CHARACTERIZATION AND ASSESSMENT OF NOVEL BULK STORAGE TECHNOLOGIES

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ABSTRACT

This paper reports the results of a high-level study to assess the technological readiness and technical and economic feasibility of 17 novel bulk energy storage technologies. The novel technologies assessed were variations of either pumped storage hydropower or compressed air energy storage. The report also identifies major technological gaps and barriers to the commercialization of each technology. Recommendations as to where future research and development efforts for the various technologies are also provided based on each technology's technological readiness and the expected time to commercialization (short, medium, or long term).

Keywords: Pumped storage hydropower, compressed air energy storage

INTRODUCTION

The U.S. Department of Energy (DOE) commissioned this assessment of novel concepts in large-scale energy storage to aid in future program planning of its Energy Storage Program. The intent of the study is to determine if any new but still unproven bulk energy storage concepts merit government support to investigate their technical and economic feasibility or to speed their commercialization. The study focuses on compressed air energy storage (CAES) and pumped storage hydropower (PSH). It identifies relevant applications for bulk storage, defines the associated technical requirements, characterizes and assesses the feasibility of the proposed new concepts to address these requirements, identifies gaps and barriers, and recommends the type of government support and research and development (R&D) needed to accelerate the commercialization of these technologies.

BULK STORAGE APPLICATIONS AND REQUIREMENTS

The study identified six applications suitable for large-scale (over 100 MW) energy storage:

- Electric Energy Time-shift
- Electric Supply Capacity
- Load Following
- Renewable Energy Time-shift
- Renewable Capacity Firming (15 to 60, 60 to 120 minutes)
- Wind Generation Grid Integration – Long Duration

The applications technically suited and cost-effective for bulk energy storage are those with long discharge duration (on the order of hours), frequent use, deep discharge depth, response time on the order of a few minutes, with a minimum cycle life (on the order of a few thousand cycles). The technical requirements for these applications were compared to the novel technologies assessed to determine whether the technologies met the needs of the applications.

TECHNOLOGY CHARACTERIZATION

This report characterizes 17 novel concepts in PSH and CAES with capacities greater than 100 MW. In some cases technologies with capacities less than 100 MW are included, given the novelty of the technology or at the request of DOE. Specifically, two of the technologies included are currently available and installed in other countries. Although not novel, these technologies are included at the request of DOE because they are not commercially available in the United States.

The novel PSH technologies considered here incorporate designs with different types of reservoirs (e.g., aquifers, underground salt domes, natural gas caverns, tanks, or the ocean). Some of the novel concepts propose alternative paradigms to an upper and lower reservoir (e.g., in-ground storage pipe and in-reservoir tube); others are ocean-based (the Archimedes' Screw and the Energy Island).

The innovations in the CAES technologies are in the storage vessel, storage medium, energy conversion process, or some other feature of the technology. Unlike traditional CAES, many of the novel technologies do not rely on underground geologic formations to store compressed air; some technologies, such as near-isothermal and underwater CAES, can store compressed air in transportable vessels or underwater bladders. The liquid air energy storage technology stores liquid instead of gas, which provides greater storage density. Other technologies, such as adiabatic and near-isothermal CAES, are considered innovative for their theoretical improvement in the efficiency of the energy conversion process. Vehicle compression and transportable CAES were included for the innovative way that they contribute to distributed generation.

The following 17 technologies assessed in this report are listed in Table 1.

Table 1. PSH and CAES Technologies Assessed.

PSH	Los Angeles
1. Aquifer PSH 2. Archimedes' Screw 3. Underground Reservoir 4. Energy Island 5. In-ground Storage Pipe 6. In-reservoir Tube with Bubbles 7. Ocean PSH 8. Variable-speed PSH	9. Adiabatic CAES 10. Adsorption-enhanced CAES 11. Diabatic CAES 12. Hydrokinetic Energy 13. Liquid Air Energy Storage 14. Near-isothermal CAES 15. Transportable CAES 16. Underwater CAES 17. Vehicle Compression

The characterization of these technologies includes both business and technical characteristics. Information for the assessment was obtained through market research and information provided by companies involved in PSH and CAES R&D.

TECHNOLOGY ASSESSMENT

The technologies were evaluated using a modified Delphi process in which five attributes were considered and given equal weight: (1) technical feasibility, (2) technical maturity, (3) engineering feasibility, (4) economic feasibility, and (5) R&D requirements. Four reviewers assessed each technology and scored each attribute on a scale of 1 to 10. The total score (5 to 50) determined the expected development time frame for the technology.

For this assessment, a score between 40 and 50 represents a technology that is expected to commercialize in the short term (5 years or less). Similarly, a technology with a score between 25 and 40 is expected to commercialize in the medium term (between 5 and 10 years). A technology with a score lower than 25 is expected to commercialize in the long term (after 10 or more years). The time frame to commercialization was also used to determine the type of government support needed to facilitate the development of the technology. Table 2 summarizes the results of the feasibility assessment.

Table 2. Time to Commercialization and Type of Government Support for Novel PSH and CAES Technologies.

	Time to Commercialization		
	Short Term (<5 years)	**Medium Term (5–10 years)**	**Long Term (>10 years)**
Type of Govern-ment Support	• Demonstration • Commerciali-zation Incentives	• R&D • Demonstrations	• R&D
PSH	• Ocean • Variable-speed	• Aquifer • Archimedes Screw • Underground	• In-reservoir Tube with Bubbles
CAES	• Near-isothermal	• Adiabatic • Diabatic • Liquid Air Energy Storage • Underwater	• Adsorption-enhanced • Hydrokinetic Energy • Transportable • Vehicle Compression

In addition to the feasibility assessment, the technologies were given a technology readiness level (TRL) as defined by the DOE. The TRLs for the various PSH and CAES technologies represent the entire range (0 to 9). Such a range is indicative of the different levels of support required to reach commercialization. The general type of support recommended for each technology depends on its stage of development and how soon it is expected to be commercialized.

TECHNOLOGY GAPS, BARRIERS, AND RECOMMENDED R&D

The assessment and the TRL combined helped to determine technological gaps and barriers to commercialization for each of the technologies studied as well as the recommended focus for future R&D. As is the case with most novel technologies, they are in the very early stages of development. Indeed, because many are still in the pre-pilot phase, many companies could not provide test data for this assessment. Additionally, several of the technologies did not have any technical or cost information available. Thus, this report includes technological gaps and barriers and recommends an R&D focus for each technology to the extent possible given the limitations in the data and the early stage of development of the technologies.

In general, PSH and CAES technologies face many barriers, including

- Limited suitable locations (large bodies of water or storage space is required),
- Site-specific engineering (difficult to mass produce),
- Site permitting issues,
- Long deployment time, and
- Being too large for distribution-level applications.

CONCLUSIONS

This assessment serves as an initial high-level review of novel technologies. The report characterizes and assesses the technologies and provides information on the gaps, barriers, and recommended R&D focus for each technology based on the level of information available. A more detailed assessment of selected individual technologies would be needed to determine the extent of the required support, should DOE decide to pursue further development of any of these technologies. In general, a clear commitment and sustained interest in meeting the nation's energy needs with the entire range of possible solutions would help facilitate the development of these technologies.

Some of the technologies may seem "futuristic" or are at early stages of development. Nevertheless, the range of technologies that were reviewed and the applications these technologies are trying to meet reflect an interest in resolving the current and future challenges facing the U.S. power system. These technologies, if developed, could help address bulk storage needs, especially as large amounts of renewable generation are integrated.

ACKNOWLEDGMENTS

This work was funded and supported by the DOE's Office of Electricity Delivery and Energy Reliability and Office of Energy Efficiency and Renewable Energy. The authors want to thank Dr. Imre Gyuk of DOE for providing useful insights and overall direction to this project.

The authors are also appreciative of the various companies that provided helpful input on the novel pumped storage hydropower and CAES technologies assessed in this report.

BIOGRAPHICAL NOTE

Conference presenter: Poonum Agrawal provides technical analysis, management, and strategic planning related to energy technology research and development (R&D), sustainability, and climate analysis. She has over 12 years of experience in the energy and environment field, particularly on issues of data collection and analysis, microgrids R&D, electricity transmission, and market analysis. Her experience spans across the executive and legislative branches of government as well as the private sector. She has a Master's degree in Technology Policy from MIT and a dual Bachelor's degree in Chemical Engineering and International Relations from Tufts University.