Commercialization of Pumped Storage Hydropower Technologies

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HydroWIRES

In April 2019, WPTO launched the HydroWIRES Initiative[1] to understand, enable, and improve hydropower and pumped storage hydropower's (PSH's) contributions to reliability, resilience, and integration in the rapidly evolving U.S. electricity system. The unique characteristics of hydropower, including PSH, make it well suited to provide a range of storage, generation flexibility, and other grid services to support the cost-effective integration of variable energy resources.

The U.S. electricity system is rapidly evolving, bringing both challenges and opportunities for the hydropower sector. While increasing deployment of variable energy resources have enabled low-cost energy in many U.S. regions, it has also created an increased need for resources that can store energy or quickly change their operations to ensure a reliable and resilient grid. Hydropower (including PSH) is not only a supplier of bulk, low-cost energy but also a source of large-scale flexibility and a force multiplier for other power generation sources. Realizing this potential requires innovation in several areas: understanding value drivers for hydropower under evolving system conditions, describing flexible capabilities and tradeoffs associated with hydropower meeting system needs, optimizing hydropower operations and planning, and developing innovative technologies that enable hydropower to operate more flexibly.

HydroWIRES is distinguished by its close engagement with the DOE National Laboratories. Five National Laboratories—Argonne National Laboratory, Idaho National Laboratory, National Laboratory of the Rockies, Oak Ridge National Laboratory, and Pacific Northwest National Laboratory—work as a team to provide strategic insight and develop connections across the HydroWIRES portfolio as well as broader DOE and National Laboratory efforts such as the Grid Modernization Initiative.

Research efforts under the HydroWIRES Initiative are designed to benefit hydropower owners and operators, independent system operators, regional transmission organizations, regulators, original equipment manufacturers, and environmental organizations by developing data, analysis, models, and technology research and development that can improve their capabilities and inform their decisions.

More information about HydroWIRES is available at https://energy.gov/hydrowires.

[1] Hydropower and Water Innovation for a Resilient Electricity System ("HydroWIRES")

Commercialization of Pumped Storage Hydropower Technologies

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Executive Summary

Argonne National Laboratory and the National Laboratory of the Rockies are partnering on this Commercialization of Pumped Storage Hydropower Technologies study to garner lessons learned from pumped storage hydropower (PSH) industry experts and investors to help drive new PSH technologies and projects through challenging commercialization and development stages. This report is designed to present insights, lessons learned, and best practices relevant to those with an interest in highlighting, informing, or advancing these PSH commercialization efforts. Target audiences for this report extend from PSH stakeholders to community groups and the general public.

Background

The U.S. electricity system is rapidly evolving, bringing both challenges and opportunities for the hydropower sector. While new electricity generation is needed in the coming decades for new data centers, manufacturing and consumer demand growth, it has also increased the need for resources that can store energy or quickly change their operations to ensure a reliable and resilient grid.

PSH currently provides over 90% of U.S. utility-scale energy storage, balancing supply and demand and supporting reliable and economical grid operations. PSH is a proven, reliable, and efficient energy storage technology that can integrate large amounts of variable generation resources. (Uría-Martínez et al. 2023).

In addition, PSH is the most mature and most widely commercially available long-duration energy storage technology, as most PSH projects have the capability to provide 8, 10, or more hours of energy storage at full capacity. This longer-term storage capability contributes to grid resilience and can help the grid overcome disturbances and disruptions, such as extreme weather events and reduce the impacts of cyber or physical attacks.

However, despite all the benefits and contributions that PSH provides to the grid, there has been relatively little new PSH capacity added to the U.S. grid in the last 25 years. Except for one small PSH plant that was commissioned in 2012 and capacity upgrades at existing PSH plants, there have been no new PSH projects developed in the U.S. since the mid-1990s.

The unique characteristics of hydropower, including PSH, make it well-suited to provide a range of storage, generation flexibility, and other grid services to support the cost-effective integration of variable energy resources. Hydropower, including PSH, is not only a supplier of bulk, low-cost, dispatchable energy but also a source of large-scale flexibility and a potential force multiplier for other power generation sources.

Realizing this potential requires advances in several areas: understanding value drivers for hydropower under evolving system conditions, describing flexible capabilities and trade-offs associated with meeting electric power system needs through hydropower, optimizing hydropower operations and planning, and developing innovative technologies that enable hydropower to operate more flexibly.

Currently, there are 43 PSH plants in the United States, and there is significant potential to add much more PSH capacity, with 96 PSH projects in the U.S. development pipeline at the end of 2022. Of the 96 proposed new PSH projects, 78 are closed-looped PSH projects where the reservoirs are not connected to existing natural water bodies such as a river or lake. Open-loop PSH projects are connected to a naturally flowing water feature. Closed-loop PSH configurations allow for more plant siting flexibility and their environmental impacts are generally lower. Since 2019, closed-loop projects have been eligible for a shorter two-year licensing process with the Federal Energy Regulatory Commission if the project can document low environmental impacts such as limited change to surface or groundwater flows and limited adverse effects on threatened species. U.S. PSH plants provide long-duration energy storage with an estimated median storage duration of 12 hours. (Uría-Martínez et al. 2023). While PSH facilities are the primary source for long-duration energy storage today, the development of new PSH projects remains a significant challenge owing to multiple factors that will be examined in this study.

Part of the mission of the U.S. Department of Energy's (DOE's) Water Power Technologies Office (WPTO) is to conduct research, development, and other activities to advance transformative, cost-effective, reliable, and environmentally sustainable hydropower and pumped storage technologies. In April 2019, WPTO launched the Hydropower and Water Innovations for a Resilient Electricity System (HydroWIRES) Initiative to understand, enable, and improve hydropower and PSH's contributions to reliability, resilience, and integration in the rapidly evolving U.S. electricity system.

HydroWIRES is distinguished by its close engagement with the DOE national laboratories. Five national laboratories—Argonne National Laboratory, Idaho National Laboratory, National Laboratory of the Rockies, Oak Ridge National Laboratory, and Pacific Northwest National Laboratory—work as a team to provide strategic insight and develop connections across the HydroWIRES portfolio as well as broader DOE and national laboratory efforts such as the Grid Modernization Initiative.

Research efforts under the HydroWIRES Initiative are designed to benefit hydropower owners and operators, independent system operators, regional transmission organizations, regulators, original equipment manufacturers, and environmental organizations by developing data, analysis, models, and technology research and development that can improve their capabilities and inform their decisions.

Objectives

To support the HydroWIRES Initiative, the Commercialization of Pumped Storage Hydropower Technologies study was developed to go beyond literature review and gather direct industry insights, lessons learned and best practices from interviews and webinars with industry specialists to create this report for PSH stakeholders and the general public. Study findings were used for additional activities, including an online resource hub providing PSH resources, tools and networking opportunities to the public.

The primary purpose of this study is to garner lessons learned from PSH industry experts and investors to help drive PSH innovations and projects through challenging commercialization and project development stages. The study advances DOE's broader goal to support pathways for PSH technology advances and capacity additions via three pillars:

- **PSH commercialization assessments** to examine potential market opportunities and challenges that may impact new PSH technologies and projects.
- **Education** to share lessons learned, best practices and next steps to advance PSH innovations and construction projects through commercialization and project development stages.
- **Networking** via an online resource hub to connect PSH researchers and developers with technology accelerators, funding sources, and other PSH specialists offering mentoring and support.

Researchers explored key challenges faced by developers of PSH projects and innovators seeking to commercialize new technologies to improve PSH design, siting, construction and operations. Along with highlighting challenges, the study sought to identify best practices in developing new PSH projects and technology innovations, as well as avenues by which DOE and national laboratories can help support and streamline the PSH commercialization and project development processes.

The study was also used to inform and guide additional project activities for the Commercialization of PSH Technologies project, including developing an online resource hub to serve as a central resource to gather information and networking opportunities for PSH developers and stakeholders, and designing a financial modeling tool to enable PSH stakeholders to create project financing scenarios and projected financial outcomes for projects.

Results – Key Findings

The study examined major themes and takeaways gathered from stakeholder interviews and webinars to highlight the opportunities, challenges and lessons learned with respect to moving forward along commercialization pathways for PSH projects and technology innovations. The interviews highlighted that there is a renewed promise for PSH in many areas of the U.S. However, challenges remain where DOE and national laboratories have the opportunity to provide support to advance development of PSH projects and innovative technologies in the U.S.

Table ES-1 highlights key findings from interviews and the webinar to capture insights on challenges, lessons learned and best practices, and how DOE and national laboratories can help.

Table ES-1. PSH Commercialization Challenges, Lessons Learned, Best Practices and How DOE and National Labs Can Help

PSH Commercialization Challenges?	What Works? Best Practices and Lessons Learned	How Can DOE and National Labs Help?
►**PSH Development Timelines:** PSH project completion can take 7+ yr (license application 5–6 yr/construction 3–5 yr).	• Long-term relationships with power authorities and utilities • PSH performance track records • Innovations to shorten construction • See PSH as a backup and support to meet electricity generation needs	Develop resources and tools to: • Reduce cost of learning curve by sharing lessons on advancing through PSH project stages • Develop PSH valuation model to value PSH services • Quantify job, infrastructure, retrofit work • Run energy mix scenarios • Apply non-U.S. lessons (Australia, Swiss project management, etc.)
►**Licensing Process Challenges:** Long license permitting timelines can occur with regulatory authorities at state and federal levels.	• Early site evaluations before starting licensing process • Smaller greenfield sites • Early regulatory feedback • Timely responses, and education	• Use energy mapping tools for siting • Simulation models for scenarios and risk assessments • Success cases to build awareness with regulators
►**Environmental Challenges:** Water quality, flora/fauna impact, siting far from transmission lines, elevations, etc., can present hurdles to development and commercialization.	• Closed-loop PSH and brownfield sites to reduce impacts and evaluation times • Narrowing studies to 1–2 breeding seasons of threatened species	• Evaluate fish-friendly infrastructure • Examine innovations to limit environmental impacts (e.g., reservoir liners) • Identify success with EPA collaboration, community groups
►**Financing and Investment Challenges:** Risk of project delays due to extended licensing and construction periods, timing of revenues, and cost escalations can be barriers to securing financing from lenders and investors.	• Identifying value of PSH's flexible long-duration energy storage, grid balancing • Defining PSH parameters before going to market • Benefitting from PUC approval with capital spending plan • Seeking investment backstops	• Provide financial closing modeling tools • Value PSH services • Examine impacts of insurance, guarantees, investment tax credits, and other risk-mitigation options • Run return-on-investment scenarios
►**Community and Social Challenges:** New PSH facilities have social and economic impacts; need to meaningfully connect with communities during PSH development to ensure benefits are maximized for those affected.	• Early meetings with tribes and communities • Early town halls to gather concerns • Changing construction traffic flows • Avoiding culturally and historically significant tribal sites	• Study leveraging existing infrastructure (retrofits, non-powered dams, abandoned mines, seawater) • Study economic benefits over decades for job and business growth
►**PSH vs. Competing Technologies:** Competing technologies such as	• Closed-loop PSH energy storage option offers benefits over competing technologies when	• Evaluate value of ancillary services, digital operation of PSH

PSH Commercialization Challenges?	What Works? Best Practices and Lessons Learned	How Can DOE and National Labs Help?
short-term energy storage (batteries) can have certain advantages over PSH because of quicker licensing and construction.	comparing life-cycle greenhouse gas emissions and long-lived PSH plants vs. the need for shorter-term battery replacement/disposal.	(smart coupling with batteries, power generation plants).

Through discovery interviews, researchers identified the above challenges along with related lessons learned, best practices, and opportunities for DOE and national laboratories to help fill in gaps, conduct further study, and support advancement of PSH technology innovations and project development.

Key Takeaways

Key takeaways from the study focus on measures and actions PSH developers and technology innovators could take to facilitate PSH commercialization efforts. They can be summarized as follows:

- PSH stakeholders must continue to move beyond old narratives about PSH technology and its challenges related to siting, land use constraints, environmental impacts, and costs. With appropriate innovations and project siting, these issues can be addressed.

- PSH innovators have shared feedback that more educational opportunities such as webinars on the role and value of PSH plants in electric power systems, would help PSH developers provide utilities and market operators with information on PSH technologies and value of their services provided to the grid.

- PSH developers and innovators need access to resources that can help connect them to a pool of potential investors. Guidance on evaluating the value of PSH projects and innovators would support PSH stakeholder efforts to work with governing organizations, regulators, power purchasers and consumers, investors and communities.

- Identifying ways to efficiently navigate the licensing process will support PSH stakeholders in advancing projects and limit potential delays in gaining approvals.

References

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List of Acronyms and Abbreviations

Argonne	Argonne National Laboratory
BAU	business as usual
CAISO	California Independent System Operator
CAPEX	capital expenditures
DOE	U.S. Department of Energy
EDAM	Extended Day-Ahead Market
EIA	U.S. Energy Information Administration
EPA	U.S. Environmental Protection Agency
ERCOT	Electric Reliability Council of Texas
FERC	Federal Energy Regulatory Commission
GEM	Geospatial Energy Mapper (computer model)
GW	gigawatt
Hydro-WIRES	Hydropower and Water Innovations for a Resilient Electricity System
IOU	investor-owned utility
IPP	independent power producer
IRP	integrated resource planning
ISO	independent system operator
ISO-NE	Independent System Operator of New England
MAD	Mid-Atlantic Dominion
MISO	Mid-Continent Independent System Operator
MW	megawatt
NERC	North American Electric Reliability Corporation
NHA	National Hydropower Association

NIMBY	not-in-my-backyard
NPD	non-powered dam
NLR	National Laboratory of the Rockies
NYISO	New York Independent System Operator
O&M	operations and maintenance
OEM	original equipment manufacturer
PJM	Pennsylvania-New Jersey-Maryland
PPA	power purchase agreement
PPE	Public Power Entities
PSH	pumped storage hydropower
PUC	public utilities commission
PV	photovoltaics
QSE	Qualified Scheduling Entity
ROI	return on investment
RPM	Reliability Pricing Model
RPS	renewable portfolio standard
RTO	regional transmission organization
SEEM	Southeast Energy Exchange Market
SPP	Southwest Power Pool
TMNSR	Ten-Minute Non-Spinning Reserves
TMOR	Thirty-Minute Operating Reserves
TMSR	Ten-Minute Spinning Reserves
TRL	technology readiness level
USACE	U.S. Army Corps of Engineers
VRE	variable renewable energy

WEIM	Western Energy Imbalance Market
WEIS	Western Energy Imbalance Service
WPTO	Water Power Technologies Office

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1.0 Introduction

The goals of supporting energy supply resiliency and expanding energy capabilities in the U.S. have led to renewed interest in expanding and building pumped storage hydropower (PSH) facilities and developing innovative PSH technologies to improve operating performance, reduce production and construction costs, reduce environmental impacts and expand potential locations for PSH facilities, either stand-alone or in combination with other energy generation. This study focuses on moving beyond literature reviews to getting direct insights and feedback from a broad spectrum of PSH stakeholders on current challenges to their projects, and more importantly, lessons learned and best practices to respond to these challenges, and how the U.S. Department of Energy (DOE) and the national laboratories can support their needs to move PSH development and technology innovations forward.

Over the last two decades, the United States has deployed a rapidly expanding fleet of inverter-based renewable energy technologies, such as wind turbines and solar photovoltaics (PV), that generate electricity intermittently. To integrate these variable renewable energy (VRE) sources into the evolving U.S. energy system at the levels needed to satisfy new electricity generation for data centers and manufacturing complexes while also maintaining grid reliability, a significant expansion in energy storage capacity is imperative.

Since the 1930s, PSH has been the main grid-scale energy storage technology in the United States, balancing supply and demand and supporting reliable and economical grid operations. The U.S. Energy Information Administration (EIA) reports that PSH provides about 22 gigawatts (GW) of U.S. energy storage capacity, which is highest among all utility-scale energy storage technologies (EIA 2023).

Although batteries and other energy storage technologies are also being deployed for grid duties, PSH has been established as a proven, reliable, and efficient energy storage technology that can support high penetrations of VRE generation. In addition, PSH is currently the most mature and widely commercially available long-duration energy storage technology, as most PSH projects have the capability to provide 8, 10, or more hours of energy storage at full capacity. This longer-term storage capability contributes to grid resilience and can help the grid overcome disturbances and disruptions, such as extreme weather events and cyber or physical attacks.

Despite all the benefits and contributions that PSH provides to the grid, however, significant challenges and barriers hinder the development and construction of new PSH projects. Except for one 40-megawatt (MW) PSH plant commissioned in 2012 and capacity upgrades at existing plants, there have been no new large-scale PSH projects developed in the United States since the mid-1990s (Rosenlieb et al. 2022).

The Federal Energy Regulatory Commission (FERC) permits and licenses nonfederal PSH projects in the United States. As of December 2024, FERC had issued licenses for 2,093 MW of new PSH capacity (Uria-Martinez et al. 2023) and had issued preliminary permits for 41,611 MW of PSH capacity (FERC 2024). A preliminary permit does not guarantee that proposed projects will receive operating licenses from FERC; it simply holds a place in the licensing queue for projects undergoing technical and economic evaluation.

The key driver for this study is to examine the challenges hindering development of PSH facilities and advancement of PSH technology innovations through development and licensing stages, and to learn from literature review and directly from PSH stakeholders (a) the lessons learned and best practices in navigating through the challenges and (b) how DOE and the national laboratories can support industry needs to move PSH development projects and innovations to commercial start-ups and applications.

1.1 Purpose and Objectives

Argonne National Laboratory (Argonne) and the National Laboratory of the Rockies (NLR) conducted this study to inform, develop, and support PSH commercialization and deployment efforts by DOE's Water Power Technologies Office (WPTO). While the primary focus is to identify avenues by which DOE and national labs can facilitate the PSH commercialization and development processes, WPTO also intends to connect the study to other national initiatives to advance electricity generation, energy storage, and resilient and secure power grids.

The overarching goal of this study is to garner lessons learned from PSH industry experts and investors to help drive new PSH technologies and deployment projects through challenging commercialization and development stages.

Guided by that goal, the research team sought to:

- Review the current PSH market environment to inform the stakeholders;
- Examine challenges that may hinder the commercialization of new technologies and the construction of new projects;
- Identify lessons learned, best practices, and potential pathways to advance PSH technology innovations and infrastructure projects; and
- Explore key challenges faced by developers of PSH projects and innovative PSH technologies.

To maximize the impact of its research, the team intends to leverage the study's findings to inform the development of an online resource hub for PSH developers and stakeholders seeking information and networking opportunities.

1.2 Organization and Scope

Sections of this report were organized to serve as a topic-driven guidebook to access summaries of challenges, lessons and best practices learned from industry experts via literature review, interviews, and webinar discussions. Each section was designed to enable users to quickly gather findings via summary tables and to offer more detailed discussions of challenges and key takeaways on lessons learned and best practices to help PSH stakeholders navigate through challenges to advance their projects. Each section also highlights potential opportunities for DOE and national labs to address barriers to PSH technology advances and project development. The contents of the Challenges, Lessons Learned and Best Practices sections are summarized below.

- **PSH Project Challenges:** Section 3.1 provides an overview of the overarching technical, innovation, financial, market, environmental/regulatory and social challenges faced by PSH developers, and how national laboratories can help PSH stakeholders meet these challenges.

- **PSH Technology Challenges:** Section 3.2 summarizes key challenges and best practices that can support advancing through commercialization pathways for PSH technology innovations, followed by a discussion of how national laboratories can help PSH stakeholders advance development of new PSH technologies.

- **Market Needs:** Section 3.3 focuses on building an understanding of how PSH competes in markets and what would encourage utilities and investors to support PSH to meet market demands for new electricity generation , long-duration storage and project returns. This includes discussion on how national laboratories can support identifying the value of PSH in serving market needs. Detailed reviews of different wholesale competitive power market needs are provided in Appendix A.

- **Environmental and Regulatory Challenges:** Section 3.4 examines potential environmental impacts and licensing/regulatory challenges faced by PSH developers, followed by lessons learned and best practices.

- **Community Business Development Outreach and Engagement Challenges:** Section 3.5 focuses on how communities can be engaged when it comes to PSH development and construction.

- **Technical Assistance:** Section 3.6 provides more in-depth summaries of how DOE national laboratories can help PSH development and what kinds of assistance the projects need at different stages.

1.3 Methodology

The research was structured around two efforts: a literature review and stakeholder interviews.

1.3.1 Literature Review

A literature review of PSH commercialization reports and activities provided foundational context and background for the study, including an initial list of commercialization challenges and lessons learned. The literature review focused on examining published overviews of PSH project and technology development, including reports by DOE, national laboratories and major hydropower industry organizations. The research was analyzed to inform the discovery of major challenges facing PSH stakeholders and organized by major topics for more detailed review.

The literature review helped the research team customize questions for the subsequent interviews.

1.3.2 Stakeholder Interviews

Numerous interviews were conducted with PSH commercialization experts and PSH stakeholders, including PSH developers, innovators, utilities, original equipment manufacturers (OEMs), regulatory/licensing specialists, and community business development and engagement experts.

Essential to advancing commercialization and deployment of PSH technologies is to identify challenges faced by PSH developers and innovators, and, more importantly, gather lessons learned and best practices culled from their experience. This was accomplished through PSH stakeholder interviews and two virtual webinars. They served not only to discuss challenges in developing PSH projects and innovations toward commercial start-up and deployment, but to focus on lessons learned and best practices to overcome and navigate through challenges to move PSH projects and technology innovations forward.

Both efforts revealed several lessons on how building awareness and demonstrating a track record of performance of PSH services and operational benefits have helped de-risk concerns and challenges in developing PSH facilities and technologies. Findings from early stakeholder interviews were incorporated to customize questions for subsequent interviews to encourage new approaches and more in-depth discussions.

Interviews were conducted via virtual meetings, with customized questions designed to get more detailed responses on the following challenges facing the five identified groups of PSH stakeholders:

- **PSH developers, consultants and investors:** to advance new PSH facilities and technologies.
- **PSH technology innovators and incubators:** to examine the needs to advance technologies and potential use of innovations in new PSH facilities.
- **OEMs:** to construct and operate PSH facilities and PSH technologies.
- **Utilities and regional/local power authorities:** to purchase PSH services and use power purchase agreements (PPAs) in contracting.
- **Hydropower industry organizations and local community outreach organizations:** to work with PSH developers and innovators to build awareness of the benefits provided by PSH plants and engage and collaborate with communities to develop PSH facilities and PSH technologies.

Interviews were conducted with over 60 PSH stakeholders who were interviewed individually or in small groups from the same organization or affiliated organizations. To foster open discussions, the project team informed interviewees that discussions would be summarized and would not be attributed to individuals or organizations.

Each stakeholder group was asked three main questions:

- What were the key challenges in developing PSH projects and new PSH technology innovations?
- What lessons learned have informed solutions to move PSH projects and technology innovations forward?
- What is needed to drive/support future PSH projects and technology innovations, and how can DOE and national laboratories help fill any gaps?

Each of the interviews with PSH stakeholders started with these three main questions regarding key challenges, lessons learned in finding solutions, and how DOE and national laboratories can help. Each interview then shifted to customized questions specific to each PSH stakeholder group to examine special needs and examples of progress in meeting challenges.

To gain a deeper understanding of PSH challenges, lessons learned, and needs, additional questions were customized to the expertise and experience of the five groups of PSH stakeholders, as outlined in Table 1 below.

Table 1. Interview Questions Developed for Five PSH Stakeholder Groups

Commercialization of PSH Technologies: Interview Questions for PSH Stakeholders, Industry, Community Organizations
Three main questions for all interviews - challenges, lessons learned & needs 1. What were the key challenges in developing PSH projects and new PSH technologies? 2. What lessons were learned to identify solutions to move forward with PSH projects? For example, what were small steps that worked, ways to engage/collaborate, or key criteria/metrics needed to generate support and approvals? 3. What is needed to drive/support future PSH projects and how can DOE and national labs help to fill any gaps?
Questions for PSH Developers, Consultants and Investors
• What are the top three nonpolicy reasons hindering U.S. (vs. non-U.S.) development of PSH projects and technologies? • What are the key challenges in developing PSH projects and innovative PSH technologies faced through stages of development with interactions with collaborators, investors and regulators? • Have you faced or observed any issues related to licensing, financing, or finding long-term PPAs (or markets for PSH power and grid services)?
Questions for PSH Technology Innovators and Incubators
• What is the potential outlook for PSH technology? • What are the key needs to improve the outlook for PSH technology? • Which technology is most likely to succeed?
Questions for PSH OEMs

- How do OEMs see the prospects of new PSH in the United States?
- What are key challenges OEMs face in working with partners?
- What new PSH technologies may accelerate PSH development or make it more likely (by reducing costs, improving performance, and/or reducing environmental impacts)?

Questions for Utilities and Regional/Local Power Authorities

- What types of capabilities brought you to consider PSH?
- What capabilities/features would you like to see developers offer that are missing from their offerings today?
- What is your primary point of concern when it comes to PPAs and purchase of PSH services?
- If you could ask developers to change one thing about their PSH offering, what would it be?

Questions for Hydropower Industry Organizations and Local Community Outreach Organizations

- Key challenges to engage stakeholders and build awareness of PSH contributions to local communities?
- What lessons learned or small steps have worked to engage, collaborate, generate support and effect changes in views?
- What strategies or tactics can be used to raise public awareness about the benefits of PSH for new electricity generation?

Subsequently, key takeaways drawn from the compiled responses to the interviews were used to form follow-up discussion topics for a pilot webinar. This pilot webinar served to introduce the project to a wider audience, encourage more in-depth discussions on topics of strong interest from the interviews and discuss what is needed to support PSH stakeholders and serve communities. Findings and learnings from the pilot webinar were used to conduct and structure a follow-up webinar.

1.3.3 PSH Stakeholder Webinars

PSH stakeholder webinars were conducted via virtual meetings with invitations across all PSH stakeholder groups, with the goals of reaching a broader audience and delving more deeply into topics discussed during the interviews. The webinars, hosted by the Argonne and NLR project team, included over 50 participants and were structured to provide initial interview summary findings per topic that were followed quickly by posing new questions to prompt responses. As with the interviews, to encourage active discussions, webinar attendees were informed that discussions would be summarized with no attributions to individuals or companies. A similar process was conducted by Argonne and NLR project team members to invite attendees to the second webinar, which introduced key project findings plus plans to build resources and tools for PSH stakeholders for feedback and suggestions. Findings from the webinars are embedded in the following sections of this report.

1.3.4 Synthesis of Interviews and Webinars

The information gathered from the interviews and webinars was organized into summarized notes. Information was also organized in accordance with the different categories of stakeholders.

This report does not attribute any details, opinions, or insights to specific stakeholders that were interviewed or to specific webinar attendees.

From the information gathered through stakeholder interviews and webinar sessions, the research team synthesized the key takeaways on challenges faced by the commercialization of PSH in the United States into the following six categories:

- **PSH Project Challenges** include overarching technical, innovation, financial, market, environmental/regulatory and social challenges faced by PSH developers.

- **PSH Technology Challenges** include the potential outlook for new PSH development in the United States and the key requirements to improve the outlook for PSH technologies.

- **Market Needs** include examining how PSH can compete against other storage technologies in meeting market demands for new electricity generation , long-duration storage and generating project returns to encourage funding for projects and technology innovations (in both traditional vertically regulated and wholesale competitive power markets).

- **Environmental and Regulatory Challenges** include the environmental impacts and licensing/regulatory challenges and potential processing delays faced by PSH developers, innovators and investors.

- **Community Business Development Outreach and Engagement Challenges** include proactively engaging and responding to stakeholder concerns on the siting, development or management of energy infrastructure projects and potential impacts on local communities, consumers and regional energy markets.

The stakeholder interviews and webinars with PSH industry experts, investors and community organizations also garnered key takeaways and insights from lessons learned through confronting challenges, which are presented as best practices for addressing the challenges.

These insights, in turn, will help inform DOE and national labs in designing and implementing technical assistance efforts to advance PSH technology and project development at various stages, as well as additional activities, such as networking opportunities, to support innovators and developers in identifying pathways to move PSH technology commercialization efforts and construction projects forward.

In addition, to complement the above work, a State of the Wholesale Electricity Markets document was developed that will provide stakeholders with easy-to-access information that summarizes storage need projections and market opportunities for the seven independent system operators (ISOs) plus the Western and Southeastern wholesale market regions. Findings from interviews and webinars were used to create short “market opportunities fact sheets” for each region, which are included in Appendix A.

2.0 Summary of Findings—Challenges, Lessons, and Best Practices

This section discusses major themes and takeaways that emerged from the PSH challenges and lessons learned gathered through stakeholder interviews. More details on the insights and opinions provided by various industry experts and stakeholders during their interviews with the study team are provided in Section 3.0.

During interviews and webinars, PSH stakeholders emphasized the following:

PSH has a competitive advantage for long-term horizons, but decision-makers typically prioritize short-term horizons.

PSH offers a competitive advantage stemming from its long lifespan (typically 50–100 years or longer), while competing storage technologies like batteries have comparatively short lifespans (typically 10–15 years or shorter). From the perspective of an interviewed stakeholder, in the process of integrated resource planning (IRP), policymakers tend to characterize PSH on the basis of pumping/generating duration, while not completely reflecting the capabilities of the technology. For example, in California, the public utilities commission (PUC) characterized PSH as a 12-hour asset to get it to qualify in the PUC's IRP planning model (Siegele 2023). On the other hand, a PSH stakeholder characterized PSH as a very flexible storage technology that can satisfy operational needs for both short- and long-term energy storage. A better understanding should be developed of PSH operational capabilities, which allow it to provide energy and power over a wide range of durations, depending on the power system needs.

Owing to the long project licensing and construction process, investors may view PSH projects as high-risk investments during the pre-licensing phase.

PSH stakeholders noted how projects face high investment risks because of potentially long permitting and licensing phases to secure approvals and because of large initial capital expenses. Interviewed PSH stakeholders see the licensing process as one of the leading factors causing elongated schedules, unexpected expenses and uncertainties during the project development period.

Perceptions exist that potential alternative technologies emerging in 10 years may replace the need for PSH and deter decision-makers from proceeding with PSH.

PSH has a 50- to 100-year lifespan. However, several interviewees pointed out that, owing to the long preliminary steps and the consequent subsequent uncertainties, which delay the completion and implementation of PSH projects, there is a risk that new alternative storage technologies may appear during the process, which may potentially undermine investing in PSH projects.

Building public awareness of PSH benefits is important for public buy-in.

The stakeholder interviews suggested that providing early educational/workshop opportunities can be instrumental in building public awareness of PSH benefits and subsequently help avoid the misunderstandings that could foster reluctance in the community. Along with building awareness of PSH benefits, it is important to gain the support of the local community, landowners, and other stakeholders. The NIMBY ("Not in My Backyard") syndrome can greatly influence the political landscape and so it is important to engage folks locally to create an interest in the project. Demonstrating PSH benefits, such as tax benefits, can help garner political support.

Making the financial case is an important factor in engaging investors and development partners.

A big part of making the financial case for PSH to development partners, investors and power purchasers is being able to demonstrate success stories or testimonials to reinforce its "proof of performance." There is also a need to identify a path to revenue recovery to get PPAs signed and evaluate how market changes can influence potential PSH project revenue streams and thus financial viability. Another aspect to investigate is the challenges faced by PSH projects in successfully achieving financial closing and the best practices to avoid or mitigate these financial challenges. All these actions can support the development of a successful business model for PSH projects.

PSH innovations: how to 'jump-start' development of technology innovations with funding, then 'demo' the technology to validate and de-risk performance measures.

New PSH concepts and innovations may offer potential new capabilities, operational efficiencies, and construction enhancements that could enable an expanded role of PSH facilities in providing support for variable energy generators, long- and short-duration energy storage, operational flexibility, power grid resiliency, and power system expansion goals. PSH innovations can offer opportunities to address current challenges by reducing the cost and time required for the construction of new PSH plants in the United States and enabling more locations for the siting of new PSH facilities, while limiting potential environmental impacts. Examples of new PSH technology innovations and applications include using tunnel boring machines to reduce construction costs or adding modular reservoir units to reduce environmental footprints and provide flexibility for plant expansions (Koritarov et al. 2022).

New methods and technologies could improve the economic and financial viability of PSH projects to make the case that PSH can provide attractive energy storage solutions to meet the needs of evolving power grids. Developers of PSH innovations continue to seek new funding to advance their technologies through successive commercialization stages, including the following: 1) research phase; 2) prototyping and demonstration phase; 3) evaluation and scenario modeling phase for validation and to examine pathways to reduce perceived risks; and 4) market launch and adoption stages.

PSH innovations: finding pathways to funding for development and market adoption.

While finding funding sources at each stage of development may be challenging, interviews revealed that many innovators have found pathways to funding sources, from early-stage research and development to industry partners at later stages of development.

Common takeaways from interviews with PSH stakeholders on how to advance development of PSH innovations:

These included suggestions for further education to build awareness of how PSH innovations offer the following:

- New opportunities to lower PSH project costs.
- The capability for smaller PSH projects in combination with electricity generators to fill power and energy storage needs.
- Reduced environmental footprints and potential impacts to pave the way for shorter licensing timelines and faster construction of new PSH facilities.

PSH innovators also noted that some technological innovations are using technologies or methodologies that have been proven in other industries and could be applied to PSH projects as well. This approach could lead to shorter concept-to-commercialization pathways to develop new PSH capacity. For example, from the study *A Review of Technology Innovations for Pumped Storage Hydropower* (Koritarov et al. 2022), innovations under development include modifications and improvement of current technologies such as proposed advances in excavation and PSH construction methods to potentially reduce costs and shorten construction timelines of new PSH plants.

Potential ways to resolve challenges and find pathways to PSH commercialization

After facing commercialization challenges for years, many PSH developers and innovators are seasoned in finding innovative ways to collaborate with communities, industries, regulators, and funding sources to move forward with their projects.

- Interviews with PSH stakeholders revealed the best practices and lessons learned to forestall or resolve multiple commercialization challenges.
- Discussions with PSH stakeholders examined pathways to meet each of the challenges presented in the following sections.

3.0 Challenges, Lessons Learned & Best Practices

The following sections summarize the findings and insights obtained during the interviews that were conducted with PSH developers, innovators, and other stakeholders.

3.1 Challenges and Opportunities to Advance PSH Projects and Technology Innovations to Commercial Startup and Deployment

3.1.1 Key Takeaways

The United States currently has 43 PSH plants that have demonstrated the technology's benefits in cost savings, operational efficiencies, and improved grid services (flexibility, resilience, and ancillary services) (U.S. Department of Energy n.d.). The United States has a significant resource potential to supplement the current PSH capacity with new PSH plants, according to the PSH resource assessment performed by NLR (Rosenlieb et al. 2022). However, according to our findings from the stakeholder interviews conducted, certain barriers need to be overcome for this to happen. The key challenges identified were as follows:

- ***PSH Development Timelines***

The PSH project development process involves several years of permitting, environmental studies, and engineering design before the start of construction. PSH project completion can take 7 years or longer, given that the FERC license application process can take about 5 years and construction can take another 4 to 5 years (Oakes 2022).

- ***Financing/Investment Challenges***

PSH projects with total project costs surpassing $1 billion may need significant capital and long-term revenue certainty (Schilling et al. n.d.). Both present challenges, considering the relatively long project development timelines and the associated uncertainties. PSH developers interviewed indicated that this uncertainty is often a significant obstacle for utilities and other potential PSH developers, especially when they see clear pathways to develop and implement battery energy storage or other advanced energy infrastructure projects in 2–3 years or less.

- ***Licensing Process Challenges***

Many PSH project developers have been facing long licensing and permitting timelines from various regulatory authorities at the state and federal levels. Uncertainties in the licensing process can result in longer license processing times and unexpected project costs. Additional challenges and resistance from local populations or landowners could result in further delays before the license is granted

- ***Siting and Environmental Challenges***

Interview and webinar participants discussed how PSH projects can face challenges when it comes to project siting because of the distance to transmission lines, the limited number of project sites with relatively low L:H ratio (where L is the length of the waterway between the upper and lower reservoirs and H is the hydraulic head), and the large land footprint the PSH reservoirs require.

PSH projects may have to go through lengthy multi-year environmental impact review processes. However, the building of closed-loop PSH projects on brownfield sites with pre-existing environmental impact reviews could offer some potential for making the process more efficient. During interviews, PSH developers and consultants noted that generally, there tend to be concerns regarding adverse impacts on water quality and availability and on the natural aquatic and terrestrial flora and fauna present at the project site.

- ***Inflation/Supply Chain Issues***

Even if a project successfully navigates supply chain constraints when it comes to components, it can face supply chain issues with respect to labor (Manwaring 2023). At least one stakeholder interviewee said that inflation could cause a significant increase in the overall project costs. The 2023 U.S. Hydropower Market Report also states that supply chain challenges for PSH implementation include limited workforce availability (due to limited industry access to new hires and high retirement rates) and decreased diversity of turbine suppliers over the last decade (Uría-Martínez et al. 2023).

- ***Competition With Other Storage Technologies***

Among long-term energy storage technologies, PSH is a more mature and efficient technology that offers the lowest total project cost of 165 $/kWh, and the longest lifespan (Blankenship 2019). However, interviewees noted that short-term energy storage technologies (e.g., batteries) could provide stiff competition in terms of performance, declining capital costs over time, and shorter licensing and project completion timelines.

A recent life cycle analysis study of closed-loop PSH suggested that it is a promising energy storage option and can play a key role in meeting U.S. grid-scale energy storage goals (Simon et al. 2023). The study established that PSH is very competitive when compared to other energy storage technologies including utility-scale lithium-ion batteries, vanadium redox flow batteries, lead-acid batteries, and compressed-air energy storage.

- ***Financing and Investment Challenges***

PSH developers and innovators of new PSH technologies face challenges when seeking financing from lenders and funding from investors, owing to uncertainties caused by potential delays in licensing/permitting, construction and start-up of new or expanded PSH facilities, and launching the manufacturing and sale of new PSH technologies. Uncertainty over the timing and projected amount of future revenue, cost escalations, and “free cash flow” streams from new

PSH plants or facility expansions will challenge the ability of providers of financing, private equity and other investment options to value the potential returns of money funded or invested. As many in the PSH industry have suggested, efforts to identify and value the additional grid services provided by PSH facilities in providing highly flexible long-duration energy storage and grid balancing can help support stronger return-on-investment (ROI) projections needed for often-lengthy PSH development projects.

Regarding industry needs, suggestions from PSH stakeholders included the need for financial modeling tools that go beyond techno-economic modeling to demonstrate the potential for financial closing to meet funding criteria and timely cash flow returns to repay loans and investments. Calls from PSH stakeholders include financial instruments offering insurance support to backstop financing, or long-term revenue or tariff support mechanisms to support longer-term revenue streams needed to repay larger capital investments for major PSH plants or facility expansions.

- ***Community/Social Challenges***

During interviews, PSH developers and innovators noted how responding to community concerns on social and economic impacts of new PSH facilities and technologies was crucial to moving forward with project development and technology commercialization efforts. The key is to build awareness of the benefits that PSH development and new technologies provide to local communities, utilities, and other purchasers of power and grid services provided by PSH facilities. Challenges stem from areas where the lack of knowledge of PSH benefits could lead to community concerns extending into economic and environmental concerns. Initiating outreach and engagement with impacted local communities (e.g., through town hall discussions) in the early stages of project development has in some cases helped project developers identify and understand stakeholder concerns and make adjustments, such as to construction siting and traffic flow, to address concerns, highlight potential benefits, and secure community support.

- ***Major challenges that are holding PSH back in the United States but have been overcome in other countries***

PSH has been successful when the electricity system operator has developed a good understanding of the future needs of the power system (energy balancing and in-depth understanding of all the services that are required by the system). During interviews, PSH stakeholders observed that the countries with success in developing PSH tend to be the ones where the system operator has decided on what services they need to make the system work and then procured a PSH facility that provides those services. When countries try to procure facilities that provide individual services, it becomes very difficult to finance a project. Israel was suggested during interviews as an example of a successful country where the transmission system operator has defined all the parameters required from a pumped storage facility.

Interviewees observed that in countries with PSH developers who are less successful in implementing PSH, there is a need for a better understanding of the power systems and of the services that PSH can provide. During interviews, PSH engineering consultants noted that because the power systems are in transition and evolving, countries will need to develop a better understanding of how to operate power systems that may look very different in a couple of decades as a result of the integration of variable energy resources. As an example, an Irish utility was identified that defined 14 services (inertia, fast response, fast ramping, black start, etc.) that it has obtained through a single existing pumped storage scheme. The system analysis helped the utility understand that the PSH system provided virtually all the services that the utility was looking for.

3.1.2 Lessons and Best Practices in Commercializing PSH Technologies

PSH developers and innovators have also found pathways to advance and commercialize their projects and technologies, ranging from success in working with early-stage funding partners to collaborating with industry equipment manufacturers and power purchasers to building awareness of how commercial start-up of PSH facilities and technologies will benefit community and consumer groups by growing the workforce and providing a lower-cost energy supply.

During the interviews and webinars, PSH stakeholders shared several lessons on how building awareness of PSH operational benefits and demonstrating a track record of performance for PSH services have helped PSH stakeholders move projects forward with utility regulatory and environmental approvals and de-risk financial outlooks to support financing and investment opportunities, thus enabling PSH projects to advance to new stages of technology and project development.

Insights on how WPTO and national laboratories can help to navigate through challenges to accelerate commercialization of PSH facilities and technologies are highlighted in Table 2 and discussed further in Section 3.6 of this report.

Table 2. PSH Commercialization Challenges, Lessons Learned, Best Practices and How DOE and National Labs Can Help

PSH Commercialization Challenges?	What Works? Best Practices and Lessons Learned	How Can DOE and National Labs Help?
►**PSH Development Timelines:** PSH project completion can take 7+ yr (license application 5–6 yr/construction 3–5 yr).	• Long-term relationships with power authorities and utilities • PSH performance track records • Innovations to shorten construction • See PSH as a backup and support to meet electricity generation needs	Develop resources and tools to: • Reduce cost of learning curve by sharing lessons on advancing through PSH project stages • Develop PSH valuation model to value PSH services • Quantify job, infrastructure, retrofit work • Run energy mix scenarios • Apply non-U.S. lessons (Australia, Swiss project management, etc.)
►**Licensing Process Challenges:** Long license permitting timelines can occur with regulatory authorities at state and federal levels.	• Early site evaluations before starting licensing process • Smaller greenfield sites • Early regulatory feedback	• Use energy mapping tools for siting • Simulation models for scenarios and risk assessments

PSH Commercialization Challenges?	What Works? Best Practices and Lessons Learned	How Can DOE and National Labs Help?
	• Timely responses, and education	• Success cases to build awareness with regulators
►**Environmental Challenges:** Water quality, flora/fauna impact, siting far from transmission lines, elevations, etc., can present hurdles to development and commercialization.	• Closed-loop PSH and brownfield sites to reduce impacts and evaluation times • Narrowing studies to 1–2 breeding seasons of threatened species	• Evaluate fish-friendly infrastructure • Examine innovations to limit environmental impacts (e.g., reservoir liners) • Identify success with EPA collaboration, community groups
►**Financing and Investment Challenges:** Risk of project delays due to extended licensing and construction periods, timing of revenues, and cost escalations can be barriers to securing financing from lenders and investors.	• Identifying value of PSH's flexible long-duration energy storage, grid balancing • Defining PSH parameters before going to market • Benefitting from PUC approval with capital spending plan • Seeking investment backstops	• Provide financial closing modeling tools • Value PSH services • Examine impacts of insurance, guarantees, investment tax credits, and other risk-mitigation options • Run return-on-investment scenarios
►**Community and Social Challenges:** New PSH facilities have social and economic impacts; need to meaningfully connect with communities during PSH development to ensure benefits are maximized for those affected.	• Early meetings with tribes and communities • Early town halls to gather concerns • Changing construction traffic flows • Avoiding culturally and historically significant tribal sites	• Study leveraging existing infrastructure (retrofits, non-powered dams, abandoned mines, seawater) • Study economic benefits over decades for job and business growth
►**PSH vs. Competing Technologies:** Competing technologies such as short-term energy storage (batteries) can have certain advantages over PSH because of quicker licensing and construction.	• Closed-loop PSH energy storage option offers benefits over competing technologies when comparing life-cycle greenhouse gas emissions and long-lived PSH plants vs. the need for shorter-term battery replacement/disposal.	• Evaluate value of ancillary services, digital operation of PSH (smart coupling with batteries, power generation plants).

Discussions during interviews and the webinar examined in greater detail how DOE and national laboratories can help PSH stakeholders by providing resources, tools and studies to accelerate development and funding of PSH projects and technologies. Takeaways from these discussions are highlighted in Table 3. These highlights will be discussed in further detail in Section 3.6 of this report.

Table 3. PSH Commercialization Goals and Actions to De-risk PSH Projects and Respond to Challenges from the Community

How to de-risk PSH?	Sharing lessons learned?
►**Building the long-term case for PSH:** demonstrate PSH ROI vs competing technologies (batteries) ►**Reduce high CAPEX:** lower licensing & construction costs via process & technology innovations ►**Reduce timelines:** licensing, environmental, construction	• **PSH site work:** build community buy-in • **Educational outreach:** need to spotlight PSH benefits to build consumer awareness • **Community concerns:** need to proactively gather info & provide responses/solutions • **Workforce needs:** rising interest in wind/solar careers ►need to show PSH as an exciting career path • **Workforce development:** now center-stage ►need to promote PSH benefits/opportunities, esp. in rural & tribal locations near PSH plants

During interviews and the webinar, PSH stakeholders highlighted the need for financial modeling tools to support PSH developers and innovators in demonstrating potential future revenue and income streams to drive ROI metrics for PSH projects. Interviewed PSH developers and consultants suggested that DOE and national laboratories can help by developing financial analysis tools to examine scenarios when developing new PSH facilities or using innovative PSH technologies to lower construction or operating costs or drive additional revenue from services provided to the grid.

PSH stakeholders interviewed also discussed how financial modeling tools and studies may help demonstrate how innovative PSH construction methods, operating processes and technology innovations can help reduce high capital expenditures and lower the licensing and construction costs. This demonstration includes the potential to illustrate how PSH innovations can reduce long timelines for the preconstruction (licensing/permitting/regulatory compliance and approval, including siting and environmental assessments) and construction phases.

PSH stakeholders also shared lessons learned on how to respond to PSH commercialization challenges in working with communities, including the following:

- Perform extensive initial PSH site work for new PSH projects, including early discussions with communities on siting locations for plants and planned construction phases to build buy-in from local communities.

- Conduct community outreach to build awareness of PSH benefits to consumers and proactively gather information via town halls during initial project planning to respond to community concerns.

- Highlight workforce needs to support PSH career paths to advance energy security goals and opportunities in rural and tribal locations near PSH plants.

3.2 Outlook for Innovative PSH Technologies

3.2.1 Key Takeaways on Advancing Innovative PSH Technologies

Responding to community concerns on social and economic impacts of new PSH facilities and technologies remains crucial for PSH developers and innovators to move forward with PSH commercialization. A 2020 IRENA report states that the following factors are essential to promoting innovative PSH technology deployment (IRENA 2020):

- Establishing a regulatory framework to support innovative operation of PSH (for example, through innovative ancillary services that address grid flexibility issues, remunerating for ancillary services related to rapid ramping requirements, etc.).

- Increasing digital operation of PSH plants (smart coupling with batteries or with VRE), operation monitoring equipment and generation forecasting through machine learning, maintenance robots, virtual reality training for operation personnel and remote-control maintenance technologies.

- Leveraging existing infrastructure through retrofitting PSH facilities (combining existing PSH projects with other VRE systems [such as floating PV], use of abandoned mines, seawater PSH, and application of PSH technology innovations).

- Investing in public/private research and development projects.

Innovative approaches to PSH deployment can be furthered through the use of advanced weather forecasting tools that could help in obtaining improved power generation forecasting. This forecasting can be further supplemented by the development of optimization software for the operation of hybrid systems, including PSH, VRE, and batteries.

The development of fish-friendly infrastructure can address some of the environmental concerns faced by PSH developers. Barrier nets, guide nets, bar racks, and behavioral deterrents appear to have the ability to reduce turbine/pump entrainment rates at pumped storage projects.

There is emerging research on retrofitting PSH at abandoned mines, underground caverns, non-powered dams (NPDs) and conventional hydropower plants, representing significant untapped PSH potential. Environmental impacts are smaller than with greenfield PSH developments, with the underground lower reservoir and upper reservoir constructed on an existing brownfield site (Koritarov et al. 2022).

3.2.2 Lessons Learned and Best Practices to Drive Innovation of PSH Technologies

Under WPTO’s Hydropower and Water Innovations for a Resilient Electricity System (HydroWIRES) Initiative, a report published by Argonne detailed a landscape analysis on the current state of PSH technologies and promising new concepts and innovations (Koritarov et al. 2022). The study performed an independent review of 12 innovative PSH technologies using predefined evaluation criteria to identify the potential to reduce cost and time required for construction of new PSH projects, while reducing environmental and other impacts.

As highlighted in Table 4, many PSH technology innovators are addressing challenges by developing new PSH designs and technologies to de-risk or offset the challenges posed by cost-reduction goals, competitive timelines to commissioning via advanced construction methods, new materials or plant design, smaller PSH plant footprints, and repurposing brownfield sites or adding modular options for expansion.

Table 4. Commercialization of Innovative PSH Technologies: Challenges, Best Practices, Lessons Learned and Support from DOE and National Laboratories

PSH Commercialization Challenges for Innovative PSH Technologies?	What Works? Best Practices & Lessons Learned	How Can DOE & Labs Help?
►**Outlook for PSH technologies over time horizons:** some investors are looking for ROI in the near-term, not 10 years from now.	Demonstrating performance of PSH plant operations beyond 10 years via success in extending operations to support longer-term time horizons and value of PSH as a 50+-yr asset	Need to educate and build awareness of PSH plant • operating performance over 10-50+ yr, • value of PSH/ancillary services over long-term (30+ yr) • multi-cycle, long-term O&M costs, capital expenditures
►Demonstrating to decision-makers how PSH innovations help to de-risk or reduce uncertainties in developing or expanding PSH facilities	Demonstrating how PSH innovations can: • reduce construction and operating costs vs conventional PSH, • reduce PSH plant footprint (▲site options, ▼costs, ▼EPA impacts) • new construction methods (▼ costs, ▼ time to completion) • lower environmental impacts (▼ time for EPA approval/licensing phase) • scalability of PSH technology (▲ capacity, ▲ locations)	Develop modeling tools to simulate future power grid service needs and evaluate potential benefits of PSH innovations in: • providing ancillary services, • lowering operating & maintenance costs, reducing capital expenditure and rebuilds • reducing time for EPA approvals, licensing and plant construction.
►Building awareness of how PSH innovations can support the changing role of PSH for resilient and secure power grids?	• Need to educate about what a future grid looks like in 5–15 yr to satisfy peak load • Look at new PSH tech. to invest now & complete in near-term, not in 10+ yr • Consider smaller projects using PSH innovations, especially for non-storage or non-powered dams	What does innovative tech need to get to commercial stage? • At the end of the day, it comes down to money. • Making more DOE funds available via competitions (e.g., FAST prize) can be helpful. • Develop modeling tools to evaluate the benefits of smaller projects with lower operating & grid connecting costs.

In interviews and webinars, PSH innovators highlighted the need to educate and build awareness of how PSH innovations are enabling near-term benefits and long-term resources to provide baseload power generation and grid-scale energy storage and how they can help reduce PSH construction times and/or lower capital expenditures. This need includes building awareness of the wide variety of ways in which PSH innovations can potentially help advance PSH project deployment. For example:

- Not all proposed PSH innovations are in early stages of development, as some have achieved higher technology readiness levels (TRLs). These innovations include proven, commercially available equipment and technologies from other industries that could be applied to hydropower projects to shorten construction times or reduce costs (e.g., tunnel boring and roadheader machines for underground excavations and modular construction techniques for the construction of PSH reservoirs).
- Technology innovations can offer options for small modular PSH designs, as well as for various hybrid and multi-purpose PSH projects.
- PSH innovations offering the opportunity to repurpose abandoned mines using current commercial equipment may lead to shorter development times and potential for job creation to garner support from local communities.

Lessons learned and best practices discussed among interviewees and webinar participants included success in working with hydropower and emerging-technology consultants, national laboratories, and other organizations to demonstrate how PSH innovations can help to de-risk or reduce uncertainties by lowering costs, improving operating performance, and reducing site or environmental impacts. These discussions include the following:

Respondents highlighted how DOE and national laboratories can play an impartial role in evaluating or validating the potential performance of these innovations and providing benchmarking studies where PSH innovations are compared to existing and alternative new technologies. Many interviewees indicated that competitions sponsored by DOE's WPTO play an important role in not only building awareness of their technology innovations, but also providing initial funding to work toward proof of performance and other early-stage research and development steps.

Regarding how national laboratories can help, many interviewees support further development of modeling tools to simulate future power grid operational needs and evaluate the benefits of PSH innovations in those simulations. This development would include using modeling tools to examine how the introduction of innovative PSH technologies could provide more ancillary or energy storage services, reduce operating and maintenance costs, reduce capital investments, etc. Many respondents expressed the need to find modeling tools to generate scenarios to demonstrate how PSH innovations may lead to reducing impacts on the environment and local communities at construction sites and shorten the time to obtain environmental or licensing approvals.

When addressing concerns of investors or funding sources that are looking for short payback periods, such as within 10 years, interviewees and webinar participants expressed the need to educate them about what a power grid may look like in 5–10 years and identify PSH technology innovations that can be invested in now and completed within 5–10 years. Interviewees noted that some PSH innovations are already in late stages of development or commercially available for other industries and can be used in PSH applications, including using tunneling equipment to shorten time to excavate to install penstocks, modular construction to shorten time to create reservoirs, and structural designs to reduce plant material costs. Participants suggested that DOE and national laboratories can help to demonstrate the performance and benefits of PSH technology innovations to support market adoption and commercial use by conducting research studies, testbeds and modeling simulations.

Lessons learned and best practices from interviews and webinars included the insight that in some cases smaller PSH projects may also be economically and financially viable. Making the financial case for smaller projects and illustrating pathways to revenue streams may help some PSH innovators move their technologies forward. Many interviewees indicated that DOE funding available via competitions, such as the FAST Commissioning for Pumped Storage Hydropower Prize competition, have been helpful in advancing viable solutions to leading hydropower challenges and suggested that more competitions would further support commercialization and deployment of innovative solutions.

3.3 Market Assessment—Demand for PSH Services, Technologies, and Funding Sources

3.3.1 Key Market Drivers for New PSH Facilities and Technologies

Rising Market Demand for New PSH Capacity and Innovations

Market drivers behind the rise in proposals for new PSH facilities and innovative technologies in the United States include the need to add more electricity generation to meet rising electricity demand for data centers, industries and consumers, and the need to provide longer-duration energy storage services to offset the rise in intermittent gaps in variable energy resources and respond to surges in electricity demand and supply to deliver flexible, resilient and secure electricity generation.

Current Market Trends Point to Emerging Opportunities

DOE's 2023 Hydropower Market Report highlighted how 96% of the nation's utility-scale energy storage capacity of 553 GWh is contributed by 43 PSH plants with a total power capacity of 22 GW (Uría-Martínez et al. 2023). According to the report, almost as much PSH capacity was added from 2010 to 2019 (1,333 MW), mostly from upgrades to existing plants, as the combined installed capacity of all other forms of energy storage in the United States (1,675 MW).

New PSH Capacity Proposed in the United States

DOE's 2023 U.S. Hydropower Market Report showed 96 new PSH projects in the U.S. development pipeline at the end of 2022, including three projects that have obtained FERC licenses (Uría-Martínez et al. 2023). As shown in Figure 1, PSH projects under consideration span the contiguous United States in states that support varying new power generation goals.

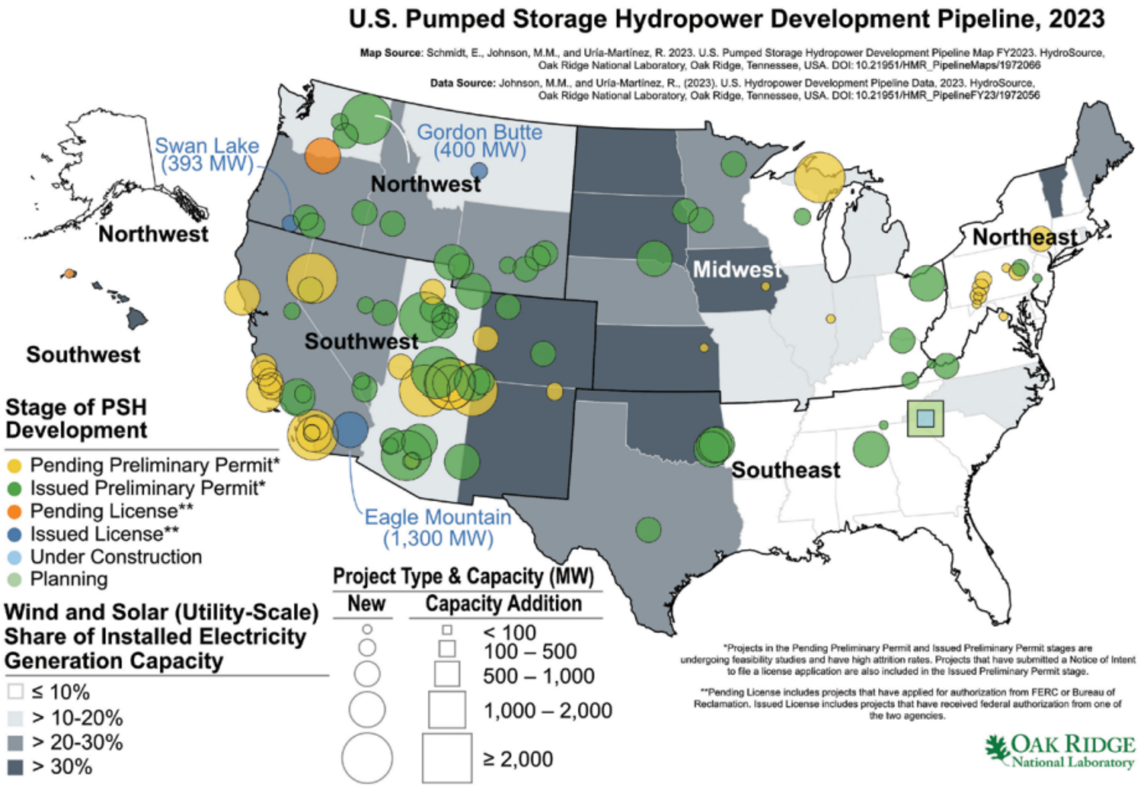

Figure 1. U.S. Pumped Storage Hydropower Development Pipeline, 2023 (Uría-Martínez et al. 2023)

Discussions during interviews and webinars with PSH stakeholders revealed renewed interest in PSH, with investor-owned utilities (IOUs) in the Northwest, Southwest and Southeast now examining the potential of new or upgraded PSH facilities to support electricity generation and fill long-duration energy storage needs. Of the 125 preliminary permits issued by FERC and the U.S. Bureau of Reclamation from 2018 to 2022, most were for PSH projects (58%) and NPDs (33%) (Uria-Martinez et al. 2023).

Proven Track Records and Detailed Scenarios Help Make the Case for PSH

Interviews with utilities confirmed that there is renewed interest in new PSH capacity—ranging from expansion projects at existing PSH facilities to new PSH plants at new sites—to meet new power generation mandates in multiple regions. Interviewees discussed how utilities with long histories operating PSH plants have benefited from proven track records and public utility commissions familiar with PSH operating performance to gain approvals for their projects. Presenting detailed "what if" scenarios enabled utilities to make the case for PSH playing a crucial role in supporting power system reliability and providing energy storage capacity in support meeting increasing electricity demand for data centers, industrial facilities and communities.

Securing Longer-Term Power Purchase Agreements Remains Challenging

While vertically integrated utilities have pathways toward incorporating PSH projects into their rate base to recover costs via tariffs and ROIs, other PSH developers are challenged by the risk of not securing longer-term PPAs and financing structures. In discovery interviews, PSH stakeholders reported a reluctance to sign long-term PPAs, which they attributed mostly to uncertainty around long PSH project timelines compounded by potential delays in approvals and start-up of operations, and the risk of new technology emerging to replace PSH in the interim.

Markets Have Yet to Recognize and Value PSH Systemwide Benefits

Interviewees expressed opinions that current market rules and structures do not properly value and/or consider the systemwide benefits provided by PSH plants. Many of the grid services that PSH provides, such as long-duration energy storage, are either undercompensated via tariffs or not compensated at all. Compensation mechanisms for frequency response, inertia, flexible ramping, voltage control, and black start are undervalued. Other interviewed PSH stakeholders said market rules and structures do not properly value and/or consider the broader, systemwide benefits PSH can provide in generating electricity when needed for a resilient power grid, which are difficult to quantify and measure, leading to subpar compensation.

Utilities and Regulators Lack Tools and Resources to Understand PSH Benefits

Many interviewed PSH stakeholders stressed the need for education and tools to help utilities and regulators to fully understand PSH benefits. For example:

- Utility employees with 20+ years of experience may not be aware of new advancements in PSH technology.
- The software many utilities use for resource planning does not account for the full value of PSH grid services.
- Educational programs present opportunities for utilities and regulators to talk about new equipment, controls and other advancements.

Financing and Investment Hurdles Waylay Financial Closing of Projects

Multiple PSH stakeholders interviewed stressed the importance of focusing on what is needed to complete financial closing of projects. These needs include finding ways to understand what financiers need to commit to an investment with a long-term payback period and debt repayments. PSH projects can be stopped, even after getting their license, because of the inability to develop a revenue source such as PPAs or an agreement to be funded as a transmission asset for the grid. These large capital-intensive projects need to be able to find off-takers that can sign long-term purchase agreements that in turn would enable developers to secure funding from investors and lenders.

PSH developers and innovators of new PSH technologies are challenged in getting long-term financing or investments from lenders and private investors because of uncertainties over project timing, revenue structures, potential cost escalations, and free cash flow streams for repayments.

Multiple PSH stakeholders interviewed stressed the need for detailed financial modeling tools that go beyond techno-economic analyses to demonstrate projected returns to satisfy funding criteria and potential repayments under different market and regulatory scenarios.

3.3.2 Lessons Learned and Best Practices to Meet Market Needs for PSH Projects

Takeaways from interview discussions revealed new interest in PSH plants, with utilities inquiring about the potential benefits of building PSH facilities in areas with new power generation mandates such as the West Coast. Reasons behind this interest included recognition of PSH's proven ability to provide bulk load electricity generating services to satisfy the need for a higher mix of power generation.

Lessons learned and best practices revealed during interviews (Table 5) included discussions by some interviewees about how some integrated IOUs with a long history of operating PSH plants are interested in investing in PSH plants and upgrades to boost power generation capacity. These utilities have garnered support from local PUCs that have been familiar with the decades of operating performance of existing PSH facilities. Discussions during interviews and the webinar included suggestions that building awareness of the operating track records of existing PSH facilities in one region may help with proposed PSH projects in other regions.

Table 5. Lessons Learned and Best Practices in Working with Utilities to Meet Market Needs

PSH Market Needs - Utility interest? Challenges?	What does PSH need to make the cut with utilities?	How can DOE & Labs help?
► Utility interest in PSH vs other technologies? • New utility interest in PSH: by West Coast IOUs due to power generation needs • PSH servicing bulk load needs: recognizes PSH's proven performance in satisfying new power generation demand • Long history operating PSH: strong interest from vertically integrated IOUs operating PSH plants • Reluctance to sign long-term PPAs: risk of new tech emerging to replace PSH	►What does PSH need to make the cut for IOUs? • Software used by utilities for resource planning doesn't account for full value of PSH ancillary services • Need to differentiate regulated vs wholesale competitive power markets • Utilities/regulators don't have a full understanding of PSH and its benefits. • Utility-side employees with 20–30 yr of service experience often aren't aware of new advancements in PSH technology.	• Need educational programs for utilities & regulators to talk about new equipment, controls, etc. • Current market rules and structures do not properly value and/or consider system-wide benefits - need studies/modeling tools to estimate value & benefits. • Many grid services provided by PSH are undercompensated or not compensated; compensation mechanisms for frequency response, inertia, flexible ramping, voltage control and black start are undervalued. • PSH can provide broader system benefits that are hard to quantify and measure, leading to subpar compensation: need modeling tools to quantify.

When asked about what is needed to help PSH garner interest and approval by utilities, respondents offered new insights, such as that software models used by utilities for resource planning do not account for the full value of ancillary services provided by PSH plants. Respondents noted that new modeling tools to account for ancillary services must be developed and then adopted for use by utility resource planners. Discussions included suggestions for DOE and national laboratories to build awareness of these tools among utility resource planners by providing access to training sessions on new modeling tools or other ways to share information.

Other interviewees and webinar participants cited the need to differentiate traditionally regulated versus wholesale competitive power markets in determining the value PSH facilities can add in providing long-duration energy storage to support resiliency in electricity services. They noted that differences in market structures and electricity pricing dynamics observed in regulated versus wholesale competitive power markets need to be understood and incorporated into modeling scenarios to identify where PSH ancillary services provide added value and support the market response to attribute value to these ancillary services.

One lesson noted during interviews and the webinar was that even experienced utility employees may not be aware of new advancements in PSH technology. Discussions followed on the need for educational programs to enable utilities and regulators to learn about new equipment, controls and other advances in PSH technology. Suggestions for DOE and national laboratories included working with hydropower associations and utilities to provide access to existing training programs and enhance those programs to inform utility employees of improvements in PSH technology.

Best practices noted by interviewees and webinar participants include the use of modeling tools to identify benefits of PSH services and benefits in supporting the power markets. However, they noted that PSH can provide broader system benefits that are hard to quantify and measure, leading to subpar compensation by the market, and they noted the need for modeling tools to quantify potential market impacts. They expressed the need for compensation mechanisms for frequency response, inertia, flexible ramping, voltage control and black start services.

With regard to working with utilities to meet market needs, many discussions during interviews and the webinar concluded that there is an opportunity for DOE and national laboratories to work with utilities to advance modeling tools and help quantify the broader system benefits provided by PSH facilities.

3.3.3 Market Needs – Finding Funding for PSH Projects and Innovations

The economic and financial requirements to meet funding criteria for PSH projects and technology innovations in electricity markets vary across development stages of PSH projects and innovations, owing to varying groups of investors and funding organizations. As shown in Table 6, PSH innovators face a multi-stage financing process where funding criteria will change as investors and funding groups evolve from:

- Early-stage PSH innovation or plant design, licensing and construction process, to
- Mid-stage project financing and the need to get banking criteria, to

- Final-stage sale of constructed or licensed PSH project to utility or independent power producer (IPP) owners and operators and the need to de-risk concerns and perform repayment modeling scenarios.

Table 6. Finding Funding for PSH Projects

What do early investors need?	Why would bankers fund this?	How can DOE & Labs help?
• Recognize multi-stage financing process • Early project stage: investor needs through design, licensing, construction • Mid-stage: funding via project financing organizations, get banking criteria • Final stage: sale to utilities or IPPs – get repayment modeling, de-risk concerns	• Need to secure revenue source for repayments • See what's working outside U.S., such as Israeli contracts for monthly service (bundled approach)	• Initiate more discussion about the financial closing of projects. • Find ways to understand what financiers need and hence convince them to enter into a long-term pay commitment. • PSH projects can be stopped if unable (after getting license) to develop revenue sources such as PPAs. Need to find ways to sign long-term agreements to secure funding.

Investment criteria and funding options may shift from different development stages and funding/investor groups. Findings from interviews and webinars reveal the common goal of needing to secure sources of revenue, earnings, and available cash flow for repayments and future reinvestment to operate facilities or develop new technologies. This discussion led to suggestions to examine the financial closing of projects and ways to understand what the financiers need to make the case for future returns and find ways to sign long-term agreements to secure funding. Discussions included seeing what is working outside the U.S., such as Israeli contracts for monthly services based on bundle service products.

Discussions during interviews and the webinars revealed a common interest by PSH developers in getting support from DOE and the national laboratories to help make the case for financial closing of their PSH projects. This included finding ways to help developers understand what financiers need in terms of earnings and return estimates, and repayment forecasts to enable them to make a long-term funding commitment. Efforts to develop an understanding of the potential for long-term agreements to support revenue streams from multiple PSH services would help PSH stakeholder efforts to develop their projects. Access to and awareness of early-stage funding sources from innovation competitions and private investors would help innovators of PSH technologies. It was noted that the development of PSH projects can stall after licenses are obtained if the developers cannot find a revenue source such as PPAs. Some suggested examining the role that PSH can play as a transmission asset for the power grid, which may lead to additional revenue streams.

3.3.4 Lessons Learned and Best Practices in Developing Funding Pathways for PSH

In each stage, potential investors and financing sources evaluate potential revenue and cost streams to estimate future cash returns to repay loans and examine the potential profitability of future operations from capital invested in PSH projects. The report entitled *Project Financing of New Hydropower Development at Existing Non-Powered Dams* (Guerrero 2021) examines project financing trends, market drivers and challenges through case studies of 15 NPD retrofit projects. The author noted that while many projects retrofitting dams benefit from some already incurred fixed capital costs and fewer of the environmental impacts associated with new dam construction, investors were still hesitant to finance NPD electrification projects because of the lack of financial literature on project valuation and economics, plus lengthy regulatory processes. Case studies revealed that acquiring financing during early planning and construction stages is challenging and dependent on the perceived risks and future revenue streams. Access to financing sources differs between types of project developers and participants because of financial structures and investment criteria. For example:

- **Independent Power Producers (IPPs)** are non-regulated, privately owned operators of power facilities generating electricity for sale; they tend to be smaller than publicly or government-owned utilities. With limited access to low-cost, tax-advantaged financing options, IPPs typically seek shorter-term, faster-payback hydropower projects financed by non-recourse bank debt, loans secured by collateral and high-cost equity funding. Non-utility smaller-scale hydropower developers can share the same investment criteria as IPPs.

- **Investor-owned utilities (IOUs)** are publicly owned electric power distributors that can issue stock to shareholders and are regulated at the state or federal level. IOUs can take a longer-term perspective on projects, with the ability to internalize the benefits of hydropower into their power systems with regulated revenue streams from the customer rate base and strong balance sheets to support lower required rates of return for corporate-financed projects. IOUs can access medium- to long-term financing from stock market equity and corporate bond issues.

- **Public Power Entities (PPEs)** are power generation utilities under city, state or federal government ownership, with longer investment and payback horizons, higher debt credit ratings due to municipal or federal government backing, and the ability to issue hydropower-backed revenue bonds.

Findings from interviews and webinars, including webinars hosted by The World Bank, included lessons learned and best practices to respond to the challenge of obtaining financing for PSH projects and technology innovation. In addition to the financing pathways described above for IPPs, IOUs and PPEs, PSH stakeholders discussed measures to help de-risk or reduce concerns, such as offering investment tax credits. Some of the financing concerns and tools for decision-makers are summarized in Table 7.

Table 7. Financing Concerns and Tools for Decision-Makers

Financing & Investment Challenges?	Financing Concerns for PSH Decision-Makers?	Financing Tools for Decision-Makers?
Why is financing challenging? • Long timelines – delayed income stream • Development risks – delayed projects • Potential technology substitution • Lack of investor knowledge	• **Independent Power Producers (IPPs)** seek short-term, quick-payback hydropower projects financed by non-recourse bank (with collateral) & high-cost equity. • **Investor-Owned Utilities (IOUs):** Long-term power system benefits can enable lower rates of return than IPPs require. • **Public Power Entities (PPEs):** Power generation utilities owned by city, state, or federal government with longer payback horizons, lower discount rates.	• **Independent Power Producers (IPPs):** Project finance tools for hydropower projects financed by non-recourse bank (with collateral) & high-cost equity. • **Investor-Owned Utilities (IOUs):** Long-term corporate finance with payback guaranteed via revenue from customer rate-base & strong balance sheets. • **Public Power Entities (PPEs):** High credit ratings with backing by municipal government; can issue hydropower-backed revenue bonds sold to fixed-income institutional investors (i.e., banks, pension funds).

Suggestions on how DOE and national laboratories can help included examining ways that PSH developers in countries outside of the U.S. often have access to insurance or guarantee instruments to back up revenue streams to encourage long-term financing. Interview and webinar participants noted that building an awareness of the use of insurance and guarantee instruments outside of the U.S. could support their discussions in the U.S. with financing and investment decision-makers.

To support development of PSH technology innovations, interviewees and webinar attendees suggested that DOE and national laboratories can help by building awareness of the broad range of potential private investors interested in early-stage technology funding for PSH technology innovations. Suggestions for the planned PSH commercialization online resource hub included adding information on investment groups with interests in funding power generation projects and innovative technologies. Further study by DOE and national laboratories was suggested on connecting with investors in early-stage PSH innovations to determine the range of evaluation practices and metrics used for decision makers.

3.3.5 The State of the Wholesale Electricity Markets

Market opportunities and challenges vary by region, with many of the differences driven by market structure. Regions that are traditionally structured, such as the Southeast Energy Exchange Market (SEEM), tend to transact energy purchases and trades via bilateral agreements, whereas in restructured markets, the transactions are through a mix of market and bilateral transactions.

Historically, energy trades in traditionally structured regions were transacted through bilateral agreements. However, in the last decade, these regions have added market overlays to facilitate increased trading efficiency (e.g., in the Western Region, the real-time Western Energy Imbalance Market (WEIM) has been operating since 2014), offering energy and storage providers new ways to participate in those regions. Restructured markets, too, are undergoing changes. Some offer capacity markets, although they tend to differ markedly in how they are implemented from region to region, while other areas rely on alternative methods to secure capacity.

To help stakeholders better understand storage growth potential in various regions, we have developed a summary document that provides information about the nine major market regions. This summary document is provided as Appendix A to this report. Included in the summary are a region and market overview, power generation and storage buildout projections, and a brief discussion of in- and out-of-market opportunities. Projections for wind, solar and storage (2-, 4-, 6-, 8- and 10-hour duration) are included for two bounding cases—business as usual (BAU) and a nationwide energy policy, providing upper and lower estimates of regional storage needs.

Finally, for regions where markets are operating, recent pricing information is provided. Both day-ahead and real-time energy and ancillary service markets are discussed, and capacity markets pricing information is provided, if available. Where capacity markets are not active, information is provided on how capacity in that region is procured.

3.4 Environmental and Regulatory Obstacles

Recent environmental studies have identified certain modifications to the PSH system configurations that will help control not only the costs (associated with equipment and construction) but also the environmental impacts (Saulsbury 2020). While open-loop PSH systems are more commonly in operation in the United States, a 2020 DOE environmental impact study showed that the environmental impacts of closed-loop projects are relatively lower than those of open-loop projects (Saulsbury 2020). It has been shown that closed-loop systems have significantly less environmental impact on aquatic life because they are not continuously connected to any naturally flowing body of water. Consequently, in recent years, more preliminary permit and licensing applications for closed-loop systems have been filed (Saulsbury 2020). However, closed-loop systems may have a significant impact on ground or surface water availability owing to the initial withdrawal of water for reservoir fill. Therefore, there is an emergent need for a better understanding of the potential environmental impacts and the steps for appropriate mitigation.

While modern PSH systems have taken steps to minimize the environmental impacts, most state and federal regulatory and permitting processes do not recognize the difference between modern advanced pumped storage and the traditional hydropower projects along a main stem river system (2021 Pumped Storage Report-NHA 2021).

3.4.1 Environmental Challenges

Project Siting Challenges:

Land use and topography are major parameters to consider during the development of a PSH project. PSH systems (open or closed loop) need large reservoirs which could take up a lot of land area. Some projects that already have an existing lower reservoir still need an upper reservoir to be constructed. The topography of a site decides the type, height, slope and shape of a dam, and the amount of earthwork required to build it. A 2021 study that analyzed the drivers and barriers that impacted PSH deployment discussed the possibility of public opposition to PSH construction because of the risk of damage due to earthquakes (Ali et al. 2021). As there are many earthquake-prone regions within the United States, geological faults can be a technical constraint to PSH development. While this is not a frequently considered parameter anymore, the study highlights a future opportunity for conducting more detailed studies on the impact of geological faults (like active faults and fracture zones and the presence of permeable bedrock). These faults could have an impact on the construction cost.

The use of existing structures, such as dams, abandoned coal mines, or lakes, to serve as PSH reservoirs can help reduce land-use conflicts and deforestation and thus help reduce construction time, water resource needs, and costs.

Many projects are focusing more on closed-loop rather than open-loop configurations. Using existing structures can make the closed-loop systems more economical, owing to the reduced cost, land usage, and water consumption. With closed-loop systems, which are typically devoid of aquatic life, there are few or no adverse impacts on aquatic species.

For smaller projects which try to employ an existing NPD as one of the reservoirs, one of the biggest challenges faced is the expense of connecting to the grid.

Social opposition due to environmental concerns:

The public can oppose PSH construction because of concerns such as water quality and availability. In this case, extensive water quality testing may be required. If the project can have adverse impacts on flora and fauna, state and local wildlife agencies may require some extra assessments to be completed before the project is granted a license. However, PSH can offer a variety of auxiliary services like flood and sediment control, and groundwater recharge and replenishment.

3.4.2 Regulatory Obstacles and Challenges

Licensing is a crucial but very time-consuming step in PSH project development. It generally takes about five to six years to obtain the license. In some cases, if there are potential impacts on endangered species or water quality issues, FERC has to await the decision of the relevant state or federal wildlife agencies before it can issue the license. Therefore, while the development process is designed to take 5 to 6 years, it can sometimes take 6.5 to 7.5 years just to obtain the license. Consequently, the development process for a PSH project can take more than 10 years. Feedback received from the interviews revealed that this could cause some developers to struggle to find financing after they’ve gotten through the licensing stage.

The duration of these licenses ranges between 30 and 50 years (the default duration is 40 years for non-federal and 50 years for federal dams) (Levine et al. 2021). If existing PSH projects require re-licensing, the application has to be submitted at least five to six years before the expiration of the current license. Anyone seeking financing to help get through the licensing process faces an obstacle because after the first submission of documents to FERC, it could take at least a decade (with no ROI) to have an operating PSH plant. Finally, it has been noted that there are not many market mechanisms that would incentivize investments and support economic viability of long-duration storage relative to short-duration energy storage technologies (for example, 2- to 4-hour battery storage).

Pre-licensing challenges:

The licensing process can add considerable cost to the project (because of additional studies that need to be conducted to study terrestrial species, challenges due to water stagnation, subsequent water quality studies, mitigation measures implementation, etc.). A closed-loop system eliminates some of the issues (e.g., fish and other aquatic species) encountered with an open-loop system. The front end of the licensing process may present the need to study everything “from scratch” (using aquatic species as an example, one may need to look at dissolved oxygen levels and in-stream flow levels). This preparation process could take about 2–4 years before the actual submission of the license application. For closed-loop pumped storage systems, FERC has developed a 2-year accelerated process which could help save about a year and a half on the licensing timeline. Different environmental agencies and non-governmental organizations may request a lot of additional studies and ultimately have to make a determination as to whether they need that information to issue the license. Every study that's required can add time to developing that project.

The following are some other key issues faced by project developers in developing new PSH facilities:

- In the western part of the United States, there is a challenge in water availability that particularly affects closed-loop pumped storage projects: such projects may plan to utilize groundwater to fill the reservoir, but there are many groundwater limitations in place. For example, the plant may need to comply with the “100-year aquifer life” rule and not deplete the aquifer by more than 1% each year (Perrone et al. n.d.).
- One of the interviewees shared that filling a reservoir could take about 3 years. It takes five to years to get through licensing, then the reservoir must be constructed and other infrastructure must be developed, and then several additional years must be spent filling the reservoir. This cumulative timeline could discourage investment in pumped storage technology.

Licensing process at state, local/municipal levels:

All state agencies have the ability to provide recommendations to FERC during the licensing process. Section 10(a) of the Federal Power Act highlights any recommendations of the state agencies for the general plan of project development (Federal Power Act 2019). Section 10(j) is the pathway by which a state’s official wildlife agency can insert the expected impacts on wildlife and recommended mitigation measures into the FERC license (Federal Power Act 2019). The two other most important areas of recommendation are water quality and water rights.

Another area for project developers to pay attention to is potential local county issues with zoning. It is essential to ensure that the area of land to be developed is zoned for that type of development. The interviewees expressed the opinion that this is not an issue if the PSH project is on a U.S. waterway. In case of any commercial or industrial development in that area, the local land use requirements may be impacted by county-level zoning rules.

3.4.3 Lessons Learned and Best Practices in Responding to Environmental and Regulatory Challenges

Table 8 summarizes some of the lessons learned and best practices associated with the environmental and regulatory challenges of PSH project development. Additionally, from information gathered through interviews, it was found that some projects may face some extra steps when it comes to filling the reservoir with water, dealing with state water regulations, and obtaining permits for supplemental water to top off the reservoir, usually every couple of years, to address the evaporative losses. Some interviewees stated, "It would be good to identify more efficient ways to fulfill these steps as we move along the licensing and project development process."

Land acquisition is also an essential aspect that needs to be addressed when it comes to reservoir development at the property. Additionally, if a PSH project uses a U.S. Army Corps of Engineer (USACE) reservoir, it will need a 408 authorization from the USACE which would state that whatever is being done to the existing Army Corps dam isn't going to impact its safety or human health at that site.

One of the interviewees revealed that there was a need for more data to be developed on how new technology would have fewer environmental impacts as the technology moved up the TRL ladder. PSH implementation could further benefit from diligent penciling out of project costs and favorable incentives and regulations that encourage long-duration storage.

Table 8. Environmental and Regulatory Challenges and Best Practices Summary

Environmental and Regulatory Challenges to PSH Commercialization	What Works? Best Practices & Lessons Learned
• High-voltage transmission is associated with pump storage. People generally dislike high-voltage transmission whether they're for or against new power generation. • In some cases, site selection has been more of a challenge than licensing and permitting. The challenge lies with the upfront interaction with landowners and local communities. As they consider potential impacts on their communities, project development may be met with some resistance. • Utilities may consider gas turbines or batteries as more economical, and subject to very quick approval by regulators. But PSH builds the	• FERC-regulated projects (like large infrastructure projects) are mandated to address environmental issues and naturally engage with local stakeholders in a public setting through one-on-one interactions. Such a community-backed project has some benefits when it comes to getting tax breaks and other federal benefits. • There's a need for educational programs directed at the utilities and the regulators to update their knowledge of PSH technology improvements. For example, fast-acting fixed-speed pumped storage units, different plant configurations, ternary and quaternary PSH, and even adjustable-speed units are new to the industry.

Environmental and Regulatory Challenges to PSH Commercialization	What Works? Best Practices & Lessons Learned
backbone of the country when it comes to energy storage in the United States. It is a challenge to get utilities to include PSH in their resource plans, as their general feedback is that it is too expensive. • The software that utilities use for developing their resource plans doesn't account for the full value of pumped storage, i.e., its ancillary services. There needs to be an improvement in resource planning that fully accounts for what a pumped-storage project can do.	• There needs to be a round-table discussion with regulators, utilities and developers to understand how major progress can be made and what major policies can move things forward. • Pumped-storage project sites may be 10, 20, or 30 miles away from the nearest transmission substation. Other key factors for siting PSH projects include water availability, proper terrain, and environmental impacts.

3.5 Community Business Development Outreach and Engagement

3.5.1 Incorporating Community Business Development Outreach and Engagement Goals

While PSH represents the largest share of energy storage on the grid and has enabled large-scale wind and solar integration, these benefits are not fully understood by the general public (2021 Pumped Storage Report-NHA 2021). Most often, there is more focus on the adverse environmental impact that PSH can have on rivers and aquatic plants and animals. The development of new PSH projects has the potential to create numerous job opportunities for the local population during the construction and operation phases.

From the stakeholder interviews, it was gathered that hydropower and PSH projects require extensive community outreach and engagement. Experiences from past community outreach programs have led to the following observations:

1) The local population may not understand the full potential benefits of PSH because of a lack of knowledge about technology and a lack of a strong energy background.
2) Those who are aware of PSH, however, usually are concerned about the technology's possible negative environmental impacts (related to land use, water quality and availability, and impact to aquatic flora and fauna).
3) In many cases, the local population thinks that PSH does not offer them exciting career opportunities comparable to what wind and solar offer.
4) The huge workforce needs of PSH projects can provide multiple job opportunities to the local residents, but they don't see a career path for themselves. Therefore, the biggest opportunity lies in creating ways to foster the appropriate interest levels in the local population with respect to these career paths.

A 2022 Hydropower workforce challenges study, conducted by NLR, highlighted that hydropower and PSH rely heavily on people working in craft-skilled jobs (crafts and tradespeople) (Daw et al. 2022). Figure 2 highlights the distribution of the different jobs by category across the U.S. There are many career paths in the hydropower industry for technical workers (construction, manufacturing, trade, transportation, pipeline, and other services) and nontechnical workers (professional and business services).

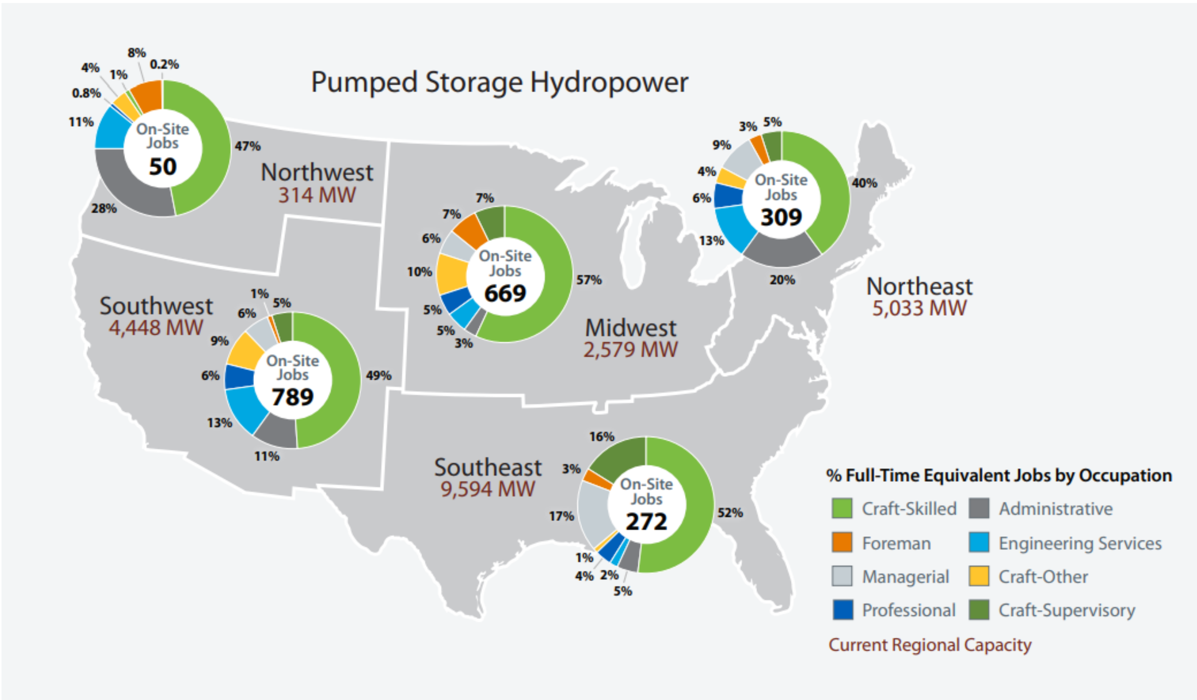

Figure 2. Regional distribution of on-site PSH jobs across the United States (Daw et al. 2022)

3.5.2 Lessons Learned and Best Practices in Working with Local Communities

Interviews and webinar discussions with PSH stakeholders were subsequently focused on meeting challenges and finding opportunities to engage with local communities for the prospective development of new PSH facilities and application of new PSH technologies. Table 9 discusses a few of these opportunities that could harmonize PSH development with community engagement.

Table 9. Summary of Community Business Development and Engagement Measures Pursued Concurrently with PSH Development

How to work with local communities?	Best way to develop partnerships?	What activities can be pursued?
• Start early during siting process. • Work with local communities and tribes to adjust construction plans (e.g., allow land access for tribal traditions/events). • Discuss economic benefits to local businesses, while ensuring limited disruptions to local communities.	• Work on educational programs at all stages. • Revisit earlier NHA educational programs and find ways to apply them locally.	• NHA educational programs • Working on referrals to organizations • Interview/webinars on financial assistance programs for PSH, including community & tribal incentives • Review work on identifying PSH sites on tribal lands – e.g., use Argonne's GEM model (https://gem.anl.gov/). • Follow up with NHA educational programs. • Engage with local business and community organizations and tribal groups to develop webinars and resource hub.

Working with local communities:

When it comes to working with the local communities through the project development phase, from a developer's perspective, it was shared that starting communication (with the communities) early during the siting process was very important. When working on buy-in for the site location, some developers shared that it would be easy for them to connect with local and tribal communities.

The best way to reach out to some of these local communities is through some of their community-based organizations or state organizations. It is important to maintain a good relationship with them throughout and after the project licensing process. However, it was mentioned that the funding plays an important role in continuing further engagements with these community-based groups. These groups may sometimes not have sufficient funding to remain actively engaged with the industry. It is important to work with local tribes to adjust construction plans and figure out the permissible limits pertaining to land access (for tribal traditions/events) and water use.

To help further build the pumped storage community, it was suggested that it would be good to develop more pilot demonstrations of small-scale pumped storage technologies. These could help developers or utilities strategize ways to get the cooperation of the local population communities and environmental organizations. Another suggestion that was emphasized by interviewees was the need for more educational outreach to utilities, market operators and environmental organizations (via webinars or workshops) that would help better explain the PSH technology and its potential benefits, impacts, and value of services provided. It would also help to have a resource that helps review financial assistance programs for PSH that include community and tribal incentives.

3.6 Technology Assistance – How National Laboratories Can Meaningfully Advance PSH

The stakeholder interviews conducted were also focused on capturing what national labs and DOE can do to promote advancements and innovations for PSH implementation. Industrial experts shared some insights that could further enrich the existing efforts to commercialize and deploy PSH. There was a general opinion that some of the traditional narratives about PSH technologies need to be challenged, as PSH has undergone some technological innovations which addressed some of the previous concerns. Subsequently, the industry and utilities need resources through which they can be more well-informed about these innovations and their operational benefits. General feedback that was shared by industry experts and stakeholders was that there is a need for more educational opportunities to inform a wider audience about PSH technology and how it works and benefits the grid and local communities. The following are some more specific aspects that need to be addressed in the upcoming years.

- **Financial analysis models:**

Multiple PSH stakeholders during the interviews and webinar expressed the need for a financial modeling tool that was characterized as a financial closing tool that will not just forecast future revenue and earning potential, but will consider the impact of different financing options, followed by repayment scenarios and ROI metrics. They explained that the financial closing model should go beyond the analyses provided by techno-economic models to address financing criteria and metrics required by banks and other lenders or investors over long-term time horizons for PSH projects from plant start-up through decades of plant operations.

- **Financial closing of projects:**

Discussions during the stakeholder interviews on how DOE and national laboratories can help to advance the development of PSH projects focused on the need to examine financial closing pathways achieved by PSH projects outside of the U.S. Suggestions included studying financing mechanisms available to reduce uncertainties in revenue generation through long-term or bundled contract agreements, insurance provisions, or tariff rate provisions. Interview participants also suggested examining market structures and regulatory frameworks that contributed to completing financial closing of PSH projects abroad and examples of financial closings in other industries.

- **PSH as transmission asset:**

PSH has the capabilities to provide a multitude of transmission services, which include voltage control, congestion management, stability services, and others. One of the key questions to be addressed was whether PSH could be used as a transmission asset. One of the interviewees commented that once you start calling PSH a transmission asset, there may not be a clear understanding of who is paying for its services. Also, if a PSH facility is needed as a solution in a transmission planning process, then the uncertainty in obtaining timely approvals for project development could threaten the grid reliability (Schilling 2022).

- **Community business development outreach and engagement support:**

Feedback from the interviews highlighted the need for more outreach programs and workshops, which would help communities understand the PSH technology and the various job opportunities associated with it.

From the interviews, it was understood that the developers felt it is important to have a talk with financiers to understand what they need (to more efficiently finance more PSH projects). As obtaining the funding for investment is an important factor in project development, there is a need to get an understanding of how to provide a solid business model to potential investors. PSH is the only currently mature technology that can provide large amounts of long-duration energy storage. This is an opportunity to emphasize the value that PSH projects bring to the grid and therefore improve the treatment of PSH resources in electricity markets. DOE and national laboratories can do more research that analyzes the role of long-duration storage in providing grid resilience and integrating high levels of variable energy resources to meet rising U.S. power generation goals.

The industry experts also suggested that there is a need to focus on economics and show aspects like the value of expected energy-not-served. There is a need to gather data from test projects for different TRLs, which will help develop better economic justification for some of these projects. There is also a need to develop some simple and efficient cost models that could help utilities and developers make very good, cost-effective decisions while taking into consideration many parameters like dam size, tunnel length, head height, and type of rock. These models could help to identify more cost-effective seasonal-duration PSH sites and achieve more development of new and expanded PSH capacity. These models could also help identify more local economic development benefits that PSH could offer over battery systems. We need more models that will help guide utilities through the complex decision-making process that PSH development needs to go through at different stages. Additionally, national laboratories could help provide educational opportunities that could inform the regulatory bodies in developing appropriate incentives and policies for getting the economics to work for long-duration storage.

Another point that was addressed by the interviewees was the valuation of services offered by PSH. This valuation was considered a critical part of promoting PSH and assessing the requirement for pumped storage. Utilities rely on the use of batteries and now they're slowly getting familiar with implementing PSH in the system. Along the way, they have a simultaneous need to understand accurate methods to value pumped storage and how PSH can benefit the system. Additionally, it could be beneficial to provide some grants or funding for demonstration and pilot projects for technology development, or test facilities.

Interviewees suggested a further examination of how DOE can work with PSH stakeholders on new loan program options and study the approaches the World Bank uses in funding major infrastructure projects abroad. Suggestions also included talking to financiers to ask what guarantees or financial metrics they need to support loans or investments. Examining how PUCs could provide loan support or how to help IPPs and utilities with insurance programs with debt lenders was also suggested. Interview and webinar discussions also focused on how a DOE and national laboratories study of financial closing successes for PSH projects outside the U.S. could lead to lessons to share with PSH stakeholders in the U.S.

3.6.1 How National Laboratories Can Support Commercializing PSH Technologies

Table 10 summarizes the responses of different categories of interviewees regarding how national labs and WPTO can further facilitate the commercialization of PSH. The most commonly received feedback was that there is a need to identify and offer educational workshops and resources which would highlight the benefits of PSH and the value of its services. PSH has progressed a lot, owing to technical innovations and improved project siting measures. Thus, there is a need to inform the local communities and stakeholders of the positive changes PSH has undergone in recent years. The PSH innovators also shared that it would be helpful to have guiding resources which would help them make a polished sales pitch to potential investors. Information gathered from industry associations also suggested that it would be beneficial to have small-scale PSH technology demonstrations for developers and utilities. These highlighted measures could help bridge some of the existing gaps, thereby bringing the different categories of stakeholders to the same page when it comes to the different steps of PSH project implementation.

Table 10. How National Labs Can Help Advance PSH Commercialization

Stakeholder Category	How Can National Labs Help?
PSH developers & consultants	• Labs have done a pretty good job over the past couple of years, focusing on PSH development without getting lost in the efforts to develop new technologies on the long-duration side. • Must continue to push back on old narratives about PSH technology and its challenges when it comes to land use constraints, environmental impact, and cost. With appropriate innovations and project siting, these issues are being addressed. • Provide utilities with resources to accurately value PSH resources on their systems from an operational standpoint.
PSH OEMs & Utilities	• Fund outreach efforts to utilities and market operators, to provide webinars and information on PSH technologies and valuation of their services. • Establish more pathways for the deployment of 400- to 1,000-MW facilities into the marketplace; right now, it is not so easy for public or private PSH developers to make this happen. • Need analysis or support to identify and value the ancillary benefits of PSH. • More domestic availability of major equipment for PSH systems. • Accessibility to training programs for labor or to build facilities that enable more domestic manufacturing of system components.
PSH innovators & investors, finance	• More educational opportunities on small-scale hydro/PSH. • Need a discussion/networking forum among PSH developers, engineers, investors and innovators. • Connection to a pool of potential investors; need resources on how to make a polished sales pitch.
Industry associations, agencies, national labs	• Help develop tools to build awareness about PSH benefits. • With a more accurate forecast of system operations, can PSH be operated differently and more efficiently? • Resources for better understanding of potential value streams for PSH.

	• Develop more small-scale PSH technology demonstrations for developers or utilities. • Develop data on early-stage understanding of reduced environmental impacts due to new improved technology (some test projects as we move up TRL ladder).

4.0 Conclusions

Given the prominent role PSH plays in the energy storage landscape, identifying the challenges and best practices that impact its wider deployment and commercialization pathways in the United States has been key. This report consolidates the information collected through literature review, interviews and webinars conducted with different categories of stakeholders about specific topic areas associated with PSH commercialization and deployment. The interviewed stakeholders consisted of PSH developers and consultants, innovators and early-stage investors, OEMs, utilities and regional/local power authorities, hydropower industry organizations, and local community outreach organizations.

In this report, we summarized our findings to not only address the challenges facing PSH stakeholders in commercializing PSH projects and innovations but also identify and share lessons learned and best practices for navigating these challenges and examine what has worked and then how to apply lessons to other regions, projects, and technologies. By examining the factors enabling market, regulatory and community responses, lessons learned could be shared and incorporated into future work by DOE and national laboratories.

The key takeaways from the interviews and webinars focus on market, innovation, techno-economic, environmental/regulatory and social challenges faced by PSH innovators and developers. Additionally, the key takeaways highlight what national labs and DOE can do to help accelerate and further the commercialization of PSH by addressing some of the gaps discussed during the course of the discovery interviews.

Challenges in advancing PSH projects and innovations to commercial deployment

The report highlights the following challenges faced by PSH commercialization:

- **Long and uncertain project development timelines** are often a significant obstacle when there are competitive short-term battery technologies that could be developed and implemented in 2–3 years or less.
- **There is also a need for more time-efficient licensing and permitting processes**, as developers work with the associated regulatory authorities at the state and federal levels.
- **Regulatory challenges** are also closely linked with some of the environmental and social challenges in PSH implementation.
- **There is a need for greater industry and public awareness** of the PSH technology innovations and improvements that have addressed some of the environmental impacts that PSH has had in the past.

Lessons to share on developing PSH projects & advancing PSH technology innovations

During interviews and webinars, PSH developers, innovators and industry consultants shared experiences and lessons learned in finding ways to collaborate with communities, industries, regulators and funding sources to move forward with their PSH plant and technology innovation projects. Lessons and best practices were shared during interviews and webinars in responding to the following challenges:

- **Long project completion times:** Lessons shared during interviews and webinars included examples of smaller plant configurations and securing timely regulatory approvals in regions with proven performance from existing PSH plants. In regions with existing PSH plants, interviewees noted that power authorities are aware of PSH operating performance and benefits to support the regional power grid, enabling the utilities to advance approvals for new PSH projects and plant expansions. Follow-on discussions focused on conducting case studies to build awareness of the operating success of existing PSH plants to share with PSH developers proposing to build new PSH plants in other regions.
- **Long environmental and regulatory approval processes:** Lessons and best practices noted during interviews and webinars included performing early site evaluations to limit potential licensing concerns and delivering timely responses and education to shorten or avoid delays in the licensing approval process. Interviewees discussed how closed-loop PSH plant designs and use of brownfield sites with existing environmental impact analyses may help to reduce evaluation timelines. Identifying state water regulations and obtaining permits for supplemental water to top off reservoirs will be needed to address evaporative losses of water from reservoirs.
- **Development of innovative PSH technologies:** During interviews and webinars, PSH stakeholders shared the challenge of demonstrating to funding decision-makers how PSH technology innovations can help to de-risk PSH development by reducing construction times and costs, enabling more sites for PSH plants, and reducing environmental impacts. Lessons learned included examples where innovators have secured funding via competitions granting early-development funding. Suggestions to advance PSH innovations included estimating potential power grid needs in 5 to 15 years with increasing new electricity generation targets and how PSH technology innovations can support future PSH plant operations and power grid needs.
- **PSH support for market needs:** Building an understanding of PSH services to encourage power purchasers to secure market contracts were recurring discussion points during interviews and webinars. Lessons learned and best practices shared included using resources and tools to demonstrate the full value of PSH grid services and power generation for 50+ years to support energy resiliency. Advancing modeling tools and examining funding options from other industry sectors were suggested during the interviews and webinars.
- **Community business development outreach and engagement:** Lessons offered during interviews and webinars to collaborate with communities and organizations near PSH sites included conducting in-depth preliminary site evaluations and holding early town halls and tribal meetings to gather feedback and offer solutions. Responses by PSH developers to community concerns included re-routing construction traffic and avoiding historically significant tribal sites. Lessons shared during interviews and webinars also highlighted the benefits of educational outreach and forging long-term relationships with groups near potential PSH plant sites well before project design stages.

Opportunities for national laboratories and DOE to support PSH stakeholders

When looking at how national labs and DOE can help address the commercialization challenges, the most commonly received comment was that there is a need to identify and offer educational workshops and resources that would highlight the benefits of PSH and the value of its services to the grid. PSH has progressed a lot owing to technical innovations and improved project siting measures. Thus, there is a need to inform the local communities and stakeholders of the positive changes PSH has made over recent years. PSH developers and innovators also shared that it would be helpful to have resources that would help them understand the best ways to secure investors to aid in project implementation. In addition, it was suggested that it would be beneficial to have small-scale PSH technology demonstrations for developers and utilities. The accurate valuation of PSH services was also a significant gap that was discussed. Therefore, there is an emerging need for more webinars and information on PSH technologies and their accurate service valuation.

Regarding how DOE and national laboratories can help, responses by interviewees and webinar participants included the need to build awareness of the value and benefits of PSH services to garner revenue recognition, and the role of DOE and national laboratories in providing impartial and valued analysis tools. This input included multiple requests to build a financial closing model to help PSH stakeholders with limited resources get a head-start in building financial projections to demonstrate timely ROIs or repayment of investment to decision-makers to gain funding for their projects and technology development.

Building awareness of the many benefits that PSH provides to the grid was also discussed in terms of sharing the information, training, knowledge, and resources with PSH stakeholders. Many suggested that the development of an online resource hub with links to PSH stakeholders, financing or investing organizations, regulators and community organizations would provide important educational and networking pathways for PSH stakeholders. As suggested during interviews and the webinar, an online resource hub and research studies that amplify how PSH can support power systems, consumers, and communities will help raise the profile of PSH with local and tribal communities, regulators and policymakers.

The findings of our study also include interview and webinar comments recognizing growing interest in adding PSH capacity to provide power grid resiliency and long-duration energy storage needs for power systems requiring rapid capacity expansion and growing variable energy resources. Interviews and the webinar included suggestions that DOE and national laboratories could provide impartial analysis to support PSH commercialization. Further research is needed on the market for PSH and the value of PSH in supporting the need for more electricity generation and to secure the power grid.

Resources from the literature review, interviews and webinars will support the development of an online resource hub, which will contain links to tools, guidance resources, publications, and other resources. The consolidated content summaries will be completed and posted on an online resource hub webpage with links to enable access to resources focused on PSH commercialization topics and tools. Some educational materials (fact sheets, guidance documents, etc.) will also be connected through the online resource hub webpage.

Overall, by systematically gathering and reviewing the feedback received from the different categories of interviewed stakeholders, this report has provided a detailed discussion of the existing best practices associated with PSH technology and the challenges associated with the commercialization pathways. It is hoped that the findings highlighted within this report will be of significant use to supplement future efforts toward commercialization of PSH technology.

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6.0 Appendix A – State of the Wholesale Electricity Markets

6.1 Overview and Purpose

The intent of these summaries is to provide PSH Commercialization stakeholders with an easy-to-access resource that summarizes market opportunities and challenges in the major market regions:

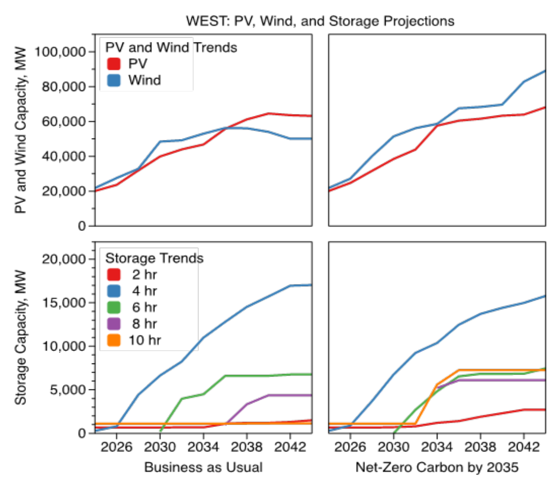
- California Independent System Operator (CAISO)
- Electric Reliability Council of Texas (ERCOT)
- Independent System Operator of New England (ISO-NE)
- Mid-Continent Independent System Operator (MISO)
- New York Independent System Operator (NYISO)
- Pennsylvania-New Jersey-Maryland (PJM)
- Southeast Wholesale Market Region
- Southwest Power Pool (SPP)
- Western Wholesale Market Region

These regions mirror those in the FERC Energy Primer[2], and most are also the names of the operating entities for the given region. The two exceptions are the Southeast Wholesale Market Region and the Western Wholesale Market Region, areas that still consist of vertically integrated, municipal, and co-operative utilities, although markets are making inroads in both.

Information included in each summary is general market background, projections of within-region energy storage buildouts, a summary of market opportunities, and a note about interconnection procedures and agreements. This document was last updated in September 2023 and includes findings from the 2022 annual market monitor reports.

<u>General Region/Market Information</u>
A paragraph or two provides background information about the region.

<u>Storage Buildout Projections</u>
To help stakeholders understand storage growth potential for a given region, Wind, Solar, and Storage (2-, 4-, 6-, 8-, and 10-hour duration) buildout projections are included. Also, to help bound these projections, results for BAU and nationwide scenarios are presented, with the BAU results providing an expected lower bound and providing an upper bound for projected storage needs. The projections are shown in a 4-by-4 grid (see the example to the right), where the wind, solar, and storage projections for the BAU scenario are shown in the first column and the same resource projections



Example Energy Storage Projections

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[2] Staff Report, Energy Primer: A Handbook for Energy Market Basics, Federal Energy Regulatory Commission, April 2020. https://www.ferc.gov/sites/default/files/2020-06/energy-primer-2020_Final.pdf

in the second. The information in the buildout projection plots is from NLR's 2022 Standard Scenarios.[3]

In- and Out-of-Market Opportunities in the Region

Most of the content in these market summaries is based on information from FERC's Energy Primer (last updated in April 2020), supplemented with updated content from the most recent annual independent market report for each region (the 2022 annual reports at the time of writing). Where information other than these sources is used, it is clearly cited.

In-Market Opportunities

A short summary of each of the markets will be presented as applicable:

- Energy (day-ahead, real-time, and, in some areas, hour-ahead)
- Ancillary services (day-ahead, real-time, and, in some areas, hour-ahead)
- Capacity (varies by region; may be out-of-market in some areas)

Out-of-Market Opportunities

Although there may be multiple out-of-market opportunities, this edition of the market summaries focuses on one:

- Capacity sales (varies by region; may be in-market in some areas)

Interconnection Procedures and Agreements

FERC issued a new rule, Order No. 2023—Improvements to Generator Interconnection Procedures and Agreements, announced July 28, 2023. The order is designed to streamline and standardize the interconnection process and will likely supersede existing processes.[4] Each RTO and ISO will work through this order in its own way, so please contact them for information regarding how they are planning to implement the new requirements.

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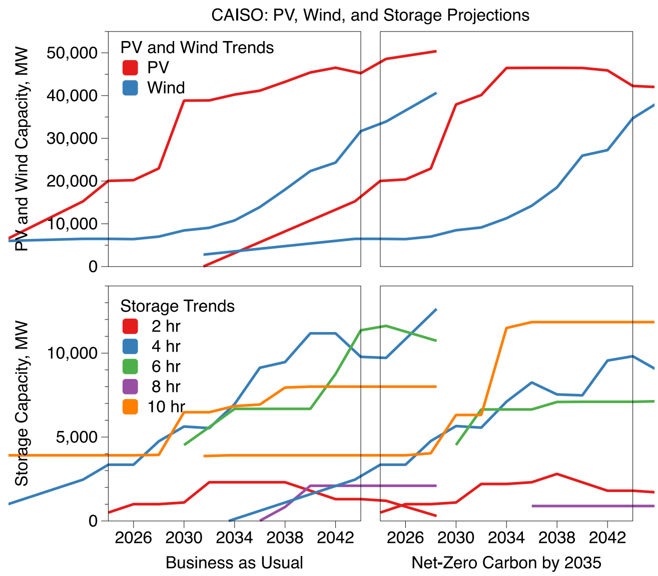
[3] Please see https://www.nrel.gov/news/program/2022/the-2022-standard-scenarios-are-now-available.html#:~:text=The%202022%20Standard%20Scenarios%20represent,credit%20for%20existing%20nuclear%20generators for more information.

[4] The order document is available at FERC's website, https://www.ferc.gov/media/e-1-order-2023-rm22-14-000.

6.2 California Independent System Operator (CAISO)

CAISO manages the flow of electricity across the high-voltage, long-distance power lines of the Western grid and serves 80% of California and a small part of Nevada. As the only independent grid operator in the western U.S., the ISO grants equal access to nearly 26,000 circuit miles of transmission and coordinates competing and diverse energy resources into the grid, where it is distributed to consumers. With California's focus on its ambitious energy generation goals, CAISO plays a vital role in balancing the grid's needs while supporting the state's transition to a more sustainable and resilient energy future.



The ISO is also the largest balancing authority in the Western Interconnection, handling over two-thirds of the electric load in the West through its Western Energy Imbalance Market (WEIM).[5] The peak load for 2022, 52,061 MW, was a record high and an 18.4% increase over the prior year.

Storage Buildout Projections
The main difference between the BAU and the 100% by 2035 scenarios is that CAISO will need increased amounts of longer duration storage (10+ hours), since CAISO will not be able to lean as heavily on neighbors who will also be busy meeting their own goals.

In-Market Opportunities
CAISO operates both energy and ancillary service markets in the day-ahead and real-time markets as well as a flexible ramping market in real time. The numbers quoted below are from CAISO's 2022 Annual Report on Market Issues & Performance Report[6] unless stated otherwise.

Day-Ahead Markets
CAISO offers both day-ahead energy and ancillary service markets, with over 95% of the energy and ancillary services procured via the day-ahead market.

Day-Ahead Energy Markets
Approximately 211 TWh of energy was procured in 2022 at an average price of $90/MW, a 70% increase over $53/MWh in 2021. The highest average quarterly price for the year was $140/MWh (Q4) and the lowest was $49/MWh (Q1), all driven by natural gas prices.

[5] For information on the WEIM, please see the Western Wholesale Market region summary later in this document.
[6] http://www.caiso.com/Documents/2022-Annual-Report-on-Market-Issues-and-Performance-Jul-11-2023.pdf

California Independent System Operator (CAISO)

Day-Ahead Ancillary Service Markets

The California ISO procures ancillary services from its internal system region, expanded system region, four internal sub-regions, and four corresponding expanded sub-regions.[8] Operating reserve (spin) requirements in the day-ahead market are typically set by the maximum of (1) 6.3 percent of the load forecast, (2) the most severe single contingency, and (3) 15 percent of forecasted solar production.[9] Regulation requirements are based on observed regulation needs during the same time period in the prior year. Note that the regulation markets also include payments for mileage.

Weighted average price ($/MW) and amount (MW)		
Day-Ahead	2021	2022
Reg down	$12.76, 400 MW	$12.04, 808 MW
Reg up	$8.09, 400 MW	$12.67, 404 MW
Spin[7]	$5.92	$9.80
Non-spin[6]	$2.09	$3.68

Real-Time Markets

CAISO offers both 5- and 15-minute energy and ancillary service markets. Note that less than 5% of the energy is traded in the real-time markets.

Real-Time Energy Markets

The combined 5-minute, 15-minute, and Energy Imbalance markets were used to procure approximately 5 TWh of energy (approximately 5% of CAISO's 2022 needs).

- 5-minute energy market
  - The average price for the year was $81/MWh. The highest average quarterly price was in Q4 ($131/MWh) and the lowest was in Q1 ($41/MWh).
- 15-minute energy market
  - The average price was $89/MWh. The highest average quarterly price was in Q4 ($136/MWh) and the lowest was in Q1 ($45/MWh).

Real-Time Ancillary Service Markets

Like in the day-ahead markets, ancillary services in the real-time markets are procured by subregion.[10] Operating reserve (spin) requirements in real-time markets are calculated similarly to the day-ahead markets except using 3 percent of the load forecast and 3 percent of generation.[11] Regulation requirements are based on observed regulation needs during the same period during the prior year. Requirements are calculated for each hour of the day, and the values are updated regularly. Furthermore, the ISO can adjust requirements manually for periods when conditions indicate higher net load variability.[12]

Weighted average price ($/MW)		
Real-Time	2021	2022
Reg down	$14.11	$22.98
Reg up	$12.09	$12.53
Spin	$6.45	$8.51
Non-spin	$1.46	$2.08

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[7] The combined operating reserve requirements (i.e., spin and non-spin) were 1,822 MW for 2022, a 3% increase from 1,770 MW the previous year.

[8] More information on ancillary service requirements and procurement for internal and expanded CAISO regions is in the Department of Market Monitoring, *2020 Annual Report on Market Issues & Performance*, August 2021, p. 161: http://www.caiso.com/Documents/2020-Annual-Report-on-Market-Issues-and-Performance.pdf

[9] Q4 2022 Report on Market Issues and Performance. California ISO. March 16, 2023.

[10] More information on ancillary service requirements and procurement for internal and expanded CAISO regions is in the Department of Market Monitoring, *2020 Annual Report on Market Issues & Performance*, August 2021, p. 161: http://www.caiso.com/Documents/2020-Annual-Report-on-Market-Issues-and-Performance.pdf

[11] Q4 2022 Report on Market Issues and Performance. California ISO. March 16, 2023.

[12] 2020 Annual Report on Market Issues & Performance. California ISO. August 2021.

In general, although the regulation prices were higher in the real-time market than in the day-ahead market, ancillary costs are largely determined by day-ahead market prices since most ancillary services are procured in the day-ahead market (only 6 percent of ancillary costs were incurred in the real-time market). The amounts of ancillary services cleared were not listed in CAISO's 2022 report.

As in the day-ahead regulation markets, the real-time markets include regulation payments for mileage.

Flexible Ramping Products

On November 1, 2016, the ISO implemented two market products in the 5- and 15-minute markets: Flexible Ramp Up and Flexible Ramp Down uncertainty awards. These products provide additional ramping capability to account for uncertainty due to demand and forecasting errors.[13]

- Flexible Ramp Up and Flexible Ramp Down
  - State of the market as of 2021: prices were zero for over 99 percent of intervals in the 15-minute market and 99.9 percent of intervals in the 5-minute market for both upward and downward flexible ramping capacity.

Out-of-Market Opportunities

- Capacity Sales

  CAISO does not have a formal capacity market, but does have resource adequacy requirements for 10 local capacity areas. Capacity resources are typically procured through bilateral or other non-market means.[14]

Interconnection Procedures and Agreements

- FERC issued a new rule, Order No. 2023 – Improvements to Generator Interconnection Procedures and Agreements, announced July 28, 2023.[15] The order is designed to streamline and standardize the interconnection process. Each RTO and ISO will work through this order in its own way, so please contact them for information on how they are planning to implement the new requirements.

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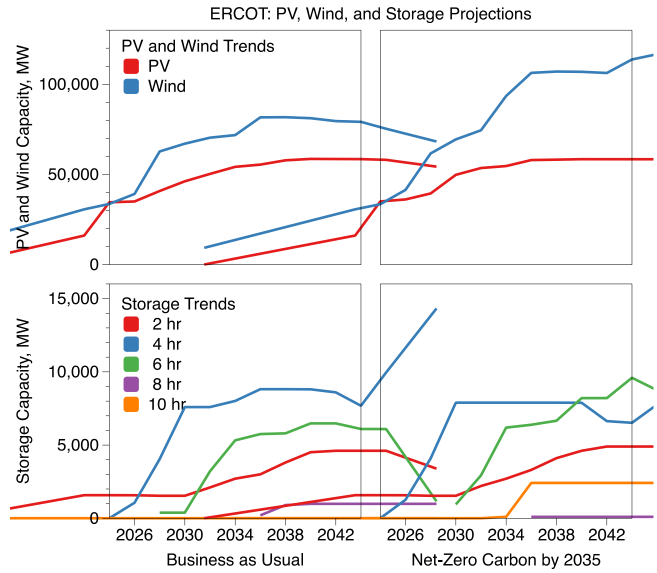
[13] Market Performance Report–Market Analysis and Forecasting, February 2023. California ISO. 2023-05-31.

[14] 2022 State of the Markets. Federal Energy Regulatory Commission. Published March 16, 2023.

[15] The order can be found at FERC's website, https://www.ferc.gov/media/e-1-order-2023-rm22-14-000.

6.3 Electric Reliability Council of Texas (ERCOT)

The Electric Reliability Council of Texas (ERCOT) is the only restructured electricity market within the United States that operates wholly within a single state, and this independence allows ERCOT to have its own set of rules, regulations, and market structures. It is subject to oversight by the Public Utility Commission of Texas and the Texas Legislature and serves more than 26 million Texas customers, representing about 90 percent of the state's electric load.



In 2022, demand peaked at 80,038 MW, a new record and 8.8% higher than the peak in 2021. In February of 2021, the ERCOT grid struggled under Winter Storm Uri to maintain power throughout its operating area. As a result, ERCOT is in the process of restructuring some of its rules and regulations; please check the ERCOT website for the latest information.

Storage Buildout Projections

The primary difference between the BAU and the high variable energy resource scenarios is the buildout of additional wind and 6- and 10-hour storage. Under a "high variable energy resources" scenario, wind buildout exceeds 120,000 MW, a 50% increase over the BAU scenario. To support the additional wind, approximately 10,000 MW of 6-hour storage and 2,500 MW of 10-hour storage buildout is projected, an increase of almost 60% more 6-hour storage and 100% more 10-hour capacity than the 8-hour storage it displaces.[16]

In-Market Opportunities (and Challenges)

ERCOT offers day-ahead and real-time energy and ancillary service markets. Note that ERCOT does not offer a direct mechanism for capacity payment, instead relying on price peaks caused by shortages in the real-time energy market to encourage investment in capacity. Because of this, it is difficult to compare prices in ERCOT to those of other regions.

Day-Ahead Markets

ERCOT offers both energy and ancillary service day-ahead markets. The ancillary service markets differ from those in most regions in that the responsibility to procure ancillary services is assigned to Qualified Scheduling Entities (QSEs).

Day-Ahead Energy Markets

The average day-ahead price in 2022 was $66/MWh, a significant reduction from the Winter Storm Uri-dominated prices of 2021 ($157/MWh). 59% of the energy for 2022 was delivered through the day-ahead market, which is noticeably lower than in other markets but is to be

[16] In the high-variable energy resources scenario, unlike the 1,000 MW of 8-hour storage projected, no 8-hour storage is procured and instead 2,500 MW of 10-hour storage is built.

expected in that ERCOT's market structure uses real-time shortage prices to incentivize capacity buildout.

Day-Ahead Ancillary Service Markets

- Day-ahead ancillary services are procured by QSEs, historical price settlements.

Day-Ahead Reserves Market[17]	2020 ($/MWh)	2021 ($/MWh)	2022 ($/MWh)
Responsive Reserve	$11.60	$21.69	$20.30
Regulation Up	$10.32	$18.95	$21.67
Regulation Down	$7.19	$13.09	$8.46

Real-Time Markets

ERCOT offers both energy and ancillary service markets.

Real-Time Energy Markets

Average real-time prices fell to approximately $75/MWh in 2022, a reduction of more than 50% from 2021 and the effect of Winter Storm Uri but an increase of almost 200% from 2020. The increase in price from 2020 was driven primarily by the increase in natural gas prices and hotter than historical summer temperatures. Note that ERCOT is an energy-only market, and it relies on high real-time prices during the shortage conditions to encourage the buildout of new capacity.

Real-Time Ancillary Service Markets

The regulation markets as well as average clearing prices for recent years are shown in the table below:

Real-Time Reserves Market	2020 ($/MWh)	2021 ($/MWh)	2022 ($/MWh)
Responsive Reserve	$11.40	$331.46	$20.27
Non-spin Reserve	$4.45	$83.75	$23.29
Regulation Up	$11.32	$289.84	$25.68
Regulation Down	$8.45	$120.70	$9.62

Out-of-Market Opportunities

ERCOT does not offer a capacity market or other form of capacity payment and instead relies on price peaks in the energy market to provide the signal to encourage the buildout of adequate capacity.

Interconnection Procedures and Agreements

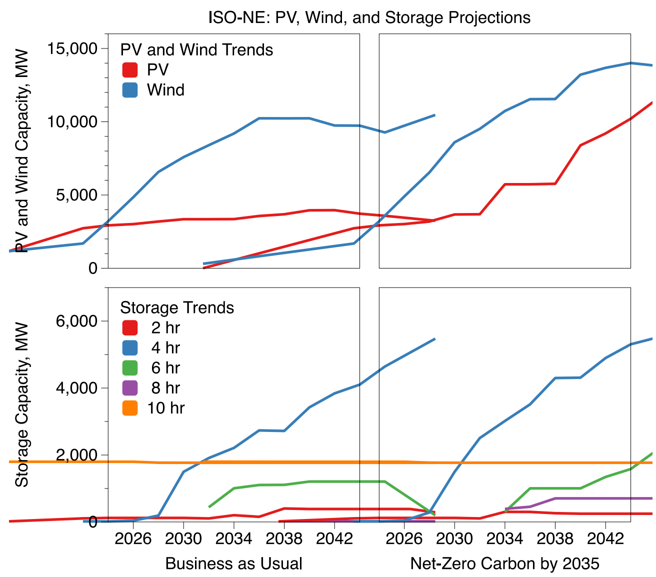
FERC issued a new rule, Order No. 2023 – Improvements to Generator Interconnection Procedures and Agreements, announced July 28, 2023.[18] The order is designed to streamline and standardize the interconnection process. Each RTO and ISO will work through this order in its own way, so please contact them for information on how they are planning to implement the new requirements. It's unclear how ERCOT will respond to this new rule.

[17] Farley, Jack. ERCOT Responsive & Regulation Prices Soften Even as the Ancillary Services Procurement Expands. See https://www.linkedin.com/pulse/ercot-responsive-regulation-prices-soften-even-ancillary-jack-farley. Note that the 2021 prices exclude effects of Winter Storm Uri.

[18] The order can be found at FERC's website, https://www.ferc.gov/media/e-1-order-2023-rm22-14-000.

6.4 Independent System Operator of New England (ISO-NE)

The ISO New England operating area comprises six states—Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont. As of June 2023, all states in the region have established RPS policies and half have clean energy standards.[19] ISO-NE forms the New England subregion of the Northeast Power Coordinating Council NERC region.[20]



New England differs from most other parts of the country in that it has limited natural resources and must import natural gas via either pipelines or LNG terminals to fuel its significant natural gas fleet. Consequently, ISO-NE has generally exhibited the highest average energy prices among RTO markets in recent years because of its higher natural gas prices.[21, 22] In 2022, demand peaked at 24,780 MW.

Storage Buildout Projections
Wind and 4- and 6-hour storage buildout increase in both scenarios, although at a higher rate in the new generation scenario. In addition, solar and 8-hour storage are projected to increase in the new generation scenario. Interestingly, no new 10-hour storage is projected, but that is likely because the region already has significant 10-hour storage capacity, almost 7% of the all-time peak load.

In-Market Opportunities (and Challenges)
ISO-NE offers day-ahead energy, real-time energy and reserves, forward capacity, and forward reserves market opportunities.

Day-Ahead Markets
ISO-NE offers an energy day-ahead market.

Day-Ahead Energy Markets

- Most energy in ISO-NE is sourced in the day-ahead market. The average day-ahead price for 2022 was $85.56/MWh, an 86% increase over the 2021 price of $45.92/MWh. Most of the price difference was attributed to an increase in the price of natural gas.

Day-Ahead Ancillary Service Markets
Currently, there are no day-ahead ancillary service markets in the ISO-NE region. Instead, the region uses Forward Reserves auctions to procure reserves ahead of time.

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[19] Barbose, G. (June 2023). U.S. State Renewables Portfolio & Clean Electricity Standards: 2023 Status Update, Lawrence Berkeley National Laboratory, Berkeley, California.
[20] 2023 Summer Reliability Assessment, North American Electric Reliability Corporation (NERC), May 2023.
[21] An Overview of New England's Wholesale Electricity Markets: A Market Primer. ISO New England, Inc. June 2023.
[22] 2022 Assessment of the ISO New England Electricity Markets, Potomac Economics, June 2023.

Real-Time Markets
ISO-NE offers real-time markets for both energy and ancillary services.

Real-Time Energy Markets
Pricing in the real-time market was similar to that in the day-ahead markets, with a marked increase from 2021 ($44.84/MWh) to 2022 ($84.92/MWh).

Real-Time Ancillary Service Markets
In addition to the Forward Reserves market discussed below, ISO-NE offers four real-time ancillary service markets:

- Ten-Minute Spinning Reserves (TMSR), see note below
- Ten-Minute Non-Spinning Reserves (TMNSR), see note below
- Thirty-Minute Operating Reserves (TMOR), see note below
- Regulation, which increased from a price of $19.23/MWh in 2021 to $30.96/MWH in 2022, with an average market size of 90 MW.

Note that except for regulation, payments for real-time services were limited. For example, 87% of the year, the price for TMSR was $0/MWh, with prices averaging $19.09/MWh in the non-zero intervals. Payments from TMNSR and TMOR were even scarcer, with only 28 and 21 hours of non-zero pricing.

Forward Reserves Markets
ISO-NE offers summer and winter forward reserves markets for the following services:

- TMNSR: Prices rose from $1,150/MW-month in Summer 2021 to $7,386/MW-month in Summer 2022, with needs averaging around 1,550 MW in both years. Winter prices also increased but less so, rising from $740/MW-month in 2021 to $2,500/MW-month in 2022. Requirements averaged approximately 1,350 MW.
- TMOR: Needs were about 800 MW, and prices declined from $550/MW-month in the summer of 2021 to about $450/MW-month for the winter of 2022-23.

Forward Capacity Markets
ISON-NE offers annual 3-year look-ahead forward capacity actions, referred to as FCAs.

- For 2022, the cleared capacity totaled 31,370 MW, leaving a surplus of about 1 GW (1,065 MW) at the auction clearing price of $2.59/kW-month. This rest-of-pool clearing price remained unchanged from 2021.

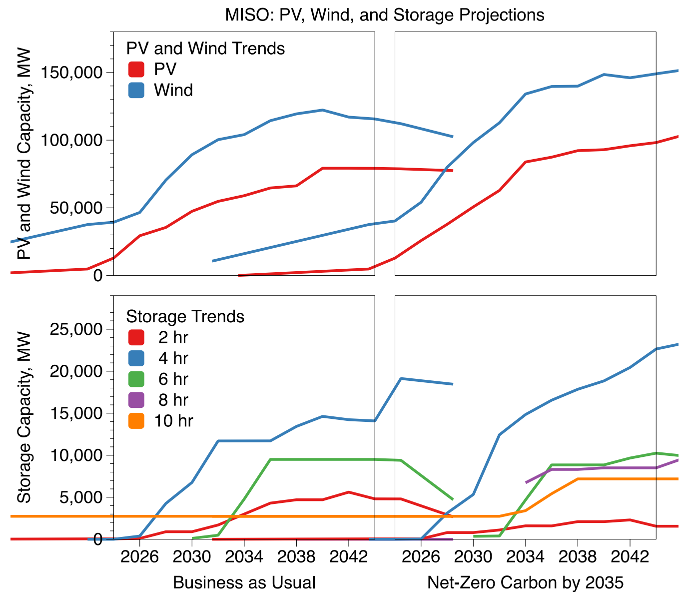
Interconnection Procedures and Agreements

- FERC issued a new rule, Order No. 2023 – Improvements to Generator Interconnection Procedures and Agreements, announced July 28, 2023.[23] The order is designed to streamline and standardize the interconnection process. Each RTO and ISO will work through this order in its own way, so please contact them for information on how they are planning to implement the new requirements.

[23] The order can be found at FERC's website, https://www.ferc.gov/media/e-1-order-2023-rm22-14-000.

6.5 Midcontinent Independent System Operator (MISO)

The MISO operates wholesale electricity markets that extend from Montana in the west to Michigan in the east, and from Manitoba, Canada, in the north to Louisiana in the south. It is a diverse operating region that encompasses all or parts of 15 states and one province, covering more areas than any of the other ISOs.



MISO had interconnections with the PJM and SPP ISOs as well as Southern Company, TVA, and the electricity systems of Ontario as well as several smaller utilities. In 2022, demand peaked at approximately 124 GW.

Storage Buildout Projections
The most marked difference between the BAU and high-variable energy resources scenarios is the increased procurement of wind and medium to longer duration (4-, 8-, and 10-hour storage needs increase by 8, 10, and 5 GW, respectively).

In-Market Opportunities (and Challenges)
MISO offers both day-ahead and real-time markets as well as a forward capacity market.

Day-Ahead Markets
MISO offers a day-ahead energy market as well as several ancillary service markets.

Day-Ahead Energy Markets
Over 98% of the energy consumed in the MISO region is procured in the day-ahead markets.

- The average day-ahead energy prices increased 74 percent from 2021 to $65 per MWh in 2022, with the price changed primarily attributed to increased natural gas prices.

Day-Ahead Ancillary Service Markets
MISO offers several day-ahead ancillary service markets:

- Regulation
- Spinning reserves
- Supplementary (non-spinning) reserves
- Short-term reserves

The market monitor report did not list the day-ahead ancillary service prices or quantities.

Real-Time Markets
MISO offers real-time energy and ancillary service markets.

Real-Time Energy Markets

- The market monitor report does not call out the real-time prices; it only states that convergence has been seen between day-ahead and real-time prices (i.e., the day-ahead and real-time market clearing prices for energy sales are similar).

Real-Time Ancillary Service Markets

Like the day-ahead markets, MISO offers several real-time ancillary service markets, with the average 2021 and 2022 prices for each of the markets shown in the table below.

Ancillary Services	Regulation	Spinning	Supplementary	Short-term
2021	$12.84/MWh	$3.31/MWh	$0.83/MWh	$0.78/MWh
2022	$17.33/MWh	$4.62/MWh	$0.82/MWh	$0.12/MWh

The market monitor report did not list the real-time ancillary service quantities.

Forward Capacity Markets

MISO offers Planning Resource Auctions (PRAs) for each of its 10 subregions.

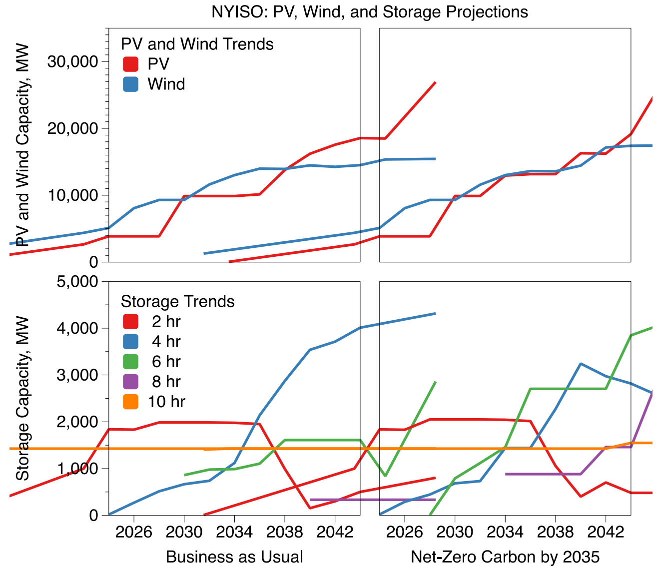
- The PRA clearing prices for the 2022–23 planning year (conducted in March 2022) ranged from $2.88/MW-d for the southern regions of MISO (Arkansas, Louisiana, Texas, and Mississippi) to $236.66/MW-d for the balance of MISO. The weighted average clearing price for all of MISO was $187.79/MW-d.

Interconnection Procedures and Agreements

- FERC issued a new rule, Order No. 2023 – Improvements to Generator Interconnection Procedures and Agreements, announced July 28, 2023.[24] The order is designed to streamline and standardize the interconnection process. Each RTO and ISO will work through this order in its own way, so please contact them for information on how they are planning to implement the new requirements.

[24] The order can be found at FERC's website, https://www.ferc.gov/media/e-1-order-2023-rm22-14-000.

6.6 New York Independent System Operator (NYISO)



The New York Independent System Operator (NYISO) footprint includes the State of New York, with New York being the southernmost state in NERC's Northeast Power Coordinating Council region.[25] Although wholly operated within one state, NYISO is heavily interconnected to the surrounding region and is thus subject to FERC jurisdiction.

NYISO assumed operation of the New York region December 1, 1999. It offers wholesale power markets that trade electricity, ancillary services, capacity, and transmission congestion contracts. In addition, NYISO offers centrally administrated, cost-based programs for the procurement of voltage support and black start services, operates the high-voltage transmission network, and serves as the reliability coordinator for its operating area.[26] In 2022, demand peaked at 30,505 MW.

Storage Buildout Projections

New York has a statutory greenhouse gas emission target[27] and thus the power generation and storage buildout for both scenarios are similar. The primary difference between the two scenarios is a significant increase in 6- and 8-hour storage built in the new power generation scenario starting in 2034 (over twice the 6-hour storage and three times the 8-hour storage).

In-Market Opportunities (and Challenges)

NYISO offers both day-ahead and real-time energy and ancillary service markets as well as a capacity market. Unless noted otherwise, all prices and quantities in this summary were taken from the 2022 State of the Market Report for the New York ISO Markets.[28]

Day-Ahead Markets

NYISO offers both day-ahead energy and ancillary service markets.

Day-Ahead Energy Market

NYISO offers a day-ahead energy market. The state-of-the-market report lists average prices by area: West New York, Central New York, North New York, the Capital area, the Hudson Valley (HV), New York City (NYC), and Long Island (LI).

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[25] ERO Enterprise and Regional Entities, North American Reliability Corporation website, accessed June 2023.

[26] Staff Report, Energy Primer—A Handbook for Energy Market Basics, Federal Energy Regulatory Commission (FERC), April 2020.

[27] State Climate Policy Maps, Center for Climate and Energy Solutions, accessed June 2023.

[28] Patton, D. et al., 2022 State of the Market Report for the New York ISO Markets, Potomac Economics, May 2023.

Average 2022 Day-Ahead Energy Prices, $/MWh						
West	Central	North	Capital	HV	NYC	LI
60.10	61.37	49.12	99.70	88.26	89.10	103.80

Note that the 2022 prices were approximately twice those of 2021, with the price increases attributed to the increased cost of natural gas.

Day-Ahead Ancillary Service Markets
NYISO offers a regulation and frequency response product and three operating reserve products. The average prices for all reserve products rose in 2022, consistent with the increase in opportunity costs associated with higher energy costs.[29]

- Regulation & Frequency Response Service: The average day-ahead price for regulation was $16.28/MWh, an 188% increase from the $8.66/MWh price in 2021.
- Operating Reserve Service: NYISO breaks out prices by area: West New York (West), the Capital Area (Capital), Southeast New York (Southeast), and New York City (NYC).

Average 2022 Day-Ahead Ancillary Service Prices, $/MWh				
Region	West	Capital	Southeast	NYC
10-Minute Spinning Reserve	6.85	8.73	8.80	9.82
10-Minute Non-Synchronized Reserve	5.57	6.39	6.54	7.50
30-Minute Operating Reserves	5.57	5.54	5.69	5.77

Hour-Ahead Market
NYISO offers hour-ahead energy and ancillary service markets. It uses these results to adjust the day-ahead schedules to account for any real-time changes or unexpected events.

Real-Time Markets
NYISO offers 5-minute energy and ancillary service markets.

Real-Time Energy Markets
NYISO offers a real-time energy market which it refers to as the Energy Imbalance Service product. As with the day-ahead prices, the state-of-the-market report lists average prices by area.

Average 2022 Real-Time Energy Prices, $/MWh						
West	Central	North	Capital	HV	NYC	LI
59.24	63.67	50.64	103.20	92.04	92.53	106.80

Note that the 2022 prices were approximately twice those of 2021, with the price increases attributed to the increased cost of natural gas.

Real-Time Ancillary Service Markets

[29] Ibid.

New York Independent System Operator (NYISO)

NYISO offers a regulation and frequency response product, three operating reserve products, and an energy imbalance product. The average prices for all reserve products rose in 2022, consistent with the increase in opportunity costs associated with higher energy costs.

- Regulation & Frequency Response Service: The average day-ahead price for regulation was $16.28/MWh, an 188% increase from the $8.66/MWh price in 2021.
- Operating Reserve Service:
  - 10-Minute Spinning Reserves
  - 10-Minute Non-Synchronized Reserves
  - 30-Minute Operating Reserves
- The market report did not list the real-time operating reserve prices or quantities.

Capacity Markets

NYISO offers capacity markets that provide a financial mechanism to encourage generators to invest in new capacity, maintain existing capacity, or retire inefficient or uneconomical resources. Three types of auctions are offered: capacity period, monthly, and spot market. These auctions are used to procure capacity for four areas: New York City, Long Island, a Locality for Southeast New York ("the G-J Locality"—mostly the Hudson River Valley area), and a New York Control Area (NYCA).

Capability Period Auctions (each procures capacity for the six-month auction period and is held no later than 30 days prior to the start of each Capability Period)

- Summer Capacity Period Auction, covers the upcoming May through October
- Winter Capacity Period Auction, covers November through April

Monthly Auctions (each procures capacity for the remaining months of the capability period and is held at least 15 days prior to the start of the Obligation Procurement Period)

- Offered monthly, may sell for the months left in the capability period

Spot Market Auction (procures capacity for the upcoming month and is run 4-5 business days prior to the start of the month)

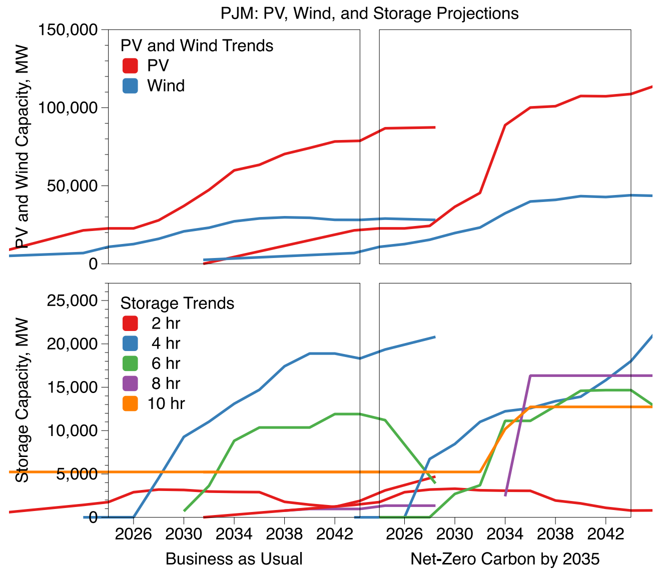
- Offered monthly, may sell for the upcoming month only

Interconnection Procedures and Agreements

FERC issued a new rule, Order No. 2023 – Improvements to Generator Interconnection Procedures and Agreements, announced July 28, 2023.[30] The order is designed to streamline and standardize the interconnection process. Each RTO and ISO will work through this order in its own way, so please contact them for information on how they are planning to implement the new requirements.

[30] The order can be found at FERC's website, https://www.ferc.gov/media/e-1-order-2023-rm22-14-000.

6.7 Pennsylvania-New Jersey-Maryland (PJM)



The PJM ISO region includes all or parts of thirteen states, including Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, and West Virginia. PJM differs from most ISOs in that its operating footprint is not contiguous, with operations in both Illinois and Michigan separate from the rest of its grid.

Its peak load for 2022 was 149,531 MW (144,356 MW of load plus 5,175 MW of gross exports), a decline of 1.4% from 2021.

Storage Buildout Projections
The most pronounced difference between the BAU and the high-variable energy resources scenarios is the longer-duration storage projections, especially for the 8- and 10-hour duration storage (8-hour projections increase from 1 GW to 16 GW, and 10-hour from 5 to 12 GW).

In-Market Opportunities (and Challenges)
PJM operates both day-ahead and real-time energy and reserve markets as well as a forward capacity market. Note that PJM restructured its day-ahead reserves markets in late 2022, so the pricing information provided in this summary may not be indicative of current market behavior. Unless noted otherwise, the pricing and demand information cited below is from the 2022 State-of-the-Market Report, Volume II.[31]

Day-Ahead Markets
PJM offers both energy and reserve day-ahead forward markets.

Day-Ahead Energy Markets
In 2022, natural gas prices had a significant impact on energy prices. The average day-ahead price increased by 91.6%, from $39.37/MWh in 2021 to $75.44/MWh.

Day-Ahead Ancillary Service Markets[32]

- Synchronized reserves: The average hourly synchronized reserve requirement in the last three months of 2022 was 1,819.0 MW in the RTO Reserve Zone and 1,818.8 in the Mid-Atlantic Dominion (MAD) Reserve Subzone. Payment is made on an opportunity cost basis, with zero or near-zero prices a majority of the time (prices averaged under $3.30/MWh in the three months since the new market structure was introduced.
- Non-synchronized (supplementary) reserves: The non-synchronized reserve weighted average prices for all intervals in the RTO Reserve Zone was $1.74 per MWh in the last three months of 2022 and $6.07 per MWh during this same time period in the MAD

[31] See (https://www.monitoringanalytics.com/reports/PJM_State_of_the_Market/2022/2022-som-pjm-vol2.pdf).
[32] Prices for prior intervals are not provided because PJM restructured its reserve markets on October 1, 2022.

Reserve Subzone. During the last three months of 2022, the average non-synchronized reserve was 1,354.5 MW in the RTO Zone and 419.2 MW in the MAD subzone.

In PJM, the 30-minute reserve requirement is equal to the greatest of 3,000 MW, the primary reserve requirement, and the largest active gas contingency, plus 190 MW. Of that, the required amount of synchronized reserve is defined to be no less than the largest single contingency, and 10-minute primary reserve as no less than 150 percent of the largest single contingency, plus 190 MW. The balance of the 30-minute reserve requirement can consist of synchronous and non-synchronous reserves.

Real-Time Markets
PJM offers both energy and reserve day-ahead real-time markets.

Real-Time Energy Markets
Price increases for the real-time energy markets were somewhat higher than for the day-ahead markets, with prices increasing from $39.78/MWh in 2021 to $80.14/MWh in 2022 (101.4%). The real-time price for the peak hour was $315.42/MWh, a substantial increase from $204.29/MWh in 2021.

Real-Time Ancillary Service Markets

- Synchronized reserves: Payment is made on an opportunity cost basis, with zero or near-zero prices much of the time, although price spikes as high as $600/MWh and $450/MWh occurred for two days in late December of 2022 (average price for the month of December was approximately $30/MWh).
- Non-synchronized reserves: During the last three months of 2022, the average non-synchronized reserve was 879.1 MW in the RTO Zone and 132.8 MW in the MAD subzone.
- Regulation: The PJM regulation market design includes three clearing price components: capability ($/MW, based on the MW being offered); performance ($/mile, based on the total MW movement requested by the control signal, known as mileage); and lost-opportunity cost ($/MW of lost revenue from the energy market as a result of providing regulation). In 2022, the average hourly cleared supply of regulation for ramp and non-ramp hours was 715.1 and 465.3 MW, respectively. The weighted average regulation market clearing price (RMCP) was $53.53 per MW, an increase of 106% from the 2021 RMCP of $26.00/MW.

Capacity Markets
PJM offers a forward-looking, locational capacity market called the Reliability Pricing Model (RPM) that includes a must-offer provision for existing generation and a must-buy provision requirement for load. Currently, variable and storage resources are exempt from the must-offer requirement. Recent auction results for weighted average prices are:

- 2022/2023 Delivery Year: $72.33/MW-day
- 2023/2024 Delivery Year: $41.37/MW-day

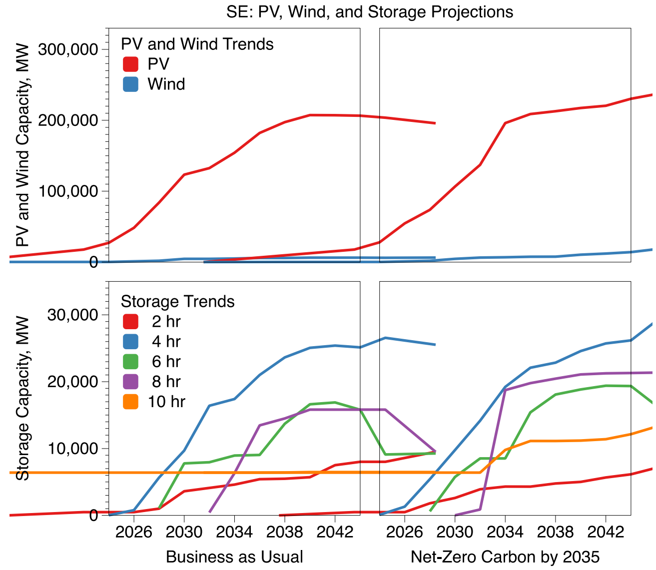
As can be noted from the auction results above, capacity prices in the PJM region are still very much in flux. The RPM installed capacity in the PJM region as of June 1, 2022, was 180,904 MW.

Interconnection Procedures and Agreements

FERC issued a new rule, Order No. 2023 – Improvements to Generator Interconnection Procedures and Agreements, announced July 28, 2023.[33] The order is designed to streamline and standardize the interconnection process. Each RTO and ISO will work through this order in its own way, so please contact them for information on how they are planning to implement the new requirements.

[33] The order can be found at FERC's website, https://www.ferc.gov/media/e-1-order-2023-rm22-14-000.

6.8 Southeast Wholesale Market Region



The Southeast Wholesale Market Region's geographic footprint includes all or parts of eight states (Alabama, Florida, Georgia, Mississippi, Missouri, North Carolina, South Carolina, and Tennessee). It encompasses all or parts of two NERC regions: the Florida Reliability Coordinating Council and the Southeastern Electric Reliability Council (including Central, East, and Southeast).[34]

This region consists of traditionally structured utilities (IOUs, cooperative utilities, and public power/municipals) that have a recently introduced market overlay: Southeast Energy Exchange Market (SEEM). SEEM operates throughout the Southeast Region as well as in much of Kentucky and the eastern part of Oklahoma. It differs from WEIM and Western Energy Imbalance Service (WEIS) offered in the West in that it is not an energy imbalance market, and it is designed as an enhancement rather than a replacement for the existing bilateral marketplace.

Note: On July 14, 2023, the Court of Appeals for the District of Columbia ("D.C. Circuit") issued an order remanding back to FERC various orders related to the establishment of the SEEM. On September 19, 2023, the D.C. Circuit formally remanded the case back to FERC for further proceedings, and the D.C. Circuit's decision to vacate those orders accepting the Tariff Rates became effective[35].

Storage Buildout Projections

Many of the Southeast States do not have greenhouse gas emission targets[36], and thus there are marked differences between scenarios. In the scenario where less than 2-hour storage is expected, increased amounts of 4-, 6-, 8-, and 10-hour storage are projected, with 10-hour storage almost doubling in capacity over existing levels. In terms of power generation buildout, both solar PV and wind are expected to increase slightly in this case.

In-Market Opportunities (and Challenges)

The SEEM is a bilateral market where transactions occur between IOUs, municipal utilities, public utility districts, IPPs, and others such as energy marketers. The market structure is undergoing legal challenges, with some claiming that the SEEM structure favors incumbent monopolies. The markets remain active as SEEM Members work through these challenges.

Day-Ahead Markets

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[34] Staff Report, Energy Primer—A Handbook for Energy Market Basics, Federal Energy Regulatory Commission (FERC), April 2020.

[35] See https://southeastenergymarket.com/wp-content/uploads/SEEM_FERC-09192023.pdf

[36] State Climate Policy Maps, Center for Climate and Energy Solutions, accessed June 2023.

Southeast Wholesale Market Region

Southern Company, which transacts business as Alabama Power, Georgia Power, and Mississippi Power, offers day-ahead auctions for both firm and recallable energy. Outside of the Sothern Company service area, forward-looking transactions (day-ahead and earlier) are handled via bilateral transactions.

- Southern Company: firm-LD energy
- Southern Company: recallable energy

Note that the firm-LD and recallable energy auctions happen simultaneously and that the primary difference between these day-ahead products is the right, but not the obligation, of the seller to curtail recallable energy in the event of a supply-side disruption. Energy is traded in 50-MW blocks for delivery "into Southern" during the 16-hour period from 6 a.m. to 10 p.m. When auction outcomes are announced, it is the responsibility of the buyers and sellers to confirm and finalize the transaction in accordance with their own enabling agreements. For additional information, please see the Southern Company Auction Information webpage.

Day-Ahead Ancillary Service Markets
Currently, there are no day-ahead ancillary service markets in the Southeast Region.

Real-Time Markets
Southern Company also offers an hour-ahead energy auction. In addition, SEEM operates regionwide.

Real-Time Energy Markets

- Southern Company: hour-ahead auction
  Energy is traded in 1-MW blocks of non-firm energy for delivery "into Southern" in the upcoming hour. When auction outcomes are announced, the buyers and sellers must confirm and finalize the transaction in accordance with their own enabling agreements. For additional information, please see the Southern Company Auction Information webpage.
- SEEM: 15-minute market
  Energy is traded in 4-MW increments. The market engine matches buyers and sellers, reserves transmission, creates e-Tags, and produces data that can be used for settlement. Buyers and sellers confirm and finalize the transaction in accordance with their own enabling agreements.

Real-Time Ancillary Service Markets
Currently, there are no real-time ancillary service markets in the Southeast Region.

Out-of-Market Opportunities
Out-of-market opportunities within the region vary by balancing authority and load-serving entity and are likely to continue to do so for the foreseeable future (e.g., there are no capacity markets).

- Capacity Sales

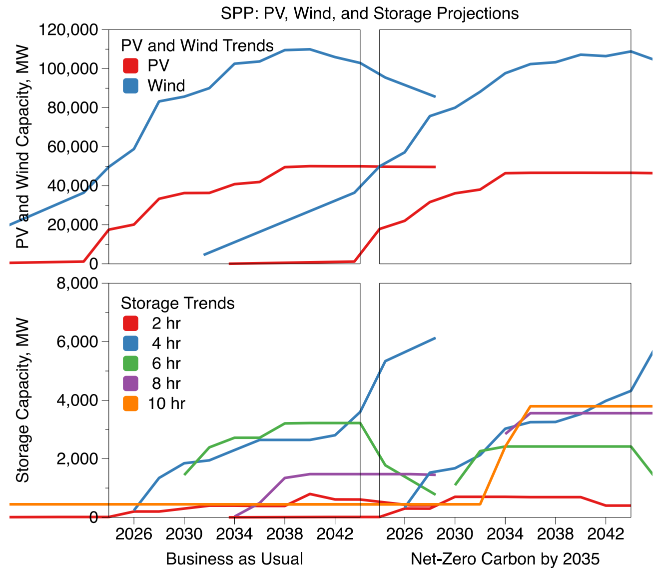
Interconnection Procedures and Agreements
FERC issued a new rule, Order No. 2023 – Improvements to Generator Interconnection Procedures and Agreements, announced July 28, 2023.[37] The order is designed to streamline and

[37] The order can be found at FERC's website, https://www.ferc.gov/media/e-1-order-2023-rm22-14-000.

standardize the interconnection process. Each RTO and ISO will work through this order in its own way, so please contact them for information on how they are planning to implement the new requirements.

6.9 Southwest Power Pool (SPP)

The Southwest Power Pool's (SPP's) geographic footprint includes all or parts of fourteen states: Arkansas, Iowa, Kansas, Louisiana, Minnesota, Missouri, Montana, Nebraska, New Mexico, North Dakota, Oklahoma, South Dakota, Texas, and Wyoming.[38] SPP is the NERC reliability coordinator for its operating area.



The region has grown significantly in the last decade, having incorporated the Heartland Consumers' Power District and Western Area Power Administration's Upper Great Plains region in 2015. Note that this summary focuses on the SPP RTO. For information about SPP's growth into the Western Wholesale Market Region, please see that market summary later in this report. The region's peak load of 53,243 MW occurred on July 19, 2022.[39]

Storage Buildout Projections

SPP operates in a wind-rich region, one that has led the nation in wind buildout. That trend is projected to continue with or without a new power generation policy. A similar trend is seen in the solar PV built, with the primary differences in buildout being a slightly accelerated schedule (4 years) the new generation scenario. In terms of storage, there are significant differences between scenarios, primarily at the 6-, 8-, and 10-hour durations, with more than four times the 10-hour storage buildout, over twice the 8-hour storage buildout, and a slight reduction in the amount of 6-hour storage buildout in the new power generation scenario as compared to the BAU projections.

In-Market Opportunities (and Challenges)

SPP offers both day-ahead and real-time markets. Currently, it does not offer a capacity market, although the market-monitoring part of its organization has suggested that it consider adding one. The last full year reported was 2022[40], and the numbers quoted below are from that report unless stated otherwise.

Day-Ahead Markets

SPP offers both energy and ancillary service day-ahead markets. It differs from other market operators in that it offers a day-ahead ramping product.

Day-Ahead Energy Market

SPP offers a day-ahead market where energy units are committed on an hourly basis.

[38] Staff Report, Energy Primer—A Handbook for Energy Market Basics, Federal Energy Regulatory Commission (FERC), April 2020.
[39] https://www.spp.org/about-us/fast-facts/
[40] Warren, G. et al. State of the Market 2022, SPP (Southwest Power Pool) Market Monitoring Unit, May 15, 2023.

- The average hourly day-ahead price was $48/MWh in 2022, 80 percent higher than the 2021 price (with February excluded) of $27/MWh

Day-Ahead Ancillary Service Markets

SPP offers day-ahead markets for:

- Regulation up: 2022 $18/MW, up 9% from $16.51 in 2021.
- Regulation down: 2022 $6/MW, flat from 2021. The mileage price was $16/MW, an increase from the 2021 price of $13.71
- Spinning reserve: $12/MW, an increase of 24% from $9/MW in 2021.
- Supplemental reserve: average prices increased by 221% from $0.82/MW in 2021 to $1.81/MW in 2022.
- Ramping capability up, implement March 1, 2022. The average price for the year was $5.69/MW.
- Ramping capability down, implement March 1, 2022. There have been no ramp down product prices since implementation.

The markets are traded and settled on an hourly basis.

Real-Time Markets

SPP offers both energy and ancillary service real-time markets. It differs from most in that its market is hourly, and from some market operators in that it offers a ramping product as a part of its ancillary service offerings.

Real-Time Energy Markets

SPP offers a real-time market where energy units are dispatched on an hourly basis. This differs from most areas that operate intra-hour markets, and this difference likely offers increased opportunities in terms of ancillary service revenues.[41]

- The average hourly energy price in 2022 was $43/MWH, an increase of 75% over the $25/MWH 2021 price

Real-Time Ancillary Service Markets

SPP offers real-time markets for the following:

Average 2022 Real-Time Ancillary Service Prices, $/MWh

Year	Regulation Up	Regulation Down	Spinning	Supplemental	Ramping Up	Ramping Down
2021	$18.42	$10.19	$6.75	$1.00	N/A	N/A
2022	$21.00	$11.00	$7.50	$1.79	$2.39	$0.00

The ramping up and ramping down markets were implemented on March 1, 2022. There have been no ramp-down product prices since implementation. The markets are traded and settled on an hourly basis.

41 Since energy is only dispatched hourly, other products are used to accommodate load and generation changes (e.g., ramping and regulation).

Capacity Markets

Currently, SPP does not offer a capacity market; however, the SPP's Market Monitoring Unit recommends that a capacity compensation mechanism be developed. It is unclear whether progress has been made on this issue (it was first suggested in 2018).

Out-of-Market Opportunities

Out-of-market opportunities within the region vary by state and load-serving entity and are likely to continue to do so for the foreseeable future.

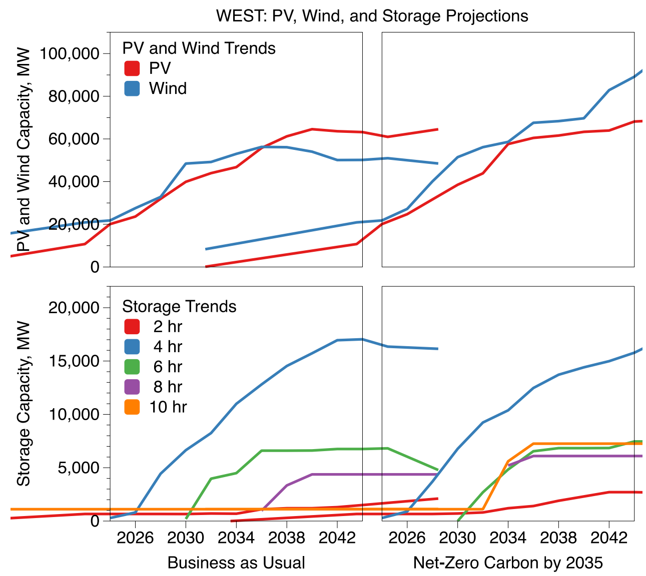
- Capacity Sales: as mentioned above, the addition of a market has been suggested by SPP's Market-Monitoring Unit, but this change is not under active consideration at this time.

Interconnection Procedures and Agreements

FERC issued a new rule, Order No. 2023 – Improvements to Generator Interconnection Procedures and Agreements, announced July 28, 2023.[42] The order is designed to streamline and standardize the interconnection process. Each RTO and ISO will work through this order in its own way, so please contact them for information on how they are planning to implement the new requirements.

[42] The order can be found at FERC's website, https://www.ferc.gov/media/e-1-order-2023-rm22-14-000.

6.10 Western Wholesale Market Region



The Western Wholesale Market Region consists of two main subregions, the Northwest Electric Region and the Southwest Electric Region. The Northwest consists of all or major portions of Idaho, Montana, Northern Nevada, Oregon, Utah, Washington, and a small portion of Northern California and has a peak demand of approximately 50 GW. The Southwest Electric Region comprises Arizona, Colorado, New Mexico, Southern Nevada, and Wyoming.

This region differs from others in that while much of it consists of traditionally structured utilities (IOUs, cooperative utilities, and public power/municipals), it also has or soon will have multiple market overlays, including CAISO's Extended Day-Ahead Market (EDAM), CAISO's Western Energy Imbalance Market (WEIM), SPP's Markets+, and SPP's Western Energy Imbalance Service (WEIS) Market. Adding to the complexity is SPP's attempt to introduce RTO West. These overlays add both challenges and opportunities for PSH developers.

Storage Buildout Projections

Since many of the Western States that have large population centers (and hence large electric loads) are already covered by statutory or executive-order-created greenhouse gas emission targets[43], there are only limited differences between the BAU and new power generation plots. The primary changes in the 2035 projections are an increase in both wind and longer duration storage (8- and 10-hour) buildout. Like the CAISO summary, the storage buildout differences are a result of each area having to be a bit more self-sufficient in the new generation scenario.

In-Market Opportunities (and Challenges)

The market opportunities in this region are numerous and quickly evolving. With these changes comes uncertainty, which can create challenges for both existing IPPs and developers (e.g., it's unclear what the market structure will be going forward five years). The section below summarizes what is known as of the date of publication, with the most certainty being in the real-time market formulations (WEIM and WEIS) followed by the day-ahead markets (EDAM and Markets+) and the possibility of an emerging capacity market (possibly Markets+? The documentation is somewhat vague) and perhaps even a new RTO (SPP's RTO West). A potential challenge for producers is that new market promoters (e.g., the EDAM team[44]) are claiming that both operational and capacity prices will fall once the new day-ahead markets are implemented.

Day-Ahead Markets

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[43] Twenty-four states plus the District of Columbia have adopted specific greenhouse gas emissions targets.

[44] Moyer, K, Ramirez, D. (2022). CAISO EDAM Benefits Study–Estimating Savings for California and the West Under EDAM Market Scenarios. Energy Strategies, November 4.

Western Wholesale Market Region

Currently, there are no day-ahead markets in the Western Wholesale Market Region; however, this situation is expected to change soon, as both CAISO and SPP are in the process of establishing markets in this region.

Day-Ahead Energy Markets
Although there are currently no day-ahead energy markets in the Western Wholesale region, CAISO's EDAM and SPP's Markets+ day-ahead energy markets were expected to go live in 2024.

- EDAM (CAISO):
  The EDAM is being modeled after CAISO's WEIM. As of June 2023, both CAISO's Board of Governors and the WEIM Governing Body approved the proposed market enhancements[45] (see the CAISO website for more information). The EDAM proposal was scheduled to be submitted to FERC in 2023, and it is projected that the market will go live by March 2025 (perhaps earlier)[46].
  - Hourly energy market, subject to EDAM Resource Sufficiency Evaluation (unclear as to how it is determined who is allowed to sell).
  - The minimum commitment period is under consideration but is expected to be like that of the WEIM. To participate in the EDAM, members must also participate in the WEIM.
  - Additional information can be found on CAISO's Day-Ahead Market Enhancements (EDAM) website.
- Markets+ (SPP):
  Markets+ is a combined day-head and real-time market structure that includes day-ahead unit commitment reliability and resource coordination (while the market operator helps schedule day-ahead unit commitments, the individual balancing authorities are not dissolved, and each balancing authority retains responsibility for its reliability and transmission buildouts). The day-ahead portion of Markets+ is projected to go live by late 2025 or early 2026[47].
  - Phase One: potential participants and stakeholders will financially commit to drafting the market protocols, tariff, and governing documents. This work is currently in process.
  - Phase Two: implementation begins upon FERC approval of the Markets+ tariff

Additional information can be found on SPP's Markets+ website

- RTO West (SPP):
  RTO West is an SPP proposed RTO. Information on RTO West is limited, although most expect that SPP's current tariff would be extended into the new geographic region. There are no firm dates as to when RTO West is expected to go live; however, speculation is

[45] Sangree, H. (2023). CAISO, WEIM Approve Day-ahead Market Enhancements, RTO Insider, May 21.
[46] Kirby, L. (2023). Organized Day Ahead Markets presentation, Bonneville Power Authority (BPA), 2023-02-09 Workshop.
[47] Balaraman, K.(2023). California energy players fear isolation, reliability impacts as SPP eyes Western market expansion. Utility Dive. Published May 30.

that it could be as early as 2024 or 2025[48]. Additional information can be found on SPP's RTO West website.

Day-Ahead Ancillary Service Markets

Currently, there are no ancillary service markets in the Western Wholesale Market Region; however, SPP and several balancing authorities within this region are exploring establishing a new RTO.

- RTO West (SPP)
  If the formation of the RTO progresses to completion, it is expected to offer markets for regulation, spinning, supplemental, and ramping product reserves for both day-ahead and real-time (these products are expected to be offered under the existing SPP tariff). Additional information about the RTO West proposal can be found in the day-ahead energy markets section above and on SPP's RTO West website.

Real-Time Markets

Both the WEIM and WEIS are active in the Western Region, and SPP is actively working to replace WEIS with Markets+ or perhaps an RTO (RTO West).

Real-Time Energy Markets

- Markets+ (SPP), not yet active:
  Markets+ is a proposed day-head and real-time market structure that includes day-ahead unit commitment reliability and resource coordination. The real-time portion of Markets+ is projected to go live by June 2024[49]. Additional information about Markets+ can be found in the day-ahead energy markets section above and on SPP's Markets+ website.
  - Five-minute energy market
  - Unclear as to the commitment period
- WEIM (CAISO):
  - Five-minute energy market
  - The minimum commitment period is six months.
  - Additional information about CAISO's Western Energy Imbalance Market can be found on the WEIM website.
- WEIS (SPP):
  - Five-minute energy market
  - Additional information can be found on SPP's Western Energy Imbalance Service (WEIS) Market website.
- RTO West (SPP), not yet active
  RTO West is an SPP-proposed RTO. Information is limited, although most expect that SPP's current tariff would be extended into the new geographic region. There are no firm dates as to when RTO West is expected to go live; however, speculation is that it could

[48] Shearer, J. (2023). A Look Ahead: The Future of the West Markets. PCI Energy Solutions blog. Published February 9.
[49] Kirby, L. (2023-02-09).

be as early as 2024 or 2025[50]. Additional information can be found on SPP's RTO West website.

Real-Time Ancillary Service Markets

- RTO West (SPP), not yet active
  Information about the RTO West proposal can be found in the day-ahead energy markets section above and on SPP's RTO West website.

Out-of-Market Opportunities
Out-of-market opportunities vary by balancing authority and are likely to continue to do so for the foreseeable future, since neither of the new market proponents (CAISO nor SPP) supports ISO-/RTO-wide practices (e.g., neither offer capacity markets).

- Capacity Sales. Payments are made on a PUC-by-PUC basis and vary throughout the region.

Interconnection Procedures and Agreements

- FERC issued a new rule, Order No. 2023 – Improvements to Generator Interconnection Procedures and Agreements, announced July 28, 2023.[51] The order is designed to streamline and standardize the interconnection process. Each RTO and ISO will work through this order in its own way, so please contact them for information on how they are planning to implement the new requirements.

[50] Shearer, J. (2023). A Look Ahead: The Future of the West Markets. PCI Energy Solutions blog. Published February 9.
[51] The order can be found at FERC's website, https://www.ferc.gov/media/e-1-order-2023-rm22-14-000.

This report is being prepared for the U.S. Department of Energy (DOE). As such, this document was prepared in compliance with Section 515 of the Treasury and General Government Appropriations Act for fiscal year 2001 (public law 106-554) and information quality guidelines issued by DOE. Though this report does not constitute "influential" information, as that term is defined in DOE's information quality guidelines or the Office of Management and Budget's Information Quality Bulletin for Peer Review, the study was reviewed both internally and externally prior to publication.

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