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Long-Duration Energy Storage

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ABSTRACT

Against the backdrop of a uniquely tumultuous year, the expansion of energy storage (ES) technologies—and the thinking around how these technologies can be used—continued on a growth trajectory throughout 2020, a pattern that started to gain momentum only several years ago. Within the ES marketplace and regulatory processes that are evaluating ES and its myriad related issues, long-duration energy storage (LDES) has emerged as a nascent operational and policy consideration for multiple stakeholders.

LDES is commonly used as a catch-all label for energy storage greater than about 4 hours. It is reasonable to recognize, however, that identifying key operational and application roles for LDES is confounded by fundamental differences in the technology sets, the potential applications, and the value streams associated with LDES over hours (4-12 hours), days, or weeks. In addition, uncertainties remain about the economics of certain LDES technologies and the specific ways in which they can be used to accelerate solar and wind penetration, improve grid resiliency, support resiliency objectives, and serve to stabilize volatile energy prices.

In other words, LDES technologies, particularly battery-based technologies, are still immature and determinations of how they can be used are still evolving. These uncertainties can create "policy paralysis" that can create delays the development of the regulatory rules that are needed to enable LDES implementation in the marketplace. Moreover, regulators are seeking to define the potential role of ES in general, and specifically LDES as well, within a broader context of grid decarbonization, 100-percent renewables, and other clean energy goals.

It is a generally accepted position within the E&U sector that LDES can potentially have a prominent role in serving needs across the U.S. electrical grid. Commitments to LDES usage on a wide-scale basis, however, remain tentative. As 2020 closes, a number of industry questions regarding the role of LDES within the E&U sector remain of great interest but largely unanswered, including how LDES should be defined, valued, and regulated. Observations regarding the operational opportunities for LDES continue to crystallize. Meanwhile, existing policies are being reconsidered and new policies are being formulated to address barriers and create opportunities for LDES to be utilized. It could be the case that 2021 proves to be a year in which the future role of LDES as a technological capability within the E&U sector becomes better defined and the operational mechanisms and policies that are needed for LDES to participate as a resource solution are developed.

BACKGROUND UP TO 2020

Until recently there was not a lot of focus on LDES because there has not been universal consensus within the E&U sector about the fundamental needs that LDES might serve and the requirements for defining its usage (i.e., essentially the "where, how, and why questions"). The lack of consensus within the sector impacts LDES directly because, without clarity on the problems that they can solve, ES technologies in general and LDES in particular have limited inherent value and find limited support for technical development or policy support. Technologies and concepts such as LDES become increasingly valuable as needs within the sector are identified and the necessary policies that allow ES and LDES to participate are developed. Up to this point, LDES has been challenged to find an official role to play, in part due to policies that do not explicitly allow LDES, or value it appropriately, along with rules that could be interpreted to disallow LDES from participating. These restrictions show signs of change in response to both market activity and the development of market rules.

Developments in two distinct regions (the PJM Market Interface in the U.S. Northeast and California) provide the current points of reference in terms of federal and individual state policy development, respectively, that are relevant to LDES. At the federal level, the Federal Energy Regulatory Commission (FERC) is evaluating regional transmission organization (RTO) / independent system operator (ISO) filings laying out plans for complying with FERC's 2018 landmark Order 841. Order 841 requires wholesale markets to create unique mechanisms within their respective regions that will enable ES technologies to provide (and ES providers to be compensated for) any of the services needed at the RTO/ISO level for which the ES technology can provide.

The continuing evaluations of how to implement Order 841 are directly relevant to LDES. For example, within PJM's compliance plan, the RTO set a minimum requirement that an ES technology must offer a 10-hour duration capability in order to be able to participate in PJM's capacity market. (This 10-hour requirement does not prevent ES technology from participating in other markets, such as frequency regulation, or the day-ahead market.) The 10-hour requirement has been met with fierce opposition from ES advocates and clean energy groups that have argued the requirement violates the objective of FERC Order 841 to create a level playing field for ES within ISO/RTO markets. The requirement makes it impossible for lithium-ion batteries – with generally a 2–4-hour duration -- to economically compete against fossil-fuel-fired plants in the PJM capacity market.

Statistically, California has been the most mature state in terms of deploying battery ES technologies of up to and including four hours duration lithium-ion batteries. The state is now becoming a focal point for LDES procurement. Two separate market studies recently commissioned by California regulators have assessed market barriers for LDES within the state. A study by Strategen Consulting study[1] found that while regulators in California made an appropriate call for broad energy requirements (e.g., the statewide procurement requirements for 1,825 MW of ES technologies and 500 MW of BTM ES technologies) these same regulators had "taken a very narrow view on the potential storage resources that could be deployed in California." The state's narrow view, according to Strategen, neglected to identify LDES

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1 https://static1.squarespace.com/static/5b96538250a54f9cd7751faa/t/5fcf9815caa95a391e73d053/1607440419530/LDES_CA_12.08.2020.pdf

requirements, distinct from broader ES requirements, that will be needed to achieve other climate goals in the state.

A separate study conducted by the California Energy Storage Alliance (CESA)[2] found that that the state will need in the range of 2-11 GW of new operational LDES by 2030, and between 45-55 GW of LDES by 2045 in order to achieve its 100 percent clean electricity goals. The study modeled LDES in California on the basis of technologies that can achieve discharge times of up to five hours, 10 hours and 100 hours. The CESA projections are significant on many levels, not the least of which is the call-out specifically for LDES in addition to what California has already established for behind-the-meter (BTM) and in-front-of-the-meter (FTM) energy storage.

Moreover, the CESA study concluded that deploying 55 GW of LDES by 2045 could provide numerous benefits to California's grid, including enabling the retirement of 10 GW of fossil fuel generation, increasing the utilization of renewable energy by 17 percent, and reducing total system costs for system capacity. All of these efforts support the correlation between how LDES can be used—and in fact may be required—to achieve broader energy transition goals with the state.

Real-world market transactions in California also highlight the drive to procure LDES. In the third quarter of 2020, a set of community choice aggregator (CCA) groups that supply retail electricity in California, issued a Request for Offers (RFO) for potential ES suppliers to provide up to 500 MW of LDES. The RFO seeks to have resources that can provide at least 50 MW of power capacity with a minimum of eight hours of discharge duration. The RFO is considered to be the first in the E&U sector that is seeking bids with specific LDES requirements. It is also noteworthy that the RFO does not call for the offerings to be available until 2026, indicating an appreciation that LDES technologies, particularly battery-based, are still immature and determinations of how they can be used are still evolving. This RFO is an example of a load-serving entity (in this case the CCA) moving forward with LDES procurement in the absence of regulatory policy directives.

It should also be noted that, at this time, a growing number of states have adopted 100% renewable or. 100% clean energy targets, the difference being that the latter category includes any non-carbon-emitting resource such as nuclear energy in addition to renewables. Discussions taking place without those states quickly need to address how the ambitious goals will be achieved in practice, which opens the door to more widespread recognition for LDES solutions.

DEFINING LONG-DURATION ENERGY STORAGE

When evaluating ES technologies at a macro level, important determinants include system size, capability for instantaneous output, ability to cycle, operational lifetime, and other operating constraints. Zooming in to the micro-level, one of the key challenges that LDES currently faces is that there is little industry consensus on how the term should be defined. The lack of consensus on an LDES definition results from a lack of agreement on what LDES technologies would, could, or should be required to do, which in turn results from the absence of a well-established marketplace in which LDES actively participates as we close 2020.

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[2] https://www.storagealliance.org/longduration

Naturally, the inclusion of the word "duration" suggests that measurements of time are pertinent in terms of defining LDES' capabilities. However, "long-duration" is a very imprecise term. It suggests the amount of energy that the LDES can store; however, being designated as an LDES also suggests a technology's discharge capability, which can be far more difficult to measure and evaluate. As the term is used today in the industry, LDES could potentially cover a range from 6 to 1,000+ hours of discharge capability. Duration in this context can also be used to address how much energy the resource can store.

Beyond that, there is not much agreement on how long a measurement of time needs to be associated with an energy storage technology for it be considered LDES. It is rather akin to defining "hot" and "cold" without recognizing the relativity of the concepts or defining them against some applicable context. LDES is being considered to address critical industry needs for meeting demand and operating the grid. One such need is the desire for LDES resources to provide hours, days, or weeks of discharging duration to aid renewable integration, provide backup power and resiliency, and defer transmission development substantially. Unfortunately, beyond that, there is no widely accepted definition of LDES.

Compare the California CCA RFO requirements of 50 MW / 8-hour battery-based LDES solution with a recently announced contract between the ES developer company Form Energy to provide a 150-hour LDES storage project to Minnesota utility Great River Energy by 2023, and it is fairly easy to see why the E&U sector lacks a firm definition of what LDES entails. Even the U.S. Department of Energy (DOE) considers LDES to refer to technologies dispatching within the range of 10 to 100 hours, which is obviously a very large range. This wide disparity suggests that the E&U sector has a broad understanding of what LDES entails. Even the U.S. Department of Energy's (DOE) considers LDES to refer to technologies dispatching within the range of 10 to 100 hours, which is obviously a very large range.

Based on the plethora of independent reports that detail utility resource needs, particularly within vertically integrated markets, some utilities have indicated a need for LDES that offers discharge capability within the range of within 6 to 12 hours, which is the range that is expected to impact load-shaping activities conducted by the utility. This range is consistent with other studies that have suggested an average of 10 hours of LDES discharge capability are needed to significantly control the daily variability of renewable resources.

An aspect of defining LDES that also will need to be addressed is ownership rights. Ownership of LDES assets can vary greatly depending on the region of the country. For example, California's battery storage installations are largely utility-owned and provide energy-oriented services (serving demand for electricity), whereas PJM's large-scale batteries are owned by competitive generators and provide regulation services (managing the stability of electricity flow on the grid).

While policy will have a direct impact on LDES ownership, perhaps more important are the economic opportunities that can be pursued by LDES owners. There is presently only one marketplace in which LDES owners would receive reimbursement simply to exist (i.e., a capacity market), and that is the PJM Capacity Market, which as stated above is adopting a controversial 10-hour requirement for duration. Without respect to a specific region, the value of LDES will be determined by the ways in can be used to meet real-world needs across the electric grid.

LDES TECHNOLOGIES

The sheer existence of LDES as a technological capability is not new; there just hasn't been a driving need for it until recently when the conflux of several dynamics has created a "perfect storm" opportunity:

- An ever-increasing reliance on renewable energy that needs to be stored, which results from falling prices making renewables economically preferable over fossil-fuel based resources
- The continuing adoption by individual states of aggressive clean-energy, 100-percent renewables, or other decarbonization goals for which ES technologies (and specifically LDES) are needed
- Emerging policies at the wholesale level that are identifying the need for LDES and establishing its defining characteristics
- Individual state policies that either enable or require the future procurement of significant amounts of ES technologies, which in turn create the opportunity for LDES to be considered

For perspective, some ES technologies have always been capable of providing long-duration needs. These technologies include pumped hydro, gravity-based, and compressed air. In particular, as of the end of 2020, most of the presently installed LDES is in the form of pumped hydro.

At this time, batteries being evaluated for LDES needs, and being deployed at a gigawatt scale, are expected to deliver full power up to four hours. Requirements for longer discharge durations may remain uneconomic until there are well-defined market needs and services, which would justify compensation for 4-hour+ LDES. However, while discharge capability of LDES technology is primarily discussed in terms of hours, discussions of "seasonal LDES" can set requirements for discharge capabilities that are measured in terms of weeks or months. It is important to note that the other ES technologies, such as thermal, mechanical, pumped hydro and gravity-based systems along compressed air are further along in development with potential for earlier impact when compared to batteries.

The following table provides a summary of traditional, non-battery forms of ES technologies with their associated advantages and challenges:

ES TECHNOLOGY	ADVANTAGES	CHALLENGES
Pumped Hydro	• Mature technology • Demonstrated large capacity (~GWh) • >90% of U.S. grid energy storage • Good reliability	• Unique geologic resources and water availability • Improved turbines and electrical systems • Small modular pumped hydro systems
Compressed Air	• Demonstrated capability at large scales • Moderate round-trip efficiency • Good potential for long-duration storage	• Unique geologic resources • Well integrity • Repository integrity
Hydrogen	• Can be stored in large capacities for long periods of time • an be used for both grid and transportation • Environmentally friendly	• Low round-trip efficiency of hydrogen production and storage • High cost • Leakage and safety of hydrogen gas

Thermal (Sensible)	• Mature technology • Demonstrated large capacity with concentrating solar power (~GWh) • Low cost	• Heat loss • Large volumes required • Heat exchanger performance and cost
Thermochemical	• Large energy density • Potential for long-duration storage	• Low maturity • High cost • Material durability and kinetics

In vertically integrated markets where utilities serve as the primary buyers (i.e., procurers) of ES technologies, economic calculations have also supported investments in battery-based ES technologies over other options due to concerns about cost recovery through rate base. Thus, unless specifically directed otherwise, most ES procurement considerations among utilities tend to focus on lower-cost, short-term duration options. A scanning of ES projects around the country, available on the DOE Global Energy Storage Database, shows the vast majority of U.S. ES resources procured to date have been lithium-ion batteries with durations of four hours or less.

LDES POLICIES

Policies developed at both the federal level and within individual states have the potential to directly impact the market opportunities for LDES. At the federal level, wholesale markets operated by RTOs and ISOs, which were formed in the late 1990s and are regulated by FERC, set policies, rules, and tariffs that monetize the multitude of benefits that ES technologies can bring to these markets. In other words, policies at the federal level can determine how various ES (including LDES) technologies will be used, and how ES/LDES owners will be compensated. Further, at the federal level Congress can adopt legislation that can incentivize R&D investments needed to advance under-developed LDES technologies.

At the state level, existing and new policies can create, fortify, or break-down barriers for the development of ES technologies, including LDES. Policymaking regarding ES is gaining momentum; examples of relevant state policies include ES procurement mandates, resource adequacy requirements that include ES, integrated resource planning (IRP) and other long-term resource planning that may include ES requirements, and incentive programs made available to ES technologies. While it could be argued that any ES policy developed at the state level could potentially have impacts on LDES considerations, as of this writing policymaking specific to LDES as a subset of ES has not advanced beyond the examples of PJM and California.

Sometimes state policies can unintentionally create biases for specific ES technologies. For instance, in California, the majority of ES installations in the state have been based on battery systems that can offer an average of 4-hour durations. This duration was specifically identified within state policies as a requirement for ES technologies to be eligible to provide resource adequacy. A potential for a bias toward short-duration battery storage over LDES in the state of California is one of the findings published in the Strategen study referenced above.

Moreover, policies created at the federal and/or individual state level can quickly become the core driver around two key determinants for ES (including LDES):

- Where (and how) the ES technology may be used
- How the ES technology provider will be compensated for the services it provides

On these two determinants, precedents are emerging, and again California is the primary point of reference. California bill AB 2255 (introduced February 13, 2020) aims to develop a process to procure and deploy gigawatts of LDES across the state and proposes adopting a new regulatory approach in order to unleash LDES resources and meet California's climate goals. The bill cites numerous LDES technologies including electrochemical, compressed air, pumped hydroelectric, flow batteries, electrolytic and renewable hydrogen, and other chemical, mechanical, gravity-based, and thermal energy storage technologies. Against the backdrop of this legislation, it is easy to see why the California CCA procurement is such a milestone—among other implications, it will establish a market value for the technology and welcome developers, investors, etc.

Arizona is also a point of reference for state policymaking specific to LDES. The state offers a battery incentive program that is structured to encourage LDES specifically, offering the full incentive only for ES technologies that offer discharge durations longer than five hours.

LDES APPLICATIONS

There has been a lot of progress in terms of developing the market uses for ES technologies within the E&U sector. Within this context, "market uses" are often referred to interchangeably as "applications." There is also an established policy concept that is referred to a "multiple use applications," which speaks to the various, simultaneous uses of ES, and which is likely to important for LDES applications, in particular.

In fact, there is an abundance of policy within the E&U sector that defines the services that ES technologies can offer to both wholesale and retail markets, and these services have been organized into categories as follows:

- Bulk energy services (e.g., arbitrage, renewable energy smoothing, peak shaving)
- Ancillary services (e.g., frequency regulation, spinning/non-spinning reserves, voltage support, black start)
- Transmission infrastructure services (e.g., upgrade deferral, congestion relief)
- Distribution infrastructure services (e.g., upgrade deferral, voltage support)
- Customer energy management services (e.g., power quality, power reliability, retail electric energy time shift, demand charge management)

By comparison, up to this point developers have had difficulty locating a marketplace in which LDES can earn money. There is great hope and numerous projections for future usage of LDES. Many analysts believe the role of LDES will continue on a growth trajectory that in large part will be correlated with the increasing percentage of electricity production that comes from renewable resources. Furthermore, 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) 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 a really important consideration, especially for systems in place for disaster relief or seasonal storage. Arbitrage alone is not going to cut it – there will need to be additional values streams tied to these technologies.

Once policy determines where (and how) ES technologies—including LDES—may be used, the applications of specific technologies become much easier to determine. Nevertheless, the inherent technological capabilities of specific ES technologies may also play an important role in determining where specific technologies can be used. In addition, the extent to which renewable resources are being added to local distribution systems will also determine the potential need (and thus applications) for ES technologies.

Some general principles for the utilization of ES technologies are emerging. For instance, ES technologies that offer very short discharge durations can be used for grid reliability functions (voltage or frequency support, reserve capacity, and regulation) and in markets with significant oscillations between high and low demand periods. However, short-duration ES technologies will likely not be sufficient to support the more aggressive decarbonization goals that are being established by an increasing number of states. More complicated and demanding needs across the grid (e.g., load shifting, peak shaving, and integrating renewable resources) will require much longer discharge durations. The nature of applications will also drive what technology sets will be suitable, along with geographical considerations that may determine appropriate LDES options.

CONCLUSION

There is general acceptance in the E&U sector is that short-duration storage (<4 hours duration) is now able to provide almost all market and utility services. Market certainty regarding the economic viability of LDES specifically and its ability to accelerate solar and wind penetration, grid resiliency, and serve to stabilize volatile energy prices, is still evolving. However, LDES will likely not become pervasive until the technology itself matures, regulators adapt to the capabilities of the technology, define the ways in which LDES applications can be used, and establish clear market rules for both the federal and individual compensation mechanisms that are lucrative for developers.

In addition, there is a growing recognition that while 4-hour technologies are acceptable today, if we wait until we need the long duration systems, lags in technology development and policy implementation will drastically impede transformation to clean, reliable energy generation, storage, and distribution.

Accordingly, policymakers and regulators need new frameworks to assess the anticipated costs and value of future storage technologies within evolving grid systems. The frameworks currently used to assess generation technologies are not sufficient to evaluate emerging storage technologies that can play multiple roles. A policy framework for LDES will likely emerge in a region as the integration of renewable resources reaches very high grid penetration levels, as already seen in California. Furthermore, the high-value potential for LDES will probably come as regions initiate pathway toward decarbonization scenarios with much more displacement of fossil energy resources.

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