The Tipping Point

How Long Duration Energy Storage Guarantees the Future Reliability of the Grid

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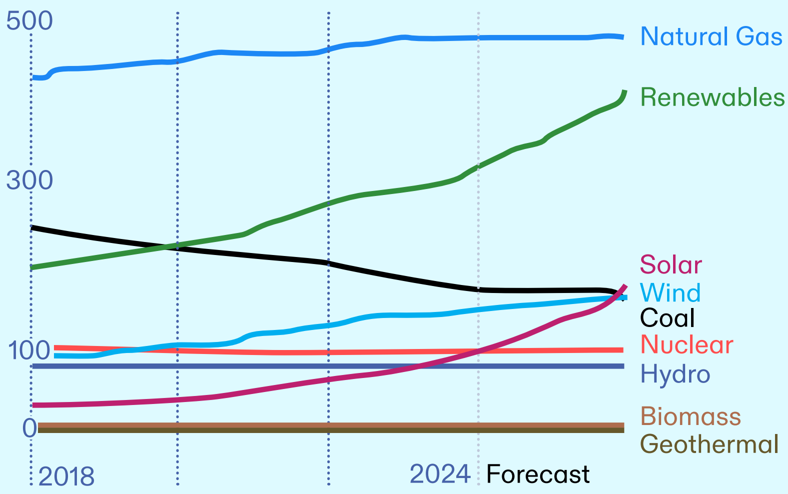
Intro

The energy systems that have powered the world's economies for over a century were built with a reliance on Earth's natural resources that has taken a massive toll on our environment.

The current—and very necessary—transition to renewable energy has flipped the script, pushing us to rely on cleaner and more sustainable, but intermittent, resources. For this transition to succeed, we need new ways to store those clean, intermittent resources and incorporate them into our rapidly changing energy system, meeting our 24/7 need for power, and ensuring we can maximize the contributions of these renewables to the grid. This is becoming an urgent challenge as renewables gain dominance.

The rise of renewables is decoupling energy generation from energy storage.

U.S. annual electric generating capacity (2018-2025), gigawatts at the end of December



The rapid growth of solar and wind power are a testament to the effectiveness of pro-renewable energy policies. To ensure the long-term stability of the grid, policymakers must now dedicate themselves to supporting the deployment of energy storage, particularly longer duration storage. [1]

In the United States, renewables are rapidly closing in on natural gas as the largest share of generating capacity—the tipping point where storage becomes essential for grid reliability. Some markets, like California, have already reached that tipping point. That's great news for decarbonization, and it's a testament to the impact of careful planning by policy makers. But to continue to ensure a stable, reliable, and resilient energy system, policy makers and other stakeholders need to accelerate the build-out of energy storage infrastructure that supports the continued growth of renewables—and they need to act now.

1. "Solar and wind to lead growth of U.S. power generation for the next two years" US Energy Information Administration Source)

1 The Renewable Revolution

Balancing Progress and Grid Stability

Renewable energy sources have been critical to advancing decarbonization—but they're also a significant challenge for the grid. Since the Industrial Revolution, our economy has been built on the predictable, baseload energy supplied by fossil fuels, and while renewables have innumerable benefits, their intermittency isn't well-matched for this foundation. Storage is key to maximizing renewables, enabling grid operators to store and use power that otherwise would have been curtailed. Without the ability to adequately store and dispatch energy as needed, energy grids will become unstable as intermittent renewables provide more electricity than fossil fuel assets. Many markets are already close to that tipping point, others will reach it in the coming years.

Renewable penetration continues to increase, driven primarily by declining costs and policy support through decarbonization and zero emissions goals. Even absent these policies, many fossil fuel assets are reaching the end of their useful lives or are being shut down for economic reasons. Today, it's no longer economically or environmentally feasible to build or refurbish gas or coal plants to meet retiring capacity in many regions. In fact, dispatchable fossil fuel generation represented 63 percent of global electricity generation capacity in 2020, but by 2050, the International

Renewable Energy Agency (IRENA) expects 90 percent of global generation will come from renewables. [2]

Further complicating an already dynamic story, the rapid push for electrification and the rise of hyper-scale data centers has upended a generation of flat energy demand. Meeting new electricity demand will require updates to many aspects of the grid, including a rapid increase in intermittent generation sources. This again has vastly increased the need for energy storage, which can allow intermittent renewables to serve as dispatchable, clean, firm power, enabling them to act as an alternative to current fossil-based baseload generation.

To ensure long-term stability of power grids, utilities, regulators, and large energy customers need to start planning now. The transition to a clean energy future requires more than just increasing renewable energy capacity—it demands comprehensive strategies that include robust energy storage solutions. For the past decade, this storage need has largely been met by battery power, though the limitations of these batteries are coming into clearer focus as the need for longer duration and more diverse sources of storage continues to increase.

The more renewables you add to the grid, the more storage you need to make up for their intermittency. For most grids, once you reach 40-50 percent of renewable electricity generation, you need longer storage durations to ensure reliability. Grid operators from California [3] to New York [4] to Ontario [5] have shown that

2. "Fast-Track Energy Transitions to Win the Race to Zero," IRENA (Source)

3. “Assessing the Value of Long-Duration Energy Storage in California,” California Energy Commission (Source)

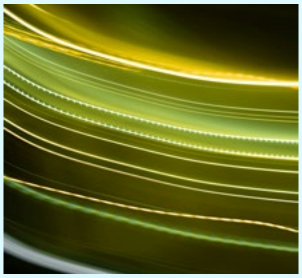
4. “New York’s 6 GW Energy Storage Roadmap: Policy Options for Continued Growth in Energy Storage,” NYSERDA (Source)

5. “Long-Term 2 RFP Stakeholder Engagement,” IESO (Source)

long duration, 8- to 10-hour, storage is the minimum duration that is needed to reliably replace fossil-fueled generation. This long duration energy storage (LDES) provides the flexibility and reliability to smooth out the intermittency of renewable sources and maintain grid stability.

2 Long Duration Energy Storage Technologies

The New Energy Infrastructure



In its simplest form, LDES uses chemical, thermal, electrochemical or mechanical mechanisms to store energy. LDES is typically defined as a technology with the capability to store energy for more than 8 hours, but many evolving technologies have the ability to store energy for even longer periods, up to and beyond 24 hours. This flexibility is important as market needs continue to evolve.

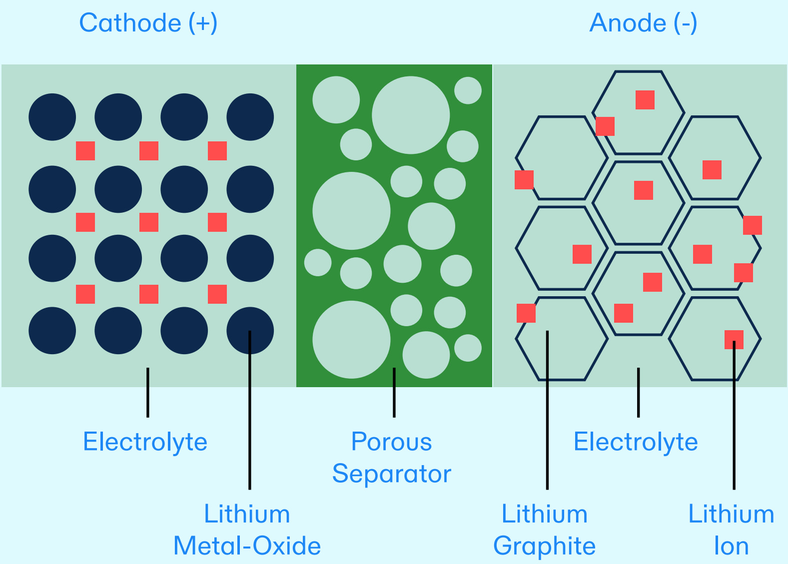
Many markets have begun to rely on battery power for energy storage. [6] But battery storage, while a key piece of the energy storage puzzle, has notable drawbacks. It's extremely resource-intensive, comes with significant supply chain and safety risks, and requires replacement roughly every 10 years due to the degrading nature of these assets. One of the most pressing problems with batteries, though, is that they're expensive for durations over six hours. [7]

6. "Batteries are a fast-growing secondary electricity source for the grid" U.S. Energy Information Administration, Today in Energy, Sept 5, 2004 (Source)

7. "Moving beyond 4-hour Li-ion batteries: Challenges and opportunities for long(er) duration energy storage" National Renewable Energy Labs. September, 2023. (Source)

Lithium-Ion Batteries

A growing solution with drawbacks

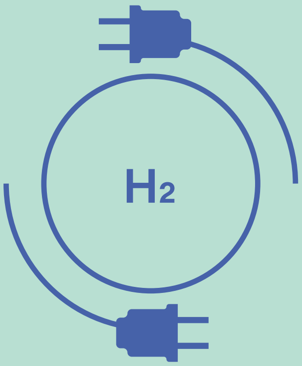


As of July 2024, the U.S. grid includes more than 20.7 GW of battery storage—up from just 4 megawatts (MW) in 2010. Batteries are critical to the energy transition, but with limited lifespan and a sweet-spot in arbitrage and short duration storage, they're just one piece in the puzzle. [8]

And with new and emerging LDES technologies coming onto the market, we have options other than batteries to meet our grid's evolving needs. These LDES technologies, along with batteries, will be an essential part of tomorrow's stable grid, and many of them provide their own benefits—like negligible degradation, limited safety concerns, and no emissions.

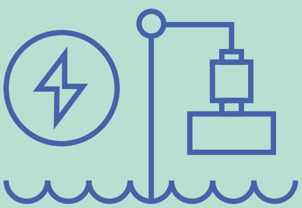
8. "Batteries are a fast-growing secondary electricity source for the grid" U.S. Energy Information Administration, Today in Energy, Sept 5, 2004 (Source)

Long Duration Energy Storage Technologies [9]



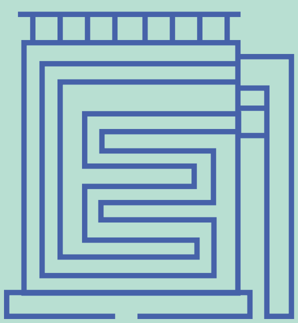
Chemical Fuels

These technologies use hydrogen or other chemicals to store energy within chemical bonds, creating high-density fuels. With the potential to feed stored energy back into the grid or support industrial or transportation applications, this strategy might become a major driver of decarbonization—once it reaches maturity.



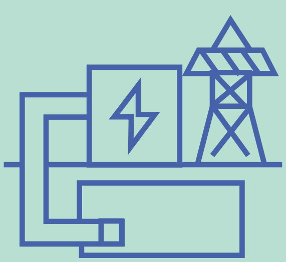
Electromechanical Batteries

These technologies include metal air and flow batteries, and can store up to 100 MW of energy. They store electricity through chemical reactions.



Thermal Energy Systems

Thermal energy storage (TES) converts excess electrical energy from the grid into thermal energy and stores it for later use. While TES is particularly important for industrial heating, it can also help balance supply and demand, potentially providing hundreds of hours of power at a relatively low cost.



Mechanical Energy Storage

These systems use water, heat, or air in combination with turbines, compressors, or other machinery to store excess energy from the grid. One such technology is Advanced Compressed Air Energy Storage (A-CAES). Mechanical LDES can store up to 1GW of power, or more.

9.
The LDES Council
(Source)

A-CAES, pioneered by Hydrostor, utilizes excess renewable energy to power a compressor that pumps air into purpose-built rock caverns deep underground. The compressed air is stored until there is a need to dispatch the system and generate electricity back on the grid. By capturing and reusing heat in the compression and release process and using hydrostatic compensation to maintain constant pressure, Hydrostor's A-CAES improves on proven compressed air energy storage technology.

Further, unlike pumped hydro, the more established mechanical storage approach, Hydrostor's A-CAES energy storage plants operate on a compact footprint and can be flexibly sited to deliver utility-scale renewable energy storage capacity of eight hours (or more). Because A-CAES relies on existing technology, supply chains and labor forces, these storage plants are compelling alternative to natural gas power plants, offering many of the same benefits to the grid, including rotational inertia.

How Hydrostor re-invented compressed air

1.
Compressed air energy storage has been around for decades. But it relied on existing salt caverns and required natural gas to heat turbines during discharge.

2.
Hydrostor's A-CAES uses a water head to maintain the system at constant pressure, which allows for the siting in hard rock vs. salt. A-CAES projects also store and re-use heat captured during compression, eliminating the need for an external fuel source (e.g. natural gas).

3.
The result is an 50+ year solution that can be sited where it is needed, bringing lasting stability to the grid.

3 Where is Long-Duration Energy Storage Needed?

The short answer? Everywhere.

While all markets are built differently, a few common themes have been the increasing penetration of renewables and the retirement of legacy fossil fuel plants driven either by decarbonization policies or economic factors. This has significantly increased the need for storage projects, both short and long duration. Incorporating energy storage helps maximize system efficiency by storing excess energy, much of which otherwise would be curtailed and wasted, for use later to help grid operators balance supply and demand on the grid.

In the best of circumstances, bringing these projects to fruition can take time. These are large energy development projects with complex permitting and financing. Adding to that timeline is the current maturity of an LDES industry in which many technologies are nascent, and most are still in the pilot phases, meaning finding investment alone can take years. Many carbon reduction targets aim for 2030, which means that even starting today may be too late to bring solutions online, and the need for storage is only going to continue to grow.

The time is now to prepare for inevitable energy storage needs. This is where proven, scalable solutions like Hydrostor's A-CAES stand out. With two advanced-stage projects in development, the 200 MW, 8hr Silver City Energy Storage Centre in Australia and the 500 MW, 8hr Willow Rock Energy Storage Center in California, Hydrostor already has a global pipeline of projects totaling over 7,000 MW of storage.

But there is more work to be done to meet rapid data-center and electrification-fueled load growth. Taken together with the ongoing energy transition, these pressures mean that soon many markets will reach their own tipping points, with more storage needed to maintain a stable grid in the United States and around the world. In April of 2024, the G7 countries highlighted the urgency of the situation, agreeing upon a 1500 GW global energy storage target for 2030, a six-fold increase of current capacity, and COP29 leaders hope to build consensus around that pledge at this year's gathering. [10]

California, long at the forefront of renewable energy adoption, has already reached its tipping point, with renewables making up more than 50 percent of the state's electricity generation. In order to stabilize the grid and meet its own ambitious decarbonization goals, the state is advancing policies that incentivize the buildout of energy storage infrastructure. California's leadership in this space is a model for other states and regions as they approach tipping points of their own.

10.
Murray, Cameron. "G7 nations set 1500GW global energy storage target for 2030" Energy Storage News, 1 May 2024
(Source)

Dickie, Gloria. "COP29 leaders unveil climate funding and energy storage goals" Reuters, 16 September 2024
(Source)

California's Forward Thinking

Long known for its leadership in renewables adoption, California created the nation's first Renewables Portfolio Standard in 2002 and has continued to push for more ambitious clean energy goals ever since. Not only did it exceed its 2020 target of 33 percent renewables—it achieved it three years early, in 2017. [11] The state's leadership has continued—in 2023, wind, solar, and hydropower grew to contribute 54 percent of the state's electricity generation, hitting the legislature's target to meet half of the state's demand from renewable sources seven years early. [12]

However, this means that 39 percent of the state's electricity demand is still met by natural gas, with a portion of the remainder provided by legacy nuclear units. In fact, to help meet these ambitious emissions reduction goals, California's Diablo Canyon nuclear power plant, a source of carbon-free energy that provides nearly 7 percent of the state's electricity supply, had its lifespan extended to 2030. [13]

California's demand issues, load growth, and eye toward the future made it an ideal early adopter of LDES. It's the first US state to issue a mid-term reliability (MTR) mandate requiring utilities to procure 1,000 MW of non-weather-dependent, zero-emission long-duration storage resources to increase grid reliability. [14] The state is also working to create additional near-term commercial pathways for LDES projects through the Reliable and Clean Power Procurement Program, and longer-term pathways by

11. "New Data Shows Growth in California's Clean Electricity Portfolio and Battery Storage Capacity," California Energy Commission (Source)

12. California State Profile and Energy Estimates, U.S. Energy Information Administration, 16 May 2024. (Source)

13. "CPUC Votes To Extend Life Of Diablo Canyon Nuclear Plant Through 2030," California Globe (Source)

14. "Fact Sheet: Decision Requiring Clean Energy Procurement for Mid-Term Reliability." California Public Utilities Commission (Source)

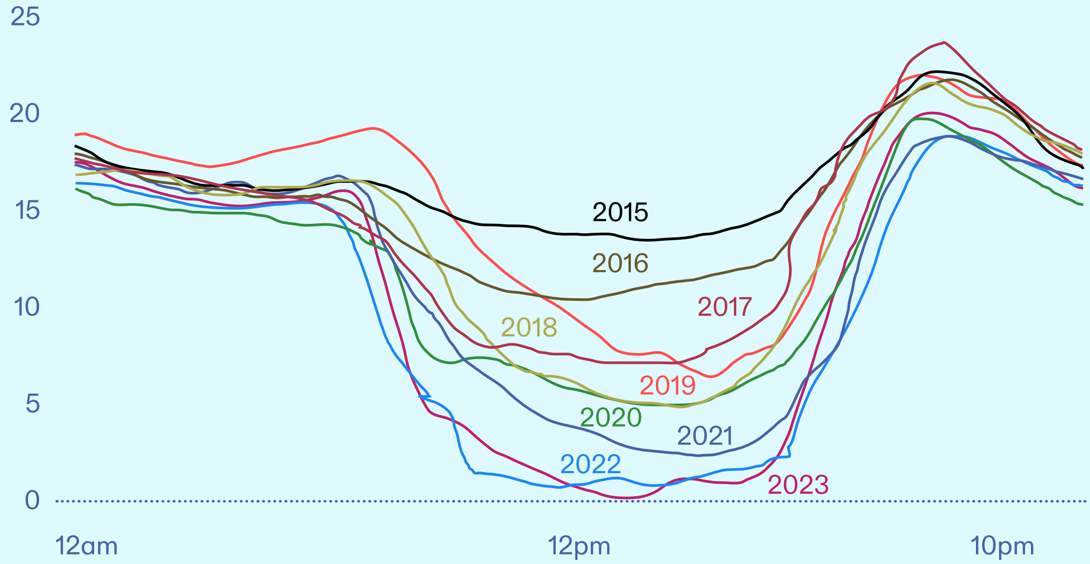
centrally procuring 12+ hour storage resources through the state Department of Water Resources. And there's likely much more to come—new data from the state's energy regulator suggests it could need up to 37GW of LDES resources to retire its remaining natural gas resources by 2045. [15]

The addition of LDES in California is crucial to smoothing out demand due to heavy renewables penetration. The "duck curve" illustrates this need by showing how the ideal renewable energy scenario—making use of energy during the day and producing it overnight—doesn't quite work with current available electricity generation supply and consumer demand. Solar energy production (the highest proportion of California's renewable generation, providing 28 percent of the state's electricity) is the highest, during the middle of the day—but when demand is peaking in the evening, solar is ramping down for the night.

15. California Energy Commission, "Assessing the Value of Long-Duration Energy Storage in California" December 2023 (Source)

California's duck curve is getting deepers [16]

CAISO lowest net load day each spring (March-May, 2015-2023), gigawatts



16. "As solar capacity grows, duck curves are getting deeper in California," US Energy Information Administration (Source)

LDES can store that excess solar energy from mid-day and distribute it when demand is peaking in the evening, smoothing out the duck curve and balancing supply with demand — particularly important when the weather is unpredicatable. This is why the California Public Utilities Commission has proposed that the state procure an additional 1GW of multi-day LDES as well as 1GW of 12-hours-plus LDES to bolster its energy resources. [17]

California's diversity and abundance of renewables—along with its commitment to LDES solutions—have made it a leader in achievable clean energy. But will other states follow?

As of July 28, 2024, California used 100% renewable energy sources to meet demand at some part of the day for the 100th day in a row. [18]

New York's Energy Storage Road Map

While California leads the way in renewable energy adoption, New York presents a compelling case study of how a state with a different climate, energy landscape, and economic structure is approaching the clean energy transition and LDES. New York similarly prioritized net-zero emissions targets, but with its cold climates still relies greatly on natural gas, but has a cold climate

17.
"California eyes central procurement of 2GW of LDES to help scale novel technologies," Energy Storage News (Source)

18.
"California reaches historic renewable energy milestone," Environment California (Source)

with a strong reliance on natural gas, which provides nearly half of its electricity. [19]

However, as of 2022, approximately 29 percent of the state's electricity comes from renewable sources, and it generates more power from renewable electricity than any other state east of the Mississippi River. [20] Most of that renewable energy comes from hydroelectric plants, which provide 21 percent of the state's power, but wind and solar are on the rise, each accounting for roughly four percent of the state's generation. [21]

New York's Climate Leadership and Community Protection Act, established in 2019, requires New York to achieve 100 percent carbon-free electricity by 2040, [22] and it's zero emissions roadmap includes an investment of $28 billion in renewables and transmission projects. [23] Though New York has an existing fleet of hydropower plants, which provide some of the most reliable renewable electricity in the world, to build a carbon-free grid the state will need to exponentially grow its wind and solar generation within the decade. Without storage to address the gaps in these intermittent energy sources, reliance on purely clean energy will be next to impossible.

New York state has recently begun to incorporate LDES into its clean-energy plans. Its 3 GW bulk energy storage procurement plan announced over the summer has carved out 20 percent, or 600 MW, for 8-hour storage resources. The same roadmap acknowledged New York will need more than 4 GW of 8-hour storage by 2035 and 6.8 GW by 2050. [24] These are positive

19.
"Renewable Electricity in New York State," OSC NY Gov (Source)

20, 21, 22.
"Profile Analysis," US EIA (Source)

23,24.
"Over $5 Million Announced For Long Duration Energy Storage Projects." NYSERDA. 12 June 2024.

signs for LDES development in New York moving forward, and as procurement awards are announced we'll soon see which LDES technologies are positioned for success in the Empire state.

Beginning as early as 2028, colder winters and gas shortages could threaten the reliability of New York's grid without more renewable energy sources and better storage capacity. [25]

The Path Forward

The energy system in the United States—and much of the world—is at an inflection point. The question is no longer whether we will transition away from fossil fuels. It's merely how fast and how disruptive that transition will be.

By understanding the role of LDES in our dynamic, renewable energy future, policy makers, regulatory bodies and other public- and private-sector stakeholders can take concrete action, right now, to encourage the development of this essential energy infrastructure.

The good news is that, as states like California and New York show, the right policies are already beginning to deliver results for the long-term stability of the grid. Just as importantly, companies like Hydrostor are proving that the LDES industry can meet the challenge—and the tipping point—head-on.

25.
"A Balanced Approach to a Clean and Reliable Grid," NY ISO (Source)

For more information about Hydrostor, visit hydrostor.ca