LDES NATIONAL CONSORTIUM

Industry Recommendations

September 2024

Sandia National Laboratories | Argonne National Laboratory | INL Idaho National Laboratory | NREL National Renewable Energy Laboratory | Oak Ridge National Laboratory | Pacific Northwest National Laboratory

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Summary

This document details the first set of recommendations developed by the National Consortium for the Advancement of Long Duration Energy Storage Technologies (LDES National Consortium).

This first set of draft recommendations is intended to address commercialization challenges facing long duration energy storage (LDES) technologies as referenced in the Department of Energy's (DOE) *Pathways to Commercialization Lift-off* report, published in 2023. The report made reference to the challenges that must be addressed in order for LDES technologies to achieve commercialization "lift-off," defined as the point at which a specific LDES technology and/or the LDES ecosystem is deemed to be self-supporting (i.e., no longer reliant on public funding) as deemed by empirical evidence such as cost performance, improved round-trip efficiency (RTE) levels, increased levels of private investments in technologies or projects, increased numbers of LDES projects, etc.

As an initial assignment for the LDES National Consortium, these challenges were assigned to one or more of the 16 Tiger Teams[1] that have been established as the core working groups comprised of official Teaming Partners within the Consortium. There were 11 challenges pulled from the Lift-off report and assigned in January 2024:

- **Challenge #1:** Cost of an LDES system needs to come down by 2030.
- **Challenge #2:** LDES technologies must achieve 7-15% improvement in roundtrip efficiency to compete with Li-ion storage and hydrogen.
- **Challenge #3:** The specific needs related to LDES workforce training (i.e., skills and training) are presently not well defined.
- **Challenge #4:** A uniform approach toward developing resource adequacy compensation for LDES technologies does not exist, in either regulated markets (PUC evaluation) or competitive markets (ISO/RTO).
- **Challenge #5:** A comprehensive assessment of necessary supply chain improvements specific to LDES technologies does not presently exist.

[1] The 16 Tiger Teams operating within the LDES National Consortium are: 1) Customer Adoption; 2) Demonstrations & Deployments; 3) Economics & Valuation; 4) Equity; 5) Grid Infrastructure; 6) Interconnection, Standards & Permitting; 7) Investor Confidence / Finance; 8) Market Planning; 9) Policy & Regulations; 10) Reliability & Resilience; 11) Safety & Grid Security; 12) Supply Chain & Manufacturing Efficiencies; 13) Technology Development, Evaluation & Testing; 14) Use Case Development; 15) Utility Resource Planning; and 16) Workforce Development.

- **Challenge #6:** There is presently a lack of resources regarding how to evaluate grid upgrades or expansions that will be necessary to accommodate both new variable renewable generation sites and LDES systems.
- **Challenge #7:** Presently, there is no publicly available evaluation of LDES technologies against primary competitive factors.
- **Challenge #8:** LDES is not included in most utility grid firming plans.
- **Challenge #9:** LDES use cases require market changes at the wholesale level.
- **Challenge #10:** ISO and RTO markets will need to develop support mechanisms specific to LDES technologies.
- **Challenge #11:** State-level policymaking specific to LDES has been very limited.

Each recommendation that has been developed to address these challenges has been drafted with the following attributes:

- A concise, action-based statement that is clearly articulated and easily understood.
- Each recommendation has (or will have) an identified public entity to which the recommendation can be submitted for implementation.

The LDES National Consortium has adopted a technology-agnostic approach in development this first set of draft recommendations with a recognition that some recommendations may require technology-, application-, or market-specific language being added. Similarly, the LDES National Consortium remains mindful of the variances across wholesale/retail markets and individual US states that comprise the domestic electric industry and will make every effort to identify these variances in the draft recommendations.

Many of these recommendations have been self-assigned to the LDES National Consortium, indicating the need for further analysis across our Lab Partners and Teaming Partners before additional industry recommendations can be developed. These self-assignments are based on an assumption that the stated activities to be undertaken by the LDES National Consortium can be achieved within the allocated funding and established timeline for the project.

Throughout this document references are made to specific external entities to which a recommendation may be submitted for implementation. It should be noted that in most of these instances the LDES National Consortium has not taken the step as of yet to consult with these external entities. This is an action item that will be assumed subsequent to having the draft recommendation language formally adopted and readied for public release.

In addition, once a recommendation is ready to be submitted to a specific entity, implementation tracking mechanisms will be added to the recommendation. Implementation tracking mechanisms will typically identify the means through which the LDES National Consortium will document the extent to which a specific recommendation has been implemented or the reasons why it has not been implemented.

ACRONYMS INCLUDED IN THIS DOCUMENT

APPA—American Public Power Association

BES—Bulk Energy System

BESS—Battery Energy Storage System

BTM—Behind the meter

C&I—Commercial & Industrial

CEM—Capacity expansion model

DOE—Department of Energy

DOE-OTT—Department of Energy—Office of Technology Transitions

DOL—Department of Labor

EEI—Edison Electric Institute

EIA—Energy Information Administration

ELCC—Electric Load Carrying Capability

EPC—Engineering, procurement & construction

EPRI—Electric Power Research Institute

ESS—Energy storage system

EUE—Expected unserved energy

FERC—Federal Energy Regulatory Commission

FOAK—First of a Kind

ICC—International Code Council

IRP—Integrated Resource Plan

ISO—Independent System Operator

KPI—Key performance indicator

LOLE—Loss of load expectation

LOLH—Loss of load hours

LCOS—Levelized cost of storage

OEM—Original equipment manufacturer

NARUC—National Association of Regulatory Utility Commissions

NASEO—National Association of State Energy Offices

NERC—North American Electric Reliability Corporation

NIST—National Institute of Standards and Technology

NFPA—National Fire Protection Association

NRECA—National Rural Electric Cooperation Association

PCS—Power conversion system

PUC—Public Utility Commission

RSC—Regional State Committee

RTE—Round-trip efficiency

RTO—Regional Transmission Organization

VRE—Variable renewable energy

Challenge #1:
Cost of an LDES system needs to come down by 2030.

Ref #	Action-based Recommendation	Recipient
1-1	Conduct further analysis to evaluate the driver of LDES costs—power or energy—and the various elements of the LCOS that can be targeted for reductions, to determine how LCOS can be improved to address LDES more effectively (or be substituted with another methodology).	Self-assigned to LDES National Consortium-- Technology Development, Evaluation and Testing Tiger Team
1-2	Assess the opportunities for increased levels of LDES demonstrations / pilot programs in specific states to facilitate the scaling of LDES technologies, which in turn will promote cost reductions. Where applicable, restructured states that have imposed restrictions on utility ownership of energy storage assets should be encouraged to reconsider this policy to allow utilities to own, build, and operate LDES in the commercial scalability of LDES can be accelerated with utility-scale	The assessment of specific states is self-assigned to the LDES National Consortium—Policy & Regulations Tiger Team. Once assessments are completed, state-specific recommendations will be submitted either directly to state regulatory commissions or disseminated through NARUC or NASEO.
1-3	Develop, and make publicly available, a public repository of targeted investment data and shared lessons learned of LDES investments through public databases and reports, which will enable LDES cost reductions by segment. (This recommendation recognizes that similar efforts are underway with external organizations such as EPRI, the DOE-OTT, and Sightline and thus incorporate collaboration to the fullest extent possible.)	The development of the repository is self-assigned to the LDES National Consortium—Investor Confidence and Economics & Valuation Tiger Teams. Upon completion the repository will be made publicly available via the Consortium's Website.
1-4	Assess how federal funding can be evaluated, prioritized, and allocated for R&D initiatives that seek to reduce raw components (e.g., capital costs) and manufacturing costs associated with LDES technologies, and deliver findings from this assessment to appropriate DOE funding sources.	Self-assigned to the LDES National Consortium—multiple Tiger Teams.
1-5	Assess how LDES project financing costs can be decreased through lowering risk factors, increasing reliability and investor certainty, and appropriately correlating private investments with technology-readiness levels.	Self-assigned to the LDES National Consortium—Economics & Valuation and Investor Confidence Tiger Teams.

1-6	Develop a strategy in which LDES project developers can target funds specific to FOAK deployments from strategic investors, large companies with sustainability goals, and/or public funding to cover the high costs and risk associated with FOAK projects. An alternative recommended path is through financial call options (i.e., warrants) targeted for FOAK projects.	Self-assigned to the LDES National Consortium—Investor Confidence Tiger Team. Upon development, the strategy will be disseminated to LDES OEMs via appropriate national trade associations.
1-7	Develop an LDES public and private FOAK/pre-commercial demonstration funding support and commercial deployment tax credit database and/or summary documentation.	Self-assigned to LDES National Consortium—Investor Confidence Tiger Team.
1-8	Create a public forum in which Any procurer and/or financier of early deployments of LDES can disclose key findings (i.e., "lessons learned"), without inclusion of proprietary / competitive information, following a contract execution for an LDES project on timeline/period of performance.	The creation of a public forum is self-assigned to the LDES National Consortium—Investor Confidence Tiger Team. Requests for public disclosure of key findings/lessons learned will be coordinated through the Demonstrations & Deployment Database being developed by the LDES National Consortium.
1-9	Prioritize FOAK deployments and/or LDES projects that demonstrate regionally focused economic impacts through supply chain build-outs to strengthen overall economic profiles for LDES technologies.	Further assessment of specific supply chain and/or technologies to emphasize is self-assigned to the LDES National Consortium—the Technology Development, Evaluation, and Testing and Supply Chain & Manufacturing Tiger Teams Upon completion of this additional assessment, more-granular level recommendations will be made to 1) OEMs (so that they can attract investment); and 2) procurers of LDES (so that their investment can have key future impact)

Challenge #2:

LDES technologies must achieve 7-15% improvement in roundtrip efficiency to compete with Li-ion storage and hydrogen.

Ref #	Action-based Recommendation	Recipient(s)
2-1	Prepare list of factors that influence roundtrip efficiencies organized by technology type and assumptions regarding how these factors can be influenced, and by which industry players. This list of factors should be 1) prioritized in terms of which factors are essential to address and 2) assigned levels of complexity to implement.	Self-assigned to the LDES National Consortium-- Technology Development, Evaluation & Testing and Use Case Development Tiger Teams.
2-2	Conduct an RTE assessment based on LDES technology type.	Self-assigned to the LDES National Consortium—Technology Development, Evaluation and Testing and Use Case Development Tiger Teams. Upon completion of this additional assessment, more-granular level recommendations will be made to OEMs and end users for their technology development and market evaluation.
2-3	Assess the potential for additional DOE-sourced R&D funding opportunities that could be made available to enhance the performance of existing LDES technologies and further enable the development of new high-performance technologies	Self-assigned to the LDES National Consortium—Technology Development, Evaluation & Testing and Investor Confidence Tiger Teams.

Challenge #3:

The specific needs related to LDES workforce training (i.e., skills and training) are presently not well defined.

Ref #	Action-based Recommendation	Recipient(s)
3-1	Conduct a comprehensive assessment of current needs for workers in the LDES industry must be conducted before more specific recommendations can be developed. Assess opportunities to correlate existing workforce programs relevant to LDES (e.g., chemicals sector, electricians, etc.) to DOE pilot/demonstration projects in current need of trained workers.	Self-assigned to the LDES National Consortium—Workforce Development Tiger Team.
3-2	Define mechanisms that will enable increased communication between the LDES industry, academia/training providers, and communities with high unemployment or underemployment to increase the ways in which shared knowledge can be leveraged to improve workforce training specific to LDES technologies.	Self-assigned to the LDES National Consortium—Workforce Development Tiger Team for further analysis. Upon completion of analysis, recommended mechanisms, at the state level recommendations will likely be submitted to state departments of labor. At the federal level, which is more likely appropriate as LDES workforce is a nation-wide issue, this recommendation would likely be submitted to the US DOL or to DOE.
3-3	Develop and implement safety and standards specifically for LDES technologies that can incorporate existing NFPA 855, Standard for the Installation of Stationary Energy Storage Systems (2023) and International Fire Code 2018. This will ensure that they are efficient and effective for training workforces for current and future LDES technologies.	This recommendation will likely be submitted to international standards organizations such as the ICC which oversees the International Fire Code and NFPA, which oversees the NFPA 855. Additionally, safety standards organizations, regulatory bodies, and industry stakeholders involved in the development, implementation, and enforcement of safety regulations and standards for energy storage systems would also play a crucial role in implementing this recommendation.

3-4	Emphasize the value proposition of having an engineering company tasked with constructing a pilot LDES system within electrolytic hydrogen production.	The Lab Partners presently leading the LDES National Consortium can take initial steps to further define the scope of such a pilot project. Upon further definition and determination of potential settings for the pilot, more specific recommendations can be submitted to state and federal funding agencies, investors, energy developers, EPC companies.
3-5	Develop a comprehensive LDES workforce training program that includes specific modules on the safe installation and maintenance of battery storage cabinets.	A collaboration between the Lab Partners leading the LDES National Consortium and Teaming Partners that are developing and manufacturing LDES technologies can develop the best practices for installations and maintenance of LDES systems. Their real-world experience would ensure the training modules are relevant and effective. Upon completion of the training program, the DOE could take the lead in coordinating development of specific modules on the safe installation and maintenance of battery storage cabinets used in LDES technologies. Technical colleges and trade schools would be responsible for integrating these training modules into their curriculum. They would work closely with the National Laboratories and other stakeholders to ensure the training program is comprehensive and up to date. Industry associations can help disseminate these training modules to their members. They can also provide industry insights and feedback to help refine the training program.

3-6	Establish a dedicated working group or task force to develop a comprehensive LDES workforce training program, with strong emphasis on grid security.	A collaboration between the Lab Partners leading the LDES National Consortium and Teaming Partners that are developing and manufacturing LDES technologies can provide research support and resources, ensuring that the training program stays up to date with the latest industry trends and technologies. FERC can provide regulatory oversight and ensure that the training program aligns with existing and future grid security regulation for LDES integration with renewable energy generation as a distributed energy resource in the grid. The DOE can provide the necessary support and resources for the implementation of this training program.

Challenge #4:

A uniform approach toward developing resource adequacy compensation for LDES technologies does not exist, in either regulated markets (PUC evaluation) or competitive markets (ISO/RTO).

Ref #	Action-based Recommendation	Recipient(s)
4-1	Conduct further assessment of how RSCs can assume a more significant role in ensuring that both decarbonization goals and resource adequacy standards at the state level are being fully considered in federal rulemaking standards and wholesale market rules.	Self-assigned to the LDES National Consortium—Policy & Regulations Tiger Team.
4-2	Evaluate alternatives to the ELCC metric as a means of evaluating the contributions that LDES can made toward resource adequacy requirements	Self-assigned to the LDES National Consortium—Economics & Valuation Tiger Team.
4-3	Evaluate alternatives to currently available reliability metrics currently in place within RTO/ISO market structures.	Self-assigned to the LDES National Consortium—Policy & Regulations Tiger Team with ultimate objective to submit more specific recommendations to FERC and/or specific RTOs and ISOs.
4-4	Encourage state regulatory commissions to evaluate the approach taken regarding the treatment and compensation of resource adequacy proposed in Massachusetts's Recent Report and Study entitled: Charging Forward: Energy Storage in a Net Zero Commonwealth with an expressed objective of determining the extent to which this approach can be adopted as a standardized approach.	Disseminate this recommendation through NARUC and/or NASEO.
4-5	Encourage state regulatory commissions to evaluate the approach that California is taking to monetize resource adequacy (its "Slice of Day" policy) with an expressed objective of determining adopting as a standardized approach.	Disseminate this recommendation through NARUC and/or NASEO.
4-6	Assess the extent to which standardized methods to determine the capacity value of all generation and storage resources, including LDES, can be adopted across all US RTOs/ISOs	Self-assigned to the LDES National Consortium—Policy & Regulations Tiger Team with ultimate objective to submit more specific recommendations to FERC and/or specific RTOs and ISOs.

4-7	Evaluate the extent to which a framework can be adopted across all US RTOs/ISOS in which LDES project developers could interconnection queues with one specific storage duration identified and then be able to increase the duration later when there is more demand for LDES (rather than be required to submit an entirely new interconnection request).	Self-assigned to the LDES National Consortium—Policy & Regulations Tiger Team with ultimate objective to submit more specific recommendations to FERC and/or specific RTOs and ISOs.
4-8	Encourage US RTOs/ISOs to develop an interconnection mechanism that enables certain resources that are in high demand and can be developed quickly to be given priority status in the interconnection queue.	Disseminate this recommendation through FERC.
4-9	Develop a suite of resource adequacy constructs based on duration that can serve a variety of use cases and support grid reliability.	Disseminate this recommendation through FERC.
4-10	Reduce the reliance on compensation paradigms that introduce revenue uncertainty.	Disseminate this recommendation through FERC.

Challenge #5:

A comprehensive assessment of necessary supply chain improvements specific to LDES technologies does not presently exist.

Ref #	Action-based Recommendation	Recipient(s)
5-1	Calculate the quantity of equipment and materials to needed to install (defined in megawatt levels) specific LDES solutions and report the information to DOE for sharing with other federal agencies (DOE, FERC, the Department of Interior's Bureau of Land Management, US Environmental Protection Agency, and the Association for Supply Chain Management. etc.).	All LDES technology developers that are currently registered as Teaming Partners within the LDES National Consortium; the DOE for potential funding requirements associated with this recommendation.
5-2	Develop a public database containing information about material-supplying countries and the capacities of each supplier within those countries.	Self-assigned to the LDES National Consortium—Supply Chain & Manufacturing Tiger Team.
5-3	Assess the value of developing and submitting a formal request for funding to the DOE to support a national assessment of manufacturing capacity relevant to LDES technologies, well as size of the manufacturing plant necessary for reasonable economies of scale to reduce unit costs.	Self-assigned to the LDES National Consortium—Supply Chain & Manufacturing Tiger Team.
5-4	Partner with national organizations to evaluate and develop more specific standards related to fire safety and other hazards impacting LDES technologies.	Self-assigned to the LDES National Consortium—Supply Chain & Manufacturing Tiger Team in anticipated collaboration with national organizations such as the National Fire Protection Association.
5-5	Partner with national organizations to conduct workforce gap analysis and provide more training opportunities to support future hiring needs.	Self-assigned to the LDES National Consortium—Supply Chain & Manufacturing Tiger Team in anticipated collaboration with national organizations such as the Bureau of Labor Statistics, DOE, Department of Education, and America's Union.
5-6	Determine the associated supply chain needs for projects identified in the Develop LDES Demonstrations & Deployments Tracking System being developed by the LDES National Consortium.	Self-assigned to the LDES National Consortium—Supply Chain & Manufacturing and Demonstration & Deployments Tiger Teams.

Challenge #6:

There is presently a lack of resources regarding how to evaluate grid upgrades or expansions that will be necessary to accommodate both new variable renewable generation sites and LDES technologies.

Ref #	Action-based Recommendation	Recipient(s)
6-1	Conduct a gap and reform analysis that examines existing interconnection standards in both retail and wholesale markets that identifies necessary revisions to address LDES technologies as a broad category and their unique requirements. It is intended that this gap and reform analysis should be technology-agnostic (i.e., not specific to any one LDES technology class), although recommended reforms that address specific LDES technologies may be needed in the future.	Self-assigned to the LDES National Consortium—Interconnection, Standards & Permitting and Policy & Regulations Tiger Teams in anticipated collaboration with an external industry research entity.
6-2	Develop security guidance documentation for interconnecting LDES with the grid that encompasses a variety of use-case scenarios.	FERC, NERC and NIST
6-3	Prioritize the development of comprehensive standards that address grid security vulnerabilities that will be introduced from LDES technologies integration.	FERC, NERC and NIST
6-4	Develop risk-based cybersecurity and physical security guidance documentation based on existing security controls that would affect interconnected LDES with the grid that encompasses a variety of use-case scenarios.	The DOE and National Laboratories should take the lead in developing this guidance document. The DOE is the sector risk management agency, and the National Laboratories have the expertise to develop security guidelines. Additionally, private sector companies and other research institutions involved in the development and operation of LDES technologies can provide practical insights and feedback, ensuring the guidance documents are feasible and effective in real-world scenarios.

6-5	Develop an interconnection primer for LDES technology providers.	Self-assigned to the LDES National Consortium—Interconnection, Standards & Permitting Tiger Team.
6-6	Initiate a docket to investigate proactive interconnection planning processes and increased sharing of upgrade costs across multiple developers.	FERC
6-7	Evaluate opportunities to streamline the authorization process of scheduled interconnection agreements within RTO/ISO markets.	FERC
6-8	Conduct a gap analysis of existing modeling software tools currently available to grid planners to identify necessary reforms necessary to capture the full value of LDES resources.	Self-assigned to the LDES National Consortium—Utility Resource Planning Tiger Team.
6-9	Evaluate the potential need for federal funding to support the effort to identify and close key modeling gaps for LDES technologies, and develop tools and datasets for closing these gaps.	Self-assigned to the LDES National Consortium—Utility Resource Planning Tiger Team.
6-10	Develop a guidance document for regulators, market operators, and utilities that outlines the fundamental components to be included in an evaluation of LDES.	Self-assigned to the LDES National Consortium—Utility Resource Planning, Policy & Regulations, and Market Planning Tiger Teams.
6-11	Evaluate locational grid infrastructure implications /constraints /needs associated with different LDES storage technologies.	Self-assigned to the LDES National Consortium—Market Planning and Policy & Regulations Tiger Teams. More granular-level recommendations that result from this evaluation would be disseminated through organization such as EEI, APPA), and NRECA to their respective members.
6-12	Identify areas on the grid that have sufficient capacity, or require less upgrades, to support the interconnection of storage resources.	Self-assigned to the LDES National Consortium—Market Planning and Policy & Regulations Tiger Teams.
6-13	Develop a Change Configuration Management plan specifically for LDES systems.	NIST should be the key standards-developing entity that provides oversight and support for the implementation of a change configuration management plan in existing cybersecurity guidance such as the NIST SP 800-82 - Guide to Operational

		Technology (OT) Security or publish new NIST security guidelines for LDES. The National Laboratories should contribute their research expertise and resources to the development of the plan, which should include working with private sector companies to develop standard software bill of materials for LDES technology. The National Laboratories should further provide insight and feedback to help refine plans and ensure they are effective in real-world operations. Private sector companies that manufacture, install, and maintain LDES technologies would be crucial in assisting asset owners in implementing the change configuration management plan in their operations.
6-14	Participate in existing or establish efforts to analyze existing NERC Reliability Standards against documented reliability risk to the BES from BESSs to determine where regulatory enhancements such as NERC Standards projects, and BES Definition Review, are necessary to reduce security risks.	FERC, NERC, BESS Asset Owners.

Challenge #7:

Presently, there is no publicly available evaluation of LDES technologies that considers the primary competitive factors.

Ref #	Recommendation	Recipient(s)
7-1	Develop an LDES technology evaluation tool based on competitive factors on various energy storage technologies is necessary in supporting use case development.	Self-assigned to the LDES National Consortium-- Technology Development, Evaluation and Testing Tiger Team.
7-2	Identify, evaluate and develop alternative evaluation methods to address deficiencies that exist with of standard LCOS assessments	Self-assigned to the LDES National Consortium—Economics & Valuation Tiger Team.
7-3	Develop and make publicly available a competitive factor matrix[2] to address what is currently an industry gap of data that is needed to evaluate the full range of LDES technologies against primary competitive factors.	Self-assigned to the LDES National Consortium-- Technology Development, Evaluation and Testing Tiger Team.
7-4	Create a centralized, public repository of cost data, collected from manufacturers, suppliers, OEMs, end-use customers, and other relevant entities to enable cross-comparisons of LDES technologies.	Self-assigned to the LDES National Consortium—Economics & Valuation Tiger Team.

[2] Please see Appendix B: Table 2: “Competitive Factor Matrix”

Challenge #8:
LDES is not included in most utility grid firming plans.

Ref #	Recommendation	Recipient(s)
8-1	Develop a public repository of accurate cost and performance data for LDES technologies.	Self-assigned to the LDES National Consortium—Economics & Valuation Tiger Team.
8-2	Develop a framework for determining long-term planning scenarios that better represent future grid needs.	Self-assigned to the LDES National Consortium—Market Planning.
8-3	Develop a plan defining support mechanisms that can be provided to utility planners in transitioning to full, 8,760-hour chronological capacity expansion modeling.	Self-assigned to the LDES National Consortium—Utility Resource Planning.
8-4	Assess how to integrate power flow models with capacity expansion models.	Self-assigned to the LDES National Consortium—Utility Resource Planning.
8-5	Require transmission planners to evaluate energy storage alternatives in transmission planning processes.	FERC
8-6	Develop guidance document to advise on utility LDES planning considerations addressing the following scenarios: diminishing baseload coal, gas and nuclear plants; substituting LDES for flexible coal and gas peaking plants; varying levels of VRE production; impacts of adverse climate events on grid demand; and grid security.	Self-assigned to the LDES National Consortium—Market Planning Tiger Team. Upon development, it is anticipated that this guidance would be submitted to: 1) all utilities including IOUs, municipal and electric co-operatives through their respective trade organizations (EEI, APPA, and NRECA); 2) EIA and DOE to forecast renewable generation and energy storage needs; 3) FERC; and 4) T&D developers.
8-7	Promote BTM LDES projects for C&I customers.	It is anticipated that this recommendation could be submitted to state PUC and/or state energy offices, utilizing distribution methods available through NARUC and NASEO, respectively.
8-8	Conduct further analysis to determine if evaluations that have been conducted in the state of Massachusetts regarding the value of LDES in firming resources can be developed as a standardized model for other states.	This recommendation will be submitted to: 1) all utilities including IOUs, municipal and electric co-operatives; 2) EIA and DOE to forecast renewable generation

		and energy storage needs; 3) FERC; and 4) T&D developers.
8-9	Socialize the rationale for establishing a requirement that grid-firming plans include scenarios of greater penetration of renewables that produce protracted energy deficit and surplus periods.	NERC, NASEO
8-10	Provide utilities and regulators with tools or other means of measuring the value of grid firming and the resilience and reliability provided by LDES.	National Laboratories in partnership with the DOE.

Challenge #9:

LDES use cases require market changes at the wholesale level.

Ref #	Action-based Recommendation	Recipient(s)
9-1	Implement new market products that capture storage costs and generate more efficient market prices.	ISOs/RTOs, FERC
9-2	Extend electricity market dispatch optimization horizons.	ISO/RTOs, FERC, Regulators/NARUC
9-3	Remove the obstacles preventing full market participation by large dispatchable loads in wholesale markets, with a focus on the tariff changes and modernization needs to enable those resources to contribute their range of services into the market.	ISO/RTOs, FERC, Regulators/NARUC
9-4	Pursue granular tariffs that accurately capture the marginal cost and benefits of loads based on time of use on transmission, distribution, energy and fuel adjustment charges.	State PUCs, Utility Associations

Challenge #10:

ISO and RTO markets will need to develop support mechanisms.

Ref #	Action-based Recommendation	Recipient(s)
10-1	Conduct a comprehensive study of which support mechanisms already exist and which need to be developed in ISO/RTO markets for LDES, including LDES technologies under development.	Self-assigned to the LDES National Consortium—Policy & Regulations and Market Planning Tiger Teams.
10-2	Create a collaborative environment or forum among RTO/ISO representatives to discuss successes and lessons learned, and entertain ideas for support mechanisms that have not yet been identified, codified or implemented.	RTOs/ISOs should organize such a forum or, absent their initiative in this space, it could be organized by the Lab Partners of the LDES National Consortium, FERC, or NARUC.
10-3	Conduct an examination of why "storage as transmission" tariffs have not been more successful in the RTOs in which they have been developed, to Identify what storage can do and cannot do in respect to transmission applications.	Effective examination of this issue likely requires it being conducted by an entity outside of the RTO / FERC chain of command, and thus an independent group formed across the National Laboratories should appropriate lead this effort. The recommendation the for the study summarized here would be submitted to DOE with a funding request to support a lab team to conduct this analysis.
10-4	Conduct further analysis to determine how to capture the value of emissions and translate value into a compensation metric in wholesale markets, based on a presumption that carbon pricing as a fixed value may not send the right market signals or achieve intended impacts toward achieving LDES commercialization	Self-assigned to the LDES National Consortium—Policy & Regulations and Market Planning Tiger Teams.
10-5	Review market mechanisms to ensure that all sources of generation, including newer LDES technologies, are considered during grid stress events.	Self-assigned to the LDES National Consortium—Policy & Regulations and Market Planning Tiger Teams.
10-6	Establish compensation mechanisms for LDES that are distinct from energy and capacity revenues.	Recommendation disseminated through FERC with implementation requested at the ISOs/RTOs.

Challenge #11:
State-level policymaking specific to LDES has been very limited.

Ref #	Action-based Recommendation	Recipient(s)
11-1	Ensure on an ongoing basis that state policymakers/regulators have the increased information/knowledge about LDES that is needed to make informed policy decisions about LDES and the value/benefit it brings to their constituents.	DOE National Labs, LDES National Consortium, State policymakers/regulators, NARUC, and LDES OEMs.
11-2	Compile/develop LDES policy recommendations for states and distribute a guidance document to state PUCs that includes input from industry representatives regarding regulatory enablers specific to LDES that should be considered.	Self-assigned to the LDES National Consortium—Policy & Regulations Tiger Team, with dissemination of recommendations through NARUC.
11-3	Encourage governments to provide financial incentives (e.g., tax credits, grants, loan guarantees) for FOAK deployments of LDES technologies and/or manufacturing facilities.	NARUC, NASEO
11-4	Require regulated utilities to improve their IRP models to appropriately reflect the need for LDES, such as adding capability of dispatching across multi-day horizons to properly value LDES.	State policymakers/regulators, Utilities, FERC, ISOs, RTOs
11-5	Produce guidance IRP document that can be provided to state PUCs), including model language for rate cases.	Self-assigned to the LDES National Consortium—Policy & Regulations Tiger Team, with dissemination of recommendations through NARUC.
11-6	Create a restricted-access repository of information where proprietary industry information (e.g., cost and performance data) can be provided without the concern that it will become public.	Self-assigned to the LDES National Consortium—Policy & Regulations and Economics & Valuation Tiger Teams.
11-7	Develop an LDES benefit/cost model, to use in utility regulatory dockets.	Self-assigned to the LDES National Consortium—Policy & Regulations and Economics & Valuation Tiger Teams, with dissemination of recommendations through EEI.
11-8	Provide a guidance document to state PUCs that include input from industry representatives regarding regulatory	Self-assigned to the LDES National Consortium—Policy & Regulations Tiger

	enablers specific to LDES that they would like to be considered.	Team, with dissemination of recommendations through NARUC.
11-9	Encourage states to conduct analysis examining the potential for an increase of "winter peaking" scenarios, which would require a significant need for LDES resources. and/or additional generations to meet customer needs.	Disseminated through NARUC and NASEO.
11-10	Encourage states to require utilities to submit grid firming plans to specifically include scenarios of greater penetrations of renewables and long-duration production limiting events.	Disseminated through NARUC and NASEO.
11-11	Encourage those states that have adopted an energy storage procurement target, goal or mandate to take a further step and specifically identify the amount of LDES that will be needed at increasing levels of VREs Further, encourage those states that have not adopted an energy storage procurement target to assess the value of taking such a step and publicly share results.	Disseminated through NARUC and NASEO.
11-12	Conduct further analysis to determine the potential for creating a "value of resilience" standard that can be offered to state regulators.	Self-assigned to the LDES National Consortium—Policy & Regulations and Economics & Valuation Tiger Teams.
11-13	Establish reporting requirements on state/regional decarbonization policies and objectives to assist with federal oversight.	State PUCs, via NARUC
11-14	Conduct further analysis on potential revenue streams for LDES such as capacity accreditation for durations beyond 4 hours and reliability attributes (e.g., voltage support, synchronous inertia).	Self-assigned to the LDES National Consortium—Policy & Regulations and Economics & Valuation Tiger Teams.
11-15	Develop clearer definitions of LDES "sub-classifications" based on important attributes and/or grid services they can provide.	Self-assigned to the LDES National Consortium—Policy & Regulations and Technology Evaluation, Development & Testing Tiger Teams.

Appendix A.

Perspectives & Rationale for Industry Recommendations

The Industry Recommendations provided in this document have been developed on the basis of perspectives and rationale shared across the Teaming Partners of the LDES National Consortium. In the interest of providing full transparency for the contextual inputs that informed these Industry Recommendations, the following provides content collected from Teaming Partners.

Challenge #1: ***Cost of an LDES system needs to come down by 2030.***

The Lift-off report has referred to the “cost” of an LDES system as a generic term when in fact there are multiple unique components that comprise the total cost of the LDES system, and these unique components are subject to different mitigating factors that can impact cost. For instance, the PCS and specific elements of EPC are both typically bundled into the cost of an LDES system and yet require different treatments to address their cost reduction.

Along with the industry recommendations to address this challenge, the LDES National Consortium is working to prepare a comprehensive list of LDES system cost components, organized by technology type and assumptions regarding the factors that influence each cost component. Included in this comprehensive list will be a definition of differentiated LDES products and associated value propositions that can be used for defining associated costs.

The output of this analysis should be made publicly available to enable “best practices” and transparency across LDES project accounting and help project developers and end-use customers avoid unnecessary expenses. As a starting point for more in-depth analysis, the following datasets that contribute to the total cost specification of an LDES system should be evaluated independently to determine the extent to which stand-alone recommendations to cost reductions can be developed for these unique components.

- Storage Block Cost ($/kWh)
- Storage Balance of System Cost ($/kWh)

Storage System Cost ($/kWh)

- Power Equipment Cost ($/kW)
- Controls & Communication Cost ($/kW)
- System Integration Cost ($/kWh)

Energy Storage System Cost ($/kWh)

- Engineering, Procurement, & Construction Cost ($/kWh)
- Project Development Cost ($/kWh)
- Grid Integration Cost ($/kW)

- Fixed O&M Cost ($/kW-year)
- Variable O&M Cost ($/kWh)
- Warranty Cost ($/kWh-year)
- Insurance Cost ($/kWh)

Operating Costs ($/kWh)

- Disconnection Cost ($/kWh)
- Disassembly/Removal Cost ($/kWh)
- Site Remediation Cost ($/kWh)
- Recycling/Disposal Cost ($/kWh)

Decommissioning Costs ($/kWh)

While there are near-commercial and commercially available LDES technologies, there is still room for significant improvements in component performance while reducing raw component costs. Continued R&D funding is needed to enhance the economics of LDES technologies. As LDES technology deployment grows, there will be a need to optimize the ease-of-manufacturing and component design to further push down costs. This can be achieved through cost-reducing innovations that reduce the capital investment needed by LDES OEMs, which would then make investments into LDES projects easier to finance. A centralized database that is maintained and easy-to-navigate would provide a "marketplace" for LDES developers and investors. The data, experience, and lessons learned from early deployments of LDES will be extremely valuable to the success of all LDES stakeholders. Therefore, the dissemination of lessons learned should be a stipulation in any funding received for early deployments. These outputs should be stored in an easily accessible repository. The lessons learned will increase investor confidence in future deployments.

In terms of how LDES costs have been measured and quantified, LCOS[3] has been generally adopted as a primary tool to compare ESS technologies across different applications and compare costs to potential revenue sources. LCOS represents a cost per unit of energy ($/kWh or $/MWh) metric that can be used to compare different storage technologies on a more equal footing than comparing their installed costs. LCOS provides a discounted unit value of all technical and economic factors that influence the lifetime cost of storing electricity by taking a technology cost perspective rather than a system one.

One observation relevant to this identified challenge is that LCOS may not be an appropriate metric for evaluation LDES costs. While it is useful for specific applications, its universal adoption as a standard metric for evaluating LDES costs is very likely specious. For example, one problem with LCOS is that calculations vary by cycling frequency. Cycling frequency in turn varies by RTE and net revenue (net of charging costs). Thus, in order to determine an accurate LCOS for LDES technologies, there would need to be assumptions are made regarding factors across technologies that presently are not available.

Additional challenges are that different LDES systems have different calendar life, cycle life, depth of discharge, depth of limitations, and O&M costs, and may require various capital expenditures over time in the form of major overhauls, augmentations, and replacements. Each of these characteristics and parameters, in addition to taxes, costs due to debt, and others, ultimately defines the total cost of a storage system over the lifetime of a project. LCOS calculations are highly dependent on several assumptions about system size, power, usage, and ageing of the system being evaluated.

A second observation is that categories of LDES system benefits are often completely overlooked in assessments that determine the overall costs of an LDES system, and these benefits are very likely to be completely missed in an LCOS calculation. Examples include the array of stability services provided by LDES technologies that support reliability and resilience, such as primary frequency response, voltage support, small signal stability, and transient stability. Ensuring that these and other system benefits are included in the determination in revenue calculations would likely have a positive impact, which in turn could be used in comprehensive benefit-cost considerations that would likely result in a more positive cost calculation for some LDES technologies.

[3] LCOS calculations are typically comprised of five components: CAPEX, including battery costs, permitting, construction, installation, and fire safety; O&M costs, including scheduled & unscheduled maintenance, and performance data monitoring and retention; augmentation / replacement, including ongoing costs to recover battery capacity lost to degradation; end of Life costs, including recycling, disposal, and remediation costs, but also any residual value; and efficiency, as the cost of energy lost to charging and discharging inefficiencies

At minimum, when considering the potential for LDES to replace other technologies, such as gas turbines or transmission, or its contribution to the overall system value, LCOS alone is very likely to be insufficient. In the case of hydrogen as an LDES category, storage may be partially or completely ignored if the LDES customer, a utility company for example, is willing to purchase hydrogen on the spot market. The opportunity for clean hydrogen in the U.S., aligned with the DOE National Clean Hydrogen Strategy and Roadmap, is 50 million metric tons per year (MMTpa) by 2050[4]. The amount of hydrogen needed for LDES applications is small compared to this.

Along with defining different mechanisms to evaluate LDES costs and benefits more accurately, there are also broader approaches that can be used to lower LDES costs. For example, several LDES cost components and "soft" costs are expected to decline as deployment increases due to economies of scale, increased experience, and reduced risk. Therefore, a critical need exists to identify further support FOAK commercial projects that are challenging to finance because their risk profiles do not fit neither venture capital nor infrastructure funds.

FOAK deployments are only valuable at reducing LDES costs if they support and lead to further second, third, and Nth of-a-kind deployments. These future deployments require a supply chain that can be matured and scaled effectively to result in cost reductions. Therefore, the limited financial support for FOAK needs to be given to projects that support LDES market growth in the most efficient manner, which likely means giving priority to LDES projects with established/emerging supply chains. Emerging supply chains can demonstrate planned regional/domestic economic benefit to further improve their changes of receiving public funding through tax credits (e.g., domestic content requirements), loan guarantees, and demonstration funding. LDES projects that can meet these criteria are more likely to strengthen private sector investor confidence and lead to other/future investments in supporting supply chains and sectors.

Moreover, an increase in the use of pilot programs (i.e., demonstrations) to test a variety of LDES technologies for different use case / applications for different customers will likely have significant positive impact the scaling of emerging technologies, which in turn would improve the level of investor confidence and contribute to decreasing costs.

Challenge #2: *LDES technologies must achieve 7-15% improvement in roundtrip efficiency to compete with Li-ion storage and hydrogen.*

The LDES National Consortium recognizes that LDES RTE is typically listed as the third most important factor affecting industry concerns creating impediments to broad commercialization, behind cost of storage and technology maturity. To compete with Li-ion batteries in a range of 80–90% RTE by achieving 7–15% improvement in storage efficiency, it means that the RTE of a storage technology needs to be above 50% at least, which also provides an acceptable cost of storage. It is a target performance parameter in evaluating storage technologies or performing technoeconomic analysis.

Moreover, the LDES National Consortium agrees with the premise that "LDES round trip efficiency needs to improve" because it will have positive impact on LCOS determinations, which is the main factor for

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[4] *Pathways to Commercial Liftoff: Clean Hydrogen*, p. 1, March 2023.

selecting/ranking LDES technologies. And also, RTE is a common issue for majority of the LDES technologies currently.

However, for necessary balancing of this discussion and the assessment of this challenge area, the LDES National Consortium posits that, while RTE is important, it is only one of the performing factors that could improve LCOS for LDES technologies. It is a KPI but just one of many KPIs for LDES. Additionally, preferable energy-efficiency metrics would be: 1) RTE, 2) discharge efficiency, and 3) charge efficiency, which should all be measured at rated power. Values at partial power (e.g., 50% rated) would also be interesting for many potential LDES applications.

Further, this challenge regarding RTE improvements that was included in the Lift-off report refers to "LDES technologies" generically and it is the position of the LDES National Consortium that RTE evaluations require technology-specific assessments. RTE is highly dependent on a technology type and commercial maturity in optimizing its design and operations. It is the position of the LDES National Consortium that a technology-agnostic approach toward evaluating LDES RTE will not be useful in terms of developing industry recommendations.

With these considerations in mind, there are additional questions associated with the challenge of improving RTE performance among LDES technologies that the LDES National Consortium continues to consider, including:

- How do LDES RTE targets change if the price of renewable electricity continues to decrease as projected (e.g., to < $0.02/kWh)?
- How do LDES RTE targets change as renewable curtailments increase?
- How are Discharge Duration (i.e., discharge time at rated power) and RTE related, i.e., is it more or less important to have a high RTE as the duration of energy storage increases?
- Should discharge efficiency be treated as more important than charging efficiency since this impacts the amount of energy-storage media required to deliver a specified energy capacity?
- Is there really a minimum RTE to be acceptable or is it case by case?

In addition, the heterogeneity of use cases will likely influence RTE potentials for specific LDES technologies and should be. Use cases identified for this analysis that should be considered for specific LDES technologies include but are not limited to, the following:

- Capacity firming
- Storage strategies for disadvantaged communities
- Avoid or delay transmission line investments
- Arbitrage
- Baseload capacity replacement
- Fast frequency response
- Electric vehicle charging during off peak hours
- Black start

- Resiliency
- 24/7 PPAs for commercial and industrial (C&I) customers (e.g., data centers)
- Transmission deferring and congestion relief

Improving the efficiency of LDES technologies demands a comprehensive approach. The recommendation encompasses enhanced R&D funding, increased collaboration with academic institutions and national labs, information/data exchange with existing demonstrations, and the establishment of performance standards. Each component is critical: R&D funding promotes technological innovation, collaborations can lead to breakthroughs in physical understandings, pilot projects and their data facilitate practical testing and optimization, and performance standards govern that development assesses efficiency metrics uniformly. Consequently, the efforts of the LDES National Consortium to effectively address this challenge require additional work to assess the factors associated with specific LDES technologies.

Challenge #3: *The specific needs related to LDES workforce training (i.e., skills and training) are presently not well defined.*

The LDES National Consortium recognizes that a thorough "needs assessment" specific to the unique workforce requirements associated with the anticipated growth of LDES technologies has not been conducted within the energy and utilities industry. This needs assessment should include workforce training needs; risks, skills, and training specific to each LDES category type; and considerations of sub-categories of specialized labor needs (e.g., engineering & construction, electric vehicle manufacturing); and preparing renewable system construction to accommodate a significant increase of LDES technologies that seek to interconnect at distribution and/or transmission grids.

As the energy landscape evolves towards a multitude of grid-connected renewable generation and storage systems, grid security becomes increasingly critical. The safe operation of LDES systems requires a well-trained workforce that understands the specific risks associated with these systems and how to mitigate them. Including modules on the safe installation and maintenance of battery storage cabinets in the training program will help to ensure that the workforce is equipped with the necessary skills to reduce risks and ensure the efficient operation of LDES systems.

A dedicated work group or task force, which can likely be formed within the scope of the LDES National Consortium, can develop a robust training program that equips the workforce with the necessary skills to ensure grid security, thereby addressing the current lack of definition in LDES workforce training needs. This program should provide clear guidelines on the necessary skills and training for ensuring the security of the grid-connected renewable generation and storage systems.

Subsequent industry recommendations related to structural changes will be most effective with a realistic picture of where obstacles exist. Accordingly, the LDES National Consortium emphasizes the following steps as a pre-requisite to developing additional recommendations: 1) a gap analysis of existing workforce studies in this and closely related industries; 2) a focus group with larger LDES companies to assess their labor needs, including companies in systems, deployments, and throughout the supply chain; and 3) a review of current publicly-posted job openings at LDES companies. The result of these three activities would be a comprehensive view of workforce needs and would highlight any knowledge gaps in this space.

Challenge #4: ***A uniform approach toward developing resource adequacy compensation for LDES technologies does not exist, in either regulated markets (PUC evaluation) or competitive markets (ISO/RTO).***

The LDES National Consortium acknowledges that a uniform definition of resource adequacy that can be utilized across regulatory jurisdictions, including both state/retail and federal/wholesale levels, does not presently exist. Clarity is needed regarding what resource adequacy actually means (i.e., what it is and what it is not), in pursuit of developing a standardized definition that can be utilized universally for rulemaking and grid planning purposes. A uniform approach toward developing resource adequacy compensation, which should be applied across all US states, would be an effective means to accelerate the adoption and commercialization of LDES technologies. The dissemination of this uniform approach should be coordinated with and potentially disseminated through national trade associations such as NARUC, NASEO and the National Governors' Association.

Current limitations of capacity accreditation methods include:

- Limited storage durations modeled: studies do not represent diverse energy storage durations (they generally only model storge with less than 10-hrs of duration).
- Limited forward-looking time-horizon: Studies do not evaluate 10-20 year long-term scenarios necessary to align with typical resource lifetimes and grid planning horizons.
- Results are entirely dependent upon limited portfolios and scenarios: ELCC results are highly sensitive to the portfolio modeled, and yet studies only consider a limited number of resource portfolios, which tend to reflect the status quo.
- Studies typically assume that existing thermal resources persist and operate more reliably than they do in reality.
- Studies typically assume that the adoption of renewable energy and storage resources remains unreasonably low.
- Studies do not consider atypical weather years and coincident reliability risks.

  Studies often fail to capture "diversity benefits" of renewables and storage: Increased penetrations of renewable resources will oftentimes make net load shapes peakier or exacerbate lull conditions, changing the ELCC of storage resources.

In addition, it is the observation of the LDES National Consortium that resource adequacy frameworks do not currently compensate LDES technologies for the diversity that they bring the grid's energy resource mix. Existing RA frameworks often rely on reliability metrics such as ELCC, EUE, LOLE, or LOLH, which seek to define the effectiveness of providing services when the grid needs it most. These existing metrics may not be adequate metrics for defining LDES' contributions to resource adequacy, or defining the appropriate levels of compensation for these contributions. It is important that resource adequacy frameworks appropriately include the cause of outages in compensation metrics, along with other system dynamics that may be unique to LDES.

Moreover, policymakers with an oversight role regarding resource adequacy rules, both at the state and federal levels, should be encouraged to investigate how to have broader capacity support on a long-term basis (i.e., thinking more like 5-10 years in terms of energy adequacy instead of capacity adequacy in the near term). There has been more support from NERC recently in this direction (e.g., NERC is reevaluating how it defines reliability and seeking to develop a uniform approach). NERC has established a balancing requirement (i.e., in operations there must be operating reserves that are met). However, NERC has not established a planning standard or required planning coordinators to address a 15% margin. There has been discussion that NERC could potentially set planning reserve margins as they have a "reliability first" approach where an area must conduct a "one-in-ten" assessment, but that is NERC's only current provisions that relates to long-term planning.

Through this process of establishing a planning standard, which is taking place at NERC, there is opportunity for state and federal agencies to work together to assess how LDES can be helpful in mitigating extreme weather events (as one example). Another area that is suitable for facilitated state-level and national collaboration is the development of a uniform modeling tool that is capable of looking across multiple weather years (e.g., extremely high precipitation year, low precipitation year to understand the variability trends in precipitation, winter storms versus summer storms, and then optimizing across those different weather years to understand what resource has the least cost resource).

The industry needs new tools, market mechanisms and valuation metrics that to determine the value of LDES technologies, and thus the basis for their respective compensations, when such technologies are required to sustain the grid during low-frequency, high-cost reliability events. Similar to IRP processes, determining resource mixes necessary for reliability will require modelling and coordination between modelers, resource adequacy market participants, resource owners and developers. These models will need to capture storage resource operational parameters to ensure reliable outcomes. These are additional complexities that are not included in most resource adequacy constructs today.

The National Laboratories can serve as a bridge between the national and state-level efforts, and can contribute to the preparation of preliminary guidance for state PUCs and ISOs/RTOs on methodologies that can be adopted to incorporate resource adequacy compensation metrics in IRP processes and wholesale tariffs, respectively. The preliminary guidance should identify specific types of reliability attributes that might be compensated in these markets (e.g., hourly energy attribute certificates, nodal and locational pricing).

The LDES National Consortium has also observed that the roles and levels of influence that RSCs have within their respective RTOs are very inconsistent. At this time, RSCs have varying levels of influence depending on the RTO market in which they engage and a more consistent, uniform role definition for these entities is an industry need that has been identified in LDES National Consortium working groups. The role of RSCs and their ability to make recommendations to their respective ISOs/RTOs also varies greatly and in a number of regions these RSCs reportedly have very little influence to ensure that developing RTO rules are consistent, or at least not in conflict, with policies that have been adopted at the state level.

Challenge #5: *A comprehensive assessment of necessary supply chain improvements specific to LDES technologies does not presently exist.*

The LDES National Consortium recognizes an industry need for low cost, high availability materials for the LDES supply chain to be resilient. However, the fact that reliable data regarding future material availability is very limited remains a particular challenge. Further, the LDES National Consortium recognizes the need for a better understanding of required capacity to support the LDES commercialization goals and develop strategies to reduce LDES costs.

Accordingly, there are a number of knowledge gaps associated with this challenge that the LDES National Consortium continues to assess, including but not limited to:

- The lack of publicly available supply chain data. Hence, the need for a centralized and publicly available repository for calculations of the volume of equipment and raw materials is necessary to scale up LDES technologies is a critical industry gap. These calculations are necessary for estimating the long-term scale of the required mining/refining/import of raw materials. Further, public information regarding LDES supplier profile will help drive demand for lower risk materials and improve the supply chain resilience.
- The energy industry presently lacks sufficient fire safety standards for LDES installations. There have been many lithium battery fires in LDES installations, but other batteries do not have the same thermal, toxicity, and fire safety problems that lithium does. A thorough assessment of fire safety and other hazards associated with the full range of LDES technologies is needed.

  The energy industry presently lacks workforce training for energy generation and storage, which in turn limits the creation of new jobs. General understanding of workforce issue is known, but specific job duty/code gap is not well understood.

At this time, the industry recommendations prepared by the LDES National Consortium to address this challenge have been broken up into the following categories: 1) the technology maturity requirements and maturation process; 2) assumptions and environmental conditions; 3) technical and administrative challenges; and 4) grid services requirements. These categories have been generalized to address a wide range of LDES technologies.

Organized by LDES technology type, the LDES National Consortium is preparing a preliminary list of supply chain considerations, inclusive of needs pertaining to raw materials, streamlined production processes, standardized installations, manufacturing & assembly efficiency improvements, automated assembly, cost-efficient sourcing, sub-components, etc. Subsequent industry recommendations will also be included on design optimization, manufacturing tool development, improvements in manufacturing processes, and precision control and optimization across production lines.

Challenge #6: ***There is presently a lack of resources regarding how to evaluate grid upgrades or expansions that will be necessary to accommodate both new variable renewable generation sites and LDES systems.***

LDES will be a necessary component of deep decarbonization plans with a transition to vast deployments of intermittent renewables. However, there is currently an unlevel playing field for evaluating the benefits of LDES relative to traditional generators and other shorter-duration storage systems. An observation formed by the LDES National Consortium with regard to this challenge is that, when evaluating grid upgrades or expansion to address reliability, a full range of models (e.g., interruption cost studies, contingent valuation studies, input-output models) have been used to evaluate reliability benefits. However, current reliability tool kits (i.e., specialized software linked to specific data sets that apply to solving specific problems) are unable to model and capture the value of LDES technologies. These are fundamental modeling challenges that need to be overcome to demonstrate the reliability benefits of LDES technologies.

For example, CEMs are widely used to evaluate the least-cost portfolio of electricity generators, transmission, and storage needed to reliably serve load over many years or decades. Various forms of CEMs are used by local utilities and regional entities to evaluate systems. Most of these modeling tools use a reduced temporal resolution to represent operations, either with several unlinked representative hours, or with several unlinked representative operational periods, such as representative days or weeks. While this approach may be appropriate for evaluating short-term (<10 hours of energy storage), it is less suitable for modeling LDES technologies. Modeling unlinked representative periods cannot represent the full value of LDES technologies, specifically since it does not allow the shifting of energy between representative periods, meaning it cannot capture multi-day or seasonal shifting operations.

Consequently, LDES is difficult to model in existing CEM planning models as it is much more dependent on an accurate representation of chronology than other technologies. Techniques exist for modeling LDES in these planning models; however, it is not known how differences in spatial and temporal resolution impact the performance of LDES, creating a research gap. Moreover, currently available modeling tools are insufficient to capture the functionality and accompanying value of the full range of LDES technologies. Specific modeling gaps relate to reliability values and transmission values. There exists an important opportunity to examine how existing modeling tools can be advanced to include sub-hourly artificial intelligence machine learning approaches to address computational challenges and full flexibility values.

In addition, current toolsets fail to capture: the full 8,760 hours in a 1-year simulation, value at all levels of the grid (e.g., bulk energy, ancillary services, distribution, transmission), sub-hourly flexibility, the value of reliability services, the value of LDES' contribution to grid resilience through an assessment of low frequency high impact events, and ways to consider siting/sizing decisions. Enhanced datasets should include those relating to future climate/weather and the associated impact on renewables production and load. Third party (i.e., national labs) validation of performance to inform cost and performance inputs to the model/planning process would also be valuable.

Thus, the capabilities of existing modeling software tools that are currently available to grid planners are insufficient and upgrades are necessary to capture the full value of LDES resources. It is the LDES National Consortium's position that to address this challenge the focus should not be on the development of a novel, comprehensive model but rather filling key gaps to support the advancement of existing commercial tools, including those related to capacity expansion, transmission expansion, production cost, resource adequacy, and other more comprehensive tools used in the integrated resource planning process.

Another factor impacting this challenge is that current standards and policies that govern energy storage interconnection (IEEE 1547 and 2800, FERC large generator interconnection and small generator interconnection agreements) were developed while lithium-ion batteries were the dominant grid energy storage technology. While emerging, inverter-based LDES technologies may be adequately covered under existing standards, many novel and new LDES technologies are not inverter-based, and may rely on technologies (such as variable frequency drives) with unique characteristics not addressed in current standards. Interconnection standards and policies should be reviewed and updated to contemplate the requirements of emerging technologies. This review should also address potential challenges for interconnecting behind-the-meter LDES technologies.

Further still, many LDES technology providers lack the engineering expertise and experience developing and maintaining electric grids, which may leave them unprepared to handle the financial and technical requirements of the grid interconnection process. Utility members of this group report that some developers of new technologies have not yet obtained performance data from their invention that is necessary for thoroughly performing interconnection studies, which can cause extensive delays in installation. Furthermore, other providers have not yet obtained sufficient funding to undertake the interconnection studies. By providing developers of emerging LDES technologies with detailed information about the interconnection process—such as technical information requirements, costs, and timelines—developers will be able to make the necessary financial and technical preparations in advance of submitting deployment projects for an interconnection study.

The LDES National Consortium recognizes that the status of both existing electricity system infrastructure and system needs vary significantly across different US geographies and demand centers. There is a need for a comprehensive study that assesses local renewable resources and weather patterns to estimate the demand for storage in a locality, as well as the type of storage that is required. For example, some localities may be able to benefit from thermal energy storage but may not have the grid infrastructure required to support this technology, or vice versa. In this case, a thermal storage developers would benefit from techno-economic analyses that capture both the availability of thermal-based resources and the corresponding grid needs in a specific location. Localized storage demand is driven by the availability of grid infrastructure, while the ideal type of storage depends on the geographical and environmental conditions, and these data are not always readily available.

A guidance document will be prepared that outlines the fundamental components to be included in an evaluation of grid infrastructure sections. Included in this guidance document will be instructions on how to evaluate grid conditions to measure both the desirability and relative feasibility of LDES in a particular state, as well as the overall generation mix. Factors include the percent penetration of variable renewables, the transmission and distribution investment gap, grid resilience as measured by SAIDI/SAIFI scores, and the ease of interconnection. The guidance document proposed by this recommendation should include instructions on LDES technology evaluation metrics, frameworks, application of new tools/data sets, and other support information as required, and followed by the preparation of a guidance document and provision of technical assistance (TA) to support the adoption of those frameworks, methods, and tools. An initial outreach effort should be used to define the information most helpful to regulators and market operations, and should include: energy storage technical performance and cost, methods used to value energy storage and key gaps/challenges addressed through the suite of frameworks/tools/data sets developed by DOE, approaches for measuring and valuing stability services including reliability/resilience, federal and state incentive policies affecting LDES deployment, and best practices in LDES consideration in the evaluation of grid infrastructure investments. Follow-on TA efforts should be defined by specific topics areas and include staff from multiple national laboratories.

Challenge #7: ***Presently, there is no publicly available evaluation of LDES technologies against primary competitive factors.***

The LDES National Consortium acknowledges that the lack of a standardized evaluation tool for comparing LDES technologies hinders the ability of project developers to make informed decisions. Within the scope of the LDES National Consortium's SOW, a "competitive factor matrix" will be prepared and made available on the Community of Knowledge and Best Practices that evaluates known LDES technologies against these six competitive factors: 1) nominal duration—measure of how long the storage system can discharge at its maximum power rating; 2) ramp rate—the speed at which a storage system can increase or decrease output; 3) response time—the time it takes for a system to provide energy at its full rated power; 4) levelized cost of storage (LCOS)—cost of the LDES system measured in $ per MWh; 5) minimum deployment size—smallest capacity deployment that is technically feasible; and 6) footprint—amount of land needed to deploy the system. These primary competitive factors should be weighted according to their relevance and hierarchy in the overall competitive matrix.

A list of LDES technologies have been put together by the Technology Evaluation & Testing Tiger team. The list currently includes an extensive list of the main physical attributes of the respective LDES technologies, but does not include financial criteria. In order to be able to compare the different LDES technologies, the cost data is required; the overall value is not trivial to quantify.

LDES technology analyses should separate storage capacity from charging/discharging electronic system. This would allow determining the flexibility in expanding storage without considering the incurred generation cost, which is unlike how batteries are considered provides both storage and power generation in one entity. Six competitive factors are specific to each energy storage technology. The technology evaluation tool should include all relevant technologies. Demonstrating emerging technologies is key to meeting various use case requirements with respect to some or all of the six competitive factors.

Different use cases can prioritize different attributes. These attributes include LCOS, capital costs, operation and maintenance costs, round-trip efficiency, lifetime, self-discharge rate, ramp rate and/or response time, supply chain, safety, and footprint. Across use cases, there is uniform agreement that LCOS (or similar cost metric) is the single most important attribute. However, after that initial priority, the attribute prioritization can vary. If the technology is aiming to participate in ancillary service markets (e.g., frequency response) ramp rates are vital. If the technology needs to be in a small patch of land due to transmission and other locational constraints, footprint becomes an important attribute. The greater the duration targeted for the device; the more self-discharge rate becomes important. Lastly, the supply chain and domestic content of LDES technologies can become more important if tax credits favor these attributes if enough to qualify for increased benefits.

By establishing a comprehensive competitive factor matrix, stakeholders can evaluate technologies based on consistent and relevant criteria. This matrix would outline the key metrics necessary for comparing different LDES technologies. The Long Duration Energy Storage National Consortium should host this matrix on its website, ensuring it is easily accessible to all stakeholders. Industry experts and research and development groups should contribute to the matrix by providing technology specific inputs for each metric, facilitated by DOE funding. Additionally, the matrix should be designed to allow for project-specific inputs, enabling precise comparisons of technologies tailored to particular applications.

This tool will enhance transparency and enable more objective assessments of technology performance, facilitating better investment and deployment decisions. The involvement of industry and R&D groups in populating the matrix ensures that the evaluations reflect current knowledge and expertise, while the review of the Lab Partners guarantees rigor and accessibility.

A prototype of the technology evaluation matrix is expected to be made public in the fourth quarter of 2024.

Challenge #8: *LDES is not included in most utility grid firming plans.*

It is the observation of the LDES National Consortium that many utilities continue to develop and executive grid firming plans with traditional resources (e.g., base-load coal, gas, and nuclear plants; flexible coal and gas peaking plants; natural gas deployments) without consideration of LDES alternatives. This is likely due to a lack of existing guidelines on how to evaluate substituting LDES technologies for planned expansions of natural gas capacity. Provide guidance document to all utilities (IOUs, municipal and electric co-operatives) outlining steps that can be taken to evaluate LDES against traditional resource investments.

Current levels and shorter-term forecasts of renewable energy generation, coupled with forecasts that do not include severe deficits and surpluses in energy production from renewables, may not necessitate LDES as the firming/grid reliability needs for that scenario is relatively easily achieved with shorter duration energy storage. However, with higher levels of renewable energy penetration and long duration events such as extreme weather that leads to long term spikes in energy demand that coincides with reduced energy production, longer duration energy storage is necessary. The fact that grid firming plans neglect LDES could be a result of not planning for these realistic scenarios. If grid firming plans were required to include scenarios that include higher penetration of renewables and protracted energy deficit and surplus periods, long duration energy storage would be a logical means of achieving decarbonization goals.

Utilities have historically struggled to identify reliable cost and performance data sources for emerging technologies, which has slowed their integration into planning models and prevented accurate modeling of their grid benefits. This challenge is particularly relevant to LDES technologies, many of which are in an early stage of development and do not yet have demonstrated cost and performance data. Gathering data for a wide range of technologies and making it publicly available will significantly reduce the transaction cost of individual utilities trying to find that data and facilitate more accurate representation of LDES technologies in resource planning models. This recommendation will likely require additional funding from the DOE.

Planners use various future scenarios to identify how grid needs change if certain market conditions emerge, or certain policies are enacted. To identify the value of LDES technologies on the grid, it is important to not only consider deep decarbonization scenarios that will derive that value, but that are designed over a sufficiently long time period and including multiple potential performance scenarios. These scenarios also need sufficient granularity within each year of the modeling period to identify how grid needs change as new energy storage technologies are added, how the need for LDES increases over time, and the inflection point at which LDES technologies become necessary, in order to send clear investment signals. Scenarios that model extreme weather events and gaps in renewable energy generation will also be needed to quantify the full value of LDES technologies in maintaining reliability for decarbonizing the energy grid.

Utility resource planning generally consists of limited-hour, chronological capacity expansion modeling approaches that take a limited number of representative days and/or weeks to assess flexibility needs. Full-year, chronological capacity expansion modeling replaces the use of representative days and weeks with full accounting across all 8,760 hours in a year. This approach provides the means to assess the entire cost, value and reliability contributions of potential long duration and seasonal storage resources of utility portfolios, in particular across daily and seasonal gaps in renewable energy generation. However, such approaches pose significant computational challenges that will require creative modeling approaches and access to advanced computing resources.

Power flow studies to assess potential transmission reliability deficiencies and recommend potential network reinforcements (e.g., upgrades, new transmission line investments) are typically performed separately from the main resource planning process. This can be problematic because changes in the network impacts the overall system topology, which in turn may limit the optimal generation and storage resource portfolios for a utility. Developing an adequate feedback loop between power flow assessments that can identify and estimate expected deficiency-correcting network reinforcements is one way to approach this issue. Another approach is to re-assess the "upstream" capacity expansion and production cost modeling studies typical of today's utility resource planning process to see how they can support more cost-effective and reliable future generation, storage, and transmission resource.

Utility resource planning and capacity firming are another category of use cases for which LDES technologies can be deployed in the near term. Utilities can more easily carry the financial burden for the initial deployments and can help developers access additional state- and federal-level funding. The Teaming Partners also indicate this as a major use case for LDES well into the future with the evolution of capacity markets to more adequately value LDES services as penetrations of renewables grow. Furthermore, the retirement of traditional baseload capacity (e.g., coal and natural gas) due to declining economics and need to meet emission reduction targets for the electricity sector indicates the inclusion of LDES technologies in resource plans is needed to be a source of dispatchable power.

The final category of use cases for which LDES is likely to deployed in the near-term is microgrid resiliency and other resilience/back-up applications. For example, LDES technologies are predicted to replace back-up diesel generators to overcome power disruptions that last longer than the storage cycle of lithium-ion batteries (i.e., 4 hours). Additionally, microgrids and islands inherently experiencing greater sensitivity to changes in renewables availability, due to the lack of aggregation across larger geographical areas; resiliency is more valued in these energy systems due the high cost of providing back-up power. Therefore, LDES systems can provide the necessary firming services across the entire year during discrete lulls in renewable production.

Moreover, the LDES National Consortium recognizes the opportunities that will be driven in the long-term from FERC Order 2222, which seeks to drive the development of wholesale market opportunities for aggregated BTM storage applications in wholesale markets. Compliance with FERC Order 2222 is currently unfolding through tariff revisions underway at the RTOs/ISOs. The relevance herein is in the extent to which aggregated BTM storage can increasingly be utilized as a means to derive LDES value and further enable commercialization opportunities.

There is also no clear definition of the value of resilience. Consideration of low frequency, high impact events would be a key component of any such evaluation. While there is a burgeoning literature on these topics and much can be learned from spending time reviewing the academic contributions to our understanding of these benefits, there is a lack of consensus among experts and such knowledge may not be particularly accessible to utilities and regulators. Additionally, traditional methods of quantifying things like value of lost load might lead to inequitable outcomes, as lower-income energy users would be valued lower than their higher income counterparts from the perspective of economic productivity or the willingness to pay to avoid outages, thus signaling a preference toward grid firming services in more socioeconomically advantaged areas.

To further address these challenges, the LDES National Consortium will seek to develop and provide guidance and tools that relies upon these recent contributions for the sake of quantifying the value of resilience and reliability services.

Challenge #9: *LDES use cases require market changes at the wholesale level.*

It the observation of the LDES National Consortium that the six use cases identified in the Liftoff reports (load management services; firming for PPAs; microgrid resiliency; utility resource planning; transmission and distribution deferral; and energy market participation) all require a varying degree of market change to become competitive. Evaluate identified use cases and recommend market planning studies (e.g., how the wholesale market structures of existing RTOs need to be revised to address specific use cases for LDES to participate and be compensated, considerations of the unique elements of specific use cases that should be assigned an economic value, and suggestions on how the “value stacking” of multiple use cases within an individual market should be approached, etc.) based on a confirmation of the validity of use case profiles.

Costs for storage resources are different than marginal costs for traditional generations, which is how typical electricity markets set prices for all participating resources. Storage resources determine electricity market profitability by the “spread” between the purchase price of energy and the sale price for energy, relative to a hurdle representing marginal for operating, opportunity costs, and round-trip efficiencies. Introducing a product like a call option – likely paid at the time a resource is charging –should be used to generate prices for services provided by energy storage. This should include a suite of products tied to duration for holding energy – where very long durations could accommodate seasonal storage. A product like this should help create more effective electricity market prices for more traditional resources and better pricing for storage resources. These should also be effective for managing resilience risk during periods when storage could be critical to maintain grid reliability.

Today electricity markets optimize over a 24-hour horizon, at most. A 24-hour window is not sufficient to optimally schedule a long duration storage resource. Storage resources are dispatched in real-time markets, these look ahead at most an hour, and often not even that long. To optimally schedule a 10-hour duration storage resource, a grid planner would likely need more than a 2-day look ahead window to consider the best times to charge the resource and the optimal times to discharge the resource. For longer duration resources, even broader windows will be necessary. Broader look-ahead windows must be considered by grid optimization procedures to effectively utilize storage resources. Look-ahead periods will need to increase as storage durations increase, with 90-day look-ahead periods being necessary to capture operations of multi-day storage resources with 24+ hour durations.

Challenge #10: ***ISO and RTO markets will need to develop support mechanisms specific to LDES technologies.***

It is the observation of the LDES National Consortium that LDES technologies have the potential to provide an array of system values that are not captured in current market mechanisms at the wholesale level. When LDES technologies are part of a least-cost resource portfolio, providing system reliability and value to customers, LDES technologies may not yet earn sufficient revenues in the existing capacity, energy, and ancillary service markets to incentivize their development. The system value that LDES provides should be codified through market products and/or compensation mechanisms that explicitly value LDES durations, contributions to reliability, and ability to act as a firm, zero-carbon resource as attributes. These mechanisms would enable states with deep decarbonization goals to procure resources that support these goals. Such mechanisms need to be structured in a way that is technology neutral but is still aligned with system needs, for example based on storage duration.

A comprehensive study of which support mechanisms need to be developed in which ISO/RTO markets, and for which LDES technologies, does not presently exist. Conduct reviews of current ISO/RTO market plans (e.g., Order 841 compliance filings) and develop ISO/RTO-specific evaluation of support mechanisms needed to create commercial pathways for LDES technologies (e.g., targeted tenders or procurement carveouts for LDES of 30–50 hours, risk-reduction mechanisms) for certain LDES technologies to scale within these regions.

Moreover, the LDES National Consortium observes that there is a concerning gap among ISOs/RTOs and FERC (along with state regulators) regarding how LDES technologies can support different use cases. This knowledge gap is likely delaying the development of effective support mechanisms. Additional work on studying LDES use case / applications needs to be encouraged more broadly across these entities, as different use cases may necessitate different recommendations, market support mechanisms, etc.

Moreover, in assessing this challenge, consideration was given to the role that ISO/RTO planners have assumed in driving portfolio changes in their respective regions. The fundamental role of ISOs/RTOs is to establish market rules that create efficient prices for resources. Support for decarbonization concepts and the supporting role of renewables and energy storage solutions, including LDES technologies specifically, must originate in state or federal policies (or both), and only then will ISOs/RTOs find it appropriate to align their market mechanisms.

Assuming a technology-neutral approach in the development of market support mechanisms is an additional theme that permeated discussions on this challenge. ISOs/RTOs should not be expected to give preference to specific resources, whereas state policymakers can and do. Thus, developing any support mechanism at the RTO level that are technology specific are unlikely to be accepted in multi-state RTOs. Rather, support mechanisms should be based on attributes, applications, and performance rather than geared toward any specific LDES technology.

Unfortunately, few support mechanisms for energy storage have been implemented by ISOs and RTOs. Those that exist vary dramatically between markets, having in common only that they tend to be focused on short-duration battery storage. A recommendation of what good practices are for these support mechanisms is not possible without further study of what has been effective in what circumstances, what other models have been proposed but not implemented, and what the values and limitations of the RTOs and ISOs themselves are. There is need for a study that assesses these existing and potential practices. This study should leverage a variety of information sources including, but not limited to, the following:

- ❖ Current RTO and ISO support mechanisms, where they exist;
- ❖ Existing studies of support mechanisms for energy storage (whether or not LDES) that have been conducted by DOE National Laboratories or published in the academic literature;
- ❖ Data collection from pilot and prototype LDES installations (either already in place or built for purposes of data collection);
- ❖ International practices and studies; and
- ❖ Focus groups of ISO and RTO representatives to better understand their values and limitations

It is unclear how RTOs/ISOs determine the value LDES assets, and whether that valuation process is consistent across the various RTOs/ISOs and consistent with industry expectations. A forum such as this would allow open communication and understanding of expectations. Furthermore, a “working forum” would allow proposed concepts to be explored and input received long before they are codified, improving the chances that they will be acceptable to all parties. This forum should be inclusive of industry, technology providers, and other stakeholders to allow feedback to RTOs/ISOs while ideas are under development.

It is the observation of the LDES National Consortium that developing market mechanisms intended to enable the use of LDES to replace the need for new transmission lines is a potentially lucrative use case. However, it does not appear that “storage as transmission” tariffs that have been developed in some RTOs have proven to be successful, and this is a discrepancy that warrants further analysis. Perhaps with the exception of ISO-NE and CA-ISO, these tariffs are having very little effect (i.e., storage is still rarely considered as an alternative to transmission and even more rarely selected).

This may be due to the fact that transmission planning processes are still predominantly focused on infrastructure solutions (i.e., continuing to build new wires as a default solution), but the question remains why the supposedly incentivizing mechanisms of the “storage as transmission” tariffs are having little if any effect on market stimulation. Moreover, FERC does not presently review transmission plans. Thus, when RTO market tariffs are submitted there does not appear to be any built-in checks-and-balances mechanism that would evaluate why storage was not pursued as an alternative to new transmission assets. The process of asset selection along with the lack of effectiveness of proposed SAT tariffs would be key components of this proposed examination.

Additional analysis is needed to develop new methods used for the pricing of emissions. Carbon pricing as a fixed value may not send the right market signals or achieve intended impacts.

Challenge #11: ***State-level policymaking specific to LDES has been very limited.***

It is the consensus of the LDES National Consortium that state policy will need to drive the development of markets in which LDES technologies can be integrated and reach commercialization. While regional or federal decarbonization policies that include renewables and/or energy storage requirements would certainly be beneficial, in reality this is unlikely to be feasible and thus state-driven activity is an appropriate focus of many market development recommendations. However, reconciling state policy with regional markets is extremely important and a significant consideration that influenced the development of recommendations addressing this challenge.

As of September 2024, only California has taken any substantive steps to create policies designed to enable the development of commercialization pathways for LDES technologies. In contrast to what is the exception of California, LDES policymaking in other states is essentially non-existent. Much of this may be due to lack of knowledge among state regulators regarding actions that can be taken, such as modifying state RPS requirements; tax breaks or other incentives to attract early deployment or manufacturing hubs; new IRP requirements; and clarifying ownership policies. State policy measures must be developed stimulate market interest in LDES technologies in state-regulated retail markets and for applications designed specifically for utility distribution networks.

Less than a handful of states have required that utilities under PUC regulation include energy storage in their IRPs. This presents a persistent gap in which utilities may not be inclined to consider energy storage technologies as an alternative to traditional resource planning unless explicitly required to do so. At the very least, energy storage alternatives, and specifically LDES, should be addressed as an option anytime new generation or T&D investment is being considered, and not confined to planning for peaking, baseload or anything else.

An observation formed by the LDES National Consortium is that state PUCs may need more direction from legislatures and/or executive directives from governors stating a desire to see LDES technologies move forward with an initial pilot procurement mechanism, which would then (hopefully) garner interest from the PUC and ultimately more adopting these technologies.

Moreover, while individual states are setting their own specific policies for utility procurement of energy storage solutions, stronger ties between states, grid operators, and regional planners is critically important and currently lacking. Greater emphasis must be continually placed on identifying the ways in which states can become engaged in regional market proceedings.

States may not have LDES policy yet, but many do have related policies, for electrification and decarbonization. This effort would provide recommendations and draft language for incorporating LDES into state electrification and decarbonization plans, RPS, distribution grid planning etc. A comprehensive LDES policy recommendations document that should be developed and provided to the states should include the following guidelines:

- Proven approaches toward LDES-related policy (i.e., “best practices”)
- Policies to avoid (i.e., policies that could inadvertently harm future LDES deployment, markets, etc.)
- Approaches for grid planning and resource adequacy planning to address multi-day events
- Steps for engaging with utilities and ISO/RTO operators in order to influence market rules and interconnection procedures.[5]

[5] (Note: PNNL did a short paper last year on how states can get started with LDES: https://www.tandfonline.com/doi/pdf/10.1080/00963402.2023.2266939. There is also a conference paper that will be published soon about using energy-based storage targets (MWh) instead of capacity-based targets (MW)).

- System planning needs to include a temporal component when incorporating LDES. Currently, state ES targets use MW as the unit of measurement. This favors short duration storage, which is the cheapest way to get to a high number of megawatts. LDES provides different services and requires MWh as a metric to judge cost effectiveness.

Another observation is a universal benefit/cost model for LDES is needed so that policymakers, regulators and program administrators can compare LDES technologies to other resources from the cost/benefit perspective. An LDES benefit/cost model should incorporate a wide variety of end-user applications, for example, resilience (both BTM and at the grid level) and grid congestion mitigation. An LDES benefit/cost model should include an avoided cost The LDES National Consortium recognizes the need across the industry to consolidate lessons learned from leading states and make them available to other states. This recommendation envisions a repository in which companies would provide cost and performance information to a neutral third party such as the National Laboratories which could control the data from being publicly accessed. (Note: This idea is already part of the LDES Consortium SOW. Also, PNNL has started a database for ES and could expand it to include pre-commercial LDES technologies. https://www.pnnl.gov/ESGC-cost-performance).

Further, more effective modeling approaches to simulate future extreme weather conditions are needed for state policymakers. Climate records and other key data sets—e.g., weather-driven demand, renewable availability, and previous outages different weather profiles—are required to conduct this analysis. States will need reliability metrics that also consider the reality that, for example, a one 10-hour event is significantly worse than 10 one-hour events or that multiple long-duration events near each other will have a greater impact than a few events that are spread out over time. This analysis should also take a holistic approach that also includes an assessment of the need of natural gas, nuclear, etc. to avoid potential significant overbuilt and high customer bills in the winter peaking scenario.

Current levels and shorter-term forecasts of renewable energy generation, coupled with forecasts that do not include severe energy limited periods, may not necessitate LDES technologies as the firming/grid reliability needs for that scenario are likely more easily achieved with shorter-duration energy storage. However, with higher levels of renewable energy penetration and long duration events, the need for LDES technologies becomes more significant. The fact that grid firming plans typically neglect LDES could be a result of not effectively planning for these realistic scenarios. Further, as utilities are bound by an obligation to serve and driven by cost-recovery concerns, without a means to quantify the benefits of grid firming/reliability services of LDES technologies they will likely not be inclined to include LDES in their grid firming plans without an explicit requirement to do so.

The LDES National Consortium posits that energy storage procurement policies will likely need to be more specific and quantifiable with regard to the ways in which LDES technologies will participate in those policies. At present, 12 states have adopted an energy storage procurement goal, target or mandate. To date, 12 states including California, Oregon, Nevada, Illinois, Virginia, New Jersey, New York, Connecticut, Massachusetts, Maine, and Maryland have established such policies, but in most cases the specific amount of LDES required within that goal, target or mandate has not been specified. California has conducted modeling to determine the amount of LDES that will be needed but that has not been translated into a regulatory mandate. Procurement targets help firm investor confidence in future demand helping facility financing today through reduced demand risk. All-source solicitations put emerging technologies, such as LDES technologies, at a disadvantage. Targets should be carefully crafted and flexible.

There is strong interest among state public utility commissions to develop a standardized resiliency standard. This might also include reconsiderations of long-standing safety and SAIDI metrics and enhancing those standards by taking into consideration various LDES technologies and how they contribute to the reliability and resiliency of the electric grid.

The federal government currently owns national decarbonization objectives; however, these are currently objectives and not legally binding policy. Rather, most decarbonization targets and mandates are implemented and enforced at the state level. This disconnect makes it difficult for the federal government to assess national progress towards achieving decarbonization targets.

Effective policymaking requires sufficient knowledge about the needs for and opportunities of LDES in a variety of use cases. State policymakers/regulators as well as utilities have expanded their capacity to gain this information in recent years so now is a more effective/valuable time to engage with these entities. Policymakers, regulators, and utilities being shown the benefit/value of LDES deployment to their constituents increases the likelihood of all state policy changes recommended. With increased support from these key stakeholders, private sector investment confidence will increase.

Appendix B.

Table 1.

Identified Factors Impacting Round-Trip-Efficiency

Factor Impacting RTE	Possible Improvements
Technology: Redox Flow Batteries (RFBs); typical SOA RTE is 80% DC/DC	
Cell Voltage Efficiency	a) Improve cell performance b) New cell materials and cell designs
Cell Coulombic Efficiency	a) New cell, stack, or system designs b) New membrane materials c) Improved stack or system designs
Parasitic power losses	a) New system designs or balance-of-plant (BOP) components b) Reduce pressure drops and pump power
Power Conversion, both DC-to-DC and DC-to-AC	a) Improved power-conversion systems (PCS) b) Higher conversion efficiency devices
Technology: Lithium Ion	
Electronic and Ionic Conductivity	a) Materials with higher conductivity and improved contact b) Electrolyte with higher solution conductivity
Thermal Management	a) Utilizing low-energy heat removal b) Increasing operating temperatures c) Increasing mass heat capacity
Coulombic Efficiency	a) Reducing parasitic reactions and minimizing SEI formation b) Reducing degradative mechanisms
Internal Resistance and Wiring	a) Improving conductivity b) Reducing resistive losses
Charge and Discharge Rates	a) Reducing resistive losses

Stand-by-losses	a) Reduced cell degradation characteristics
Technology: Flow Batteries	
Electronic and Ionic Conductivity	a) Materials with higher conductivity and improved contact b) Electrolyte with higher solution conductivity
Thermal Management	a) Materials with higher conductivity and improved contact b) Electrolyte with higher solution conductivity
Coulombic Efficiency	a) Reducing parasitic reactions and degradative mechanisms
Charge and Discharge Rates	a) Reducing resistive losses
Internal Resistance and Wiring	a) Reducing resistive losses b) Increasing conductivity
Stand-by-losses	a) Reduced cell degradation characteristics
Technology: Electrochemical energy storage system	
Battery chemistry	a) Alternative battery chemistries
Irreversible side reactions and internal resistance	a) Reduction of side reactions/resistance through improved structural design
Charging and discharging efficiency	a) Improved hardware materials and design
Service life	a) Improved degradation characteristics b) Improved resistance to ambient temperature conditions
State of charge	a) Increased range of charge/discharge
Technology: Large Format Aqueous Supercapacitors	
Electronic and Ionic Conductivity	a) Materials with higher conductivity and improved contact b) Electrolyte with higher solution conductivity
Thermal Management	a) Utilizing low-energy heat removal

	b) Increasing operating temperatures c) Increasing mass heat capacity
Coulombic Efficiency	a) Reducing parasitic reactions
Internal Resistance and Wiring	a) Improving conductivity b) Reducing resistive losses
Charge and Discharge Rates	a) Reducing resistive losses
Technology: Compressed Hydrogen Storage	
Compression Efficiency	a) OEM developments
Storage Pressure	a) Optimized for volume / pressure b) Stages of compression.
Thermal Energy	a) Recover thermal energy of compression and vessel fill
Energy conversion device	a) Improved fuel cell chemistry b) Improved combustion engine performance c) Electrochemical pressurization
Technology: Underground Pumped Storage Hydroelectric using Salt Domes (UPSH)	
Size of wellbores into salt dome	a) Move to single larger wellbore per cavern +5% RTE
Technology: Thermal Energy Storage	
Thermal to electric conversion device	a) Improved power cycle technology: Combined Brayton cycle, sCO2 Brayton cycle, improved thermal photovoltaics
Electric to thermal conversion device	a) High temperature heat pumps b) Joule heating c) Improved resistive heater designs d) Increased operating life of resistive heaters
Storage heat loss rate (hold period)	a) Improved insulating materials b) Improved heat loss designs (i.e. self insulating designs)

Storage media handling	a) High temperature solid media skip-hoists for movement of solid storage media in circulating storage formats b) Improved low cost insulation materials c) Improved system design to minimize media movement
Primary storage-to-working fluid heat exchanger	a) Increased heat transfer coefficients in heat transfer fluid to working fluid heat exchange devices b) Embedded heat exchanger designs
Parasitic power consumption	a) Reduced pressure drop designs in gas heat transfer fluid systems b) Use of natural circulation to mitigate Use of pumps c) Improved design minimizing usage of valves and ancillary power equipment
Bore depth (DHDRG technology)	a) Utilization of "lessons learned" in oil & gas industry

Appendix C.

Table 2.

Competitive Factor Matrix

Technical Specs	
Competitive Factor	**Definition**
Energy Rating (MWh)	Rated energy capacity
Power Rating (MW)	Rated charge/discharge power capacity of the system. Specify if charge & discharge ratings differ.
Minimum feasible power and energy ratings (MW and MWh)	Smallest feasible power and energy rating based on current technology
Maximum feasible power and energy ratings (MW and MWh)	Largest feasible power rating based on current technology
Nominal discharge duration (h)	Time for the system to discharge at the designed power rating (Energy capacity/power rating).
Round trip efficiency	Ratio of energy discharged from the system from a starting state of charge to the energy received to bring the system to the same starting charge. Includes all losses within the system boundary (Use-Case Dependent)
Footprint (m2/MWh)	Amount of land required to deploy 1 unit energy capacity of the ESS
Operational Life (Yrs)	Maximum designed years of operation prior to removal from service
Degradation Rate (% Energy Capacity Change/Cycle)	Rate at which the energy capacity of the ESS degrades. Rate is dependent on Ambient Conditions, Depth of Discharge, Charge Rate, Discharge Rate.
Ramp rate (%rated power/hr)	The speed at which storage can increase or decrease input/output
Response time from off state (h)	Time required for a system to output (or input) energy at full rated power from shutdown state
Response time from active state (h)	Time required for a system to output (or input) energy at full rated power from idle condition (state value of assumed idle, e.g., 10% of rated power)
Power Capacity De-Rating Factor (%)	A de-rate factor applied to either the charge/discharge power of a system based on charge status, weather, etc. Example: the de-rating of a systems peak charging power based on an 80% charge status
Expected Downtime (frequency & hr)	Disruption to service for maintenance or for other events; frequency and duration of expected downtime

Operating temperature range (C)	Temperatures that the system can operate at stated efficiencies without requiring auxiliary support
Operating Voltage range (V)	Voltages that the system can operate at stated efficiencies without requiring auxiliary support
Operating Current range(I)	Current that the system can operate at stated efficiencies without requiring auxiliary support
Operating Power Quality Requirement	Power quality that the system can operate at stated efficiencies without requiring auxiliary support
Auxiliary Energy Consumption (kWh/yr)	Annual consumption of electricity for lighting, controls, etc. systems beyond energy use reflected in RTE calculation
Lifecycle GHG Emissions (CO2_eq/kWh over lifetime)	CO2 equivalent emissions per energy capacity of storage technology over lifecycle: Material sourcing, processing and manufacturing, distribution, usage, end of life
Safety/Security/Resiliency	
Lower Flammability Limit (g/m3)	Minimum concentration at which substance is flammable at a given temperature and pressure
Toxicity (mg/kWh)	Toxicity of active (or most active) material in the energy storage system
Radioactivity (Curie)	The frequency of radioactive decay produced by a given amount of material
Population Proximity Restrictions	Restriction(s) on the locations/proximity to populations the ESS system can be located at (e.g. system cannot be located within 0.5 miles of population center)
Environmental Impact	Will the system be negatively intrusive in the natural environment in which it is situated (water consumption, soil erosion, form-factor, etc.)
Catastrophic Event Safety Considerations	Safety, cleanup, and total (community, environmental) impact mitigation considerations in a catastrophic event
System Security	The vulnerabilities of a system to damage by human or natural causes, particularly as it may result in a loss of function or pose a safety risk. Examples are damage from extreme weather events, arson, or damage from theft of valuable components. Considerations include equipment, housing materials, and workforce to protect the system from damage
Supply Chain Security	The vulnerabilities of a system supply chain, including storage and power components, to disruption via pandemic, natural disaster, global catastrophe, war, etc.
Material Sustainability	Current and future environmental impact of sourcing/manufacturing/processing/disposing of materials
Long term resiliency	lack of sensitivity to supply chain issues and ongoing effects of climate change or natural disaster or severe weather
Deployment	
Intended Use Case(s)	Use cases of the system intended by the manufacturer. Grid and non-grid applications (e.g., the ability to charge/discharge simultaneously, support ancillary services, and

	contribute to black start, droop, frequency, reactive power, energy arbitrage, delivery heat to industrial processes etc.)
Technology Readiness Level (#)	Level of technology maturity and readiness for commercialization (1-9 scale)
Market Maturity/Acceptance Readiness Level (#)	Willingness of market to adopt technology (1-9 scale)
Controls / communication Interoperability	Storage system adheres to interoperability standards and has demonstrated correct interaction with utility control systems and the storage internal control systems (EMS to BMS)
Cost Specifications	
Storage Block Cost ($/kWh)	Cost of the energy component of the ESS on a unit energy basis
Storage Balance of System Cost ($/kWh)	Additional equipment costs for suppering the storage block
Storage System Cost ($/kWh)	***Sum of Storage Block Cost and Storage Balance of System Cost***
Power Equipment Cost ($/kW)	Power conversion system equipment for both charging and discharging
Controls & Comms Cost ($/kW)	Control equipment required to control the system.
System Integration Cost ($/kWh)	Cost associated with integrating system components into a cohesive system and integrating the system into the deployment site
Energy Storage System Cost ($/kWh)	**Sum of Storage System Cost, Power Equipment cost, Controls Communication Cost, and System Integration cost**
Engineering, Procurement, & Construction Cost ($/kWh)	Single occurrence engineering and construction costs. Includes siting, installation and commissioning.
Project Development Cost ($/kWh)	Permitting, PPA, interconnection agreement, site control, and financing costs
Grid Integration Cost ($/kW)	Cost for connecting to the grid including hardware
Fixed O&M Cost ($/kW-year)	Costs necessary to keep the storage system operational throughout its life that do not fluctuate based on energy throughput.
Variable O&M Cost ($/kWh)	Costs necessary to keep the storage system operational throughout its life that fluctuate based on energy throughput
Warranty Cost ($/kWh-year)	Fees to maintain equipment warranties

Insurance Cost ($/kWh)	Insurance fees to cover risks
Operating Costs ($/kWh)	**Sum of Fixed O&M, Variable O&M, Warranty, and Insurance Costs**
Disconnection Cost ($/kWh)	Costs associated with the disconnection from the grid
Disassembly / Removal Cost ($/kWh)	Costs associated with removing the equipment from the site
Site Remediation Cost ($/kWh)	Costs associated with remediating the project site
Recycling / Disposal Cost ($/kWh)	Costs associated with recycling materials of the ESS
Decom Costs ($/kWh)	**Sum of Disconnection, Disassembly, Site Remediation, and Recycling Costs**
Total Installed Costs ($/kWh)	**Sum of Energy Storage System Cost, Operating Costs, Decommissioning Costs, EPC Costs, Project Development Costs, and Grid Integration Costs**
Marginal Cost of Electricity ($/kWh)	The cost of electricity and fuel associated with a LDES technology as dictated by energy input to output efficiency.
LCOSNT ($/kWh)	The average $/kWh value that energy discharged from a T hr storage system must be sold at to recover total project revenue requirements over a N year analysis period Methodology: https://www.pnnl.gov/sites/default/files/media/file/ESGC%20Cost%20Performance%20Report%202022%20PNNL-33283.pdf