CENTER FOR CLIMATE AND ENERGY SOLUTIONS

TECHNOLOGY WORKING GROUPS

Reliability in Reserve: Long-Duration Energy Storage for an Abundant American Energy Future

October 2025

Long-duration energy storage (LDES) is any storage technology that can supply energy—typically as electricity, and in some cases as heat—continuously for at least ten consecutive hours at full power.[1] LDES systems offer an alternative to shorter-duration energy storage technologies like lithium-ion batteries. There are three main storage classifications for LDES: inter-day, multi-day, and seasonal shifting. Inter-day storage provides 10 to 36 hours of energy, while multi-day storage extends that range from 36 to 160 hours of energy. Seasonal shifting storage offers energy over extended durations exceeding 160 hours, often spanning several months. LDES is a diverse technology class with a range of forms, including electrochemical, mechanical, thermal, and chemical energy storage.[2] It is a flexible resource with many potential end users, including electric utilities, data centers, critical facilities such as hospitals and military bases (sometimes with microgrids), remote communities, and heat-intensive industrial operations.[3]

Author:

Diandra Angiello

HIGHLIGHTS

Energy Abundance: LDES is critical to maintaining U.S. energy abundance as the nation faces a period of significant growth in electricity demand, projected to rise by 15 to 20 percent over the next decade.

Domestic Manufacturing & Jobs: LDES encompasses a wide range of technologies, many of which leverage existing domestic supply chains from adjacent industries—reducing U.S. dependence on imported batteries. If the United States can scale LDES manufacturing and deployment to 3 GW annually by 2030, the sector could generate up to 2.1 million direct job-years.

Energy Reliability: LDES can provide sustained backup power during prolonged periods of high electricity demand or grid stress events, helping to prevent blackouts, safeguard lives, and reduce economic disruption.

Innovation Unlocks Value: Continued federal investment in innovation is essential to unlocking the full potential of LDES and other emerging technologies. Sustained funding for research, development, and demonstration not only accelerates the creation of new LDES approaches with added value but also enhances existing approaches by making them more cost-effective and scalable.

Key LDES Approaches & Their Associated Co-Benefits

Electrochemical: Unlike lithium-ion batteries, electrochemical LDES technologies encompass a wide range of materials, many of which are widely available, rather than relying on a single critical mineral. This diversity helps reduce supply chain vulnerabilities, costs, and related national security risks. Certain materials, including iron and zinc, have the advantage of an established domestic raw material market.[4]

Mechanical: Many mechanical LDES systems can repurpose and utilize existing infrastructure like mine shafts, dams, and reservoirs.[5] This can accelerate the permitting process and lower costs, while also reducing reliance on critical minerals and international supply chains.

Thermal: By delivering electricity and high-temperature heat for industrial applications, thermal LDES technologies are highly efficient and can unlock multiple revenue streams.[6]

Chemical: By either returning stored energy to the grid or selling the resulting chemical products for use in industrial and transportation applications, chemical LDES technologies are versatile and offer diverse business models.[7]

FIGURE 1: FOUR KEY LDES TECHNOLOGIES

Electrochemical LDES technologies—such as aqueous electrolyte and metal anode flow batteries—store and discharge energy through chemical processes.

Mechanical LDES technologies—such as pumped hydro, compressed air, gravity-based, liquid air, and liquid carbon dioxide systems—store and discharge energy using kinetic or gravitational forces.

Thermal LDES technologies store high temperature heat for later use—either directly as heat or by conversion to electricity—using methods such as sensible (e.g., molten salt, rock, concrete), latent (e.g., aluminum alloys), or thermochemical (e.g., silica gel) storage.

Chemical LDES technologies convert electricity into energy-carrying chemicals—such as hydrogen, ammonia, and electrofuels—that can be stored, transported as fuels, and later converted back into electricity.

Source: Katheryn Scott et al., *Pathways to Commercial Liftoff. Long Duration Energy Storage* (Washington, DC: U.S. Department of Energy 2023), https://yardsale.energy/wp-content/uploads/2025/05/DOE-Liftoff-LDES-2023.pdf

The Value of LDES

Successfully deploying LDES will strengthen grid reliability and increase system resilience, while delivering

$10–20 BILLION

in annualized savings

Energy Abundance: LDES is critical to maintaining U.S. energy abundance as the nation faces a period of significant growth in electricity demand, projected to rise by 15 to 20 percent over the next decade. This surge is driven by factors such as the expansion of data centers, reshoring manufacturing, and the increasing electrification of transportation, buildings, and industry.[8] To meet this growing demand, the United States should take an "all of the above" approach—firming existing variable renewable sources by pairing them with LDES that can reduce curtailments. Successfully deploying LDES has the potential to strengthen grid reliability and increase resilience, while delivering $10–20 billion in annualized savings for operators and avoided capital expenditures.[9]

Domestic Manufacturing and Jobs: Scaling up domestically manufactured LDES technologies offers a strategic opportunity to reduce U.S. reliance on imported batteries, particularly lithium-ion, which in 2024 accounted for over 90 percent of global installed energy storage capacity.[10] China currently leads both in battery manufacturing and in processing the key raw materials required for lithium-ion production.[11] By contrast, LDES encompasses a wide variety of technologies, some of which rely less on critical minerals and can tap into existing supply chains from adjacent industries.[12] If the United States can scale LDES manufacturing and deployment to 3 GW annually by 2030, the sector could generate up to 2.1 million direct job-years—that is, the equivalent of one full-time job for one person for one year—in areas such as engineering and construction and deliver as much as $530 billion in cumulative economic benefits over the next 25 years.[13] LDES projects are already being developed and constructed across the county, signaling the technology's momentum and near-term potential to deliver manufacturing and jobs benefits.

Energy Reliability: LDES can strengthen grid reliability by storing excess energy and dispatching it during prolonged periods of high demand. The U.S. power system faces heightened variability in electricity generation and consumption, alongside an increasing frequency of grid stress events triggered by extreme weather. These dynamics erode grid resilience and contribute to more frequent, longer-lasting power outages. A stark example occurred in Texas in February 2021, when a historic winter storm brought snow, ice, and record-low temperatures over multiple days. The extreme conditions caused power demand to exceed available supply, forcing grid operators to implement rolling blackouts to avoid a total system collapse.[14] The consequences were devastating: at least 146 lives were lost due to hypothermia, and the estimated economic cost of the blackout reached $195 billion.[15] In such a scenario, LDES could have played a crucial role by providing sustained backup power, reducing reliance on emergency measures, and helping to prevent loss of life and economic disruption.

Reduced Land-Use Impacts: LDES can store surplus power and release it during peak demand, which optimizes grid utilization and can even defer the need for new transmission and distribution infrastructure to keep pace with rising electricity demand.[16] By relieving pressure to expand the physical grid, land disruption is minimized, To fully realize the benefits of LDES and other emerging technologies, **continued federal investment in innovation is essential**

communities are shielded from displacement, and ecologically sensitive areas and wildlife habitats are better protected from the impacts of large-scale energy development. LDES can also minimize new land takings by repowering or upsizing existing power plants (i.e., brownfields development).[17] Inevitably, new generation projects will be needed as electricity demand continues to grow, but maximizing the land efficiency of existing power plants can reduce the number of new projects required and limit land disruption.

Unlocking Added Value with Innovation

The United States has long stood at the forefront of innovation by pairing public investment in new technologies with the ingenuity and scale of the private sector. These partnerships position the country to lead in the development and deployment of emerging technologies—including LDES. However, to fully realize the benefits of LDES and other emerging technologies, continued federal investment in innovation is essential. Numerous LDES approaches already exist—and many more remain to be discovered—each with the potential to add additional value. Unlocking these opportunities requires sustained funding for scientific research, which can advance new storage pathways and improve existing ones by making them more cost-effective and scalable.

Endnotes

1 "Long Duration Energy Storage for the Power System," Future Cleantech Architects, accessed August 12, 2025, https://fcarchitects.org/content/the-basic-the-gaps-ldes.

2 Katheryn Scott et al., *Pathways to Commercial Liftoff: Long Duration Energy Storage* (Washington, DC: U.S. Department of Energy 2023), https://yardsale.energy/wp-content/uploads/2025/05/DOE-Liftoff-LDES-2023.pdf.

3 Electric Power Research Institute et al., Long-Duration Energy Storage Use Cases (Palo Alto, CA: EPRI, 2024), https://www.epri.com/research/products/000000003002030919.

4 Margaret Mann et al., *Grid Energy Storage* (Washington, DC: U.S. Department of Energy, 2022), https://www.energy.gov/sites/default/files/2024-12/Energy%2520Storage%2520Supply%2520Chain%2520Report%2520-%2520final%5B1%5D.pdf.

5 Katheryn Scott et al., *Pathways to Commercial Liftoff: Long Duration Energy Storage*.

6 Ibid.

7 "LDES Technologies," LDES Council, accessed August 12, 2025, https://www.ldescouncil.com/ldes-technologies.

8 U.S. Department of Energy, *How Clean Energy is the Solution to Rising Electricity Demand, Liftoff Topic Brief* (Washington, DC: U.S. Department of Energy, 2024), https://yardsale.energy/wp-content/uploads/2025/05/DOE-Liftoff-Demand-Growth-Topic-Brief.pdf.

9 Katheryn Scott et al., *Pathways to Commercial Liftoff: Long Duration Energy Storage*.

10 Susan Taylor and Henrique Ribeiro, "The risks of leaving long-duration energy storage short of money," S&P Global, June 28, 2024, https://www.spglobal.com/commodityinsights/en/market-insights/blogs/electric-power/062824-the-risks-of-leaving-long-duration-energy-storage-short-of-money.

11 Varun Sivaram, Noah Gordon, and Daniel Helmeci, *Winning the Battery Race: How the United States Can Leapfrog China to Dominate Next-Generation Battery Technologies* (Washington DC: Carnegie Endowment for International Peace, 2024), https://carnegieendowment.org/research/2024/10/winning-the-battery-race-how-the-united-states-can-leapfrog-china-to-dominate-next-generation-battery-technologies?lang=en.

12 Susan Taylor and Henrique Ribeiro, "The risks of leaving long-duration energy storage short of money."

13 Katheryn Scott et al., *Pathways to Commercial Liftoff: Long Duration Energy Storage*.

14 Cheng-Chun Lee, Mikel Maron, and Ali Mostafavi, "Community-scale big data reveals disparate impacts of the Texas winter storm of 2021 and its managed power outage," Humanities and Social Sciences Communications 9 (September 2022), https://www.nature.com/articles/s41599-022-01353-8.

15 Texas Department of Health and Human Services, "February 2021 Winter Storm-Related Deaths – Texas," December 31, 2021, https://www.dshs.texas.gov/sites/ default/files/news/updates/SMOC_FebWinterStorm_MortalitySurvReport_12-30-21.pdf; see also Cheng-Chun Lee, Mikel Maron, and Ali Mostafavi, "Community-scale big data reveals disparate impacts of the Texas winter storm of 2021 and its managed power outage."

16 LDES Council and McKinsey & Company, *Net-zero Power: Long duration energy storage for a renewable grid*, (LDES Council and McKinsey & Company, 2021), https://www.ldescouncil.com/assets/pdf/LDES-brochure-F3-HighRes.pdf.

17 Ibid.