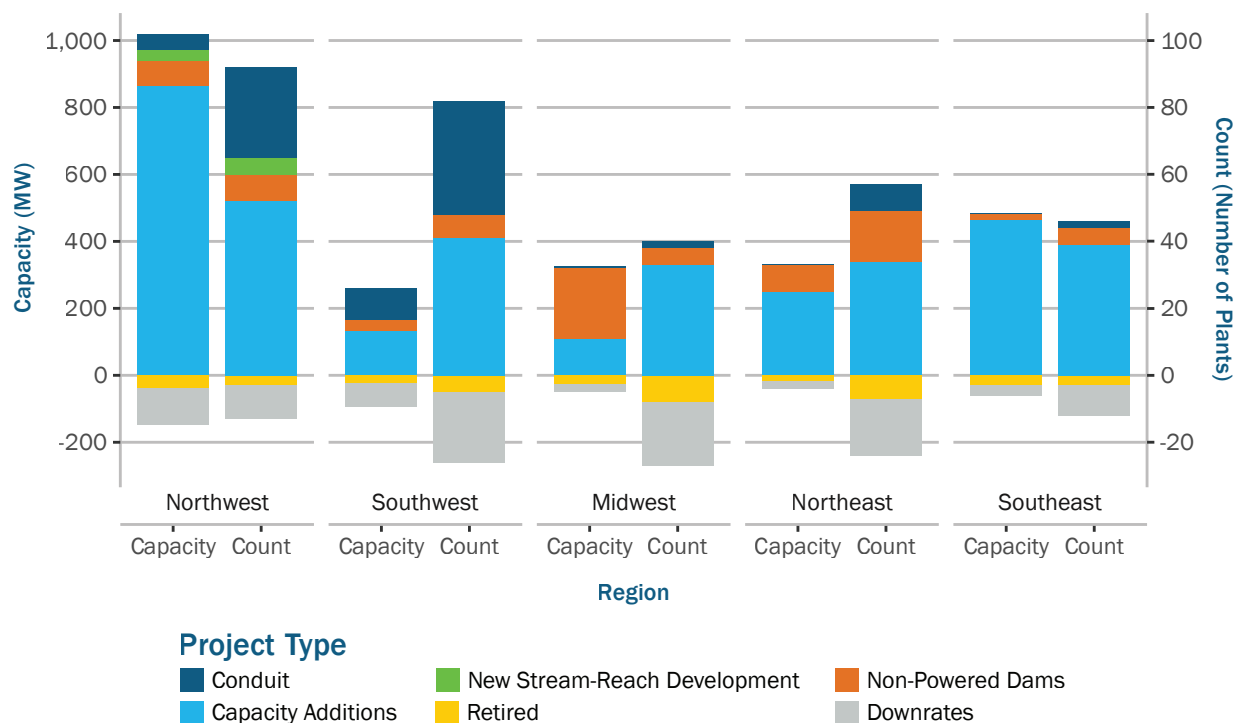


Figure 1. Hydropower capacity changes by region and type (2006-2016)

Sources: EIA Form 860, NHAAP, FERC eLibrary

Note: Each instance of a capacity increase or decrease reported in EIA Form 860 is counted separately. Some plants reported multiple capacity changes during this period.

At the end of 2017, there are 214 projects with combined proposed capacity of 1,712 MW in the U.S. hydropower project development pipeline.

The addition of hydropower generation equipment to existing water resource infrastructure is the dominant trend in planned new developments. Predominant project type varies by region. Proposed developments in the Midwest, Southeast, and Northeast region are almost exclusively NPD projects. In the Southwest, most projects would add hydropower to existing conduits and irrigation canals. The Northwest has the most diverse project pipeline and contains all proposed new stream-reach developments (except for 1 in New York). Nationally, NPD projects account for 92% of proposed capacity. Thus, the success of recent initiatives to improve the efficiency of the authorization process for this type of project is crucial.

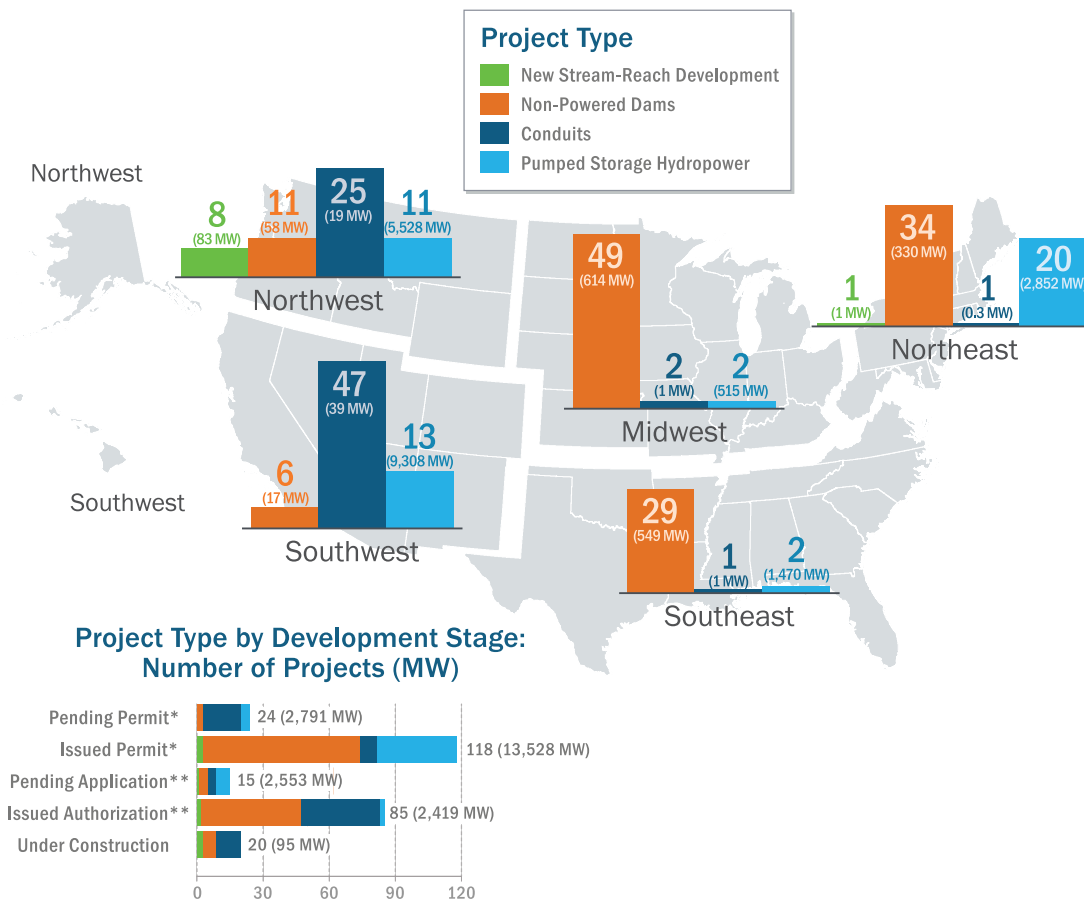


Figure 2. Hydropower and pumped storage hydropower project development pipeline by project type, region, and development stage

Sources: FERC eLibrary, Reclamation LOPP database, web searches

*Projects in the *Pending Permit* and *Issued Permit* stages have high attrition rates. *Pending Permit* includes projects pending a preliminary lease in the Bureau of Reclamation Lease of Power Privilege (LOPP) process and projects pending issuance of a preliminary permit. *Issued Permit* includes projects that have received a preliminary lease in the LOPP process, projects that have obtained a FERC preliminary permit, and projects whose preliminary permit has expired but have submitted a Notice of Intent to file a license or a draft license application.

***Pending Application* includes projects that have applied for an original FERC license or a FERC exemption or have requested to be considered a “qualifying conduit” hydropower facility by FERC. *Issued Authorization* includes projects that have been issued an original FERC license or FERC exemption, have been approved by FERC for “qualifying conduit” hydropower status, or that have received a final lease contract under the LOPP process.

As with hydropower, substantial PSH capacity increases (2,074 MW) have been achieved since 2006 by upgrading turbine-generator units in the existing fleet; only one new PSH facility (40 MW) has started operation in that period.

The lack of PSH construction in the United States contrasts with abundant PSH development around the world. Since 2006, 22 PSH facilities have been built in East Asia—mostly China—and nine in Europe. In addition, these two regions have 26 and 7 more PSH plants under construction respectively. This disparity in PSH development activity between the United States and the rest of the world could be due to differences in the authorization process and/or the available revenue streams and deserves further analysis.

The new generation of PSH facilities being proposed in the United States are substantially different in a number of ways from the existing PSH fleet. Most of the proposed new projects are closed-loop facilities, not connected directly to rivers. This lowers their likely environmental impact and potentially opens up a variety of new candidate sites. They also differ in their proposed mode of operation. Much of the existing fleet was built as a complement to baseload coal or nuclear plants, and business models were mainly focused on taking advantage of price differentials between on-peak generation hours and off-peak pumping hours. However, with lower electricity prices observed for most of the last decade, such modes of operation would not lead to attractive rates of return for new projects in most locations. Instead, new PSH license applications emphasize their versatility as providers of grid services, particularly in areas of the country with ambitious RPS targets. At the end of 2017, developers were investigating PSH feasibility on 40 sites and had six pending FERC license applications. In addition, two projects (Eagle Mountain in California and Gordon Butte in Montana) have FERC licenses and could become the first large new PSH facilities in more than 20 years if they proceed to construction.

The U.S. hydropower and PSH fleets contribute to grid reliability and resilience through their significant ramping capabilities and the provision of a host of ancillary services ranging from frequency regulation to operation reserves and black start.

Hydropower provides load following flexibility in all ISO/RTO markets; daily patterns of hydropower generation follow electricity use patterns closely. The California market (CAISO) is the only ISO/RTO in which variable renewables have notably changed the typical daily hydropower generation profile. In CAISO, hydropower is more closely correlated with net load (i.e., load net of wind and solar generation) than with load.

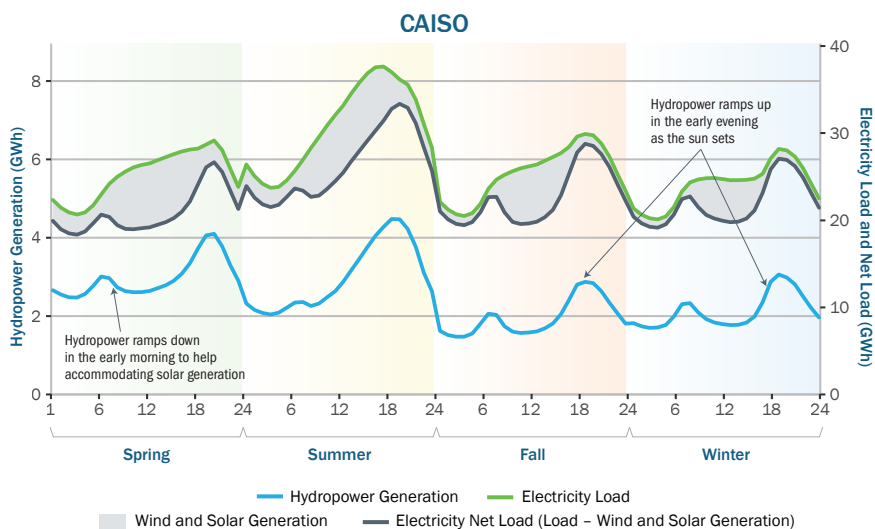


Figure 3. Average hourly hydropower and PSH generation, electricity load, and electricity net load by season in CAISO (2014-2017)

Source: CAISO website

Hydropower’s ability to quickly adjust output up or down to follow changes in net load (total electric load minus wind and solar generation) makes it play a key role as complement to the much larger, and also highly flexible, natural gas fleet in integrating variable renewables.

The average one-hour ramp for the hydropower fleet (as a percentage of installed capacity) is greater than for natural gas in all ISO/RTOs. In addition, hydropower adjusts its output up or down by more than 5% of its installed capacity from one hour to the next more frequently than natural gas, especially in the ISO/RTOs with most PSH capacity. Nevertheless, natural gas follows net load more closely (i.e., its ramps are more highly correlated with net load than those from the hydropower fleet) likely due to the fact that its operations are not subject to the restrictions experienced by hydropower due to non-power purposes of storage reservoirs, minimum flow requirements, or water quality constraints.

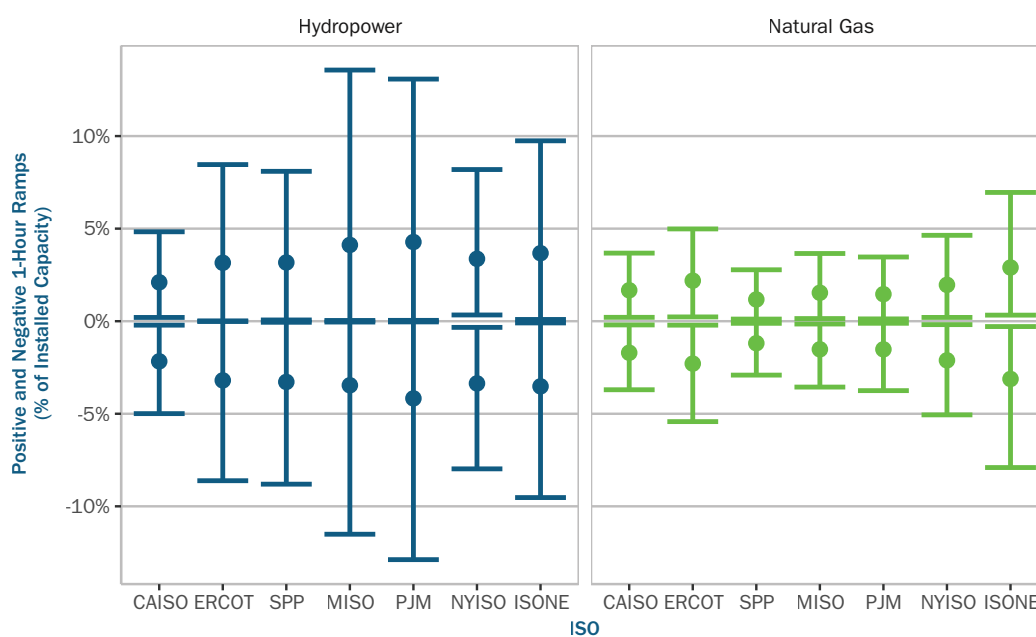


Figure 4. Average and 10th-90th percentile interval for one-hour ramps (both positive and negative) per installed megawatt for hydropower and pumped storage hydropower vs. natural gas by ISO/RTO

Source: ISO/RTO websites

Note: CAISO, MISO, and ERCOT values are based on 1/1/2014–12/31/2017 data. For other ISO/RTOs, the period represented in the plots is dictated by data availability: 5/20/2015–12/31/2017 for PJM, 1/1/2015–12/31/2017 for SPP, 8/18/2016–12/31/2017 for ISONE, and 12/09/2015–12/31/2017 for NYISO.

U.S. hydropower refurbishment and upgrade (R&U) projects worth \$8.9 billion have started from 2007 to 2017.

Based on a snapshot of active R&U projects around the world at the end of 2017, the United States has one of the highest expenditures per installed kilowatt. With a capacity-weighted average fleet age of 56 years, it also has one of the oldest fleets. Investment is not evenly distributed across the fleet. In particular, the fraction of non-PSH tracked R&U investment that corresponds to the federal fleet (39%) is significantly lower than the fraction of capacity the federal fleet represents (49%).

The scope of 80% of the tracked R&U projects includes work on turbines and generators. At least 223 turbines units distributed across 93 plants were installed in the United States between 2007 and 2017. It can be estimated that for at least half the turbines, machining and assembly operations were performed domestically.

U.S. hydropower availability factor—the number of hours that a hydropower unit is connected to the grid or stands ready to connect as needed—has declined over the last decade.

From 2005 to 2008, the availability ratio was 84% for large units, 85% for small units, and 88% for PSH units. The 2009-2016 average availability ratio has been 81%, 83%, and 83% for those three unit types respectively.

For small units, average forced outage hours have increased by 68% in 2013-2016 relative to 2005-2012, and the average number of planned outages has decreased by 8%. Small plants face the highest O&M costs in a per-kilowatt basis and their failure is less costly for fleet operators than that of larger units; therefore, they are low in the priority order for a fixed O&M budget that needs to cover the whole fleet. For large units (>= 100 MW), there have been increases in both planned and forced outages. Longer or more frequent planned outages in these units are meant to prevent forced outages at times in which they would be most costly based on hydrologic or market conditions.

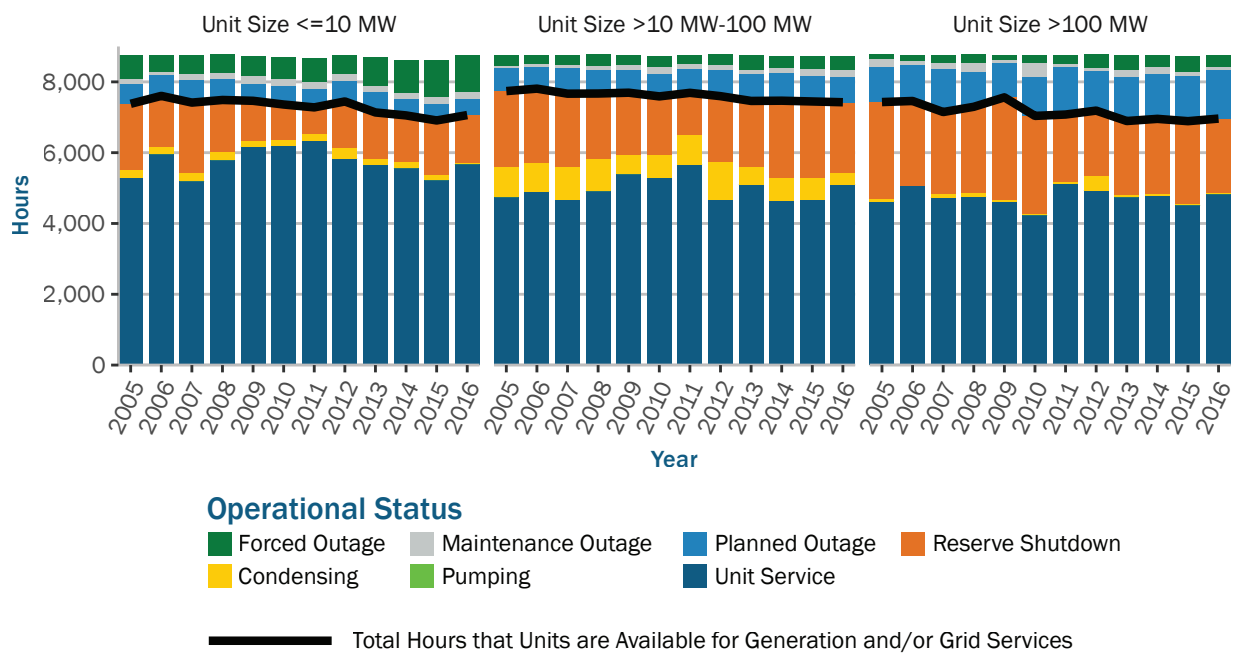


Figure 5. Average hydropower operational status (hourly breakdown by unit size classes of units reporting to NERC GADS)

Source: NERC GADS

Note: Operation and outage state definitions from the NERC Glossary of Terms: *Forced Outage* (unplanned component failure or other conditions that require the unit to be removed from service immediately, within six hours or before the next weekend), *Maintenance Outage* (unit removed from service to perform work on specific components that can be deferred beyond the end of the next weekend but not until the next planned outage), *Planned Outage* (unit removed from service to perform work on specific components that is scheduled well in advance and has a predetermined start date and duration), *Reserve Shutdown* (a state in which the unit was available for service but not electrically connected to the transmission system for economic reasons), *Pumping Hours* (hours the turbine-generator operated as a pump/motor), *Condensing* (units operated in synchronous mode), and *Unit Service Hours* (number of hours synchronized to the grid).

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Percentage of U.S. hydropower fleet coverage for each unit size shown in the panel titles varies slightly year to year. On average, 16% of U.S. hydropower units <=10 MW, 65% of U.S. hydropower units >10 MW and <=100 MW, and 76% of U.S. hydropower units >100 MW reported data to NERC GADS in 2005-2016.

Accelerated wear and tear associated to the transition toward operational modes involving more frequent or pronounced ramping and unit starts or stops could also explain some of the outages for medium and large units. However, trends in this regard get lost in the national average data from NERC GADS. Case studies for facilities in parts of the country with high penetrations of variable renewables (e.g., hydropower facilities participating in the Western Energy Imbalance Market) would be valuable in illuminating the extent of changes in operation mode and associated effects on unit availability.

Except for the largest hydropower plants, operations and maintenance (O&M) costs have risen at rates higher than inflation for the last decade.

Since 2007, O&M costs for hydropower projects have risen by as much as 40% compared to inflation of 16% over the same time period. These cost increases are particularly challenging for the smallest plants, which are spending much more to remain operational on a relative (\$ per kilowatt) basis than larger counterparts.

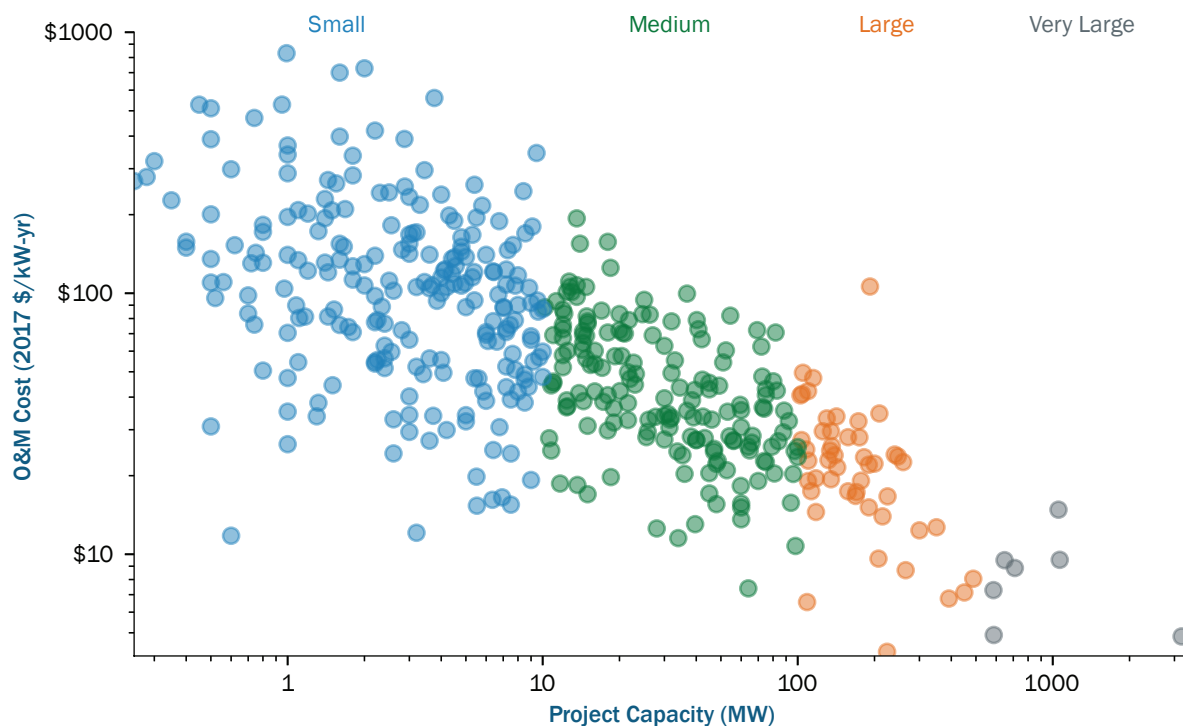


Figure 6. 2016 O&M expenditures for hydropower plants reporting on FERC Form 1

Source: FERC Form 1

Download a copy of the report
by visiting energy.gov/hydropowerreport

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Front Cover Image

Norris Dam hydropower plant, TN
(Image courtesy of Brennan Smith)



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