VedeniEnergy
Plugged Into The Energy Industry

MARCH 2026

LDES

The Growing Role of Long-Duration Energy Storage

WHITEPAPER

VedeniEnergy
Plugged Into The Energy Industry

+1 463-266-4496
www.vedeni.energy
info@vedeni.energy
Whitestown, in 46075, US.

Executive Summary

Technology, Policy, and Market Pathways for Multi-Day Grid Storage in the United States

Long-duration energy storage is shifting from a niche topic in grid planning to a key issue in designing a reliable, lower-carbon electricity system. The reason is simple. The United States is adding wind, solar, and battery storage at large scales, yet the operating challenge the grid faces is no longer just balancing the system over minutes or during a few evening hours. In a power system with much higher shares of variable renewable generation, the more difficult problem is maintaining reliability through multi-day weather events, extended renewable shortfalls, and seasonal mismatches between production and demand. That is where long-duration energy storage, or LDES, becomes strategically essential.

The current storage market is led by lithium-ion batteries, and for valid reasons. They are commercially mature, modular, quick to respond, and gradually becoming more affordable for short-duration needs. They excel at frequency regulation, ramping support, congestion relief, shifting solar power into the evening peak, and building resource adequacy products around four-hour performance. However, the chemistry that has revolutionized short-duration storage does not automatically serve as the best solution for ten-hour, twenty-four-hour, or one-hundred-hour applications. As storage duration extends, factors such as economics, materials needs, degradation patterns, safety issues, and operational functions all evolve. Therefore, the power sector is increasingly exploring beyond lithium-ion to a wider range of LDES technologies that might be more appropriate for multi-day grid storage.

These technologies include iron-air batteries, vanadium and other flow batteries, compressed air energy storage, liquid air energy storage, thermal storage, and pumped storage hydropower, along with several emerging hybrid concepts. They vary significantly in maturity, efficiency, siting requirements, duration, and reliability. Some are designed to be cost-effective on the energy side and are therefore appealing when very long discharge durations are needed. Others are better understood technologically but limited by site availability, permitting challenges, or high capital costs. None should be viewed as a single solution. The likely future for LDES in the United States involves a diverse range of technologies shaped by regional resource mixes, market regulations, resilience needs, and local geography.

Policy is beginning to shift in this direction. The U.S. Department of Energy has made long-duration storage a formal cost-reduction goal through the Long Duration Storage Shot and has published a commercial launch roadmap that outlines the scale of the need and the obstacles to adoption. Federal tax policy now clearly includes energy storage technology within clean electricity investment credits for qualifying projects placed in service after 2024. States, most notably California, are also starting to procure or authorize long-duration and multi-day storage as part of broader clean firming and reliability strategies. At the same time, market design still lags behind operational needs. Most organized power markets reward storage most when it cycles frequently and profits from short-term spreads. In contrast, long-duration systems may generate much of their value by being available during rare but high-impact system stress events.

This white paper explores the increasing importance of long-duration energy storage in U.S. electricity markets. It evaluates the technology landscape, policy incentives, and market structures necessary to make LDES financially viable and operationally effective. It also considers how long-duration energy storage can support renewable integration, enhance reliability during extended grid stress, and provide seasonal balancing over time. The main conclusion is that LDES is no longer a speculative addition to the energy transition. Instead, it is becoming a crucial component of grid-scale storage innovation if the United States aims to build a reliable, deeply decarbonized power system.

Introduction

Why the Storage Question Has Changed

Throughout most of the modern history of the U.S. electricity sector, reliability planning was based on the assumption that the system would rely on dispatchable generation. Coal plants, combined-cycle gas facilities, combustion turbines, hydropower, and nuclear stations supplied controllable capacity. Demand fluctuated by hour, season, and weather, but operators could generally turn to thermal or hydro resources to meet the need. Storage existed mainly as pumped storage hydropower, but it was a specialized asset rather than a core element of grid design.

That assumption is shifting. Wind and solar are now being added in large quantities because they are cost-competitive, supported by policy, and increasingly central to utility procurement strategies. The Energy Information Administration expects solar and battery storage to lead new U.S. generating capacity additions, with battery installations in 2025 projected to reach 18.2 gigawatts after a record 10.3 gigawatts were added in 2024. At the same time, the modeling conventions used by the EIA still often assume four-hour lithium-ion battery configurations for utility-scale and hybrid projects, highlighting how deeply the current market is focused on short-duration storage.

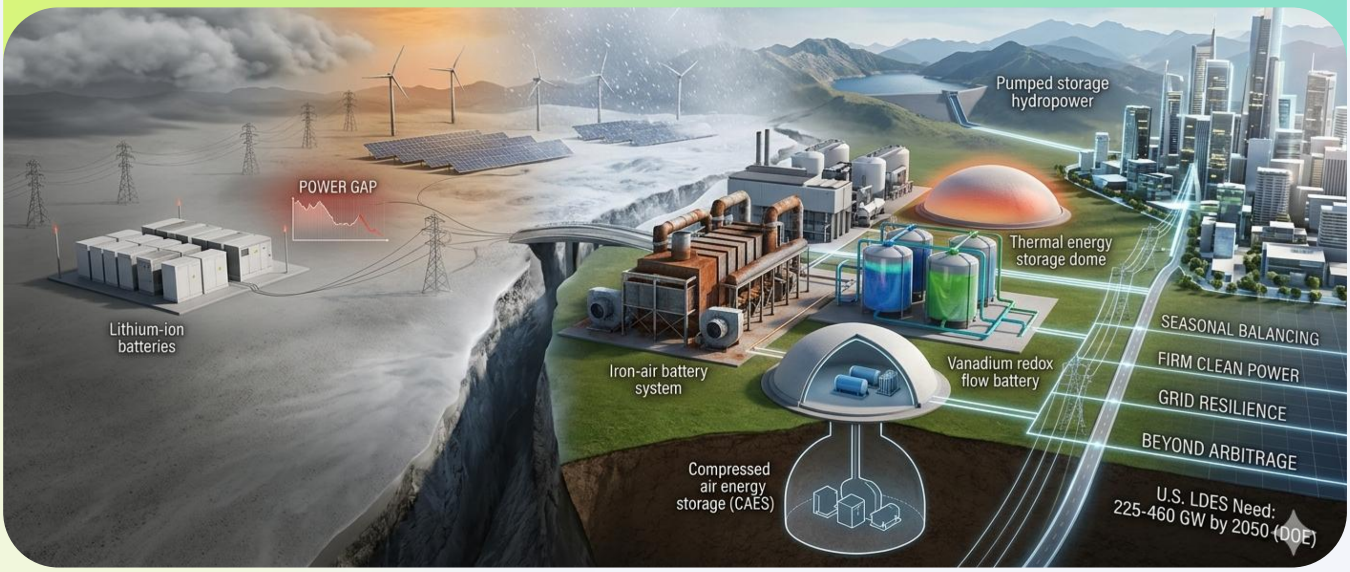
That short-duration orientation makes sense in today's market environment. Much of the immediate value of storage comes from services that do not need very long discharge times: frequency response, regulation, spinning reserve substitution, transmission and distribution deferral in some cases, and the familiar task of shifting solar generation from midday into the evening net load peak. In California and other markets, the four-hour standard has also become part of resource adequacy thinking and procurement practices. However, four-hour storage only addresses one layer of the flexibility challenge. As renewable penetration increases, the system more frequently faces hours, days, and even weeks when the problem isn't just the evening peak but an extended shortfall caused by low wind, weak solar output, transmission congestion, fuel constraints, or simultaneous outages.

This is why the industry's language has shifted from "battery storage" in general to specific discussions of long-duration energy storage, multi-day grid storage, and clean firming. The Department of Energy's commercial liftoff work on LDES clearly outlined the issue: as variable renewable energy expands, storage duration needs are expected to exceed four hours and move into applications that commercially deployed lithium-ion systems may not serve as effectively. DOE also indicated that the U.S. grid might require approximately 225 to 460 gigawatts of LDES by 2050 for power-market applications, suggesting a scale of need that cannot realistically be met by a single chemistry or business model.

Long-duration energy storage is generally defined as storage capable of discharging for ten hours or more. However, in practice, the duration ranges matter. Ten to twelve hours can serve overnight shifts, long ramps, and some reliability reserve needs. Twenty-four hours and beyond begin to enable different use cases: covering a full day of low renewable output, maintaining reserves during weather-driven stress events, and supporting systems aiming to reduce reliance on gas peakers or other thermal backups. At multi-day durations, the discussion shifts toward resource adequacy, resilience, and clean firm capacity rather than just arbitrage.

This shift carries significant implications for both technology choice and market design. A four-hour lithium-ion battery can justify its economics through frequent cycling and relatively predictable energy spreads. In contrast, a hundred-hour iron-air battery or a long-duration compressed-air facility may cycle much less often. Its value may primarily manifest during rare but impactful conditions when the grid is most stressed and prices or outage risks are highest. That means LDES cannot be judged solely by the metrics used for short-duration batteries. The key question is not whether LDES can dominate today's storage market immediately, but whether a high-renewables power system can stay reliable at an acceptable cost without a portfolio of renewable energy storage solutions that extend beyond four hours.

> The conclusion from federal analysis, utility planning, and recent market experience is that it cannot. The February 2021 Texas freeze, California's late-summer reliability issues, and ongoing concerns over winter gas delivery in several areas all teach the same lesson from different perspectives: reliability issues become much harder when stress lasts beyond a few hours. LDES technologies are drawing attention because they might be some of the few scalable tools capable of filling that gap without simply replacing the fossil backup system that decarbonization policies aim to eliminate.



Why Lithium-Ion Dominates Today

but Does Not Solve the Whole Problem

Lithium-ion batteries dominate current storage deployments because they meet the needs of today's market better than any other commercially available alternative. They are modular, can be installed relatively quickly, integrate well with solar interconnection and hybrid systems, and have benefited from a global manufacturing expansion driven by electric vehicles as much as by the power sector. The International Energy Agency notes that grid-scale battery storage needs to increase significantly under net-zero pathways, and in 2025, battery prices continued to decline, with average energy storage system costs dropping to about one-third of 2020 levels.

There is no strong argument that lithium-ion should be removed from the grid. It will continue to be essential for many applications. The question isn't whether lithium-ion is useful, but whether it stays cost-effective and operationally efficient as storage duration increases. For short-term uses, lithium-ion benefits from high round-trip efficiency, proven controls, established supply chains, and a reputation that developers, lenders, and utilities trust. However, for very long durations, costs can increase significantly because extending discharge time usually requires adding more battery cells and related balance-of-system parts. In other words, the same modular design that makes lithium-ion adaptable can also lead to higher costs when the energy capacity needs to be very large.

There are also performance and planning considerations. Four-hour systems are excellent at solving the duck-curve problem and participating in daily energy markets. They are less naturally suited to providing insurance against a three-day wind lull or a prolonged winter reliability event unless the

project is heavily oversized. Additionally, when many short-duration batteries are dispatched simultaneously into the same evening peak, they can end up recharging at similar times, creating new load shapes and system constraints. The question becomes not just whether a battery can discharge for four hours, but whether the entire storage fleet can support the system through a sequence of stressed periods without running out of capacity.

Federal and national-laboratory work increasingly views this as a matter of system evolution rather than technology ideology. NREL's Storage Futures work and subsequent LDES studies highlight that storage needs change as renewable energy penetration increases. In the early stages of renewable adoption, shorter-duration batteries provide much of the value because the grid still relies on abundant dispatchable thermal generation to handle longer events. In later stages, very long-duration storage can become more valuable, particularly in scenarios with extensive wind and solar deployment and stricter decarbonization goals. NREL's 2025 report on LDES grid integration and valuation similarly finds that LDES can significantly boost operational flexibility and system value, but the economics heavily depend on the future generation mix, operational assumptions, and how planners model these technologies.

The practical implication is that the market is entering a period of differentiation. Lithium-ion will likely remain the default storage resource for short-duration needs. However, as utilities and system operators face higher renewable shares, they are likely to begin segmenting storage needs by function. Some will still be met with two- to four-hour batteries, while others will require six- to twelve-hour systems. Still, others will demand genuine multi-day grid storage. This segmentation is beneficial because it recognizes that "storage" is not a single product. Instead, it is a family of products with different cost structures and roles in reliability.

This is also why the LDES debate shouldn't be viewed as a direct competition with lithium-ion. That's the wrong perspective. The more realistic future involves a layered storage system where lithium-ion manages high-frequency and intraday balancing, while LDES technologies address the longer durations that short-term batteries and demand-side flexibility can't economically support. In this way, long-duration energy storage is not so much a replacement for current batteries as it is a complement, becoming increasingly important as the grid relies more on weather-dependent supply.

The LDES Technology Landscape

The term long-duration energy storage covers a broad array of technologies, and a common mistake in public discussion is to treat LDES as if it were a single category with uniform traits. It is not. The technologies within the LDES category vary greatly in their technological readiness, duration, siting flexibility, efficiency, safety profile, and likely commercial application.

Iron-air batteries have attracted significant attention because they deliver on the main promise of LDES: much lower energy costs for very long discharge times. Form Energy’s approach relies on reversible iron oxidation, effectively using rusting and de-rusting for charging and discharging. The company aims for around 100-hour durations, placing it in the multi-day grid storage category rather than just extended intraday storage. The benefit is clear. Iron is abundant, cheap, and less geopolitically risky than some other battery minerals. If the technology performs as expected at scale, it could become a key solution for long-duration renewable energy storage, helping to deliver reliable clean power. The main challenge, like with all new chemistries, is scaling from promising pilot and initial commercial projects to dependable, bankable deployments.

Flow batteries, especially vanadium redox flow batteries, occupy a different place on the maturity curve. They are better understood than some newer battery technologies and have been used in various grid applications worldwide. Their key feature is the separation of power and energy. Power mainly depends on the cell stack, while energy is primarily determined by the size of the electrolyte tanks. This design is attractive for long-duration storage because expanding capacity doesn't require replicating the entire power system. Sumitomo Electric and other vendors have demonstrated how flow batteries support renewable integration and grid stability, especially where long cycle life and deep discharges are important. However, flow batteries have not yet reached the same deployment scale as lithium-ion batteries in the U.S. market, partly due to high initial costs, project complexity, and procurement norms that still favor the established technology for many near-term uses.

Compressed air energy storage, or CAES, is one of the oldest long-duration energy storage (LDES) concepts not based on hydro. Traditional CAES uses off-peak electricity to compress air and store it in underground caverns; later, the air is released to drive a turbine and generate power. Newer adiabatic or advanced designs aim to capture and reuse the heat generated during compression, which improves efficiency and can reduce or eliminate the need for fossil fuels. The appeal of CAES comes from its potential for large-scale, long-duration storage with relatively conventional turbomachinery. However, limitations are clear: suitable geology is essential for many configurations, project lead times can be long, and efficiency may lag behind electrochemical alternatives. Still, CAES remains one of the few technologies with clear relevance for utility-scale, multi-day storage. DOE's technology strategy continues to see it as a promising pathway toward affordable, long-duration energy storage.

Liquid air energy storage, or LAES, addresses some of the siting limitations of CAES by storing air in liquid form at cryogenic temperatures in insulated tanks rather than underground caverns. The air is liquefied using electricity, stored, and then reheated and expanded through turbines. LAES is attractive because it can provide potentially long durations with fewer geological constraints, and it can sometimes be combined with waste heat or cold from industrial processes to improve economics. Europe has been especially active in developing this technology. Although it is less mature than lithium-ion and pumped hydro, it is among the more feasible mechanical-storage options in the LDES portfolio.

Thermal storage is a crucial yet often overlooked part of the LDES landscape. The core idea is straightforward: storing heat is generally cheaper than storing electricity. If electricity can be converted into thermal energy and later turned back into power with acceptable efficiency, it may be ideal for long-duration storage. DOE and NREL have studied several thermal concepts, including the ENDURING system, which combines low-cost particle thermal energy storage with a highly efficient power cycle. Thermal methods can be particularly appealing where electricity storage aligns with industrial heat needs or where both power and thermal services have value.

Pumped storage hydropower, although not new and quite old, still serves as the standard by which many LDES ideas are evaluated. It is the most common long-duration storage technology used worldwide. Its advantages include proven scalability, long asset life, and well-understood operational features. Its drawbacks are also well known: project development is slow, siting is difficult, permitting can be complex, and community and environmental issues can be significant. Closed-loop designs can lessen some environmental impacts, but pumped hydro alone likely won't grow quickly enough to meet all future U.S. LDES needs.

What emerges from this landscape is not a simple ranking but a portfolio approach. Ten- to twenty-hour applications may favor certain technologies, while multi-day reliability might support others. Some regions will naturally prefer electrochemical systems that can be deployed flexibly near load centers. Others may rely on mechanical or hydro solutions where geography permits. The market should not anticipate a single winner but rather specialization. That is likely what a mature LDES sector will look like.

U.S. Policy, Incentives, and Demonstration Support

The policy landscape for long-duration energy storage in the United States has significantly improved, but it is still transitional rather than fully established. The main change is that federal policy now views storage as a growing key component of grid decarbonization instead of just an accessory to generation expansion.

DOE's Long Duration Storage Shot clearly exemplifies that shift. The goal is to cut the levelized cost of storage for grid use by 90 percent for systems providing over ten hours of duration, aiming for about $0.05 per kilowatt-hour by 2030. DOE's broader Earthshots initiatives and the 2024 strategy document "Achieving the Promise of Low-Cost Long Duration Energy Storage" emphasize that long-duration technologies are a national innovation priority. The commercial liftoff report is equally crucial because it moves beyond laboratory goals and addresses bankability, project sequencing, market needs, and the scale of deployment needed. DOE also highlights significant capital support for demonstrations through the Office of Clean Energy Demonstrations and related programs, with hundreds of millions of dollars allocated for long-duration storage demonstration pathways.

This is important because LDES faces a typical commercialization gap. Many technologies are too advanced to be just laboratory science but not developed enough to attract affordable private capital at scale. First-of-a-kind and early commercial projects are costly, seen as risky, and often hard to insure or finance. Public demonstration support can therefore be especially valuable, not because it replaces markets, but because it reduces uncertainty about performance, operations, maintenance, and degradation. In this way, demonstration policy isn't a subsidy for its own sake. It acts as a bridge to investability.

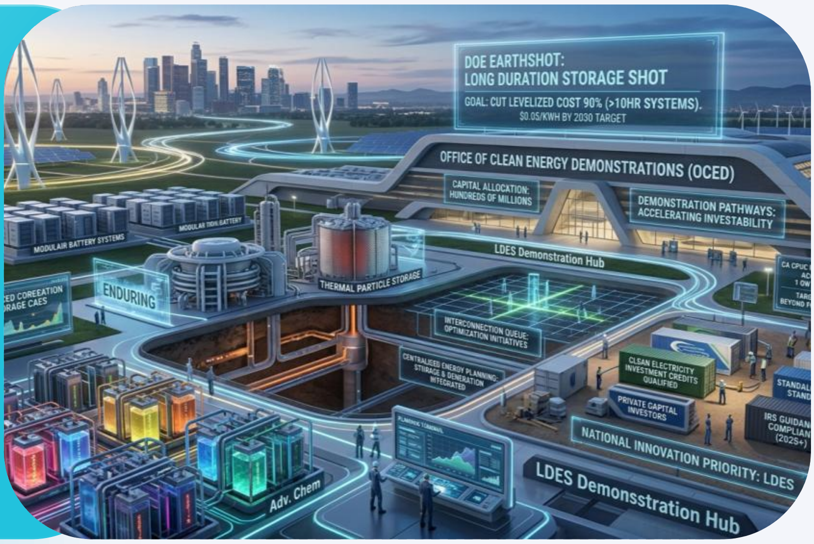
Tax policy is becoming increasingly important. The Internal Revenue Service's guidance on clean electricity investment credits clarifies that energy storage technology placed in service after December 31, 2024, qualifies under the clean electricity investment credit framework, following the relevant rules. This significantly improves investability because standalone storage is no longer considered a policy gray area. Credit transferability and elective pay options also expand the range of parties that can effectively use federal incentives. However, for LDES developers, eligibility for tax credits is helpful but not enough. A project must also convince offtakers, regulators, and lenders that the technology will operate as expected and that market revenues will be sustained over time.

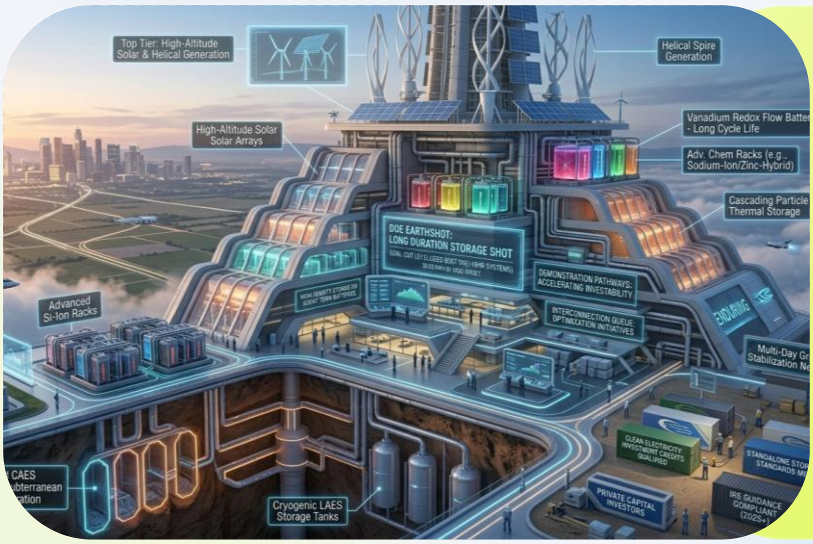
State policy is starting to more directly influence the deployment question. California is the most significant case because it has a large storage market and a resource mix that highlights the limitations of short-duration storage. The CPUC's 2024 procurement decision authorized the Department of Water Resources to acquire emerging technologies, including up to 1 gigawatt of multi-day long-duration energy storage and up to 1 gigawatt of storage with at least a twelve-hour discharge period. This is not just a generic storage goal; it's a deliberate effort to incorporate longer-duration technologies into the procurement process. In March 2026, the CPUC also approved a new centralized procurement plan for additional clean capacity through 2032, further emphasizing that storage and clean generation are being planned together rather than separately.

Other states are proceeding cautiously but following a similar logic. New York and Massachusetts have both recognized long-duration storage as important for future system flexibility and resilience. The main point is the overall trend: policy is moving from general support for storage to more targeted backing for LDES technologies. This change is crucial because a procurement system focused only on four-hour lithium-ion systems won't naturally foster the market conditions needed for truly long-duration technologies to demonstrate their value.

Nonetheless, policy gaps still exist. Interconnection queues remain slow. Cost recovery for innovative utility-owned assets can be contentious. Many integrated resource plans still model storage in a simplistic way. Organized markets continue to compensate short-duration flexibility more transparently than rare-event resilience. Therefore, the next policy phase must go beyond demonstration funding and tax incentives to include planning rules, procurement design, and valuation methods that acknowledge the unique role of long-duration energy storage.

U.S. policy is shifting to treat long-duration energy storage (LDES) as a core component of grid decarbonization, with strong federal support (e.g., DOE targets, tax incentives, and demonstration funding) improving its path toward commercial viability.





Despite progress, LDES still faces commercialization and market challenges, requiring better policy design in areas like procurement, planning, and valuation to fully enable large-scale deployment.

Market Structures Needed to Enable LDES

If policy enables LDES deployment, the market structure determines if it can be sustainable. This is where the current system falls short. The U.S. storage market has been shaped by rules that reward resources capable of earning revenue consistently, transparently, and through standardized products. That's precisely why four-hour lithium-ion systems have expanded. They can participate in energy arbitrage, ancillary services, and in some markets, capacity or resource adequacy measures that are reasonably clear to investors.

FERC Order No. 841 marked a major turning point because it required regional transmission organizations and independent system operators to remove barriers to electric storage participation in wholesale markets. This was a foundational step. Without it, storage would have remained confined to generation, load, and transmission categories, which could distort participation. However, Order 841 was technology-neutral; it broadly opened the door for storage, not specifically for LDES. The rule alone did not resolve the issue that the most valuable contributions of long-duration storage might occur infrequently and could be undercompensated if markets mainly emphasize daily spreads and routine ancillary services.

That is the main challenge in market design. A long-lasting asset might sit unused for long periods and still make economic sense if it provides insurance during rare system stress. However, revenue models based solely on energy or arbitrage often undervalue insurance. This creates a gap between social value and private earnings. Grid operators may need resources that can withstand a three-day renewable lull, but developers can only fund what markets are willing to pay for.

Several solutions are possible, and the most practical answer likely involves a combination of them. One is long-term procurement outside spot markets, especially by regulated utilities or central

buyers who can contract for clean firming and resilience attributes over ten to twenty years. Another is reforming capacity accreditation so that resources with long discharge durations receive credit that better reflects their contribution during stressed conditions. A third is developing new reliability products that are specifically tied to sustained availability rather than just rapid response. Planning reform also has a role. If integrated resource plans and ISO reliability studies begin to model multi-day risks more explicitly, the value of LDES will become more evident in procurement decisions even before wholesale market products evolve.

NREL's work on LDES valuation is particularly relevant because it highlights that system value heavily relies on modeling assumptions. If planners view storage solely as an arbitrage tool, they tend to undervalue long-duration systems. However, if they account for avoided curtailment, reduced loss-of-load risk, fuel-risk mitigation, delayed peaking investments, and clean-firming benefits, the economic outlook can change significantly.

Bankability is a key financial concept that increasingly dominates serious discussions on long-duration energy storage (LDES). The Long Duration Energy Storage Council's recent work on deployment and bankability shows what the market has learned: developers need more than just favorable technology stories. They require clear contracts, warranties, operational data, insurance structures, EPC frameworks, and creditworthy offtakers. An LDES project that cannot be underwritten will not scale, regardless of how compelling its theoretical role in decarbonization models may be. This is why the next phase of grid-scale storage innovation focuses as much on commercial structure as on engineering. The sector now has enough potential technologies to support serious market design efforts. The main bottleneck is shifting from "can it work" to "who will pay for it, when, and under what risk conditions."

> **Current electricity markets undervalue long-duration energy storage because they reward frequent, short-term revenue, while LDES provides value mainly during rare grid stress events. To make it viable, new market structures, better valuation methods, and strong financial frameworks are needed to ensure bankability and attract investment.**

How LDES Supports Reliability, Renewable Integration, and Seasonal Balancing

The strongest argument for long-duration energy storage isn't about new technology. It's about system function. LDES is important because there are specific grid issues that short-duration resources can't effectively address once variable renewable energy makes up a much larger share of the supply.

The first of these issues is renewable curtailment and temporal mismatch. Wind and solar energy often produce power when it is not most needed. Solar is the clearest example: strong midday generation can surpass local demand and push prices down, yet the system still faces sharp ramps and narrower margins after sunset. Four-hour batteries help address this, but as solar adoption grows, the problem's shape changes. There can be long periods of excess energy followed by similar stretches of shortages, especially when cloud cover and load patterns interact unfavorably. LDES can store surplus renewable energy over longer periods and release it later, reducing curtailment and making renewable power more useful to the system.

The second issue is extended weather-caused shortages. This is where multi-day grid storage becomes essential. A widespread high-pressure system can limit wind power over a large area for days. A winter storm can reduce generation, restrict fuel supply, disrupt transportation, and increase demand simultaneously. In these cases, a storage system designed only for daily cycling might not be sufficient. Long-duration systems can act as a reliability bridge, providing extra time for other resources and decreasing the need to hold large amounts of fossil backup for rare events.

The third issue is resilience. Reliability and resilience are not the same. Reliability refers to expected system performance under normal conditions. Resilience relates to the system's ability to withstand and recover from severe, unpredictable disruptions. LDES is relevant to resilience because duration acts as a form of insurance. A resource that can operate for many hours or days without fuel delivery is valuable when the threat extends beyond a typical peak day to include events like transmission outages, fuel shortages, wildfire risks, or other system stresses. That is why long-duration storage is increasingly considered not just for bulk power markets but also for microgrids, remote communities, military bases, and critical infrastructure.

The fourth and longest-horizon problem is seasonal balancing. This is the most debated use case because it pushes beyond what most current LDES projects are designed to do. Still, the concept is important. In deeply decarbonized systems, generation and load can vary not just hourly but seasonally. Some regions have abundant spring winds, strong summer solar, and challenging winter reliability conditions. Thermal demand and electrification can amplify these patterns. NREL and other researchers have noted that the value of very long-duration storage, including storage beyond twelve hours and seasonal storage, increases in scenarios with extremely high renewable penetration. That does not mean all seasonal balancing will be handled with batteries or storage tanks. It means the planning challenge eventually extends beyond intraday flexibility. LDES is part of the resource family that can help address that challenge.

The practical takeaway is that long-duration energy storage should be regarded primarily as a reliability and integration resource, with arbitrage potential being secondary. Its strategic importance lies in converting more renewable megawatt-hours into reliable service, minimizing exposure to rare yet severe stress events, and providing system planners an alternative to excessive short-duration battery overbuilding or extensive thermal standby. In a grid with limited renewable integration, these benefits may seem optional. However, in a grid aiming for deep decarbonization, avoiding these advantages becomes increasingly difficult.

Global Experience
and What It Means for the United States

The United States is not the only country facing the LDES challenge, and international progress offers valuable lessons. Japan has long been involved in flow battery deployment and grid support applications, especially where resilience and renewable integration intersect. Europe has explored liquid air energy storage, thermal storage, and industrial decarbonization methods that expand the concept of LDES beyond just electricity projects. China has heavily invested in both battery manufacturing and large-scale storage infrastructure, including advanced compressed-air systems, showing what rapid industrial scaling can look like when aligned with national strategy.

The key lesson for the United States isn't that a foreign model should be copied exactly. Power markets, regulations, and geography vary too much for that. The real takeaway is that countries making the fastest progress on LDES tend to do three things well. First, they align industrial policy with grid requirements. Second, they establish visible early markets through procurement or demonstration programs. Third, they consider storage duration as a planning factor rather than assuming all storage is interchangeable.

The Long Duration Energy Storage Council's annual report also emphasizes the need for standardized commercial practices, clear policies, and guidance for implementation. Global deployment will not rely on engineering alone. Instead, it depends on whether policymakers, utilities, developers, and financiers can agree on how to contract for and value long-duration performance.

For the United States, the opportunity for action is now. Waiting until renewable penetration becomes so high that multi-day reliability becomes a strict constraint will force the country to commercialize LDES under pressure. Acting earlier allows it to develop the technology, supply chain, and market institutions in a more controlled and efficient manner.

Conclusion

From Promising Option to Necessary Layer of the Future Grid

The long-duration energy storage debate has moved past being a speculative technology story. The U.S. power sector already knows how to deploy short-duration batteries at scale and will continue to do so. The more challenging question is what happens next as renewable energy use increases, clean-energy policies deepen, and expectations for reliability remain high.

The answer is not that every region requires the same LDES technology, nor that long-duration storage will immediately surpass lithium-ion on every metric. The real answer is that the grid is evolving to include a new class of operational needs that cannot be efficiently met with four-hour batteries alone. Multi-day grid storage, extended clean firming, resilience during prolonged stress, and seasonal balancing over time all lead to the same conclusion: the United States will need a mix of long-duration energy storage technologies if it aims to operate a highly renewable power system without relying solely on a parallel fossil backup structure.

That portfolio is beginning to take shape. Iron-air batteries may address very long electrochemical duration. Flow batteries may serve applications where cycle life and decoupled energy scaling matter. Mechanical systems such as CAES and LAES may prove attractive at large scale in the right locations. Thermal approaches may create lower-cost pathways where electricity and heat can be linked. Pumped hydro will remain a foundational reference point where geography and permitting allow. None will succeed at scale, however, unless policy support, market structures, and project finance evolve together.

The good news is that the institutional groundwork is finally being established. DOE has outlined a cost-reduction goal and a pathway for launch. Federal tax policy now more clearly considers storage as a viable form of clean-energy infrastructure investment. States like California are starting to explicitly procure long-duration and multi-day resources. Organized markets, although not fully aligned yet, have at least begun to open the door for storage participation through rules such as Order 841.

The task ahead is more about business and regulation than ideas. The sector must determine how to value long-lasting reliability, how to verify storage that is most useful during rare events, how to design offtake agreements for new technologies, and how to include LDES into transmission planning, integrated resource planning, and reliability evaluations. These are not minor issues. They are the real conditions under which long-duration energy storage will either become a lasting part of the U.S. electricity system or remain trapped in ongoing pilot programs.

The strategic case, however, is already clear. Long-duration energy storage is becoming one of the main renewable energy storage solutions for a grid that needs to be both cleaner and more reliable. In that sense, LDES is not just another technology category. It is part of the infrastructure of a power system that can support high levels of wind and solar without sacrificing dependability when the weather isn't cooperating.

References

01 **U.S. Department of Energy**
Pathways to Commercial Liftoff: Long Duration Energy Storage, Washington, DC, USA, Jul. 2023

02 **U.S. Department of Energy**
Achieving the Promise of Low-Cost Long Duration Energy Storage, Washington, DC, USA, Aug. 2024

03 **U.S. Department of Energy**
Charting the Path: An Energy Earthshots Initiative Report, Washington, DC, USA, Jan. 2025

04 **U.S. Energy Information Administration**
Solar, battery storage to lead new U.S. generating capacity additions in 2025, Today in Energy, Feb. 24, 2025

05 **U.S. Energy Information Administration**
Assumptions to the Annual Energy Outlook 2025: Electricity Market Module, Washington, DC, USA, Apr. 2025

06 **Federal Energy Regulatory Commission**
Electric Storage Participation in Markets Operated by Regional Transmission Organizations and Independent System Operators, Order No. 841, Feb. 15, 2018

07 **Internal Revenue Service**
Clean Electricity Investment Credit, Jan. 5, 2026

08 **California Public Utilities Commission**
CPUC Advances Clean Energy with Centralized Procurement Strategy, Aug. 26, 2024

09 **California Public Utilities Commission**
CPUC Advances Clean and Affordable Electricity with New Procurement Decision, Mar. 2, 2026

10 **National Renewable Energy Laboratory**
Storage Futures Study: Key Learnings for the Coming Decades, Golden, CO, USA, Jan. 2022

References

11
National Renewable Energy Laboratory
Benefit Analysis of Long-Duration Energy Storage in Power Systems, Golden, CO, USA, 2020

12
National Renewable Energy Laboratory
Exploring the Future Energy Value of Long-Duration Energy Storage, Golden, CO, USA, Mar. 2025

13
National Renewable Energy Laboratory
Long-Duration Energy Storage Grid Integration-Valuation Framework and Use Cases, Golden, CO, USA, 2025

14
International Energy Agency
Grid-Scale Storage, Paris, France, accessed Mar. 18, 2026

15
International Energy Agency
Global Battery Markets Are Growing Strongly and So Are the Supply Risks, Feb. 13, 2026

16
Long Duration Energy Storage Council
2024 LDES Annual Report, 2025

17
Long Duration Energy Storage Council
Accelerating LDES Bankability, Dec. 2025

18
Form Energy
Battery Technology, accessed Mar. 18, 2026

19
Sumitomo Electric Industries
The Role of Long Duration Energy Storage and Flow Batteries, accessed Mar. 18, 2026

About Vedeni Energy

VedeniEnergy

Vedeni Energy offers specialized services designed to help businesses navigate the complexities of the modern energy landscape. Our offerings are tailored to meet the unique needs of utilities, independent power producers, regulatory bodies, and other stakeholders, ensuring success through strategic insights, expert guidance, and innovative solutions.

Vedeni.Insights+

Vedeni.Insights+ is Vedeni Energy's subscription-based service, granting subscribers full access to Vedeni Energy's extensive library of whitepapers and in-depth technical analyses. These authoritative resources offer comprehensive examinations of the energy sector's critical topics, from market trends and regulatory changes to emerging technologies and strategic investment opportunities.

Vedeni.IQ+

Vedeni Energy's **Vedeni.IQ+** service provides actionable wholesale electric power market intelligence that enables clients to make informed decisions confidently. Our expert analysis and reporting distill complex energy market information into clear, concise insights, helping organizations elevate their market strategies, influence policy, and identify new opportunities.

Vedeni.Spark+

Vedeni.Spark+, a service provided by Vedeni Energy, is designed to help startups and established companies secure the capital funding necessary for growth and success. Our team of seasoned advisors works closely with clients to develop tailored funding strategies that align with their business goals and financial requirements.

TO LEARN MORE, VISIT US AT

WWW.VEDENI.ENERGY