Long-Duration Energy Storage Use Cases

A Primer on Defining Applications to Aid in Technology Selection

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Utilities, energy companies, industrial companies, and large electricity consumers have a diverse set of pathways to achieve their own decarbonization goals and comply with similar regulations at the national, regional, and local levels, all while prioritizing reliability and affordability. Long-duration energy storage (LDES) is an emerging tool that is an enabler for decarbonization and is important for companies to consider as part of a portfolio of solutions to achieve their greenhouse gas reduction goals. LDES comprises an array of developing energy storage technologies that aspire to be available at lower costs than alternative technologies and capable of providing diverse services required to keep the grid stable and reliable.

This white paper lays out basic energy-related services that LDES can provide and highlights several key applications in which these services may be particularly beneficial. Companies interested in how LDES may facilitate their decarbonization goals can use this document as a primer to begin the process of defining their desired use case and then explore the market to select LDES technologies capable of meeting their performance needs and deployment timelines.

LDES is complementary to the growing fleet of grid energy storage resources currently represented almost entirely by lithium-ion batteries and pumped storage hydropower. LDES is commonly defined as energy storage with a capability to discharge at full power for longer than 10 hours.[1] Many short-duration energy storage systems can be operated like LDES if they are charged and discharged at lower power levels. However, they may lack the low marginal capital cost for energy capacity (low capital cost per added hour of duration) that is characteristic of many LDES technology types. Similarly, LDES can perform services that require shorter storage durations but might cost more per kilowatt of power capacity than a short-duration system.

LDES technology types fall into four primary categories defined by the energy storage medium: chemical, electrochemical, mechanical, and thermal (illustrated in Figure 1). Each type has a different set of strengths and weaknesses. It will not be a one-size-fits-all world with a single LDES technology dominating deployment; more likely, there will be a portfolio of resources of different technology types that each serve different energy needs and use cases.[2] A use case can be defined by the energy service or combination of services that a given customer is seeking.

When considering LDES, it is important to start with the desired use case in mind, then select the technology that can best provide the services when needed. The matrix shown in Figure 2 includes several key customer types who may benefit from LDES deployment. Each customer has varying energy services needs which align with LDES capabilities as shown in the columns. Energy services include electrical energy, capacity, resilience, balancing and reserves, and low-

1 "Pathways to Commercial Liftoff: Long Duration Energy Storage," U.S. Department of Energy, 2023. Some groups define the minimum LDES duration as 8 hours while others use 12 hours.

2 J. Dowling et al., "Role of Long-Duration Energy Storage in Variable Renewable Electricity Systems," Joule, vol. 4, 2020.

CHEMICAL	ELECTROCHEMICAL	MECHANICAL	THERMAL
Reaction results in product that can be used to generate heat or power	Reversible chemical reaction generates an electrical potential difference	Kinetic or potential energy storage via compression, gravity, or rotation	Energy storage achieved by heating bulk media

Figure 1: LDES technology types.

carbon heat (see sidebar). This is not an exhaustive list of services but is sufficiently broad to highlight an illustrative set of use cases. Building up a suite of energy services, prioritized accordingly, results in a single use case for a customer. A brief discussion for the selected customer types follows.

Electric Utility: Many utilities have announced decarbonization goals with net-zero targets by 2050 or earlier. LDES technologies can be an important tool for achieving these goals as a source of dispatchable energy to match a generation portfolio with a high penetration of variable renewable energy.[3] Price signals in organized markets incentivize energy storage resources to move energy from times when prices are relatively low (periods of excess supply) to times when prices are relatively high (periods when supply is tight). This can include moving energy intraday, between days, and even across seasons.[4] Market mechanisms are still under development to adequately compensate LDES for these services beyond the more established four-hour storage duration. In the meantime, LDES can offer value via some existing electricity market constructs.[5] Storage resources with enough capacity and duration have the potential to play the role of peaker plants. For example, LDES resources that are capable of supplying energy for more than 100 hours can supply low-carbon firm power during the most challenging times on the grid. LDES can also provide various balancing and reserve services to minimize service interruptions to customers.

3 E. Gardow, T. Kelly, and E. Minear, "Battery Energy Storage Roadmap," EPRI, Palo Alto, CA: 2024. 3002029646

4 J. Raade, "Seasonal Energy Storage: A Technical and Economic Framework," EPRI, Palo Alto, CA: 2022. 3002025178

5 J. Rushkoff, "Energy Storage Market Review: Case Studies on Long-Duration Energy Storage Performance in CAISO, ERCOT, and MISO," EPRI, Palo Alto, CA: 2024. 3002026108

ENERGY SERVICE DEFINITIONS

Electrical Energy: The quantity of electrical energy delivered to a customer, denoted in kilowatt-hour (kWh) or megawatt-hour (MWh). LDES can generate value via energy shifting, for example moving solar energy from daytime hours to peak load hours in the evening. This type of service results in peak shaving when the customer uses energy delivered by an LDES system to reduce the amount of generation needed to meet peak loads. Energy services sometimes generate additional value from arbitrage (charging when energy prices are low and discharging when prices are high).

Capacity: Capacity refers to the ability of the grid to supply additional electric load when the grid is under the most stress. Capacity is typically denoted in terms of power (kW or MW).

Resilience: Resilience is related to capacity but is more often associated with the capability of an energy system to withstand exceptional, unexpected events (such as a storm or natural disaster). Providing backup power is one aspect of resilience. Resilience services are typically denoted in terms of power (kW or MW).

Balancing and Reserves: Energy systems need to deliver their value on a day-to-day basis, with minimal interruption. This reliability is enabled by a suite of ancillary services that keep the electrical grid operating normally. These services include frequency regulation, spinning reserve, and a variety of other constructs defined by grid operators. Some LDES types offer additional features such as synchronous inertia, short-circuit current capability for voltage support, black-start capability, and other aspects that may be also beneficial for reliability.

Low-Carbon Heat: The quantity of thermal energy delivered to a customer, denoted in MMBtu or MWh. The nature and quality of heat delivered depends on the process requirements and may take the form of hot water, steam, hot air, or some other heated medium.

Data Center: The broad category of commercial and industrial customers includes the developers and owners of data centers. These firms are responding to the growing demand for computing power, driven by the increasing use of artificial intelligence, cloud computing, and other needs.[6] Data center owners are increasingly seeking low-carbon, firm, reliable power for their facilities. Data centers typically sign long-term procurement agreements with utilities for the energy they need and install redundant on-site backup power to meet their ultra-high uptime requirements. This need makes resilience the highest priority service, with backup storage duration requirements ranging from seconds (immediately following a fault) to minutes (buffering between short-duration and long-duration responses), to several days. LDES may be well-suited to provide the many hours to multi-day portion of this resiliency strategy.

Microgrid: Research campuses and critical facilities such as hospitals and military bases often seek to develop their own generation resources with the ability to disconnect from the broader grid during interruptions or operate separately from the grid in general. LDES solutions could be used in these applications as a direct replacement of backup diesel generators already in place, potentially reducing greenhouse gas emissions. Sometimes these systems also rely on local variable renewable energy for a portion of their energy generation on a day-to-day basis, which LDES can smooth. Some district heating systems for cities and university campuses are effectively “heat microgrids” that may benefit from renewable energy coupled with thermal LDES to supply low-carbon heat to the network.

Island Grid: Remote locations and islands often have limited or no options to connect to a larger grid, so they must generate their own energy. These unique needs require island grid operators to have access to resources that enable the system to withstand unexpected weather events or equipment failures. LDES can help enhance resilience by smoothing out and backing up variable renewable energy resources. It also can offer additional capabilities that support grid stability, such as synchronous inertia and black-start capabilities.

6 J. Aljbour, T. Wilson, and P. Patel, “Powering Intelligence: Analyzing Artificial Intelligence and Data Center Energy Consumption,” EPRI, Palo Alto, CA: 2024. 3002028905

	ELECTRICAL ENERGY	CAPACITY	RESILIENCE	BALANCING AND RESERVES	LOW-CARBON HEAT
Electric Utility	High	High	High	High	Low
Data Center	Low	Medium	High	Medium	Low
Microgrid	Low	Medium	High	Medium	Medium
Island Grid	High	High	High	Medium	Low
Industrial Process	Medium	Low	Low	Low	High

Alignment with LDES: Low, Medium, High

Figure 2: Matrix of customer types and potential energy services from LDES.

Industrial Process: There is growing interest in the need to decarbonize industrial processes that use fossil-fuel-derived heat for manufacturing basic materials and products. The production of iron and steel, chemicals, petroleum refining, cement, glass, and aluminum are major contributors to greenhouse gas emissions and do not yet have scalable solutions for low-carbon heat.[7] Thermal LDES technologies may offer a pathway to store electrical energy as heat and deliver it on-demand to an industrial process.[8] Additionally, thermal LDES can provide ancillary services and can respond to real-time dispatch instructions. These services also help integrate renewable generation, which helps the energy sector reduce carbon emissions.

Where to find additional information:
EPRI: http://www.epri.com/
LDES Council: https://ldescouncil.com/
EEI: http://www.eei.org/
DOE: http://www.energy.gov/

7 "Pathways to Commercial Liftoff: Industrial Decarbonization," U.S. Department of Energy, 2023.
8 "Driving to Net Zero Industry Through Long Duration Energy Storage," LDES Council, 2023.

STEPS TO CONSIDER FOR DEPLOYING LDES AFTER READING THIS PRIMER

1. Review the customer types and find the one that most closely matches the required energy profile.
2. Select the energy services needed and weight them according to priority.
3. Build a well-defined use case that lays out the desired energy services and the relative importance of each.
4. Use the results to develop resource planning and procurement efforts for suitable LDES technologies.
5. Engage with industry trade groups and research institutions to explore the market and identify candidate technologies that may be capable of meeting the desired application and timeline.

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