DEPLOYING LONG-DURATION ENERGY STORAGE IN VIRGINIA

C2ES CENTER FOR CLIMATE AND ENERGY SOLUTIONS

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Energy storage is crucial to enabling new clean energy to serve as firm, reliable electricity generation. Virginia has one of the largest state-level energy storage targets in the country, with a goal to deploy 3.1 GW of energy storage capacity by 2035—enough to power more than 2.3 million homes—and aims to procure 100 percent of its electricity from non-emitting sources by 2045.[1] As the state looks to grow its share of renewable energy, deploying energy storage—and particularly long-duration storage—can help to maximize the utilization of this energy while supporting grid reliability. This brief provides insights from a roundtable hosted in Richmond in June 2024 that explored the opportunity for long-duration storage in Virginia, and the associated market, regulatory, and technological challenges.

INTRODUCTION

REGIONAL ROUNDTABLES

Efforts to facilitate the transition to the low-carbon economy of the future are accelerating across all sectors of the economy. To chart a pathway to sustainable and long-term prosperity, communities must be able to leverage their unique strengths and capitalize on emerging economic opportunities while addressing barriers that are often poorly understood outside of their communities. To that end, the Center for Climate and Energy Solutions (C2ES) hosts regional roundtables that bring together local, state, and federal policymakers; businesses of all sizes; community organizations and nonprofits; academics and issue experts; trade associations; investors; economic development organizations; and others. These conversations are meant to elevate the perspectives of a diverse set of stakeholders who are deeply embedded in their communities and uniquely positioned to speak to the needs of their states and regions. They are also meant to create opportunities to integrate local perspectives into state and federal policy decisions and, importantly, identify concrete steps to better align the long-term vitality of these communities with the urgent task of reaching net-zero emissions economywide.

Our June 2024 roundtable, held in Richmond, Virginia, brought together more than 30 participants representing companies, industry groups, state and local government, nonprofits, academic experts, and others for a discussion focused on how long duration storage can help to support the build out of renewables and contribute to resource adequacy and reliability in the state. This brief summarizes key takeaways from the discussion and—building on insights from the event and other conversations with local stakeholders—provides C2ES recommendations meant to advance the deployment of long-duration energy storage in the state in a way that achieves both climate and economic development goals.

BOX 1: Long- vs. Short-Duration Energy Storage

Most energy storage today is short-duration energy storage (SDES), providing up to six hours of storage capacity. The current market is dominated by lithium-ion batteries, which generally provide up to four hours of storage capacity. However, a plethora of companies and new technologies are emerging to offer solutions to store energy in new kinds of systems and for significantly longer durations.

Long-duration energy storage (LDES) describes a system capable of storing energy and dispatching it for extended periods of time. Energy storage is often measured by the hours of usable storage that can be delivered to the grid at the power output of its maximum discharge rate.* It is important to note that usable storage is not a measure of how long the energy can be stored before it is used, rather it is the length of time a storage type can discharge at maximum output.

Most organizations, including the U.S. Department of Energy (DOE), consider the threshold for "long duration" to be 10 hours or greater.† Other organizations may focus the definition not on storage duration but on its ability to provide firm capacity and support grid resource adequacy, the use case that sets long-duration apart from short-duration storage in practicality.*

There are two main categories for long-duration energy storage:

- **"Inter-day"** storage provides 10–36 hours of energy, which can shift excess power produced at one point in the day to another point in the same day or the next day. For example, excess solar generated during the day can be stored to provide power at night.
- **"Multi-day"** storage provides 36–160 hours of energy, which can both shift energy produced at one point in the day to later in the week and serve as backup power in the event of an extended outage. For example, power generated during good weather can be stored to provide power through a winter storm, when solar or gas generation may be down for multiple days.

DOE projects that the U.S. grid will need 225–460 GW of LDES capacity by 2050 to support achieving a net-zero emission power sector.†

** Paul Denholm et al., The Challenge of Defining Long-Duration Energy Storage (Washington, D.C.: National Renewable Energy Laboratory, 2021), https://www.nrel.gov/docs/fy22osti/80583.pdf.*

† Katheryn Scott et al., Pathways to Commercial Liftoff: Long Duration Energy Storage (Washington, D.C.: U.S. Department of Energy, 2023), https://liftoff.energy.gov/wp-content/uploads/2023/03/20230320-Liftoff-LDES-vPUB.pdf.

KEY TAKEAWAYS FROM THE DISCUSSION

Throughout the discussion, participants shared optimism that Virginia could strategically deploy enough long-duration energy storage to meet its economic and clean energy goals. Alongside this optimism, several key themes emerged from the discussion.

First, there was broad agreement that LDES solutions can bolster clean energy deployment in Virginia, both demand-side and generation. Participants noted that as energy demand grows in the coming decades, LDES can help meet this demand while mitigating the strain this new demand could put on the grid. Additionally, participants pointed to the variable generation of many renewable energy technologies. They agreed that deploying LDES will be critical to managing the generation variability and maximizing the utilization of electricity resources.

Participants also agreed that successfully deploying LDES will require more comprehensive, far-reaching, and proactive efforts to educate policymakers, companies, and the general public about the nuances of LDES. Generally, people are less familiar with long-duration than short-duration storage, including its unique opportunities and challenges, available technologies, and potential physical impacts (i.e., projects' physical footprints, environmental impacts, and siting considerations) than they are with short-duration storage. By proactively educating communities, LDES developers can also help local-level decisionmakers better understand the unique use cases, opportunities, and potential impacts of LDES projects. Educating these decisionmakers would allow them to more productively ask questions and make determinations about potential projects.

Differentiating between storage types in policy and regulatory decisions is also a crucial prerequisite for successfully deploying LDES. The current policy, regulatory, and market environment is undifferentiated and does not fully capture the additional benefits of LDES compared to shorter-duration technologies, such as supporting resource adequacy, grid reliability, and resilience . Because the current market largely values the base value of electricity sent to the grid and ignores the ancillary benefits of LDES, short-duration storage technologies are more cost effective. Differentiating between the two types can allow LDES to flourish where these benefits are most additive. Roundtable participants called on policymakers to more clearly differentiate between long- and short-duration storage in incentives, procurement targets, and other policies. They also would encourage regulators to consider LDES' full range of benefits into their planning.

Finally, participants highlighted the importance of authentic, comprehensive, and transparent community engagement around new projects. Some communities in Virginia have obstructed new clean energy development—particularly utility-scale solar projects—because of their opposition to the proposed projects' physical footprints, including its ecological and aesthetic impacts. Community engagement for LDES projects should create a forum for communities' questions, concerns, and needs, while demonstrating accountability to communities directly; one example raised in the roundtable was a binding action like a formal community benefits agreement.

POLICY RECOMMENDATIONS

Educate businesses, policymakers, and communities about LDES technologies and use cases.

- **DOE's Office of Energy Efficiency & Renewable Energy** should include messaging on LDES as one of its "emerging clean energy strategies" through the Clean Energy to Communities program administered by the National Renewable Energy Laboratory.[2]
- **Utilities, regional transmission organizations (RTOs)/independent system operators (ISOs), consultants, energy modelers**, and indirectly, **solution providers** should educate utility commissioners on the full value of long-duration energy storage resources outside their value as a capacity resource, by providing them with a report of use cases and examples of successful LDES demonstrations and deployments. This report could be modeled after the Virginia Energy Storage Task Force's Final Report published in 2021.[3]
- **The Virginia Department of Energy** should conduct a study on the education gaps among policymakers, companies, workers, and the general public, including: potential use cases; economic impacts; and geographic limitations of long-duration energy storage in the state.
  - Informed by the study's results, **Virginia Energy** should create an independent organization, modeled after the Virginia Nuclear Energy Consortium, to address public awareness gaps and serve as an educational resource on LDES in the state.
  - This independent organization could also provide guidance to counties on the development of ordinances relating to energy storage to support standardization across the state.

Engage communities proactively, transparently, and comprehensively

- **Local governments** interested in deploying long-duration energy storage should host collaborative sessions with stakeholder groups to identify their needs, concerns, and interests in the technology, which can help inform permitting decisions and project development processes.

Value the benefits of long duration energy storage in policy incentives and markets.

- **States setting energy storage procurement/portfolio requirements** should differentiate between short-and-long duration energy storage.
- **States procuring renewable electricity** like offshore wind should procure storage in parallel to support grid reliability as the share of renewable energy increases. Before issuing a request for proposals, the state should conduct a commensurate study to determine the type of storage and timing of deployment to identify the most cost-effective solution.

INTRODUCTION TO LONG-DURATION ENERGY STORAGE

WHAT IS LDES?

Because "long-duration" energy storage can encompass storage capacities ranging from inter-day to multi-day, a wide variety of different technologies and configurations fall under this designation (See **Box 1**). There are four main categories of LDES technologies: mechanical, thermal, electrochemical, and chemical:

- **Mechanical storage** technologies use kinetic or gravitational forces to store and discharge energy. Examples of mechanical storage technologies include pumped hydroelectric power, compressed air, gravity-based storage, liquid air, and liquid carbon dioxide. Mechanical storage provides inter-day storage and can discharge up to 15–25 hours. Many of these technologies can also be used for short-duration storage (less than 10 hours).[4]
- **Thermal storage** technologies use high heat to store energy that can later be used either as heat or to generate electricity. Examples of thermal storage include "sensible heat" like molten salt, rock material, and concrete; "latent heat" like aluminum alloy; and "thermochemical heat" like silica gel. Thermal storage can be used for inter-day or multi-day storage, and can discharge 10-200 hours.[5]
- **Electrochemical storage** technologies use chemical processes to store and discharge energy. Examples of electrochemical storage technologies include aqueous electrolyte flow and metal flow batteries. Electrochemical storage can be classified as inter-day or multi-day, and can discharge 8+ hours.[6]
- **Chemical storage** technologies convert electricity into energy-carrying chemicals such as hydrogen, which can be stored and/or transported as fuel and used to produce electricity at a later time or in a different location. Chemical storage is sometimes considered "seasonal storage" as it can shift energy produced in one season to use in another.[7]

This brief will focus on mechanical, thermal, and electrochemical storage technologies, which include bespoke technologies designed for long-duration energy storage as their primary purpose. Chemical technologies can be used for LDES applications, but may also or alternatively be deployed to transport energy over distance or convert electricity to a dispatchable fuel for mobile applications. For this reason, this discussion did not include chemical storage technologies as including it would have introduced additional, tangential variables. **Figure 1** represents the different types of storage technologies, their nominal durations, costs, and minimum deployment sizes.

FIGURE 1: Groupings of LDES Technologies

Duration	Energy Storage Form	Technology	Nominal duration (hr)	Min. deployment size (MW)
Inter-day	Mechanical	Traditional pumped hydro (PSH)	0–15	200–400
		Novel pumped hydro (PSH)	0–15	10–100
		Gravity-based	0–15	20–1000
		Compressed air (CAES)	6–24	200–500
		Liquid air (LAES)	10–25	50–100
		Liquid CO2	4–24	10–500
	Electrochemical	Aqueous electrolyte flow batteries	8–16	10–100
		Hybrid flow battery, with liquid electrolyte and metal anode	8+	>100
Multi-day/ week	Thermal	Sensible heat (e.g., molten salts, rock material, concrete)	10–200	10–500
		Latent heat (e.g., aluminum alloy)	25–100	10–100
		Thermochemical heat (e.g., zeolites, silica gel)	XX	XX
	Electrochemical	Metal anode batteries	50–200	10–100

Inter-day   Multi-day/week   Less Desirable   More Desirable

A selection of LDES technologies grouped based on physical characteristics and stages of development.

Note: Current commercial hybrid flow batteries offer 8–12 hours of storage.

Source: U.S. Department of Energy, 2023; Conversations with roundtable participants.

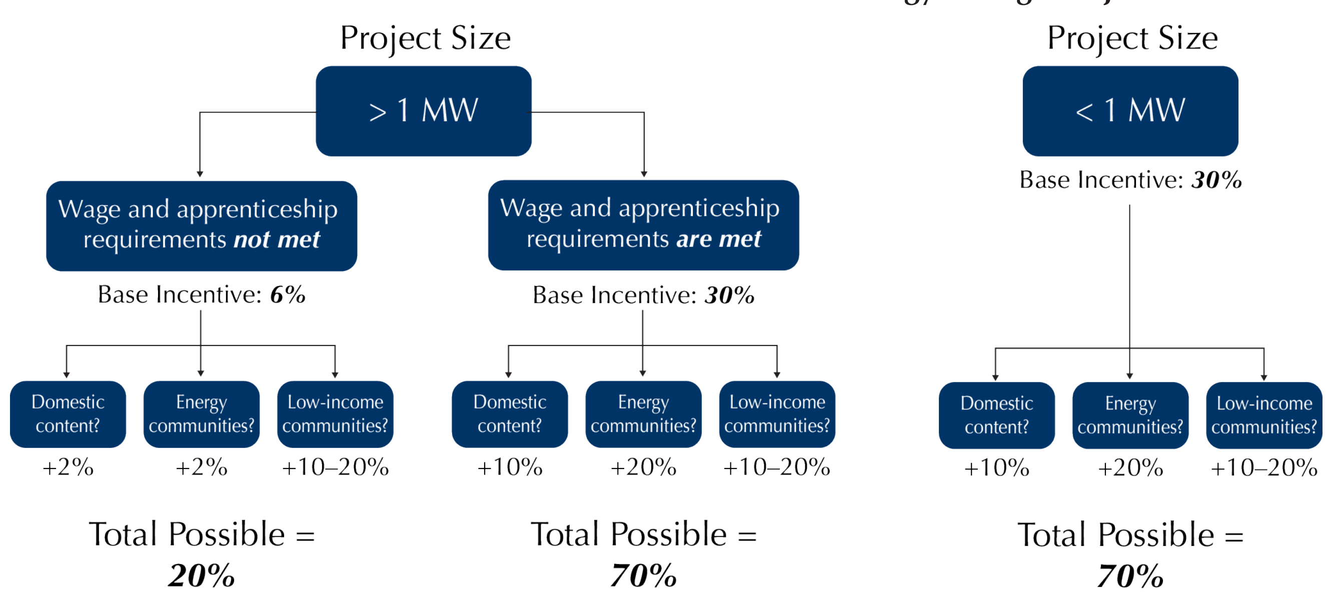
In comparison to lithium-ion batteries, the most prevalent short-duration storage technology, many LDES technologies do not use large quantities of critical materials like lithium, which are reliant on foreign supply chains.[8] Rather, many LDES technologies utilize domestically available materials like iron, zinc, and salt. However, electrochemical or mechanical LDES technologies may require more acreage than present day lithium-ion battery technologies based on their different energy densities or mechanical operations.[9]

The U.S. federal energy storage landscape

The Inflation Reduction Act of 2022 (IRA) includes several provisions that incentivize energy storage installation. The IRA's Section 48E clean energy investment tax credit (ITC) includes eligibility for standalone energy storage assets.[10] Prior to the IRA, energy storage technologies had to be paired with renewable generation to be eligible for the ITC. If wage and apprenticeship requirements are met, grid-scale energy storage projects can receive a credit of up to 30 percent of their eligible project costs and can receive bonus credits of up to 70 percent.[11] These bonus credits help amplify the benefits of energy storage technologies to local economies by incentivizing (1) projects that meet domestic manufacturing requirements, (2) projects that are sited in energy communities, and (3) projects that are located in low-income communities or on tribal lands.[12] **Figure 2** shows a breakdown of the IRA Section 48E tax credits and bonuses for energy storage projects.

The Infrastructure Investment and Jobs Act (IIJA, or Bipartisan Infrastructure Law) allocated $505 million for long duration energy storage projects through DOE's Office of Clean Energy Demonstrations (OCED) Long Duration Energy Storage Pilot program and Long Duration Energy Storage Demonstrations Program, as well as the DOE/Department of Defense Long Duration Energy Storage Joint Program to support the development and utilization of LDES technologies. [13] Over the past few years, OCED has leveraged this funding to help progress the DOE's Long Duration Storage Shot goal of reducing the cost of LDES by 2030.[14] Fifteen projects across 17 states and one tribal nation received up to $325 million in September 2023 to fund LDES demonstration projects.[15] In July 2024, OCED issued a notice of intent to provide up to $100 million in funding for pilot-scale energy storage demonstration projects, specifically prioritizing non-lithium technologies and LDES systems.[16] This investment aims to bolster the development of diverse LDES technologies and advance them toward commercial viability and, ultimately, utility-scale deployment.[17]

FIGURE 2: IRA 48E Investment Tax Credits and Bonuses for Energy Storage Projects



Source: Inflation Reduction Act of 2022, Pub. L. No. 117-169 §40007. https://www.congress.gov/117/plaws/publ169/PLAW-117publ169.pdf.

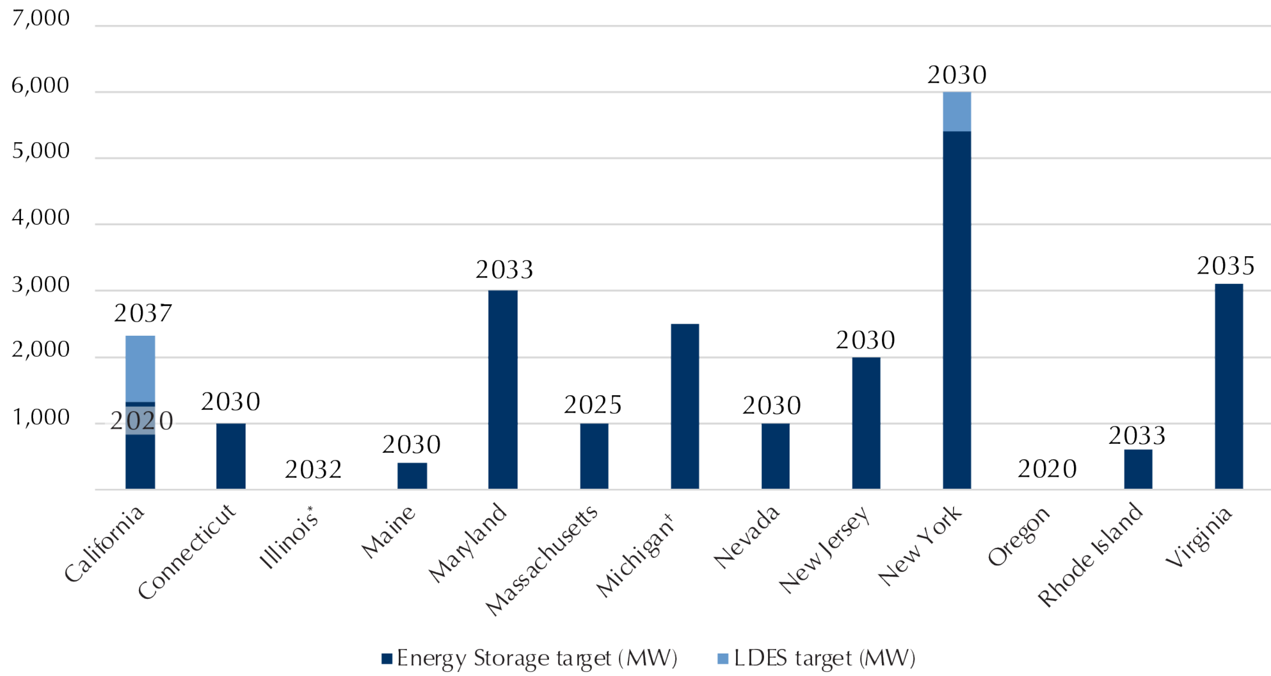
State-level energy storage landscape

Virginia has a statutory energy storage procurement target of 3.1 GW by 2035, one of the largest state-level storage procurement targets in the country, and second only to New York.[18] A total of twelve states have direct storage procurement targets (see **Figure 3**), and Illinois has a law requiring utilities to establish their own targets by 2032. Only California's and New York's targets specifically mention long-duration storage, with New York requiring 20 percent of each of three 100-MW bulk storage procurements be for 8-hour storage, and California requiring up to 1 GW of 12-hour storage by 2037.[19]

In addition to procurement targets, some states offer demonstration and deployment funding, regulatory adjustments to accommodate the integration of energy storage, or financial incentives. Other states have begun LDES-specific studies. For example:

- California's Long Duration Energy Storage program invests up to $330 million for the demonstration of "non-Lithium-ion" energy storage and LDES systems across the state.[20]
- New York's Renewable Optimization and Energy Storage Innovation Program has offered more than $20 million in funding for LDES projects with durations of 10–100 hours.[21]
- Maine's Act Relating to Energy Storage and the States Energy Goals (LD 1850) directed the Governor's Energy Office to study potential LDES solutions for Maine. The report was published in early 2024.[22]
- Massachusetts' 2022 Climate Act authorized a study on mid- and long- duration storage technologies, including a market overview, its potential benefit to ratepayers, and its contribution to the Commonwealth's net-zero strategy. The report was released in late 2023.[23]
- Until 2023, New Jersey offered a financial incentive for energy storage systems integrated with renewable energy projects installed behind the meter.[24]

FIGURE 3: Energy storage procurement requirements by state



* Illinois does not have a set procurement target but does require the Illinois Commerce Commission to establish storage procurement targets for utilities serving more than 200,000 customers to achieve by 2032.

† Michigan has not set a target deadline, but requires utilities to submit a plan for how they will meet their portion of the energy storage target to the Michigan Public Service Commission by December 31, 2029.

Sources available in Figure Endnotes.[1]

BENEFITS OF DEPLOYING LDES

Energy storage is a crucial element of the transition to a net-zero power sector, as it enables intermittent renewable generation to serve more as firm, dispatchable assets. Long-duration energy storage, particularly at durations greater than 10–20 hours, offers additional benefits to the grid. These benefits include bolstering resource adequacy, reducing transmission congestion, enhancing resilience to extended extreme weather events, and utilizing a domestic supply chain.

Maximize Utilization of Intermittent Renewable Generation

In grid regions with high shares of renewable generation, such as California (CAISO) and Texas (ERCOT), rates of curtailment—i.e., when a resource produces more electricity than the grid is able to accept due to either high supply or low demand, and the output must be deliberately reduced—are significant.[25] In the PJM region, which serves 13 states including all of Virginia, curtailment rates have not yet reached the same levels due to lower shares of renewable generation. Still, curtailment rates for wind generation were between 1–5 percent of monthly generation in 2017–22.[26] Deploying energy storage can store the excess electricity generated that would otherwise have been curtailed, and discharge it at a later time when there is reduced supply of renewable electricity.

The DOE's Pathways to Commercial Liftoff: Long Duration Energy Storage Report projected costs and needed infrastructure across three different scenarios to reach net-zero emissions from the U.S. electricity sector by 2050.[27] The report found that pathways that deploy LDES are $10–20 billion cheaper than those that do not, based on system savings in operating costs from reduced renewable curtailment and fuel spend, as well as reduced capital investment for dispatchable firm generation.[28] It also identifies that LDES, to a greater extent than SDES, can reduce the need to over-build renewables to meet the same resource adequacy requirements, because it provides more firm generation on the grid for longer periods.[29]

PJM projects its region will retire 40 GW of coal, oil, and natural gas generation by 2030, while bringing online more than 45 GW of solar and more than 32 GW of onshore and offshore wind.[30] To support resource adequacy while accelerating deployment of clean energy, PJM projects the region will need 6.4–27.4 GW of energy storage capacity to support a 95 percent carbon-free grid by 2035.[31] Making more of this energy storage capacity long-duration storage could help to reduce the necessary additional renewable capacity.

As the share of intermittent renewable generation from sources like solar and wind increases, utility-scale energy storage resources are necessary to smooth peaks and reduce strain on the grid. For example, solar electricity generated during the day can be stored and discharged at night when there is no solar generation, or excess wind electricity generated in the middle of the day during a period of relatively lower demand can be shifted to discharge in the late afternoon, commensurate with high demand. Similarly, small-scale energy storage systems can be installed in homes and businesses to extend rooftop solar resources and/or to provide backup power in the event of an outage, often replacing gas or diesel generators.

An advantage of deploying LDES is its flexibility—many technologies can be used both as short-duration and long-duration assets, providing many of the services 2–4 hour storage solutions can provide in the interim between discharging extended durations of charge. Additionally, greater storage capacity may allow the battery to cycle significantly less frequently than a SDES battery, allowing it to last longer and maintain performance with less maintenance.[32]

Bolster Resource Adequacy

Resource adequacy is the ability of the grid to meet the electricity needs of all end-use customers at all times.[33] As intermittent electricity generation increases relative to firm generation, grid operators may rely increasingly on storage solutions to ensure power is dispatchable all hours of the day.[34] Storage with durations longer than 10 hours can meet a longer generation shortfall and therefore may be more useful to grid operators. DOE estimates that the resource adequacy benefits of LDES are "roughly equivalent to an additional $50–75 per kW per year by 2030 when considering other potential energy market payments."[35]

Some states are exploring the opportunity for energy storage to offset capacity losses from retiring generation assets, particularly "peaking" resources that help support the grid in times of high-demand. For example, power plant operator Talen Energy has proposed building at least 600-MW of battery storage on the site of its retiring coal-fired power plant near Baltimore, Maryland.[36] PJM has raised concerns that the proposed battery project would not be sufficient to replace the generation and resource adequacy benefits the coal-fired plants originally supported, and despite relatively faster construction times, would not be able to be constructed in time to make up for the shortfall when the coal-fired power plant retires. These concerns raise an important point that while LDES can help to spread generation over long time periods, storage alone cannot replace lost generation. Therefore, additional generation capacity must be deployed alongside storage to meet demand. However, other power plant operators may explore similar opportunities for energy storage to support resource adequacy when generation assets are retired and additional renewable generation assets are planned.

Reduce Transmission Congestion

Rising electricity demand and/or growing generation can put pressure on existing transmission infrastructure, exacerbating congestion in the network.[37] Energy storage can be deployed to alleviate some of this congestion by storing power when congestion is high and disbursing power when congestion is relatively low, potentially reducing the need to build new transmission infrastructure.[38] Similarly, as more large, utility-scale renewable generation is constructed, existing transmission capacity may not be sufficient to bring power generated in more remote or rural areas to dense population centers. LDES assets can help to alleviate that strain over longer time periods.[39] Roundtable participants highlighted the reduced permitting and construction timelines of energy storage projects compared to new transmission infrastructure, making it possible for LDES to serve as a more expedient solution in particularly strained areas of the grid.

Enhance Resilience to Extended Extreme Weather Events

Extreme weather events like winter storms in southern states and heat waves across the United States have highlighted the need for enhanced grid resilience. In 2021, Texas experienced an unprecedented spell of extreme cold temperatures that lasted for almost three days, which both caused a spike in demand for electricity to power home heating systems while significantly reducing supply as the storm caused 49 percent of the generation fleet to go offline.[40] Short-duration storage solutions would have been helpful, but would not have been able to provide power for the 71 hours of the event. Eventually, multi-day storage solutions will be needed to help fill supply gaps in extended extreme weather outages, especially for critical infrastructure like hospitals and community resilience centers. Additionally, deploying non-lithium storage solutions can help to compensate for the reduced performance of lithium-ion batteries in the cold.

On the other extreme, extended summer heat waves can produce similar strain on electricity supply, as air conditioning and cooling systems spike demand. Long-duration storage can help to provide support to the grid when demand remains high over several days in a row and there is limited capacity to recharge 2–4 hour batteries. California has installed more than 10 GW of energy storage since 2020, which helped to mitigate the strain on the grid during the 2024 heat wave.[41] An extended heat wave in the summer of 2024, which began shortly after the June roundtable event and spread across most of the United States, brought attention to the risks that are only increasing as the global climate grows hotter.[42] For example, Richmond, Virginia, is projected to experience 45 days per year over 95 degrees Fahrenheit by 2041, up from 11 days per year today, with up to 20 extended heat waves (i.e., periods of 3 days or more over 95 degrees) expected each year.[43]

Utilize a Domestic Supply Chain

Currently, lithium-ion batteries are the main technology used for short-duration energy storage. One criticism leveled against lithium-ion batteries for energy storage, electric vehicle, and consumer electronics applications is the need to source critical materials like lithium and cobalt from foreign mines and processing facilities. While Congress recently enacted changes to the tax code to incentivize onshoring the mining, refining, and processing segments of the battery supply chain, there remains very limited capacity in the United States.[44] For this reason, non-lithium energy storage solutions present an opportunity to utilize abundant domestic resources and existing supply chains for materials like zinc, iron, and coal ash—or other reusable waste products—to build electrochemical and mechanical storage components.[45]

FRAMING THE LDES DISCUSSION IN VIRGINIA

THE VIRGINIA CLEAN ECONOMY ACT

In 2020, Virginia passed the Virginia Clean Economy Act (VCEA), which required the Virginia Department of Energy (Virginia Energy), the State Corporation Commission (SCC), and the Council on Environmental Justice, among others, to produce recommendations on how to reach 100 percent carbon-free electricity generation by 2045 at the least cost to ratepayers.[46] The law mandates that utilities Dominion Energy and Appalachian Power Company supply 30 percent of their power from renewables by 2030, and to close all carbon-emitting power plants by 2045 (Dominion) or 2050 (Appalachian).[47]

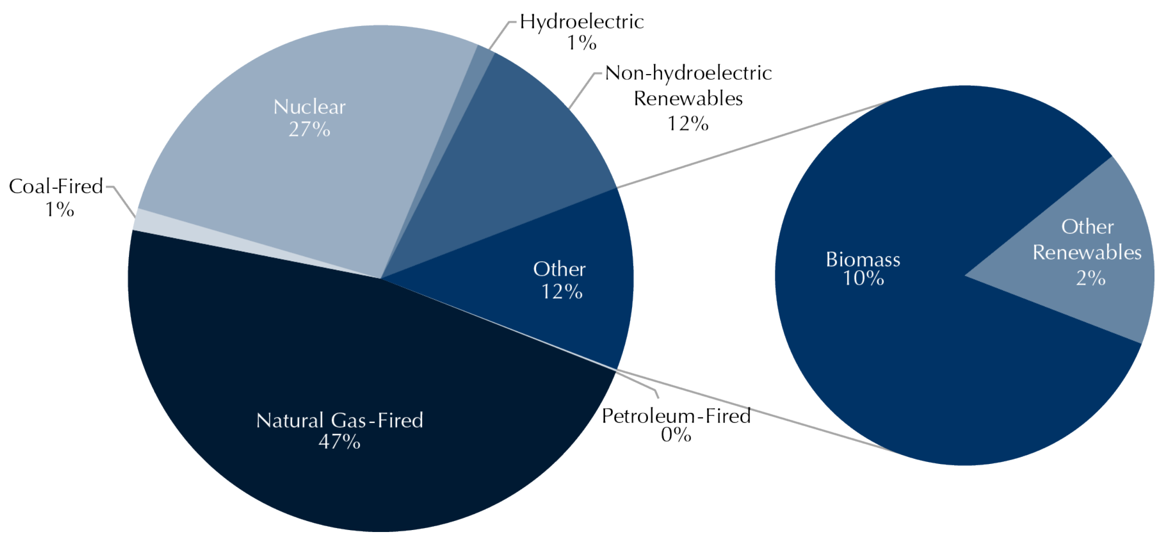
The VCEA sets statutory requirements for energy storage deployment that incrementally increase beginning in 2021 to reach 3,100 MW by 2035.[48] After New York, this is the largest energy storage portfolio requirement of any U.S. state.[49] Under the law, Dominion Energy and Appalachian Power Company are required to procure 2.7 GW and 400 MW, respectively, of storage. The utilities are also required to include energy storage plans in their integrated resource plans, but the act does not specify the duration of storage.

Additionally, the VCEA states that a single storage system may only count for up to 25 percent of deployment target in a given year and that 10 percent of interim storage targets must be realized through distribution-connected systems. It also requires the inclusion of an energy storage plan in electric utility's integrated resource plan containing a description of the utility's progress and plan to meet the target.

CLEAN ENERGY AND ENERGY STORAGE IN VIRGINIA

Virginia's electricity mix is dominated by natural gas and nuclear, making up 62 percent and 28 percent of net generation, respectively.[50] **Figure 4** shows Virginia's net electricity generation as of April 2024. Currently, non-hydroelectric renewables (i.e., solar and biomass) make up 13 percent of net generation, although, as the 2.6 GW Coastal Virginia Offshore Wind project comes online in the second half of the decade, offshore wind will make up a significant portion of the state's renewable generation.[51] As the share of intermittent solar and wind grows in Virginia's energy mix, it will become increasingly necessary for the state to consider how deploying storage, and particularly long-duration storage, can help to smooth out the peaks and valleys of electricity supply, while ensuring those energy sources can be integrated to their greatest potential.

FIGURE 4: Virginia's Electricity Mix: Net Generation



Source: U.S. Energy Information Administration, "Virginia Net Electricity Generation by Source Apr. 2024," accessed August 1, 2024.

Virginia currently has one pumped storage hydropower system, the Bath County Pumped Storage station.[52] This technology uses two bodies of water at different elevations to pump water upstream to store potential energy, which can be discharged through a hydroelectric generator. The Bath County station is the largest power plant by capacity in Virginia at 3 GW and is the largest pumped-storage hydroelectric plant in the United States.[53] Pumped storage hydropower uses a very large land area, and is therefore geographically constrained to areas with the necessary natural resources. Creating new projects can have significant impact on the local environment and communities.[54]

Virginia also has several operational lithium-ion energy storage projects. In addition to several small-scale projects, Dominion Energy operates the 20-MW Dry Bridge energy storage facility in Chesterfield County and is building a 50-MW project at Dulles Airport.[55] In May 2024, Appalachian Power Company released a request for proposals for up to 800 MW of wind and/or solar resources, which specifically includes co-located and standalone battery storage systems.[56] In total, the state has 30.5 MW of installed capacity of utility-scale short-duration energy storage, with 110 MW of capacity in the pipeline as of July 2024, according to the U.S. Energy Information Administration.[57]

OPPORTUNITIES FOR LDES IN VIRGINIA

GROWING ELECTRICITY SUPPLY: OFFSHORE WIND AND SOLAR DEPLOYMENT

The supply of intermittent renewable generation in Virginia is growing. Utility-scale solar accounts for the largest portion of the state's renewable portfolio, making up around 6 percent of the state's electricity generation in 2024.[58] Since the passage of the VCEA in 2020, the state has more than tripled its utility-scale solar installations.[59] Additionally, Dominion Energy plans to bring the 2.6-GW Coastal Virginia Offshore Wind (CVOW) project online at the end of the decade, which will contribute another 2–3 percent of the state's total energy production.[60] With the growing supply of intermittent renewable energy, storage capacity will be needed to maximize the utilization of this energy and smooth peaks and valleys in supply and demand.

GROWING ELECTRICITY DEMAND: DATA CENTERS

Virginia is home to 70 percent of the world's data centers, which make up a significant portion of the state's energy demand.[61] On average, individual installations demand 20–50 MW of electricity, although with the rapid scaling and proliferation of artificial intelligence (AI), new data centers built for AI computing could require ten times that capacity.[62] By the end of 2024, Dominion Energy projects there will be 109 data centers operating in Virginia, which will account for almost a quarter of the utility's annual electricity sales.[63]

Roundtable participants emphasized the opportunity to help address this new demand with long-duration energy storage projects. They highlighted that LDES solutions could reduce transmission congestion, provide backup power, and help data center operators maximize their utilization of onsite renewable capacity.[64]

THE WORKFORCE OPPORTUNITY

In addition to utilizing a domestic supply chain, building out LDES in Virginia and across the United States presents an opportunity to boost the local workforce. DOE estimates that scaling up LDES over 30 years to meet mid-century targets will create 1.5–2.1 million job-years nationwide, with most work falling to skilled engineers and construction workers.[65] However, DOE cautions that without significant investment in workforce development, including through on-the-job training and registered apprenticeship programs, the U.S. workforce will not be prepared to accelerate this buildout.[66]

Roundtable participants were optimistic about the workforce opportunity for Virginia and the surrounding region of building out LDES components and projects, particularly in the near term. They cited Form Energy's manufacturing facility, currently under construction on the site of a former steel plant in Weirton, West Virginia.[67] In the construction phase, the company said it employed 100 Form workers and more than 500 contractors onsite daily.[68]

Universities like Virginia Tech and the University of Virginia offer highly-ranked engineering programs, creating a potential pipeline for LDES project design and development.[69] State programs like Virginia Energy's Abandon Mine Land Economic Revitalization Program could support LDES projects developed on former mine lands while uplifting local communities.[70] Additionally, the Virginia Energy Workforce Consortium (VEWC) engages utilities, energy companies, labor unions, industry associations, educational institutions, the public workforce system, and government agencies to train and place energy industry workers to fulfill the state's labor needs.[71] Working together, these leading programs could help Virginia's workers take advantage of the LDES opportunity, while ensuring project developers and utilities have the workforce they need to construct, operate and maintain these assets in the years to come.

BARRIERS TO THE DEPLOYMENT OF LDES IN VIRGINIA

Most electrochemical and mechanical LDES technologies are relatively new to the market. There are several long-duration storage technologies in the early stages of commercialization, with technologies like sodium-ion batteries and compressed air energy storage systems ready for commercial deployment. However, individual projects utilizing these technologies are limited to small-scale installations—on the order of tens of Megawatts—making widespread adoption seem many years away.[72] Many developers and municipalities are focused on incorporating shorter duration lithium-ion battery projects, rather than investing in longer-duration technologies that may better serve their energy storage needs in the future. While LDES technologies offer promising opportunities to help integrate renewable electricity onto the grid, there are several barriers to the adoption of these technologies, which participants highlighted in the roundtable.

A NASCENT TECHNOLOGY WITH KNOWLEDGE GAPS

A common thread connects conversations with LDES technology developers and energy market experts: there is a general lack of understanding of what constitutes long-duration energy storage and the ultimate value it can provide to an energy market. Stakeholders at all levels—industry representatives, policymakers, regulators, community members, or private sector companies—require significantly more education on the technologies, opportunities, and potential impacts (e.g., physical footprint, site development, and economic impacts) of LDES, and how it could contribute to the clean energy transition. Indeed, several roundtable participants from state and local energy planners to electrical and energy labor organizations were learning about LDES for the first time through the event. LDES proponents noted that educating decisionmakers, including regulators, power market operators, and policy makers will help inform and shape the evolution of our future power grid.

A FAILURE TO REFLECT VALUE IN REGULATORY AND MARKET STRUCTURES

Market and regulatory structures have not evolved at the pace necessary to realize the full value of long-duration energy storage. Existing capacity markets and resource adequacy mechanisms are typically limited to a capacity of four hours or fewer, which excludes the reliability value and resource adequacy benefit of LDES.[73] Insufficient and out-of-date market and regulatory structures hinder long-duration energy storage's ability to compete on price and cost with short-duration energy storage. Adjusting market design to reflect the benefits of LDES is further complicated by the rapid entrance of emerging storage technologies on the market, as it is difficult for a singular regulatory structure to accommodate the nuances of each technology.

As LDES technologies become more commonly understood and categorized, it may be easier for policymakers to design incentive structures. Dialogue is necessary between utilities, solution providers, public utility commissions (PUCs), regional transmission organizations (RTOs), and other stakeholders to develop a flexible framework that can address the market need for LDES and the value it offers to the power system, while fostering innovation in a nascent and rapidly evolving industry.

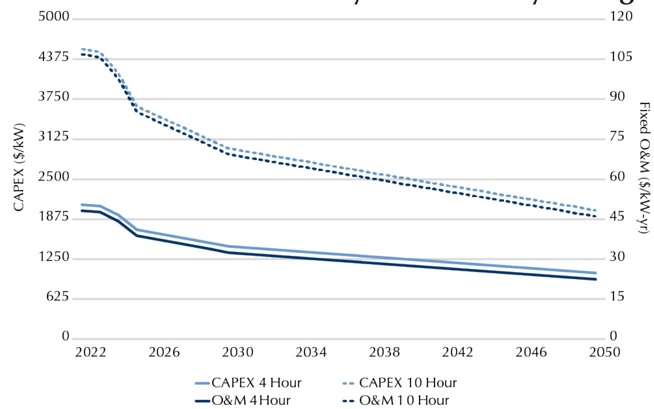
For example, starting in 2021 California ISO (CAISO) conducted a stakeholder engagement process to determine energy storage enhancements to help stor-

age scheduling coordinators ensure efficient market outcomes. This led to several policy proposals released in a final report from October 2022 that may benefit long-duration storage technologies. For example, CAISO proposed policies to help anticipate energy that will be lost or gained by storage technologies providing ancillary services and to require coordinators to submit economic bids when a storage system provides these services.[74]
To ensure energy system operators are incentivized to maintain necessary levels of dispatchable charge, CAISO proposed providing compensation based on the opportunity cost of the revenues that would have been received if a storage system forgoes optimally participating in the market. Following this stakeholder engagement initiative, CAISO filed a docket for the Federal Energy Regulatory Commission to afford due consideration to the proposed market revisions.[75]

RELATIVELY HIGH PER-UNIT COSTS

Project costs, on a dollar-per-energy unit basis, are currently higher for LDES relative to short-duration lithium-ion battery storage, making the latter appear significantly more attractive and competitive, when only the total capacity of the project is considered. Notably, lithium-ion battery technology is far more mature, benefits from economies of scale, and learning through doing (i.e., technology improvements over decades). For example, BloombergNEF finds the average capital cost of a lithium-ion battery energy storage system was around $304 per kWh, in comparison to the $444 per kWh capital cost of long-duration flow batteries, the most prevalent electrochemical energy storage technology outside of lithium-ion.[76] **Figure 5** shows projections of project cost recovery over 30 years on a per-kW basis for four-hour storage compared to 10-hour storage installed today; under current market conditions, longer-duration storage costs significantly more than shorter-duration storage. As LDES technologies become more mature, costs can be expected to fall as LDES benefits from economies of scale. In the near- to mid-term, however, finding ways to value or credit the additional benefits of longer duration storage could help overcome this hurdle.

FIGURE 5: Comparative cost recovery for 10- and 4-hour duration utility-scale battery storage



The left axis represents capital expentures on a per kW basis, while the right axis represents fixed operating and maintanence costs on a per kW-year basis. The dotted lines represent costs for 10-hour duration storage, and the solid lines represent 4-hour duration storage.

Source: National Renewable Energy Laboratory, 2024.

PERMITTING AND INTERCONNECTION QUEUE TIMELINES

Along with other power sector infrastructure, energy storage projects face headwinds because of long timelines for study, review, permitting, and interconnection to the grid. The length of the siting, permitting and, especially, the interconnection process is considered the top non-financial challenge to project development of renewable energy projects.[77] These challenges are exacerbated for LDES by the evolving nature and nuances of the technology, requiring each project to be considered uniquely, as well as the unique workforce needs to build out projects.

In Virginia, there are 218 energy storage projects in the interconnection queue for the regional transmission organization PJM—almost all of which are short duration. This backlog indicates a significant interest among Virginian companies in building out energy storage solutions. However, many projects are stuck waiting to be connected to the grid. A recent report on the outlook for PJM's interconnection queue estimated that most projects entering the queue today are unlikely to come online before 2030.[78]

SOLUTIONS TO SUPPORT THE DEPLOYMENT OF LDES IN VIRGINIA

EDUCATE BUSINESSES, POLICYMAKERS, & COMMUNITIES

Given long-duration energy storage's nascence in the market, there is a need for increased education on the technology to deploy it at utility scale. Compared to shorter-duration, lithium-ion storage options, and especially other renewable energy sources, there is little public knowledge of the market, supply-chain, and safety benefits many LDES technologies offer. Furthermore, not knowing where the education gaps exist will make it difficult for companies and policymakers to address them in planning forward-looking workforce development for the industry.

To identify education gaps for the long-duration storage industry, Virginia Energy should conduct a study engaging with policymakers, local communities, companies, and workers to gauge the understanding of where and how LDES can be implemented and the awareness of associated economic benefits. This study would help inform the strategic development of a long-duration energy storage coalition that could serve as an independent clearinghouse for stakeholders to access educational resources and build support for the development of LDES in Virginia.

The Virginia Nuclear Energy Consortium could be viewed as a model for successful stakeholder mobilization to achieve industry awareness and growth. This independent organization run by the Commonwealth has helped advance the nuclear industry in meaningful ways that, if replicated by a similar LDES-focused organization, could contribute to the development of the industry in the state. These accomplishments include developing and submitting a strategic nuclear development plan to the Commonwealth, securing a one-time planning grant to develop a nuclear research and innovation hub in Virginia, and advocating for the passage of legislation to create an energy education career cluster.[79]

There are additional steps a Virginia LDES consortium could take to further their specific industry. Roundtable participants highlighted the need to proactively provide guidance to communities interested in hosting storage projects to assist in the development of standardized ordinances across the state. This would help avoid any lengthy delays or surprises in the project development process that have derailed storage projects in the past. Furthermore, a Virginia LDES consortium could help launch an educational campaign driven by utilities, transmission operators, and energy modelers, among others. This campaign could serve to educate utility commissioners on the value of LDES as a capacity resource, report on potential use cases, and highlight successful long-duration storage deployments.

At the national level, the U.S. DOE can play a role in messaging and engagement on LDES technologies with local communities across the country. This could be accomplished by including long-duration energy storage in DOE's emerging clean energy strategies under its Clean Energy to Communities program. This program helps facilitate technical partnerships and foster peer learning exchanges among community leaders and technical experts to tailor assistance to overcome sector specific challenges.[80] The most recent cohorts include peer groups exchanging best practices related to implementing agrivoltaics projects, designing programs to increase energy efficiency in residential buildings, and electrifying municipal fleets.[81] Using a similar approach to socialize Virginia stakeholders with likeminded organizations looking to implement LDES projects across the country would help the Commonwealth scale the industry.

Policy Recommendations:

- DOE's Office of Energy Efficiency & Renewable Energy should include messaging on LDES as one of its "emerging clean energy strategies" through the Clean Energy to Communities program administered by the National Renewable Energy Laboratory.[82]
- Utilities, regional transmission organizations (RTOs)/independent system operators (ISOs), consultants, energy modelers, and indirectly, solution providers should educate utility commissioners on the full value of long-duration energy storage resources outside their value as a capacity resource, by providing them with a report of use cases and examples of successful LDES demonstrations and deployments. This report could be modeled after the Virginia Energy Storage Task Force's Final Report published in 2021.[83]

- The Virginia Department of Energy should conduct a study on the education gaps among policymakers, companies, workers, and the general public, including: potential use cases; economic impacts; and geographic limitations of long-duration energy storage in the state.
  - Informed by the study's results, Virginia Energy should create an independent organization, modeled after the Virginia Nuclear Energy Consortium, to address public awareness gaps and serve as an educational resource on LDES in the state.
  - This independent organization could also provide guidance to counties on the development of ordinances relating to energy storage to support standardization across the state.

ENGAGE COMMUNITIES PROACTIVELY, TRANSPARENTLY, AND COMPREHENSIVELY

Effective community engagement, from the initial stages of project design to implementation, is crucial for the successful development of LDES projects. Involving communities throughout the development process can significantly reduce opposition and potential conflicts, as well as ensure an equitable distribution of project benefits.[84] Roundtable participants stressed the importance of building trust between developers and community members, not only to ease the permitting process but also to form meaningful relationships that are beneficial for project implementation. They emphasized that developers should prioritize community engagement through early and transparent communication, inclusive decision-making processes, and educational programs.

Participants highlighted the robust network of conservation and environmental non-governmental organizations in Virginia as an important set of stakeholders in the development of clean energy technologies like LDES. The Virginia Conservation Network, for example, includes more than 150 environmental organizations that work with communities and policymakers to advance solutions to support environmental goals.[85] Participants suggested that developers should conduct outreach, education, and engagement initiatives with these organizations to help them understand how LDES can support environmental goals, as well as to build trust and buy-in from an influential constituency.

Political Polarization and Community Opposition

The development of solar energy in Virginia has faced public resistance and political polarization. Thirty-two of 95 counties have enacted solar restrictions, making Virginia one of the top states for such restrictions.[86] Opposition in rural Virginia is especially prevalent, as misinformation on the health and environmental risks of solar projects has led to increased concerns in communities.[87] Roundtable participants pointed to examples of poor community engagement practices that helped foster this opposition. For example, they highlighted that a solar energy project planned for Staunton, Virginia, produced widespread community opposition after the developer failed to proactively reach out to the community ahead of development. As a result, the Staunton City Council rejected the project.[88] As the LDES industry continues to grow in the state, companies can learn from the past experience of solar energy project developers, particularly by improving community involvement.

Participants emphasized that engaging communities early in the LDES development process will help the industry avoid the community opposition some solar projects have encountered. According to recent polling data, voters are generally more supportive of solar power in Virginia after they have been informed on the subject, regardless of their political ideology, indicating that educating communities contributes to more positive perceptions of new energy technologies.[89] Though political polarization around solar energy in Virginia has already become a significant barrier in several communities, the LDES industry has an opportunity to begin educating the public on LDES technologies before polarization can take root. Proactively providing communities with information on LDES projects—including the benefits, safety mechanisms, and potential environmental impacts—will help prevent misconceptions from taking root.

Although engaging communities early on in a project's timeline can lead to wider public acceptance of LDES, it can be difficult for developers to engage before site selection is finalized, particularly when information relating to site selection and project design may not be public. Participants commented on the difficulties of companies attempting to interact with communities before certain project details are finalized, including site purchasing agreements, which could jeopardize the viability of the projects themselves. Community engagement that occurs too early, such as before LDES development in a locality is confirmed, can weaken relationships between developers and communities. If there is not a tangible project to discuss, developers risk wasting community members' time and falsely promising benefits that are not yet guaranteed, ultimately weakening the trust that is essential to meaningful LDES development. This creates a tension where developers are hesitant to engage too early with communities, fearing premature engagement could lead to confusion, unrealistic expectations, or the spread of incorrect information. Developers must design community engagement strategies that involve communities at the earliest possible stage in the development process without damaging the community's trust and cooperation. Local governments hoping to attract LDES projects can proactively educate and engage their communities to identify their questions, needs, concerns, and interests relating to the technology to lay the groundwork for future engagement with project developers and ensure community members are informed.

Participants agreed that engaging the local workforce and local businesses is an important step toward building buy-in from communities for LDES development. Projects that employ local workers rather than out-of-state workers demonstrate commitment to promoting local economic growth, leading to more positive public perceptions and greater community support. Where it is difficult to find sufficient skilled local workers that can meet the needs of new projects, developers can also invest in workforce training to build local capacity and support long-term economic stability in communities. Furthermore, by integrating local expertise and resources into project design and implementation, developers can improve project efficiency and reduce logistical challenges.

Project agreements, including community benefits agreements and community workforce agreements, offer an opportunity for communities to negotiate with developers and secure positive project outcomes. Provisions can include hiring local employees, directing funding to job training programs, ensuring the participation of local businesses in projects, and other community-based benefits. Small business owners, community leaders, community organizations, and local governments are the most trusted groups to negotiate on behalf of communities, and their engagement in the development of project agreements often leads to widespread voter support.[90]

Policy Recommendations

- Local governments interested in deploying long-duration energy storage should host collaborative sessions with stakeholder groups to identify their needs, concerns, and interests in the technology, which can help inform permitting decisions and project development processes.

VALUE THE BENEFITS OF LDES IN POLICY INCENTIVES AND MARKETS

Adjust Metrics to Internalize Reliability Impacts

Because the technology is new, power markets are not currently set up to account for the resource adequacy impacts of long-duration energy storage. Since LDES can serve as a generation, transmission, and distribution asset, current modeling and regulatory structures do adequately capture the full utility of LDES to the grid.[91]

Currently, the key metric of measuring resource adequacy is loss-of-load expectation (LOLE), which includes the expected number of days in a given year in which electricity supply cannot meet electricity demand.[92] Critics argue this metric is outdated as it does not measure the severity or longevity of outages. For instance, the LOLE metric values a one-hour event the same as a 22-hour event.[93] Other metrics, such as effective load carrying capacity (ELCC) and expected unserved energy (EUE), account for the magnitude and duration of energy shortfalls and can more accurately weight resource adequacy against risk over time. These other metrics may be more suitable for a grid that incorporates many different kinds of generation and storage resources. At the project level, LOLE is used to estimate the extent to which an additional resource will reduce the probability of loss-of-load.[94] The effective load carrying capacity (ELCC) metric enables planners to assess the degree to which a given resource can support resource adequacy and decrease LOLE, and may be better able to capture the resource adequacy contributions of resources like LDES.[95] Another metric that could help paint a fuller picture is expected unserved energy (EUE), which measures the expected amount of unserved energy per year—i.e., the average annual energy shortfall, averaged across resource adequacy simulations.[96]

As increasing shares of renewables and storage contribute to the energy mix, a multi-metric resource adequacy framework may be necessary to fully capture the complexity of the evolving system. State and federal energy regulators should proactively explore these potential metrics to determine the most effective multi-metric measure of resource adequacy, taking into account each individual metric's limitations.

Differentiate Between Storage Types

Throughout the roundtable, participants highlighted the need for expanded differentiation between short-duration and long-duration storage solutions, across education and outreach initiatives, state- and local-level policy regimes, and project development proposals. Participants gave particular attention to the state's energy storage procurement requirement, which does not specify storage duration, and recommended that in the future, states specify a minimum requirement for long-duration storage within their energy storage procurement targets.

Additionally, participants highlighted the opportunity for states or municipalities to deploy LDES alongside new renewable energy projects, for example by releasing a joint request for proposals for renewable generation and LDES. A 2021 study by the Lawrence Berkeley National Lab found that by the end of 2020, 34 percent of solar and 6 percent of wind projects in interconnection queues were hybrid generation and storage systems.[97] States, local governments, and utilities could specify LDES in these hybrid procurement proposals.

Policy Recommendations

- States setting energy storage procurement/portfolio requirements should differentiate between short- and-long duration energy storage.
- States procuring renewable electricity like offshore wind should procure storage in parallel to support grid reliability as the share of renewable energy increases. Before issuing a request for proposals, the state should conduct a commensurate study to determine the type of storage and timing of deployment to identify the most cost-effective solution.

CONCLUSION

As Virginia looks to scale up its clean energy resources and energy storage capacity, long-duration energy storage provides a unique opportunity to bridge the intermittency of renewables like solar and wind to provide firm, dispatchable, reliable power to the Commonwealth. Growing electricity demand from data centers and other large industrial customers, alongside increasing risks of extreme weather exacerbated by a warming climate, also create an opportunity for LDES to provide additional benefits. Additionally, production of components and construction of projects could create large-scale employment opportunities for Virginia's skilled workers. However, many policymakers, regulators, developers, and communities remain unfamiliar with the nuances of the technology and opportunities to deploy it locally. Significantly more education about the barriers and opportunities of this technology can help position Virginia to meet and exceed its ambitious energy storage goals.

Additional C2ES Resources

Regional Roundtables
https://www.c2es.org/accelerating-the-us-net-zero-transition/regional-roundtables

Technology Working Groups
https://www.c2es.org/accelerating-the-us-net-zero-transition/c2es-technology-working-groups

Spinning the Mid-Atlantic Offshore Wind Industry into Economic Opportunity
https://www.c2es.org/document/spinning-the-mid-atlantic-offshore-wind-industry-into-economic-opportunity

Creating a Circular Economy for Critical Minerals in Ohio
https://www.c2es.org/document/creating-a-circular-economy-for-critical-materials-in-ohio

Power Infrastructure Needs for Economywide Decarbonization
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