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Opportunities and barriers to pumped-hydro energy storage in the United States

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ABSTRACT

As concerns about global warming grow, societies are increasingly turning to the use of intermittent renewable energy resources, where energy storage becomes more and more important. Pumped-hydro energy storage (PHES) is the most established technology for utility-scale electricity storage. Although PHES has continued to be deployed globally, its development in the United States has largely been dormant since the 1990s. In recent years, however, there has been a revival of commercial interests in developing PHES facilities. In this paper we examine the historical development of PHES facilities in the United States, analyze case studies on the controversies of disputed projects, examine the challenges to and conflicting views of future development in the United States, and discuss new development activities and approaches. The main limiting factors for PHES appear to be environmental concerns and financial uncertainties rather than the availability of technically feasible sites. PHES developers are proposing innovative ways of addressing the environmental impacts, including the potential use of waste water in PHES applications. In some cases, a properly designed PHES system can even be used to improve water quality through aeration and other processes. Such new opportunities and the increasing need for greater energy storage may lead policymakers to reassess the potential of PHES in the United States, particularly for coupling with intermittent renewable energy sources such as wind and solar power.

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1. Introduction: significance of bulk electricity storage in a carbon-constrained world

Most low-carbon electricity resources cannot flexibly adjust their output to match fluctuating power demands. For instance, nuclear power plants best operate continuously and their output cannot be ramped up and down quickly. Wind power and solar energy are intermittent and their operators sometimes have no control over the schedule of electricity output. Utility-scale electricity storage to maintain balance and prevent blackouts remains a significant barrier to a de-carbonized power system.

There are only two large-scale (>100 MW) technologies available commercially for grid-tied electricity storage, pumped-hydro energy storage (PHES) and compressed air energy storage (CAES). Of the two, PHES is far more widely adopted. In the United States, there are 40 PHES stations with a total capacity of ~20 GW.

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Worldwide, there are hundreds of PHES stations operating with total capacity of 127 GW [1]. Only two CAES facilities, one 110 MW facility in the United States and another 290 MW facility in Germany, are currently operating globally. Unlike CAES, PHES does not require burning fossil fuels and is generally cheaper than CAES for energy storage [2].

A PHES facility is typically equipped with reversible pumps/generators connecting an upper and a lower reservoir. The pumps utilize relatively cheap electricity from the grid during off-peak hours to move water from the lower reservoir to the upper one to store energy. During periods of high electricity demand (peak-hours), water is released from the upper reservoir to generate power at higher price.

In recent years, there has been increasing commercial interest in PHES [3]. Developers are actively pursuing new PHES projects around the world. An additional 76 GW PHES capacity worldwide is expected by 2014 [1]. In the United States, the Federal Energy Regulatory Commission (FERC) has granted 32 preliminary permits (as of April 5, 2010) to 25 licensees who are interested in developing new PHES facilities [4]. The total capacity of these proposed PHES facilities is 28.6 GW, more than the existing PHES capacity in the United States. Nevertheless, based on historical and economic considerations, a number of these proposed projects are unlikely to be built. A brief review of the history of PHES development in the United States reveals the many challenges and barriers that exist today.

2. Historical PHES development in the United States

Connecticut Light & Power's Rocky River Station, completed in 1929, is the oldest pumped-hydro storage facility in the United States. The development of PHES remained relatively slow until the 1960s [5,6], when utilities began to consider the possibility of a dominant role for nuclear power [7]. Fig. 1 shows the cumulative installed PHES capacity in the United States.

Because the output of nuclear power cannot be ramped up and down quickly to meet fluctuating demands, pumped storage was perceived as an important complement to nuclear power for providing peaking power [8]. When nuclear development in the United States came to a standstill in the 1980s, PHES development also slowed dramatically. From 1986 to 2005, FERC issued 45 preliminary permits to study the feasibility of pumped storage projects. Only seven of the projects filed for licenses. Six of the seven projects were eventually abandoned (see Table 1) [9], and only one project from that period is still being studied through another preliminary permit.

Market uncertainties were a primary cause of termination of these projects. Beginning in the 1990s, electricity regulators in the United States started restructuring the power sector, transitioning to competitive wholesale markets that often separated power generation and transmission [10]. Electricity storage, unfortunately, sits in the gray area between generation and transmission [11]. A PHES facility does not qualify as a power-generating facility

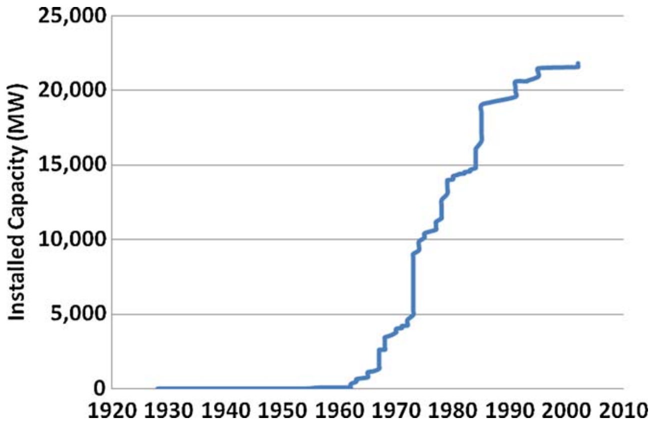

Fig. 1. Installed PHES capacity in the United States by date.

because its net power output is negative (i.e., a typical project recaptures only 70 or 80% of the power inputs). In the restructured wholesale power market, reserve capacity and ancillary services are typically fulfilled by peaking power generators. In the earlier stages of restructuring, it was unclear how or whether non-generating resources such as PHES could participate in these restructured markets. This regulatory uncertainty remained a serious deterrent to investment in energy storage until 2007. In that year, FERC issued Order 890 "Preventing Undue Discrimination and Preference in Transmission Service." The order required that non-generation resources (including energy storage and demand response) be evaluated on a comparable basis to services provided by generation resources in meeting mandatory reliability standards, providing ancillary services, and planning the expansion of the transmission grid. Since the issuance of this order, organizations responsible for transmission have been amending rules to allow energy storage to have greater market access.

Although PHES provides crucial load-balancing and ancillary services to the grid and reduces the needs for transmission upgrades, PHES facilities do not typically qualify as transmission infrastructure. For instance, the Lake Elsinore Advanced Pumped Storage project applied to be operated and/or managed by the California Independent System Operator (ISO), allowing it to be categorized as a transmission facility for purposes of rate recovery. However, FERC denied this request [12].

The benefits of bulk electricity storage are potentially useful to many sectors of society, including power generators, system operators, distribution companies, and end users. When regulators partially unbundled the power sector in the 1990s, they broke up PHES's potential revenues into pieces in different market sectors. Utilities generally recognize the value of PHES in the overall power system. However, operators were unsure if and how the PHES owners would be paid for their services after the restructuring.

Relatively low natural gas prices in the late 1980s and 1990s increased the use of natural gas in the U.S. power sector (see Fig. 2)

Table 1
Abandoned projects from 1986 to 2006.

Project name	Utility	Location	Duration	Stated cause of termination
Dry Fork	Little Horn Energy Wyoming, Inc.	Wyoming	1989–2000	Market uncertainty
Crystal Creek	Creamer & Noble Energy	California	1993–2000	Failure to obtain approval from California water quality board
River Mountain	JDJ Energy Co.	Arkansas	1994–2003	Market uncertainty, financial instability, inability to secure purchase agreement
Summit	Summit Energy Storage, Inc.	Ohio	1991–2001	Market uncertainty
Blue Diamond	Blue Diamond South Pumped Storage Power Company, Inc.	Nevada	1997–2005	Nevada electricity restructuring was taking longer than expected
Mt. Hope	Mt. Hope Waterpower Project, LLP	New Jersey	1992–2005	Market uncertainty

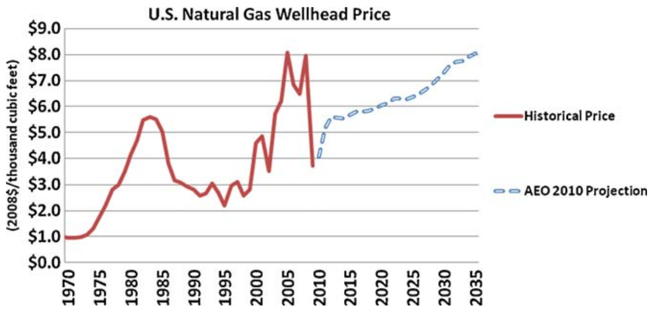

Fig. 2. U.S. natural gas wellhead price.

[13]. In the 1990s, almost all of the new electrical generation capacity was gas-fired [14]. Because PHES is essentially a peak-load technology, which competes directly with gas-fired power, low natural gas prices also help to explain the hiatus in PHES development in the late 1980s and 1990s along with the slow-down in new nuclear-power capacity.

Siting difficulties and environmental impacts were additional constraints on the development of PHES during this time. For example, the Department of Energy and the Electric Power Research Institute's handbook on energy storage concluded that "the addition of pumped hydro facilities is very limited, due to the scarcity of further cost-effective and environmentally acceptable sites in the U.S." [15]. Since the 1960s, there were many cases where proposed PHES projects were opposed by environmental groups. Some projects were eventually abandoned, while others were completed. The following five case studies from 1963 to 2006 illustrate some prominent cases relevant for understanding the potential development of PHES in the future.

2.1. Storm King

In 1963, Consolidated Edison (Con Ed) proposed to build a PHES facility at Storm King Mountain to help address the rapid growth of power demand in New York City. Had it been built, the project would have been the world's largest PHES facility at that time. Some local stakeholders objected to the potential damage the plant would cause to the environment of the Hudson Highlands and founded several environmental groups to block construction of the facility on the grounds that it posed a threat to the local water supply, Hudson River fisheries, and the scenic beauty and historic significance of Storm King Mountain [16]. Some researchers have even argued that Storm King helped start a new era of environmental advocacy in the United States that combined legal action with media outreach, public relations, and government lobbying [17].

In March 1964, FERC rejected the opponents' petitions and granted Con Ed a license. Opponents continued to challenge the FERC decision in court over the course of a 17-year legal battle [18]. Con Ed eventually terminated the Storming King project in 1981 and surrendered its Storm King license to FERC.

2.2. Richard B. Russell

The Richard B. Russell dam and conventional hydropower station in South Carolina offers a contrasting example where extensive cooperation with stakeholders and analysis of environmental impacts led to eventual project approval, despite early objections from environmental interests. The Russell hydropower station was completed and began operation in 1986. The Army Corps of Engineers, which owns the Richard B. Russell project, proceeded to add pump-hydro units to this facility. In 1988 the South Carolina Department of Wildlife and Marine Resources, joined by the South Carolina, Georgia, and National Wildlife Federations, filed an injunction to stop installation of the pump units. In 1992, the Army Corps developed a testing and monitoring plan in conjunction with opponents to evaluate the environmental impacts of PHES operation [19]. The assessment was divided into three phases. In phase I, lasting from July 1992 to August 1993, only short-duration pumping was allowed for purposes of collecting data for mechanical and electrical certifications of the four pump-back units. Phase II (August 1993 and August 1994) allowed only two unit pumping operations for collecting data for environmental impact assessments. Phase III (April 1996 and October 1996) simulated commercial operation for further assessment of environmental impacts. During this assessment, fish deterrent systems were installed and the pumping schedule was adjusted to minimize fish entrapment. An oxygen injection system was also installed to offset the potential oxygen loss due to warming of the water because of pumping. With these extensive modifications and preventive measures, the three-phase environmental assessment concluded that there were no significant impacts from the pump unit operation [20]. In 2002 the Federal District Court in Charleston, South Carolina lifted the injunction and the four pump units began commercial operation.

2.3. Bear Lake/Hook Canyon

In 2006, a private developer, Symbiotics LLC, applied for a preliminary permit for a proposed Hook Canyon Pump Storage Project. FERC granted the permit later that year. The PHES facility proposed to use an existing lake (Bear Lake in Utah) as the lower reservoir and an upper reservoir to be built on elevated dry land in Hook Canyon, Utah. The proposed upper reservoir was on public lands that belong to Utah Division of State Parks. In December 2007, the Utah Division of State Parks issued a letter stating that it was willing to enter into negotiations with Symbiotics to supply a lease across State Parks property for the Hook Canyon project.

Local environmental groups' concerns included the perceived profitability of the project and the objection to the concept of energy storage itself. They called this project a "perpetual money machine" [21] and made statements such as "This project is NOT renewable energy." and "This is power arbitrage, not power generation." [22]. The opponents were also concerned with environmental impacts such as those on water quality and aquatic habitats. As the confrontation continued, in April 2009 the Utah Governor's Office directed the Division of State Parks to cease negotiations on the leasing of State Parks property for this project. Subsequently, the developer withdrew its license application the following month.

2.4. Lake Elsinore advance pumped storage (LEAPS)

The Elsinore Valley Municipal Water District (EVMWD) in California originally conceived the Lake Elsinore PHES project in 1987. A primary purpose of the project was to stabilize water levels and maintain water quality in Lake Elsinore. The lake was vulnerable to drought conditions that caused water and oxygen levels to drop dramatically on many occasions, causing excessive algal growth, fish kills, and violations of water quality standards. When this occurred, EVMWD was forced to purchase reclaimed water to replenish the lake in order to comply with water quality standards. A PHES facility was expected to increase aeration and improve circulation, preventing algal growth and fish kills, and also to generate income to help defer costs of the purchased water [23].

The EVMWD completed preliminary feasibility studies in 1997, and a private company was formed in 1997 to manage the project. EVMWD and the company completed the environmental impact statement and filed for a license in 2007. FERC has not yet decided whether to grant the license.

Economic viability appears to be a primary cause of delays in this project. Three economic assessment reports all point out that, without revenues from ancillary service, the revenues from power arbitrage alone would not justify the cost of this project. In fact, one of the reports anticipates ancillary service to be the primary source of income for this project [24]. Because the California ISO is still in the process of amending its participation rule to allow non-generator resources in ancillary service markets [25], the economic viability of this project through provision of ancillary services is still uncertain.

2.5. Olivenhain–Hodges

The Olivenhain–Hodges PHES facility is a byproduct of the San Diego County Water Authority's Emergency Storage Project, which is an interconnected system of reservoirs with pipelines and pumping stations designed to make water available to the San Diego region in the event of an interruption in regular water supplies. In the plan, the Olivenhain reservoir and Lake Hodges would be connected with a pipeline and a pump station. Because there is a 196-m difference in the elevation between the Olivenhain reservoir and Lake Hodges, the pump station could function as a PHES facility by using a reversible pump [26]. Because this 40-MW project qualifies as small hydro, FERC approved its license exemption and no environmental impact assessment was required. This project is currently under construction (90% completed) and is expected to start operation in 2010 [27].

The aforementioned case studies reveal a great diversity in the nature of PHES projects and the challenges they faced then and are likely to face in the future. Some were abandoned or delayed due to concerns over environmental impacts, while one was initiated as a means to improve water quality. The Bear Lake/Hook Canyon project was opposed at least partly for concerns over using state parklands for profit, while the LEAPS is delayed because of questionable profitability. The Olivenhain–Hodges and LEAPS cases indicate that PHES could be designed to serve multiple purposes (energy storage, water resource management, water quality protection, etc.). In the Bear Lake case, the environmental groups' objection to energy storage suggests that the value of energy storage in integrating renewable energy is not commonly understood or accepted. Overall, the lack of public awareness of the benefits of bulk electricity storage is a considerable barrier for PHES development.

3. Current developments and new approaches

As of April 5, 2010, FERC had issued 32 preliminary permits in the United States for new PHES facilities and listed 4 applications for preliminary permits pending approval. In examining the designs of these proposals, we found that the proposed projects differ significantly from those of conventional PHES facilities, for which reservoirs were created mostly by damming rivers. Of the 36 proposed PHES projects, 29 are of close-loop/off-stream design. Roughly a quarter of the proposed capacities plan to use underground caverns as lower reservoirs. Some plan to use abandoned quarries or mine pits as upper reservoirs. Less than a quarter of them proposed to dam a river.

As shown in Figs. 3 and 4, these new approaches, including off-stream systems, and those using underground reservoirs, groundwater system and abandoned quarries and mines, signal a substantive change in the direction of pump-hydro storage that addresses many of the historical difficulties in development reviewed in the case studies above. Off-stream designs do not dam rivers and pose fewer problems for aquatic ecosystems. Utilizing abandoned quarries, mines, and underground caverns avoid some impacts to existing water bodies, although the hydrological and environmental interactions still need considerable evaluation for each project. Utilizing groundwater instead of surface water also reduces or eliminates the impacts to fish populations in most situations.

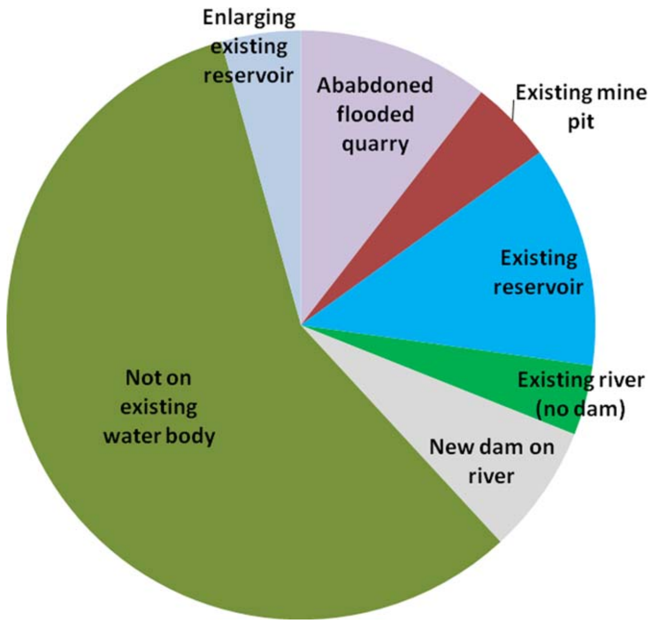

Fig. 3. Upper reservoir design of proposed projects.

One of the new proposed projects, Mulqueeney Ranch in California, is particularly interesting. This project proposes to use recycled wastewater as the water resource for an off-stream PHES system. This innovative approach may have several advantages. Not only would the use of wastewater alleviate concerns for fish populations, but the PHES operation may actually improve the quality of the water it uses to operate. The pumping operation can

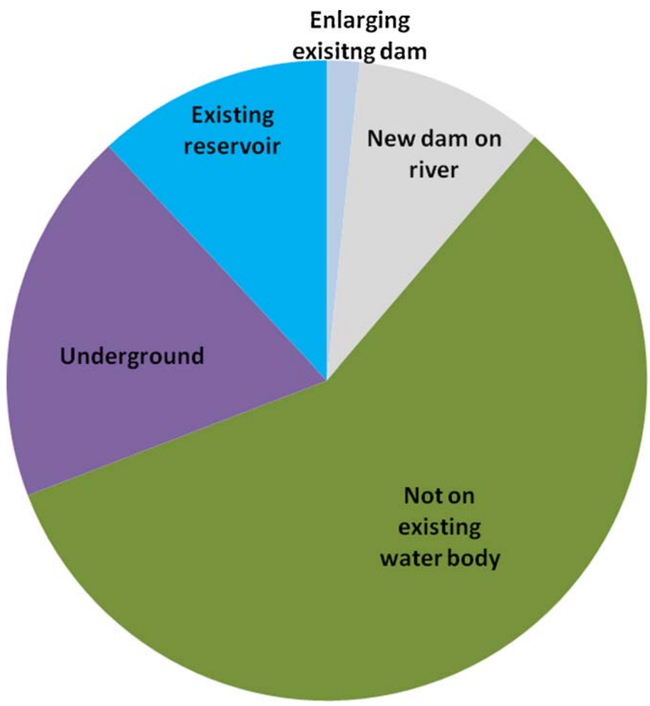

Fig. 4. Lower reservoir design of proposed projects.

be designed to aerate the water, and storage could become an extended aerobic biological treatment. In addition, wastewater treatment plants (WWTPs) are typically located near major population centers, which are demand centers for electricity. Storing electricity nearby would reduce the need for transmission upgrades.

Because such novel wastewater PHES projects may be applicable to other parts of the United States, we briefly examine the design of the Mulqueeney Ranch project as a benchmark for the required minimum WWTP flow rate for PHES.

The 280-MW Mulqueeney Ranch project proposes to divert 500 acre-feet of recycled wastewater per year from the Tracy City WWTP. Five hundred acre-feet per year is equivalent to 0.446 million gallons per day (MGD). According to the U.S. Environmental Protection Agency's Clean Watershed Survey 2004 data, there are 6135 WWTPs in the United States with output flows of more than 0.45 MGD. Certainly, suitable terrains for PHES reservoirs will not always be available near WWTPs. Nevertheless, among the thousands of WWTPs, it is likely that some of them may find suitable PHES opportunities nearby.

4. Future prospects

Perceptions about the potential for adding PHES capacity in the United States have gone through an interesting cycle. The most comprehensive assessment of PHES opportunities conducted in the Unites States was by the Army Corps of Engineers in 1982 [28]. According to that assessment, the United States is endowed with potential PHES sites capable of handling $>$1000 GW of power. To our knowledge, no comprehensive assessment of PHES potentials has been conducted in the United States since that report. After the development of PHES slowed in the late 1980s, a misconception arose that the United States had run out of feasible PHES sites, a perception that was fairly prevalent [29,30,31,32]. PHES has since largely disappeared from U.S. energy policy. The recent surge of proposed projects indicates renewed interest and increased needs for bulk electricity storage. Today, it is still premature to judge how many of the dozens of proposed projects will ultimately be successful.

Many factors contribute to the uncertain outlook of PHES development in the United States. In recent years, natural gas production from shale formations has been expanding quickly [33]. Increased supply of unconventional natural gas (shale gas) may significantly lower natural gas prices again and render PHES uncompetitive compared to gas for use in peaking power supply. On the other hand, the prospect of a legislated price or cap on carbon dioxide emissions is likely to strengthen the economic outlook of PHES. As intermittent renewable power gains market share, the need for bulk electricity storage will increase, potentially increasing the development of PHES.

Our case studies reveal diversity in the design, and in the environmental and institutional contexts of PHES projects. It is difficult to reach a categorical conclusion about PHES technology overall, in part because each PHES project is unique and must be evaluated on a case-by-case basis. Our review of recently proposed projects in the United States indicates that PHES developers are adapting and responding to the historical drawbacks of PHES and adopting new approaches to reduce environmental impacts. Some of these new approaches include the use of wastewater in PHES systems and the use of off-stream systems to minimize effects on water quality and biodiversity. It is premature to judge whether these new approaches will be sufficient to make PHES more socially acceptable. If properly deployed, however, PHES could play an important role in a low-carbon electricity system in the United States. Policymakers should reconsider and reassess the potential of PHES in the United States, particularly for coupling with intermittent renewable energy sources such as wind and solar power.

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