The Value of Long-Duration Energy Storage: Policy and Perception

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Abstract. This paper summarizes policies and market drivers that are relevant to long-duration energy storage (LDES). U.S. federal and state policies, as well as a few international policies, are described and categorized under the following market drivers: 1) LDES needs to solve a grid problem, 2) LDES needs to make money and be cost competitive, and 3) LDES needs to support a safe and reliable grid. Equity and justice policies are also described regarding clean-energy initiatives. Finally, a survey of nearly 500 energy storage stakeholders is summarized, providing perceptions of LDES regarding duration, use cases, technologies, and challenges. Statistical differences observed in the responses from different sectors (e.g., industry, academia, national labs, utilities) are reported.

INTRODUCTION

Global policies and responses to the threat of climate change aim to reduce or eliminate the use of fossil fuels, both in terms of electricity and end-use energy consumption. This increases reliance on renewable and carbon-free electric resources – solar, wind, hydroelectric, conceivably nuclear, and other technologies such as geothermal, tidal, etc., as well as increased focus on energy-efficiency measures. In addition, electrification and carbon-free alternatives for transportation, industrial processes, chemical manufacturing, and other energy-intensive applications are being sought.

As a result, intermittent renewable energy sources have increased rapidly around the world, propagating the deployment of hundreds of megawatts of lithium-ion-battery storage systems to time-shift and firm these intermittent resources. However, most of these recent battery-storage deployments are for durations of four hours or less. Long-duration energy storage (LDES) technologies have not been widely utilized or valued in any major market in the U.S. (or globally) today. This is largely due to the fact that policy gaps persist in both federal and state markets (and other international markets), which result in tremendous uncertainties about how these technologies can, should, or will be utilized and compensated for the value they will bring to future grid operations. This has perhaps adversely impacted the widespread adoption of concentrating solar power (CSP), which has commercially demonstrated the ability to provide up to ~15 hours of storage at rated capacities up to ~100 MW, yielding greater than 1 GWh of storage for a single CSP plant. These policy gaps can be considered against the backdrop of the following fundamental questions and a lack of consensus regarding the answers to these questions: 1) What is the problem that LDES needs to solve? 2) How can LDES make money and be cost competitive when compared to alternatives?

A long-duration energy storage workshop sponsored by the U.S. Department of Energy and hosted by Sandia National Laboratories, Pacific Northwest National Laboratory, and Oak Ridge National Laboratory was held in March of 2021. The goal was to bring together energy-storage researchers and stakeholders from industry, academia, national labs, utilities, and government to discuss needs, gaps, technologies, and use cases associated with LDES. Over 1,000 attendees registered for the event, and nearly 500 completed a survey regarding LDES that provides interesting perceptions among different stakeholders. In addition, a session and report on LDES policy were presented.

The purpose of this paper is to summarize the findings from this workshop and evaluate policies and perceptions that may impact the future of LDES, including the determination of how LDES will be utilized, how it will be valued, how to ensure system reliability, and how energy equity goals can be achieved.

LDES SURVEY RESULTS AND PERCEPTIONS

Nearly 500 participants of the DOE LDES workshop completed a survey to identify perceptions regarding long-duration storage. Respondents included representatives from industry, academia, national labs, utility, government, and "other" (mainly non-profit). Figure 1 provides a sampling of the survey questions and results. Regarding the definition of LDES, a majority of respondents defined LDES as >24 hrs. Industry had a statistically higher percentage of respondents that reported >4 hrs as the definition of LDES relative to government, while academia had a statistically higher percentage of respondents reporting >24 hrs as the definition for LDES relative to industry and utility (95% confidence interval, p=0.05).

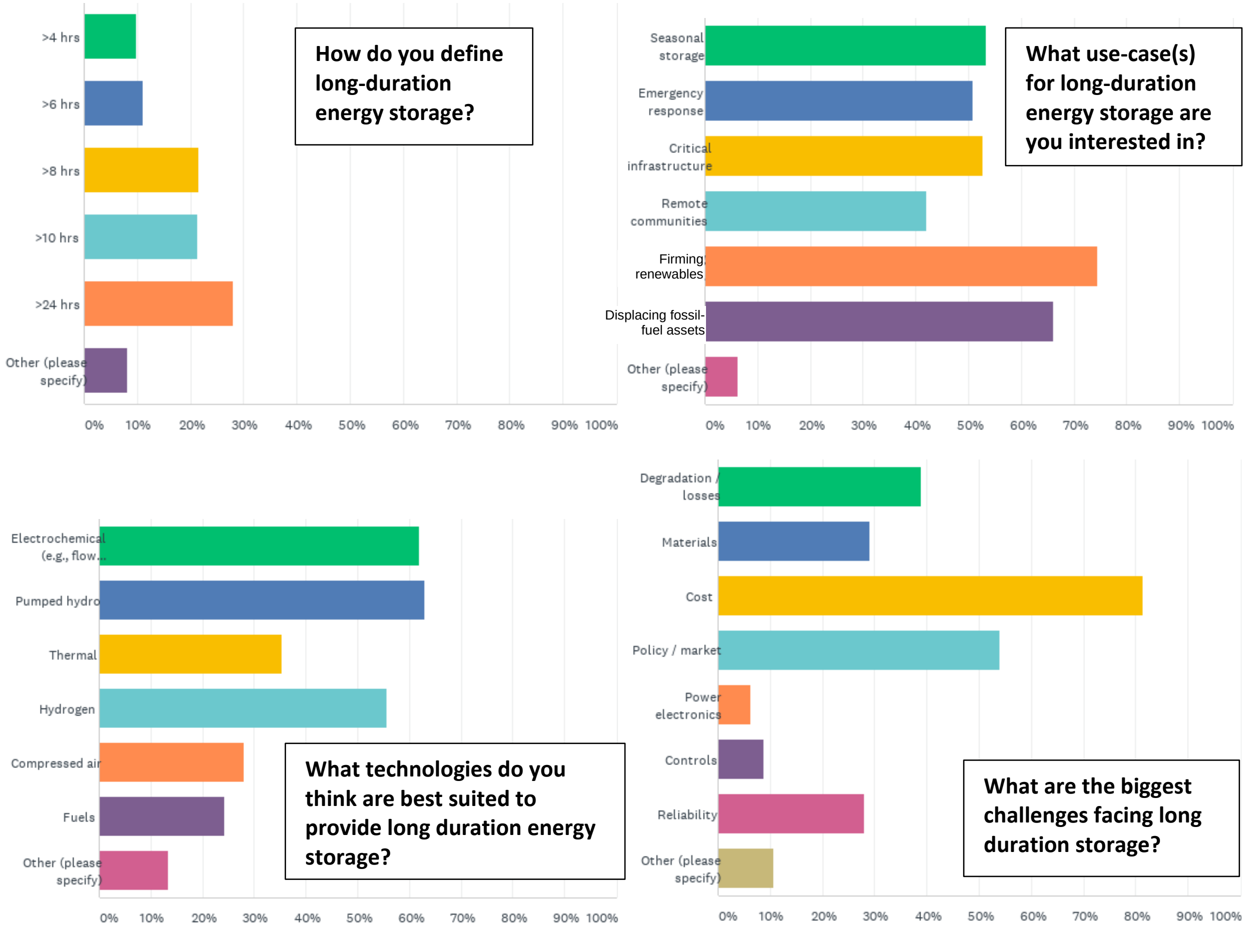

Figure 1. Sample of survey results from 464 respondents attending the DOE LDES workshop held in March 2021.[†]

Use cases of interest to participants included firming of intermittent renewables and displacement of existing fossil-fuel assets, followed by seasonal storage, critical infrastructure, emergency response, and remote communities. Industry had a statistically lower percentage of responses for seasonal storage relative to national labs. Perceived technologies that could provide LDES were identified as pumped hydro, electrochemical (e.g., flow batteries), hydrogen, thermal, compressed air, and fuels. Thermal storage technologies were rated higher statistically by industry than by utilities among the alternatives. Compressed air was rated higher by utilities than by industry, academia, and national labs among the alternatives. Top perceived challenges with LDES technologies included cost, policy/market, degradation/losses, materials, and reliability. National labs had statistically higher responses for degradation/losses

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[†] https://www.sandia.gov/ess-ssl/ldes/

than industry, and utilities had statistically higher responses for controls relative to industry, national labs, and government.

Nearly 300 respondents provided written responses to the following questions: “What is the best way to value long-duration energy storage (I.e., what metrics can be used)” and “How can DOE and the national labs best address the challenges of long duration energy storage?” Figure 2 and Figure 3 show the number of times key words were cited in the responses to these two questions. With regard to metrics and the best way to value LDES, Figure 2 shows that the use of the levelized cost of energy (LCOE) or levelized cost of storage (LCOS), and the use of capacity were mentioned the most. Efficiency and reliability were also cited highly, followed by “avoided” (e.g., avoided costs and avoided pollution or carbon), “displace” (e.g., displacing fossil-fuel), and “arbitrage” (e.g., time shifting of energy when it is most needed and valued).

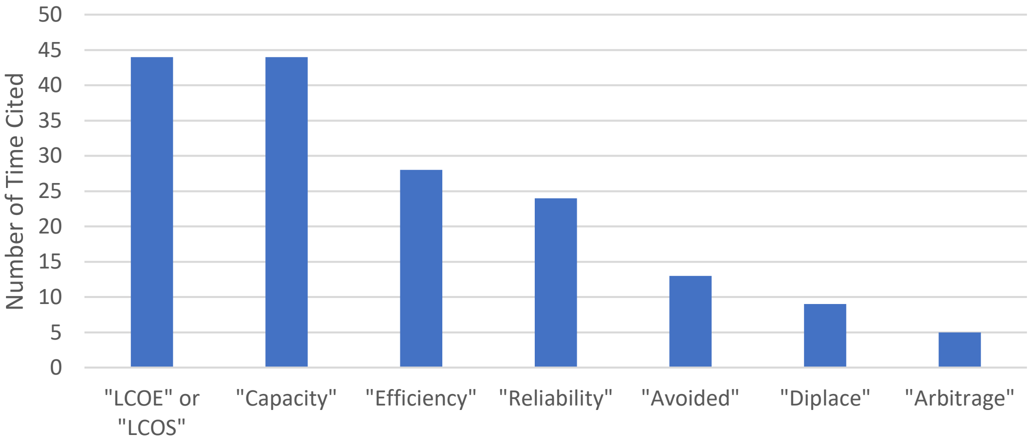


Figure 2. Number of times words were mentioned in survey responses to the question, “ What is the best way to value long-duration energy storage (I.e., what metrics can be used)?”

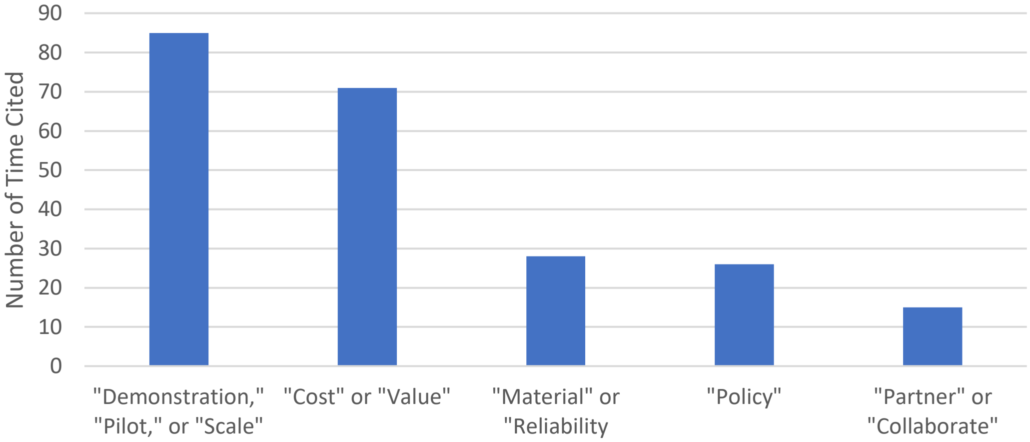


Figure 3. Number of times words were mentioned in survey responses to the question, “How can DOE and the national labs best address the challenges of long duration energy storage?”

Figure 3 charts the number of times key words were cited in the responses to the question regarding how DOE and national labs can address the challenges facing LDES. Funding demonstration projects at scale and bridging the valley of death to commercialization were leading responses, followed by assessing costs and value of LDES in different use cases. One example included performing technoeconomic analyses for future carbon-free scenarios and architectures for individual utilities and regions. Improving LDES technologies to increase reliability/bankability was also frequently mentioned, as well as ensuring policy to enable LDES deployment. Finally, fostering collaborations between universities, national labs, and industry was cited a number of times by respondents.

LDES POLICIES AND MARKET DRIVERS

Forecasting, planning, and building a national grid system that will be able to meet clean energy goals and safely operate decades into the future poses an extreme challenge for grid planners, policymakers, and other industry stakeholders. This extreme challenge is exacerbated by the fact that technologies enabling the use of renewable energy and energy-storage technologies are rapidly evolving in real-time. Moreover, no single entity has total responsibility for managing and executing this enormous challenge; rather, the process relies on a multitude of disparate market participants that may hold different visions for how LDES should be defined, utilized, managed, and priced.

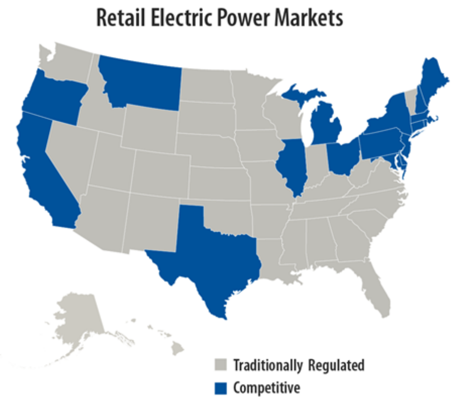
In the U.S., 16 states, territories, and districts have set either 100% renewable energy targets or 100% clean energy targets. However, the mechanics of this evolution are quite difficult to summarize as the market drivers and emerging policies are changing rapidly within disparate regulatory frameworks across the U.S. As a result of restructuring of the electric industry in the U.S. that began in earnest in the late 1990s, states are now characterized as either being regulated/vertically-integrated markets, or restructured markets. Figure 4 illustrates how U.S. states are organized into regulated or restructured (sometimes called deregulated) markets. There are multiple distinctions between how these different markets are regulated, and consequently, how renewable resources and energy storage are being integrated into local electric grids. Moreover, even though a state may have adopted a broad clean energy goal, the specifics of how the state will achieve this goal may remain unclear. This is particularly true when considering the role that energy storage technologies will be utilized, managed, and priced.

Regulated Market

- "Vertically integrated" utility **owns or controls** generation, transmission, and distribution
- **Regulated by states** (public utility commissions)
- Cost recovery via rates charged to customers
- **LDES needs to solve grid problem and be reliable, low-risk**

Deregulated (Restructured) Market

- Prohibited from owning generation and transmission
- RTOs* and ISOs* responsible for inter-/intra-state transmission, distribution, O&M
- Interstate transmission governed by **Federal Energy Regulation Commission (FERC)**
- Market is **competitive**
- **LDES needs to make money**



https://www.epa.gov/repowertoolbox/understanding-electricity-market-frameworks-policies

*RTO = Regional transmission operator, ISO = Independent system operator

Figure 4. Electricity markets in the United States and features that impact LDES.

At the federal level, wholesale markets operated by Regional Transmission Organizations (RTOs) and Independent System Operators (ISOs), which were formed in the late 1990s as a result of the aforementioned restructuring efforts, set policies, rules, and tariffs that monetize the multitude of benefits that energy-storage technologies can bring to these markets. In other words, policies, which are regulated by the Federal Energy Regulatory Commission (FERC), can determine how various energy storage (including LDES) technologies will be used, and how owners will be compensated. The 2018 landmark FERC Order 841 is the primary example of this, as it has required RTOs and ISOs to create a level playing field for storage technologies in wholesale transactions, and can also influence regional and state policies, determine where and how LDES can be used, and specify how the LDES provider can be compensated.

Barriers that may exist primarily within state policies include: non-existing policies for energy storage in general or LDES specifically (only about 15 U.S. states have substantive energy storage policies, and only a few have addressed LDES specifically); inconsistencies regarding ownership for energy-storage assets, which determines how the assets are used; and in vertically-integrated markets, concerns about cost recovery through ratebase have created a bias toward lower-cost, short-term duration storage options, thereby limiting opportunities for LDES to participate.

Barriers that may exist primarily within federal or regional policies include: wholesale structures and incentives that do not provide a favorable environment for investment in existing or new LDES technologies; revenue opportunities for LDES at the wholesale that presently derive primarily from arbitrage services, which typically are insufficient to cover the high capital costs associated with LDES technologies; and capacity markets (where they exist) that aim to ensure resource adequacy at the lowest possible cost, and typically do not acknowledge the key benefits that LDES technologies can deliver to the system.

The following sections describe policies relevant to LDES and the following market drivers: 1) LDES needs to solve a grid problem, 2) LDES nees to make money and be cost-competitive, and 3) LDES needs to support a safe and reliable grid. In addition, due to recent policies in the U.S. executive administration, energy equity and justice for underserved and disadvantaged communities also need to be considered for LDES technologies and applications.

LDES Needs to Solve a Grid Problem

In general, energy-storage technologies can provide a series of services to power systems, including energy arbitrage, transmission and distribution congestion relief, investment deferral, demand shifting and peak reduction, spinning and non-spinning reserves, support for the replacement of peaker units, and seasonal energy shifting. At present, there is no marketplace within the U.S., either at the wholesale or retail level, that compensates LDES technologies simply to exist. While there are commodity markets for coal and natural gas, and emerging markets for renewable energy, no such market exists for LDES. Ultimately, the role that LDES will play in industry will be determined by the ways in which their applications address actual market needs.

When FERC Order 841 was issued in 2018, requiring RTOs and ISOs to establish market rules to accommodate energy storage, including energy storage durations to receive full capacity or resource adequacy credit in wholesale electricity markets, nearly all regions adopted 4 hour-or-less energy storage requirements due to a lack of need for longer duration storage. Assuming a 4-hour duration requirement, \$90/kW-yr capacity payment, and 2019 market prices for energy time shifting, Denholm et al. [1] showed that there was little total value (energy and capacity) for storage systems beyond four hours. As a result, some may view LDES as a solution looking for a problem, but the general consensus is that after ~5 – 10 years, as penetration of intermittent renewables on the grid increases to ~70 – 80%, the need for LDES will increase significantly. For example, Strategen [2] found that 45 – 55 GW of LDES will be needed for California after 2030, a staggering amount relative to the 80 GW of current total electricity generation in California.

LDES Needs to Make Money and be Cost Competitive

The greatest obstacle LDES faces in terms of defining its role in the future grid is economics. It is difficult for developers to find a marketplace in which LDES can generate revenue today. The industry consensus in the U.S. is that a robust market for LDES may not develop in earnest for another ~5 – 10 years as policy frameworks in individuals states increasingly require larger amounts of intermittent renewables. In addition, there is little consensus regarding how envisioned (and critical) services such as time shifting, resource adequacy contributions, ancillary services, and resiliency should be priced. Policies that enable value stacking or dual-use would certainly benefit LDES, particularly in the energy market (time shifting of MWh), capacity market (resource adequacy in terms of MW), and as a transmission asset (mitigating thermal overload and deferring upgrades). In addition, policies that value long-term resiliency following natural disasters and other threats to the grid can also benefit LDES.

Cost Competitiveness

One benchmark for energy storage capacity costs are lithium-ion batteries (LIBs). In 2020, BloombergNEF's annual battery price report[‡] listed the average capacity costs of LIB battery packs at \$137/kWh (down 89% from 2010), projected to reach \$100/kWh by 2023. That gives some context to the next finding that also came from the Bloomberg study: not until prices hit \$50/kWh will LDES even begin to see meaningful deployment or declining costs. Not until \$20/kWh will they reduce system costs by 10 percent. And "to deliver more significant savings in electricity costs (>10 percent), storage technologies must exhibit capital costs in the \$1-\$10/kWh range and discharge efficiencies greater than 60 percent." Some market projections have indicated that the *levelized* cost of LDES will

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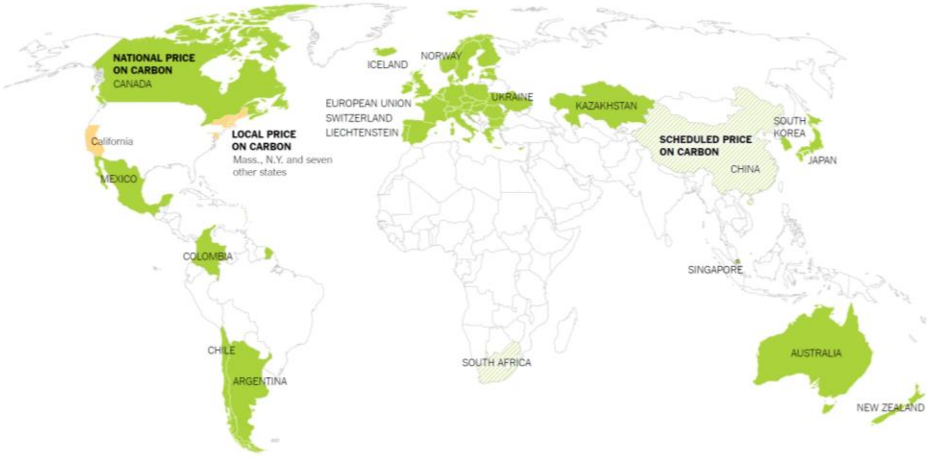
[‡] https://about.bnef.com/blog/battery-pack-prices-cited-below-100-kwh-for-the-first-time-in-2020-while-market-average-sits-at-137-kwh/

need to decrease to about 4 to 5 cents/kWh, and maybe even lower, to warrant an investment in these technologies when compared against more traditional resources. However, if policies are in place to use carbon-free resources, cost comparisons among various renewable and clean LDES options need to be made. Schöniger et al. [3] demonstrate that CSP with thermal energy storage can be more economical than photovoltaics (PV) with batteries (or PV with thermal energy storage) when the duration of storage exceeds ~4 – 10 hours. The levelized cost of CSP with >10 hours of thermal energy storage was estimated to be ~$0.10/kWh.

Carbon Pricing

A related topic that factors into the valuation of LDES is carbon pricing. Some countries, but not the U.S., have established a price for carbon. Carbon pricing establishes a price on carbon emissions to mitigate the negative externalities created by greenhouse gas emissions, which can increase the value of LDES. There are two common structures for carbon pricing scheme: 1) a carbon tax, through which governments levy a fixed fee that institutions must pay on every ton of carbon they emit; and 2) an emissions trading scheme, frequently referred to as a "cap and trade" system. In the absence of a federal policy, some U.S. states have enacted their own carbon pricing systems: California launched its cap-and-trade system in 2013, while the state of Washington voted to enact its own carbon pricing system in April 2021. Figure 5 illustrates the countries that have adopted a carbon pricing policy.



Note: A local price on carbon is only highlighted where no national or European Union rules are in place. Some countries with a national price on carbon also have local-level programs that operate under separate rules. | Source: World Bank

Figure 5. Countries with a national price on carbon.[§]

The lack of U.S. carbon price is directly relevant to the challenges associated with valuing LDES. For example, part of the "value of LDES" that is not recognized is that the requirements for 30-day onsite capacity storage for fossil fuel plants (e.g., coal resources) will need to be replaced if we eliminate fossil fuel sources with renewables. This is not a value concept that is widely recognized today but will have to be addressed as renewables displace current power sources. In addition, from a regulated utility perspective, avoiding stranded assets for LDES systems is an important consideration, especially for systems in place for disaster relief or seasonal storage. Arbitrage alone, in those marketplaces where energy storage technologies for arbitrage services is allowed, has proven to be insufficient to justify investments, which has perpetuated the need for additional values streams tied to these technologies.

International Policies

Although this paper has focused on U.S. policies and markets, it is important to note that international markets and policies are facing the same challenges as in the U.S. In Europe, some positive developments in the European Union Electricity Market Design Directive (recast) include aims to reduce barriers to energy storage, such as encompassing reconversion of energy storage back to electricity and conversion to another energy carrier. Energy storage is also

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[§] https://www.nytimes.com/interactive/2019/04/02/climate/pricing-carbon-emissions.html recognized as a distinct asset class, separate from generation. Some challenges facing the European union include double taxation on energy storage systems. Both Germany and France currently impose taxes on energy storage systems for both charging (as a consumer) and discharging (as a generator).

LDES Needs to Support a Safe and Reliable Grid

An important driver for regulated markets is the implementation of technologies that are reliable and low-risk. The LDES survey highlighted the perception that many people believe that government can and should implement policies and programs to deploy and demonstrate emerging LDES technologies at pilot and larger scales. Demonstration projects can help decrease technology risks and increase "bankability."

U.S federal policies and programs that can help promote deployment of LDES technologies and reduce associated risks include the following:

- 2020 BEST Act
    - Requires DOE to establish cross-cutting energy storage R&D to reduce cost and extend duration of energy storage systems
- A total of $119 million investment in grid scale energy storage is included in President Biden's FY 2022 Budget Request for the Office of Electricity
- The Bipartisan Infrastructure Framework includes significant investment in energy storage technologies and demonstrations
- Energy Storage Grand Challenge
    - Developing domestically manufactured energy storage technologies that can meet all U.S. market demands by 2030
- DOE Long Duration Storage Energy Earthshot
    - Reduce cost of grid-scale energy storage by 90% for systems that deliver 10+ hours of duration within a decade
- DOE Hydrogen Energy Earthshot
    - Reduce the cost of hydrogen to $1 per kg in a decade
- The DOE ARPA-E DAYS and SETO CSP programs provide funding for LDES projects

Examples of state-level programs and policies include the following:

- Arizona
    - Offers a battery incentive program structured to encourage LDES, offering the full incentive only for storage technologies that offer discharge durations longer than five hours.
- New York
    - $12.5 million is being made available through the New York State Energy Research & Development Authority's Renewable Optimization and Energy Storage Innovation Program, which seeks pre-commercial stage LDES technologies including hydrogen, electrical, chemical, mechanical or thermal storage technologies that are six hours or more in duration.
- California
    - Governor Newsom recently proposed US$350 million of support for "pre-commercial long-duration storage projects."
    - California Energy Commission (2020 GFO-19-308) – Issued funding for "Assessing Long-duration Energy Storage Deployment Scenarios to Meet California's Energy Goals."
    - Eight community choice aggregators (CCAs) launched a joint request for offers to procure up to 500 MW of long-duration storage in October 2020.

LDES can Enable Equity and Social Justice

Energy equity is a critical component in resilient, secure, and stable social, economic, and political systems. Energy equity refers to the condition in which energy is provided to all in a consistent and systematically fair, just, and impartial manner regardless of race, geography, social standing, or economic position. Long ignored, energy equity and justice measures are being adopted by U.S. federal government and many states through legislation and policy measures. The Justice40 Initiative is part of a U.S. presidential executive order[**] with a goal of delivering 40% of the overall benefits of federal investments to disadvantaged communities, which includes energy investments. Disadvantaged and underserved populations generally suffer disproportionately from power outages, high energy prices, and polluting energy generation facilities. Policy measures that include energy storage and LDES technologies can help provide energy equity to all populations.

CONCLUSIONS

Policies are currently lacking to address long-duration storage. For LDES systems that discharge infrequently, these adverse policies and a lack of incentives such as capacity payments for storage systems create a cost-prohibitive and non-conducive environment to deployment for identified needs and use-cases (e.g., firming renewables, displacing fossil fuels, emergency response, remote communities). In this paper, we have identified how current policies can play a role in the following key market drivers: 1) LDES needs to solve a grid problem, 2) LDES needs to make money and be cost competitive, and 3) LDES needs to support a safe and reliable grid. In addition, recent policies have mandated that disadvantaged communities benefit from future investment in clean energy and infrastructure, including LDES. The following summarizes how existing and future policies can play a role in electricity and other energy markets:

- **Policies for monetization and multiple value streams**
    - Energy market (time shifting, MWh)
    - Capacity market (meeting loads, MW)
    - Transmission asset (preventing thermal overloads)
    - Resilience/insurance (recovering from natural disasters and other long-duration threats)
    - Elimination of double taxation (consumption and generation)
    - Carbon pricing (cost avoidance)
- **Technology demonstrations to lower risk of adoption**
    - Federal assistance for technology development (e.g., DOE Storage and Hydrogen Earthshots, DOE CSP program, DOE ARPA-E DAYS)
    - State mandates for storage deployment
- **Equity and justice**
    - Ensure disadvantaged communities benefit from policies

With regard to LDES survey responses from nearly 500 energy-storage stakeholders, results included the following: different sectors define duration, technologies, and challenges differently; key technologies include pumped hydro, electrochemical, hydrogen, and thermal storage; key challenges include cost, policy/market, degradation/losses, reliability/materials; government should focus on larger-scale demonstrations, cost reductions, and policies that enable LDES. From a technical perspective, key attributes that were cited in the survey and elsewhere for successful LDES deployment include the following:

- Low-cost, reliable, high-energy-density storage material to reduce the marginal cost of energy capacity
- Decoupling of energy and power capacities in the storage system (e.g., generator that is decoupled from the storage media)
- Flexible siting and operations to address different discharge strategies (diurnal vs. weekly)
- Fast charging and discharging capabilities (ramp rate)
- Minimal degradation and losses during storage and operation
- Ability to be charged by various inexpensive options (e.g., electricity, thermal)

CSP and thermal energy storage demonstrate many of these positive attributes. Challenges for CSP include the need for siting in high-irradiance regions, relatively slow ramp rates (vs. batteries), thermal losses, and perceived

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[**] Biden-Harris January 2021 Executive Order No. 13,985, "Advancing Racial Equity and Support for Underserved Communities" (Exec. Order No. 13,985, 2021).

reliability issues. However, the economies of scale—both in terms of cost and performance—are significant advantages for CSP and large-scale, long-duration thermal energy storage.

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