GREEN
HYDROGEN
COALITION

EXPANDING HORIZONS:

BEST PRACTICES FOR MODELING LONG-DURATION ENERGY STORAGE

PREPARED BY STRATEGEN

TABLE OF CONTENTS

1 | EXECUTIVE SUMMARY 4

  1.1 | The Challenge 4

  1.2 | LDES Modeling and Planning Best Practice 4

2 | INTRODUCTION 6

  2.1 | What is Long-Duration Energy Storage? 6

  2.2 | Why Do We Need LDES? 7

  2.3 | Defining the Modeling Toolset 8

  2.4 | The Need for an LDES Modeling Toolkit 9

3 | BEST PRACTICES IN MODELING LDES FOR LONG-TERM PLANNING 10

  3.1 | Phase 1: Pre-Modeling Scoping & Planning 10

  3.2 | Phase 2: Modeling 15

  3.3 | Phase 3: Application & Implementation 17

4 | RECOMMENDATIONS FOR AGENCIES, REGULATORS, AND POLICYMAKERS 19

PREPARED BY STRATEGEN CONSULTING INC. FOR THE GREEN HYDROGEN COALITION.

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1. EXECUTIVE SUMMARY

1.1 | THE CHALLENGE

As states and utilities pursue strategies to achieve a low- and even zero-carbon grid, many are concluding that an 80-90% decarbonization of the electric sector can be achieved with currently available technology, but the remainder will require the adoption of new technologies that can provide clean, flexible capacity, and integrate renewable resources across increasingly long time horizons. This fundamental grid imperative is the motivation underlying the significant investment that private and public entities are making in long-duration energy storage (LDES) technologies.

However, these technologies can only be deployed at scale if grid planners and policymakers can accurately assess the benefits provided by LDES, and efficiently incorporate LDES into their resource and decarbonization planning strategies. Yet integrating LDES into modeling and planning activities has been challenging, due to the complexity and rapid evolution of the technological and regulatory landscapes, paired with the computational demands of modeling the long dispatch horizons of LDES.

This report highlights findings and best practices from LDES modeling practitioners to help policymakers, utilities, and grid planners manage these challenges and accurately and effectively incorporate LDES into their modeling and planning activities.

1.2 | LDES MODELING AND PLANNING BEST PRACTICES

LDES modeling is still a maturing discipline in energy systems planning and analysis, and new research is continuing to pave the way for more effective and insightful approaches. Early-stage studies and interviews with LDES modeling practitioners have helped to highlight some “must-haves” for modeling LDES for long-term planning purposes. Here, findings and best practices are categorized into three phases:

- **Pre-Modeling Scoping & Planning**
- **Modeling Analytics, and**
- **Application & Implementation.**

During the Pre-Modeling Scoping & Planning phase, it is crucial to establish a strong foundation for effective LDES modeling. Doing so begins with developing a clear problem statement or analytical question that provides valuable insights to inform the modeling scope, priorities, and trade-offs. Identifying the key questions to be answered allows for a more focused and strategic approach to utilizing LDES technologies. Furthermore, a diverse representative portfolio of different energy storage resources and technologies must be included in the modeling process to ensure comprehensive results. These considerations enable a holistic assessment of various LDES options and their potential contributions to grid decarbonization. Additionally, in selecting modeling tools, it is imperative to select those with appropriate dispatch horizons, enabling full optimization of resources with longer discharge durations. A well-chosen modeling tool allows for the accurate representation of LDES capabilities and their integration into the broader energy system, supporting more informed and effective decision-making in subsequent phases of the planning process.

Accordingly, it is recommended that all LDES modelers undertake the following three steps in their pre-modeling scoping and planning activities:

1. **Scope:** Develop a clear problem statement or analytical question to inform modeling scope, priorities, and trade-offs.
2. **Inputs:** Include a diverse representative portfolio of different energy storage resources and technologies.
3. **Modeling Tool Selection:** Select modeling tools with appropriate dispatch horizons to fully optimize resources with longer discharge durations.

During the Modeling Analytics phase, meticulous attention must be paid to two critical aspects. First, it is imperative to ensure that the modeling approach accurately captures and appropriately values all resource benefits and value streams associated with LDES, including capacity, energy, ancillary services, and resilience, to enable a comprehensive understanding of the multifaceted benefits LDES technologies can provide to the grid.

Second, incorporating uncertainty & risk is vital to effectively assess the potential impact and role of LDES in future energy scenarios. Therefore, all LDES modeling efforts should encompass a broad range of scenarios that account for various factors, such as technology cost, load forecasts, policy changes, weather conditions, and other uncertainties that may influence grid operations. By exploring these scenarios, changes in the grid, policy, economics, and technology can be thoroughly examined, empowering decisionmakers to gauge the effectiveness of LDES solutions in diverse future scenarios. LDES modelers should verify that their selected model can address the following two recommendations:

4. **Valuation:** Ensure that the modeling approach appropriately captures and values all LDES resource benefits and value streams.
5. **Incorporating Uncertainty & Risk:** All LDES modeling should include an appropriate range of scenarios to examine grid and technology uncertainties, and the role that LDES can play in those potential futures.

Finally, the Application & Implementation phase focuses on translating LDES modeling outcomes into actionable strategies. The findings and results should prioritize insights that inform “no regrets” planning actions rather than specific numerical values to guide future modeling and planning activities. While modeling exercises identify grid needs and allow utilities to initiate procurement actions, they do not replace the evaluation of the cost-effectiveness and value proposition of individual LDES projects. By adhering to the following two recommendations, stakeholders can make informed decisions, strategically plan for LDES integration, and foster sustainable and resilient energy systems to achieve decarbonization goals.

6. **Findings & Results:** Modeling findings and results should focus on identifying insights that can inform no-regrets planning actions rather than focus on specific numerical results and should help to inform future and/or ongoing modeling and planning activities.
7. **Implementation & Procurement:** Modeling exercises should be used to identify grid needs and begin procurement activities but are not a substitute for evaluating the cost-effectiveness and the value proposition of specific projects.

These modeling best practices should inform policy and planning guidelines as states continue to progress toward a decarbonized grid. Utilities must include LDES in Integrated Resource Planning (IRP) processes and use appropriate modeling tools and approaches to ensure these resources are being properly valued in a holistic portfolio assessment. Policymakers and regulatory bodies should enforce an open and transparent stakeholder process for IRPs and other resource-planning activities. Allowing access to data inputs and modeling processes will invite feedback from stakeholders who can help ensure equity and community buy-in. Finally, interconnection operators and balancing authorities should lead regional coordination to maximize the benefits of LDES for the broader grid.

By adopting the best practices identified in this report, stakeholders can pave the way for establishing a process that will drive the deployment of cutting-edge LDES technologies and ensure their integration into long-term energy planning. This foundational approach to incorporating LDES in the planning process will help achieve a more sustainable, resilient, and decarbonized grid.

2. INTRODUCTION

To understand the potential impact of LDES and the need for LDES modeling best practices, it is important to first establish a clear definition of LDES, as well as clarify the array of technologies that are encompassed by this definition.

This categorization underlines the role LDES technologies will play in decarbonizing the electric grid. An overview of the modeling process within energy system planning is also included to provide valuable context for identifying the gaps and challenges that make it difficult to properly represent LDES in modeling and planning processes.

2.1 | WHAT IS LONG-DURATION ENERGY STORAGE?

There is no universal standard for the definition of LDES. Typically, the term "long-duration energy storage" is used to refer to storage that can provide firm capacity, according to capacity credit.[1] The Advanced Research Projects Agency-Energy (ARPA-E), in its DAYS program, focuses on solutions that provide between 10 and 100 hours of storage, but other systems can achieve their needed firm capacity from durations as low as 2 to 4 hours.[2,3] In California, within the California Public Utilities Commission's (CPUC) IRP proceeding, LDES has been defined as storage systems that are "able to deliver at maximum capacity for at least eight hours from a single resource" for procurement. Alternatively, the U.S. Department of Energy (DOE) has defined LDES as "storage systems that can deliver 10+ hours of duration" within its Long Duration Storage Shot.[5] These varied definitions highlight the need for a diverse portfolio of resources that can provide firm power for multiple days, multiple weeks, and even seasons. All these technologies and solutions will be critical to reaching fully decarbonized electric grids.[6]

The three primary categories of LDES technologies are electrochemical, mechanical, and thermal. Most mechanical forms of energy storage are inter-day, meaning their duration is typically less than 24 hours, while thermal and electrochemical LDES technologies can achieve multi-day or even multi-week durations. Mechanical forms of LDES include pumped storage hydropower (PSH), gravity-based storage, compressed air energy storage (CAES), liquid air energy storage (LAES), and liquid CO_2 energy storage. Thermal LDES generally refers to sensible-, latent-, and thermochemical-heat technologies. Electrochemical LDES technologies include hydrogen, aqueous electrolyte flow batteries, metal anode batteries, and hybrid flow batteries.

Each technology differs in its method of collecting, storing, and releasing power. Mechanical technologies apply power to move weight to a higher potential energy for future release, thermal technologies store energy as heat for future application, and electrochemical technologies, such as hydrogen, store the energy as fuel and later deliver it through combustion. This report will use the terms "charge" and "discharge" to refer to the collection and later distribution of energy from all storage technologies. Round-trip efficiency (RTE) varies widely across all technology types, with a range of 20% to 90%. Please refer to *Table 1* for a thorough breakdown. Table 1 also includes the Technology Readiness Level (TRL), which is a number indicating the relative maturity and market readiness of a technology. A TRL of 1 denotes that the technology is in its infancy, while a TRL of 11 means that the technology is mature and has reached commercial operation.

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[1] "An Evolving Dictionary for an Evolving Grid: Defining Long-Duration Energy Storage." National Renewable Energy Laboratory, November 8, 2021, www.nrel.gov/news/program/2021/an-evolving-dictionary-for-an-evolving-grid-defining-long-duration-energy-storage.html.

[2] Max Tuttman & Dr. Scott Litzelman, "Why Long-Duration Energy Storage Matters." April 1, 2020, https://arpa-e.energy.gov/news-and-media/blog-posts/why-long-duration-energy-storage-matters#:~:text=ARPA-E's%20Duration%20Addition%20to,5%20cents%2FkWh%20or%20less.

[3] Paul Denholm, et. al., "Storage Futures Study: The Challenge of Defining Long-Duration Energy Storage." National Renewable Energy Laboratory, 2021, https://www.nrel.gov/docs/fy22osti/80583.pdf.

[4] "Decision 21-06-035." California Public Service Commission, June 24, 2021 https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M389/K603/389603637.PDF.

[5] "Long Duration Storage Shot." Office of Energy Efficiency & Renewable Energy, U.S. Department of Energy, September 2021, https://www.energy.gov/eere/long-duration-storage-shot#:~:text=Long%20Duration%20Storage%20Shot%20Summit,-In%20September%202021&text=DOE%20is%20all%20in%20for,and%20affordable%20for%20ALL%20Americans.

[6] Paul Denholm, et. al., "Storage Futures Study: The Challenge of Defining Long-Duration Energy Storage." National Renewable Energy Laboratory, 2021 https://www.nrel.gov/docs/fy22osti/80583.pdf.

Table 1 | Example LDES Technologies

Technology	Duration (Hours)	Avg. Round Trip Efficiency (RTE %)	Technology Readiness Level (TRL)
Pumped Storage Hydropower (PSH)	0 - 15	70 - 80	11
Gravity Storage	0 - 15	70 - 90	6 - 8
Compressed Air Energy Storage (CAES)	6 - 24	40 - 70	7 - 9
Liquid Air Energy Storage (LAES)	10 - 25	40 - 70	6 - 9
Liquid CO_2	4 - 24	70 - 80	4 - 6
Sensible Heat (molten salts, rock material)	10 - 200	55 - 90	6 - 9
Latent Heat (e.g., aluminum alloy)	25 - 100	20 - 50	3 - 5
Flow Batteries	25 - 100	50 - 80	4 - 9
Metal Anode Batteries	50 - 200	40 - 70	4 - 9
Hybrid Flow Batteries	5 - 50	55 - 75	4 - 9

Source: DOE, adapted by Strategen Consulting[7]

2.2 | WHY DO WE NEED LDES?

Many states and sub-jurisdictions have adopted goals of 100% carbon-free electricity. Current pathways to 100% carbon-free electricity generation include significant increases in variable renewable energy, such as wind and solar. Grid planners are also incorporating an increasing amount of energy storage to help address the variability of renewable energy supply across hours, days, and seasons.[8,9] At the current penetration levels of variable energy resources, there is a strong market for energy storage technologies with two to four hours of duration, such as lithium-ion batteries, which can shift excess solar generation during the middle of the day to meet evening peak loads. While these assets can address intra-day variance, the amount of generation from variable renewable resources is increasing and will continue to grow, leading to longer-term daily and seasonal variations in generation. Two to four hour storage is not effective for addressing seasonal differences or the increasingly frequent extreme weather events that require multi-day grid support. Longer durations will therefore be necessary to reliably meet grid needs across days, weeks, and seasons, as the share of intermittent renewable generation continues to grow to meet 100% carbon-free electricity targets.

This result was confirmed in a recent modeling study performed by the Western Electricity Coordinating Council (WECC).[10] WECC's modeling was able to achieve 80% to 90% carbon-free with storage durations of up to 12 hours but ultimately found that unless new dispatchable generation that is fast-ramping and carbon-free became available, storage with significantly longer durations than 12 hours must be deployed to achieve 100% decarbonization. Another report prepared by Energy & Environmental Economics, Inc. (E3), on behalf of the California Energy Commission (CEC), concluded that there is a significant role for LDES in deep decarbonization scenarios (in the context of California's clean energy and reliability goals), because LDES:[11]

- **Operates throughout the year, providing intra-day through seasonal energy arbitrage,**
- **Can serve much of the same role as natural gas power plants, enabling gas retirement,**
- **Supports operations during energy-constrained conditions,**
- **Significantly reduces renewable curtailment in highly renewable grids, and**
- **Makes portfolios more robust to inter-annual renewable variability.**

Additionally, New York's updated 2018 Energy Storage Road map found that long duration energy storage will be needed to support a cost-effective decarbonized grid by providing critical benefits in terms of reliability and renewable integration.[12] In their analysis, LDES's

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[7] Katheryn Scott, et. al., "Pathways to Commercial Liftoff: Long Duration Energy Storage." U.S. Department of Energy, March 2023, https://liftoff.energy.gov/wp-content/uploads/2023/03/20230320-Liftoff-LDES-vPUB-0329-update.pdf.

[8] Daniel Steinberg, et. al., "The Los Angeles 100% Renewable Energy Study." Chapter 6, Los Angeles Department of Water and Power, National Renewable Energy Laboratory, March 2021, https://www.nrel.gov/docs/fy21osti/79444-6.pdf.

[9] Paul Denholm, et. al., "Examining Supply-Side Options to Achieve 100% Clean Electricity by 2035." National Renewable Energy Laboratory, https://www.nrel.gov/docs/fy22osti/81644.pdf.

[10] Bharath Ketineni, Bhavana Katyal, "Long-Duration Energy Storage Assessment." Western Electricity Coordinating Council, February 3, 2023, https://www.wecc.org/Reliability/LDES_Final_Report.pdf.

[11] "Staff Workshop on Long Duration Energy Storage Analysis." May 9, 2023, https://www.energy.ca.gov/event/workshop/2023-05/staff-workshop-long-duration-energy-storage-analysis.

primary role will be to provide power during multi-day-long events when demand is high and the contributions from variable energy resources are insufficient, mitigating the duration of loss of load events. Specifically for New York, LDES will play a critical role in maintaining the reliability of the electricity supply during winter due to the electrification of building heating.

Each of the three reports published by the WECC, E3, and New York detail real-world applications to the different value streams offered by LDES. Given their need to support and accelerate carbon-free electricity scenarios, the focus of regulators and grid planners now should turn to the necessary changes in the resource planning process to enable no-regrets investments in LDES. Modern energy system planning processes are models-based, and these modeling tools are dynamic, much like the systems they seek to represent and optimize. As the range of commercial LDES technologies continues to develop, modeling tools and practices will need to evolve as well, to accurately represent these technologies.

2.3 | DEFINING THE MODELING TOOLSET

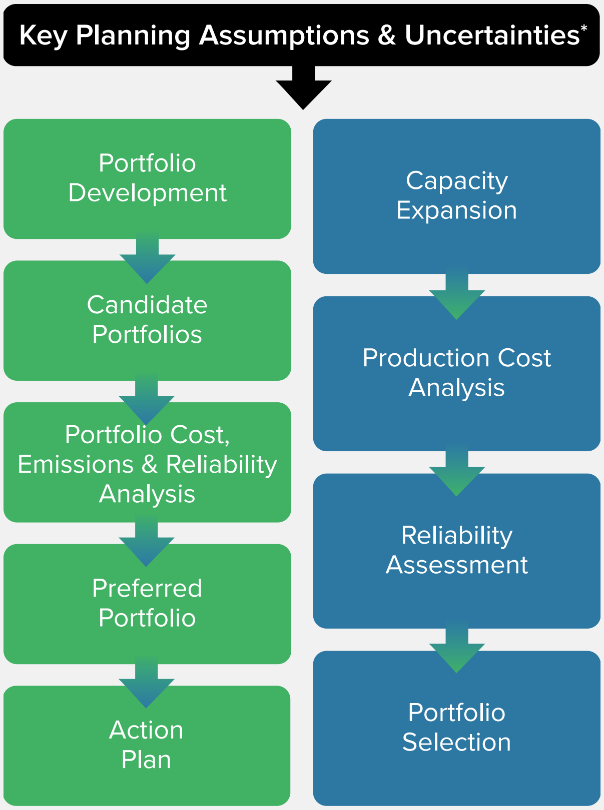
Several different types of modeling tools are used in the energy system planning process, each with a distinct function. A robust resource planning process will include the use of multiple modeling tools to ensure that the result is an economically optimal and adequately reliable portfolio. *Figure 1* illustrates the portfolio evaluation steps within a standard resource planning process, as well as the modeling performed at each step. A fundamental understanding of the purpose of each model type is necessary before discussing best practices for future LDES modeling. The next sections describe the capacity expansion modeling, production cost modeling, and reliability evaluations used in resource portfolio development.

CAPACITY EXPANSION

Capacity expansion models determine the optimal investments in generation capacity to meet an expected future demand level while adhering to policy or regulatory goals or requirements and minimizing costs. These models typically cover utility-level portfolios but can also be used to model generation capacity across regions or even nationally. The optimal portfolio is often constrained by parameters such as reliability requirements, renewable portfolio standards, emissions limits, etc. Some capacity expansion models may also include the ability to expand transmission networks to meet demand. These models usually have lower temporal granularity and less accuracy in modeling physical constraints than production cost models, providing high-level portfolio selection rather than refined chronological economic dispatch.

Capacity expansion models currently are the most critical tools to drive the inclusion of LDES in long-term resource planning. While utilities may develop alternative portfolios to assess the manual addition of LDES, the optimal portfolio developed in the capacity expansion model typically has an oversized impact on the final preferred portfolio selected by the planning entity. If the capacity expansion model does not include LDES candidate resources or does not reasonably model the contributions of LDES in serving load and providing other grid services, then LDES is unlikely to ultimately be included in the proposed resource plan. While LDES technologies are typically more capital-intensive than other resource types, the operational value can provide a significant upside relative to over-building other clean energy resources. Capacity expansion models must be able to recognize this benefit and select resources accordingly.

Figure 1 | Portfolio Evaluation Steps within Resource Planning Processes



*Including loads, prices, supply-side resources, fuel costs, granularity adjustment, operating constraints, reserve requirements, etc.

Source: PacifiCorp 2023 IR0P, adapted by Strategen Consulting

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[12] Stephanie McDermott, "Re: Case 18-E-0130 – In the Matter of Energy Storage Deployment Program." New York Public Service Commission, December 28, 2022, https://www.nyserda.ny.gov/-/media/Project/Nyserda/Files/Programs/Energy-Storage/ny-6-gw-energy-storage-roadmap.pdf.

[13] "2023 Integrated Resource Plan." PacifiCorp, May 31, 2023, https://www.pacificorp.com/content/dam/pcorp/documents/en/pacificorp/energy/integrated-resource-plan/2023-irp/2023_IRP_Volume_I_Final_5-31-23.pdf.

PRODUCTION COST

Production cost models determine the optimal dispatch of a predetermined portfolio of generation assets over a given timeframe, considering electricity prices, demand, fuel, operating costs, reliability, and other energy resources. These models generally include a high level of detail on the economic dispatch of assets from both a physical and financial perspective, optimizing operations at the hourly or sub-hourly level. Typically, production cost models have many parameters to model physical operating characteristics, such as ramp rates and minimum uptime limits that can only be applied when simulating sequential time steps. They may include simulation engines for prices, load, renewable generation, etc., or these forecasts may be applied as inputs. These tools are not designed to optimize the addition or retirement of new resources to meet future capacity requirements, but instead to provide high-granularity and high-fidelity optimization of a predetermined portfolio of resources.

Production cost models are critical to quantify the total value of LDES as part of a broader portfolio analysis. Modeling hourly or even sub-hourly operations, as well as multi-day or weekly operations, is critical to an accurate determination of the total net cost. It is particularly important that production cost models allow for sufficient optimization horizons for LDES. LDES needs to optimize both charging and discharging times across longer time horizons than the typical single day optimization cycle of traditional lithium-ion batteries. LDES will charge during periods of excess renewable generation and/or lower power prices and dispatch when it is most economical; that optimization of charging and discharging can take place over days or months. Unique physical characteristics of each LDES technology can also be properly accounted for, such as the duration of storage, RTE, and contributions to various ancillary services, among others.

RESOURCE ADEQUACY/RELIABILITY

After a portfolio is developed in a capacity expansion model and subsequently valued in a production cost model, the final necessary test is to assess whether the portfolio will be able to achieve the fundamental goal of resource planning — providing reliable electricity to the grid under a wide array of circumstances. Resource Adequacy/Reliability models are the third tool applied in a robust resource planning process. This class of tools is characterized by their ability to examine risk profiles for the likelihood of reliability events and output metrics, such as loss of load expectation (LOLE)[14] and expected unserved energy (EUE).[15] They may be a module within a production cost model, or a separate tool altogether.

Resource adequacy models use probabilistic simulations to create a diverse range of future scenarios to see how a portfolio performs under a variety of conditions. Stochastic simulations will typically include a wide array of load demand, renewable generation, hydro flow, weather, and thermal forced-outage scenarios. These parameters are increasingly important to simulate as uncertainty grows on both the demand and supply sides. Demand is now significantly impacted by variable factors such as electric vehicle-grid integration (VGI), demand response (DR), and distributed energy resources (DER). High penetration rates of variable renewable generation can have a strong impact on the supply side, as do extreme weather events — which routinely cause outages in traditionally stable generation, such as winter storms causing failures in natural gas supply. Moreover, variable power generation is further complicated by its interactions with energy storage resources and the economics of charging and discharging. Stochastic simulation provides better insight into the likelihood that storage will be sufficiently charged when a load event occurs. These determinations are critical to understanding the value that LDES provides to the reliability of a portfolio.

2.4 | THE NEED FOR AN LDES MODELING TOOLKIT

Today, current modeling methodologies used for IRP do not consider and value the full range of economic and reliability benefits offered by LDES. Capacity expansion and production cost models usually lack the temporal granularity and horizon to capture the range of grid benefits LDES assets can provide. In addition, these models, along with Resource Adequacy models, often ignore the added time-shifting, resource adequacy, and ancillary services LDES can provide. Finally, LDES can provide long-term resiliency in the case of natural disasters or extreme weather events, scenarios seldom considered outside of the most comprehensive production cost modeling processes.

For these reasons, there are still many challenges in properly valuing these different capabilities during the resource planning process. Finding a way to accurately model the different types and durations of energy storage technologies will be key to identifying the least-cost pathways to attain 100% carbon-free electricity and other emissions goals.

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[14] LOLE is the measurement of the expected days in a year that could face generation shortfall.

[15] EUE is a measurement of the estimated energy (MWh) not likely to be served by the generation portfolio.

3. BEST PRACTICES IN MODELING LDES FOR LONG-TERM PLANNING

Modeling LDES is a new and developing area. Until recently, most utilities, policymakers, and balancing authorities were not evaluating 100% clean energy scenarios, so it was not necessary for models to include LDES. As more states implement 100% clean policies, doing so has become critical for accurate and effective planning. However, many organizations are running into challenges when attempting to incorporate LDES into existing planning and modeling activities, whether due to limitations in a software's functionality, computational constraints, or simply sub-optimal modeling strategies for including LDES. The following section outlines important considerations across three key phases for modeling LDES in long-term resource planning. These best practices were developed through interviews with several industry leaders, including modeling experts from academia, national labs, private consulting firms, a community choice aggregator, and the WECC. These modelers each provide a unique perspective, that together informs a robust LDES planning practice.

WECC
Electric Reliability and Security for the West

Saad Malik
Director Reliability Assessments
WECC

Preferred Modeling Tool
GridView by ABB[16]

Primary Modeling Question
What role can LDES play in supporting reliable operations of the Western Interconnect in a deeply decarbonized future?

Advice for Modeling LDES
Different models have different strengths, and especially for resources like LDES that have highly complex operations and dispatch requirements, it's important to ensure that models have the appropriate analytical capabilities to accurately optimize LDES.

3.1 | PHASE 1: PRE-MODELING SCOPING & PLANNING

The first phase of the resource planning process is crucial for setting up models that can address timely, meaningful questions in an efficient manner, considering both priorities and tradeoffs. In this first phase, planners should define the scope for modeling efforts, determine initial inputs, and select an appropriate modeling tool.

SCOPE

Develop a clear problem statement or analytical question to inform modeling scope, priorities, and trade-offs.

One of the first steps is developing a clear problem statement or an analytical question that outlines key questions that a modeling activity is trying to answer. The problem statement guides decisions about necessary modeling tradeoffs, determining where simplifications can be made, and where higher levels of detail should be prioritized to ensure that the model setup is sufficient and appropriate to answer the key questions. For example, the question "How much LDES is needed in California to meet clean energy goals?" will encourage a very different modeling approach than "What price point do LDES technologies need to hit to be cost-competitive with lithium-ion?"

One of the biggest challenges in modeling LDES is that the longer-dispatch horizons can create computational challenges for most tools. Computational challenges can result in models that take significant time (i.e., several days) to produce a completed model run, or in the worst case are unable to solve a model run at all. For this reason, it is key to determine and focus on a specific analytical priority. It is incredibly challenging to create a model that is capable of accurately capturing every detail of the electric power sector, and the attempt to do so results in a significant risk of conducting a modeling activity that is unable to provide valuable insights. Clarifying a specific modeling scope and problem statement will allow prioritization on where to ensure higher precision analysis, and where approximations or aggregation can reduce complexity.

The WECC developed an LDES assessment to understand the role that LDES could play in supporting a zero-carbon energy supply across the Western Interconnection.[17] WECC's primary role is promoting bulk power system reliability and security in the Western Interconnection but it does not have a role in resource procurement or deployment, so the WECC's modeling

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[16] Learn more about GridView here: https://www.hitachienergy.com/products-and-solutions/energy-portfolio-management/enterprise/gridview.

[17] Bharath Ketineni, Bhavana Katyal, "Long-Duration Energy Storage Assessment." Western Electricity Coordinating Council, February 3, 2023, https://www.wecc.org/Reliability/LDES_Final_Report.pdf.

approach focuses on understanding the reliability benefits that the region might realize from LDES. WECC used GridView software to run a nodal hourly production cost model over an entire year to achieve 100% renewable energy. A key challenge that WECC faced in their modeling exercise was that their expansive operating region requires significant computational complexity to model at a nodal level. While GridView has excellent capabilities in performing these granular simulations with the current and near-term generation mix, computational challenges arose when they attempted to incorporate the longer dispatch horizons that are common for LDES. In part due to those limitations, the model was constrained to 12-hour duration storage. With that limitation in mind, WECC determined that 12-hour storage could still enable increased clean energy penetration up to 80-90% under normal operating conditions.

While additional analysis may be needed to explore the longer optimization horizons needed for LDES greater than 12 hours, the modeling and analysis that WECC conducted with GridView provides value for near-term planning and operations of the WECC before there is significant deployment of LDES.

From a different planning perspective, researchers at University of California Merced used E3's RESOLVE tool to run capacity expansion models across California and posed the question, "As a first step toward studying the value of long-duration energy storage, how can we reduce the computational intensity of modeling LDES while still capturing its value?" Researchers found that full-year modeling, particularly the inclusion of multiple consecutive days in the storage balancing horizon, significantly impacts the usage of LDES.[18] However, the researchers determined that a "critical time steps" approach, where they model two critical hours per day (an hour after sunrise and an hour before sunset, the hours when the storage switches between charging and discharging) through the entire year, allows them to reduce the total number of time steps from 8,760 to 730, while still resulting in similar resource deployment plans.[19]

Since one of their analytical priorities was to evaluate a wide range of scenarios, they chose to reduce the number of time steps, while still obtaining an accurate estimation of the needed storage capacity. Researchers were successful in identifying a strategy for exploring a range of generation and load profiles (both of which can have a large effect on the needed storage) while introducing only a small error and enabling a more useful set of insights.

These two organizations applied significantly different approaches to modeling LDES, but both methods were justified given their objectives. Likewise, utilities or planners who seek to determine a specific portfolio of resources may employ a different methodology than researchers or groups looking for more general insights. However, given the current state of modeling tools, it would be unreasonable to attempt to model both long optimization horizons and a full suite of additional complex modeling elements and expect results in a reasonable timeframe. Until modeling capabilities have evolved sufficiently to allow for more complex models, planners may need to limit their modeling scope by carefully selecting scenarios and technology options while preserving a higher temporal resolution.

UCMERCED

Sarah Kurtz
Professor & Graduate Program Chair
UC Merced

Preferred Modeling Tool
RESOLVE by E3[20]

Primary Modeling Question
How can we improve the available analytical approaches to forecast the operations of and demand for LDES in CA?

Advice for Modeling LDES
For systems like California with a relatively predictable renewable mix, there are a variety of computational approximations that can significantly improve modeling speed without significantly compromising the accuracy of model findings. Having a computationally efficient model allows exploration of the effects of many other assumptions, such as future weather and costs, to better understand the risks associated with a clean energy portfolio that includes LDES.

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[18] P.A. Sánchez-Pérez, et. al., "Effect of modeled time horizon on quantifying the need for long-duration storage" Applied Energy, vol. 317, Elsevier BV, July 2022, p. 119022. https://doi.org/10.1016/j.apenergy.2022.119022. https://www.sciencedirect.com/science/article/pii/S0306261922004275.

[19] Farzan ZareAfifi, Zabir Mahmud, Sarah Kurtz, "Diurnal, physics-based strategy for computationally efficient capacity-expansion optimizations for solar-dominated grids." Energy, Elsevier BV, June 2023, p. 128206. https://www.sciencedirect.com/science/article/pii/S0360544223016006?via%3Dihub=.

[20] Learn more about RESOLVE here: https://www.ethree.com/tools/resolve/.

INPUTS

Include a diverse representative portfolio of different energy storage resources and technologies.

The second step in pre-model scoping and planning is determining what inputs will be included. Proper representation of LDES characteristics and intrinsic benefits is crucial for the selection of various technologies in capacity expansion modeling. There are a variety of LDES technologies both commercially available and in development with unique physical and operational characteristics (refer to *Table 1*). Therefore, including a diverse representative portfolio of different energy storage solutions ensures that there are multiple pathways to unlock their benefits.

The inclusion of the range of LDES technologies will directly influence how the model captures the energy value and capacity contribution of LDES technologies in an evolving grid with increasing adoption of variable energy resources. It allows the model to make tradeoffs across the range of storage solutions.

As such, models must consider that LDES technologies vary in the following areas:

- **Cost portfolios compared to short-duration storage/lithium batteries:**
  - – LDES usually requires higher upfront capital costs and investment.
- **Lifespans:**
  - – LDES technologies have extended operational and maintenance requirements.
- **Duration and capacity:**
  - – Inter-day LDES can shift power by 10-36 hours (e.g., flow batteries, mechanical storage technologies).
  - – Multi-day LDES can shift power by 36-100+ hours (e.g., thermal, and electrochemical technologies).
- **Efficiency and roundtrip losses:**
  - – Round trip efficiencies range from 20-90%, which further differs between charging and discharging states.
- **Operational constraints:**
  - – For example, PSH and CAES are geographically constrained.
- **Lifetime and degradation:**
  - – Longer lifetimes require longer contracts.
  - – Degradation will occur over time.
- **System integration and grid services** (see *Phase 2: Modeling, Valuation*)
  - – LDES can act as a transmission asset or be used for ancillary services.
  - – LDES can provide reliability and resiliency for localized grid needs.

Incorporating a suite of LDES solutions in capacity expansion models allows for a more comprehensive and accurate assessment of energy system needs and the respective contributions of each technology in reducing curtailment and providing grid flexibility, time-shifting, and other grid services. A study on capacity expansion model features concluded that pre-defining technology parameters such as fixed energy-to-power ratios or pre-ordered supply stacks can lead to vastly different capacity expansion portfolios while establishing a variety of options in the initial dataset will result in a more optimal solution.[21] Strategen Consulting's Long Duration Energy Storage for California's Clean, Reliable Grid (2020) report found that, when modeling different storage options and grid conditions, storage deployment is based on the interaction between grid conditions, storage price points, and renewable resources, among other factors.[22]

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[21] Jonas van Ouwerkerk, et. al., "Impacts of Power Sector Model Features on Optimal Capacity Expansion: A Comparative Study." Renewable & Sustainable Energy Reviews, vol. 157, Elsevier BV, Apr. 2022, p. 112004. https://doi.org/10.1016/j.rser.2021.112004.

[22] Erin Childs, et. al., "Long Duration Energy Storage for California's Clean, Reliable Grid." Strategen Consulting, December 8, 2020, https://www.storagealliance.org/longduration.

MITSUBISHI POWER

Hari Gopalakrishnan
Lead Consultant
Mitsubishi Power

Preferred Modeling Tool
PLEXOS by Energy Exemplar[23]

Primary Modeling Question
How can we accurately capture the value that seasonal energy storage provides in a deeply decarbonized electric grid?

Advice for Modeling LDES
It is imperative to base analytical assessments on a robust modeling foundation, especially when it comes to complex co-optimizations between the electric, gas, and water sectors.

To highlight the need for diverse parameters and their impact on capacity expansion models, consider a hydrogen electrolyzer. This device uses electricity to split water into hydrogen and oxygen through a process called electrolysis. The hydrogen gas can be collected, stored, and used as an "energy carrier" later. Mitsubishi Power's efforts to incorporate hydrogen into their PLEXOS model demonstrate the significant level of architectural development required to represent green hydrogen effectively and accurately as LDES in capacity expansion modeling. Considering that producing hydrogen with an electrolyzer and storing it for later use involves the consumption of water, electricity from a power node, and moving the hydrogen into the gas module, Mitsubishi Power is co-optimizing three high-fidelity sector models to account for the entire life cycle of the electrolyzer and its operational characteristics, leading to some of the most sophisticated modeling of hydrogen seen to-date.

It is important to note that, because of the breadth of long-duration storage solutions available, models can be configured in a way that accounts for them in a technology-based or technology-neutral approach to limit the computational intensity of the model and in the scope of the problem statement. Sometimes, it is unnecessary to limit resource options solely to technology-based solutions. Instead, it is more important to understand the order of magnitude of the problem. Strategen Consulting's 2020 LDES report used a technology-neutral approach to explore the opportunities for LDES to help California reach its decarbonization goals. Utilizing GridPath, the study's resource options were intended to capture trends in technical characteristics and were thought of as "generic, technology-neutral resource options." Recognizing the inherent uncertainty in LDES costs, this study projected a single cost level relative to the project cost level of lithium-ion batteries (a more mature technology with an established place in the industry). Assumptions for LDES included: higher capacity costs, long energy capacity costs, and RTEs declining as duration increased. Overall, Strategen was able to discover important trends and trade-offs of LDES technologies in a manner that was not too computationally intensive.

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[23] Learn more about PLEXOS here: https://www.energyexemplar.com/plexos.

The EPRI US-REGEN Model optimizes investments in the energy capacity (MWh) and power capacity (MW) of energy storage candidate technologies independently. This approach obviates the need to explicitly specify duration, making it instead a result of the optimization of power and energy capacities. EPRI refers to this modeling approach as the “room and door” approach, where the room represents the energy capacity (MWh), and the door represents the power capacity (MW). This approach allows candidate energy storage technologies to be differentiated by their energy capacity cost, power capacity cost, and roundtrip efficiency. The characteristics of candidate technologies determine how they are operated and their value to the power system under different scenarios. Using this approach, EPRI finds that a combination of LDES technologies could be deployed under the right scenario conditions, and given the rapid evolution in this space, utilities should remain open to any technology that supports their needs.

EPRI also has a group that is focused on informing the cost and performance parameters of the candidate energy storage technologies represented in the model. Researchers develop multiple cost projections for each technology to capture uncertainties related to development and how these uncertainties might impact the value and deployment of individual technologies. Finally, they look at regional differences in the availability of renewable and other low-carbon generation resources and explore how regional differences impact the value and operation of individual energy storage technologies. For example, in their analysis of the Asian Pacific, hydrogen is deployed with more frequency than in some of the other regions that EPRI explored.

MODELING TOOL

Select modeling tools with appropriate dispatch horizons to fully optimize resources with longer discharge durations.

Once the scope has been defined and the inputs have been identified, the modeling tool can be selected. As mentioned above, each type of tool has a different function, and within a specific function, there is a range of product offerings with different capabilities and features. The chosen scope, or the analytical question at the core of the modeling effort, can help identify which modeling capabilities are necessary.

One of the primary limitations of some current modeling tools is a lack of appropriate dispatch horizons needed to model multi-day and seasonal storage. Although some techniques have been applied to simplify dispatch into representative blocks (such as UC Merced’s critical time step approach), the most accurate way to capture multi-day and seasonal storage is to model each year as 8,760 consecutive hours. Given current constraints on computational complexity, an initial focus on “snapshot” years can be used to make the problem tractable, instead of attempting to model 10-20 years in a single study. Additional value can be gained from studying reliability and storage dispatch over additional years as needed.

EPRI

Nils Johnson
Principal Technical Leader
EPRI

Preferred Modeling Tool
REGEN by EPRI[24]

Primary Modeling Question
What types of energy storage technologies might be valuable for decarbonizing the power sector and under what policy and market conditions?

Advice for Modeling LDES
Given the inevitable churn of technologies in this space, focus on modeling the technology-neutral cost and performance characteristics that will lead to system value rather than modeling specific technologies. 8760 hourly resolution is absolutely needed to capture the value of LDES technologies in our analysis.

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[24] Learn more about the EPRI US-REGEN model here: https://www.epri.com/research/products/000000003002016601.

STRATEGEN

Maria Roumpani
Technical Director
Strategen

Preferred Modeling Tool
EnCompass by Anchor Solutions[25]

Primary Modeling Question
How should utilities approach their planning processes to assess LDES's ability to provide the services previously served by fossil fuel power plants?

Advice for Modeling LDES
Accurate and efficient modeling of LDES requires both identifying an appropriate balance between computational complexity of longer dispatch horizons and allowing LDES to optimally dispatch across the year, while also properly defining the input configurations and scenario assumptions to properly value LDES.

Strategen uses EnCompass, a versatile tool from Anchor Power Solutions, for capacity expansion and production cost modeling. In production cost mode, EnCompass can optimize dispatch operations over 8,760 consecutive hours. When performing capacity expansion modeling, users can define the look-ahead optimization window for each analysis depending on the question at hand. To capture the potential benefit of multi-day storage over weeks and even seasons in the investment decision stage, users can use the power-to-gas module or pumped hydro resources to simulate LDES. In addition, EnCompass can endogenously model ancillary service requirements as a function of renewable deployment. This feature more accurately presents the need for storage technologies, and therefore the additional value of energy storage, for the overall portfolio.

3.2 | PHASE 2: MODELING

Once the appropriate tool has been selected and the inputs have been determined, the modeling phase begins. This phase is centered around accurately representing LDES and properly valuing its various benefits. The other key part of the modeling phase is incorporating risk and uncertainty, to represent the wide range of potential scenarios that might impact the role and value of LDES technologies.

VALUATION

Ensure that the modeling approach appropriately captures and values all LDES resource benefits and value streams.

To accurately assess the value of LDES in the context of long-term resource planning, it is important to ensure that the model appropriately values and incorporates all resource value streams, including capacity, energy, ancillary services, and resilience. A key benefit of LDES is its ability to provide reliability that cannot be delivered by variable renewable generation. Methodologies for valuing the reliability contribution of energy storage resources, including shorter-duration resources, are still relatively new and are not always easily integrated into larger system models.[26] For example, production cost models that operate at an hourly resolution are unable to capture the full value of the sub-hourly operations of storage technologies with the ability to quickly ramp up and down.

The specific resource adequacy needs for any given power system change based on the mix of generation resources. This can be difficult to capture in resource planning models, so models that are capable of endogenously modeling local resource adequacy needs can provide a more accurate picture of how LDES impacts reliability. One example is the work that the Pacific Northwest National Laboratory (PNNL) did in collaboration with Strategen to model future resource needs in the Los Angeles Basin using GridPath. Specifically, PNNL used GridPath to run capacity expansion models that included the LA Basin as a 3-zone model connected to a larger 7-zone model, designed by the CPUC that represented the rest of California and other key import or export regions. Each zone in the model represented an aggregated load and generation region, connected to other regions by transmission lines.[27,28] Using three additional zones to further specify the local transmission constraints and resource needs within the LA Basin allowed PNNL to focus its analysis on the local impacts of deploying new resources.

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[25] Learn more about EnCompass here: https://anchor-power.com/encompass-power-planning-software/.

[26] Vinod Siberry, et. al., "Energy Storage Valuation: A Review of Use Cases and Modeling Tools.", U.S. Department of Energy, June 2022, https://www.energy.gov/sites/default/files/2022-06/MSP_Report_2022June_Final_508_v3.pdf.

[27] Patrick Maloney, et. al., "Capacity Expansion Planning for LA Basin: the Role of Energy Storage", Pacific Northwest National Laboratory, January 31, 2023, https://www.pnnl.gov/publications/capacity-expansion-planning-la-basin-role-energy-storage.

[28] Erin Childs, et. al., "Gridlocked: How Local Planning and Energy Storage Can Help Surmount Grid Congestion and Enable a Clean and Just Energy Transition." Strategen Consulting, June 2023, https://www.strategen.com/strategen-blog/cesa-la-storage-study-gridlocked.

Part of the proper valuation of LDES is ensuring that LDES is dispatching accurately and appropriately given its cost and performance characteristics. LDES should dispatch differently than shorter-duration energy storage technologies and dispatch strategy should vary across different forms of LDES, depending on their specific technical characteristics and the current needs of the system. For example, metal-air batteries typically have lower roundtrip efficiency than lithium-ion batteries or redox flow batteries, making them more suitable for long discharge periods at infrequent intervals.

INCORPORATING UNCERTAINTY & RISK

All LDES modeling should include an appropriate range of scenarios to examine grid and technology uncertainties, and the role that LDES can play in those potential futures.

Incorporating uncertainty and risk into resource expansion models allows decisionmakers to consider potential future variability and unpredictability. Models should include a wide range of scenarios in energy system planning efforts to prepare for dynamic energy markets, resource variability, technology performance and cost variability, regulatory and policy changes, weather, and fluctuations in load.

In the context of LDES, incorporating uncertainty and risk can effectively identify the value streams associated with LDES and the role LDES can play in potential futures. Considering a range of scenarios will allow decisionmakers to make more informed choices that can maximize the economic and reliability benefits of LDES and design a robust energy infrastructure for the future.

Some modeling tools can incorporate stochastic simulations, which are used to model and analyze energy systems that consider the variability and probabilistic nature of different factors. This is done to reflect the inherent uncertainties in forecasting. This type of modeling is unlike deterministic simulations, which rely on fixed inputs and assumptions. Deterministic simulations assume that all variables are known with certainty, which can lead to unreliable grids due to emerging factors such as increasing variable resource adoption and the impacts of climate change.

Take for example Peninsula Clean Energy (PCE), which uses the capacity expansion and production cost model PowerSIMM for planning and analyzing portfolio risk. PCE, which serves customers in County of San Mateo and the City of Los Baños in California, is a primarily winter-peaking load-serving entity, which impacts the energy arbitrage of LDES. PCE simulates dozens or hundreds of future paths (e.g., weather, demand, renewable generation, commodity prices) to accurately optimize their storage dispatch. This stochastic analysis examines how costs change over time, how adding new resources impacts the portfolio, and what financial risks exist with added uncertainty. Most importantly, these models simulate outlier events that are low probability but high risk. Doing so enables the implementation of risk mitigation strategies like physical and financial hedging, and the identification of system bottlenecks, so planners can make informed decisions on issues like resource expansion and power procurement. For PCE, this means optimizing their storage resources to enhance the operation of their portfolio.

PENINSULA CLEAN ENERGY

Mehdi Shahriari
Planning and Analytics Manager
Peninsula Clean Energy

Preferred Modeling Tool
PowerSIMM by Ascend[30]

Primary Modeling Question
How can LDES help us provide 100% renewable energy to our customers in an affordable and sustainable way?

Advice for Modeling LDES
At the end of the day, it's imperative to understand the value proposition of LDES for customers, and so you must perform cost-benefit analysis relative to other available technologies to find the optimal portfolio to achieve your sustainability goals.

Outlier events go beyond extreme weather. As mentioned, Mitsubishi Power's PLEXOS model utilizes gas prices and water availability when modeling hydrogen resource options. Modeling a range of resource costs and fuel prices provides the best opportunity for cost optimization, revenue estimation, customer affordability, and insights into the feasibility of investing in emerging technologies.

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[29] Learn more about GridPath here: https://www.gridpath.io/.

Patrick Maloney
Power Systems Engineer
PNNL

Preferred Modeling Tool
GridPath by BlueMarble[29]

Primary Modeling Question
How does the LDES impact reliability for a carbon-free grid at the local, regional, and state-wide level?

Advice for Modeling LDES
Users must choose the level of modeling granularity appropriate for their objective. Transmission constraints at the local level can significantly impact the level of storage necessary to provide adequate reliability.

3.3 | PHASE 3: APPLICATION & IMPLEMENTATION

The first phase of the resource planning process is crucial for setting up models that can address timely, meaningful questions in an efficient manner, considering both priorities and tradeoffs. In this first phase, planners should define the scope for modeling efforts, determine initial inputs, and select an appropriate modeling tool.

FINDINGS & RESULTS

Modeling findings and results should focus on identifying insights that can inform no-regrets planning actions, rather than focus on specific numerical results, and should help to inform future and/or ongoing modeling and planning activities.

At this stage of LDES technology development and commercialization, modeling findings and results should focus on identifying insights that can inform no-regrets planning actions or continued modeling activities, rather than focusing on specific numerical results. Examples of no-regrets planning actions include initiating procurement activities or the pursuit of additional research tracks that will provide value under a wide range of possible future scenarios. For example, if modeling results show that deployment of 500 MW of LDES is needed to achieve a zero-carbon grid in a particular region, this determination will allow the utility to begin procuring a fraction of that total resource need with confidence that the new resources will provide value.

Numerical findings help identify trends and make comparisons, but as technology costs and performance continue to evolve over the coming decade, the specific numerical findings will continue to change accordingly. Instead, focusing on directional insights can yield higher-value findings for resource planners. For example, tools like EPRI's US-REGEN and E3's RESOLVE allow for the modular selection of capacity and energy in their capacity expansion models. In other words, the model is not constrained by specific capacity and duration configurations but instead can solve for the optimal combination. The findings can then provide insights into what storage configurations might be best given current cost and performance projections, even as the size and cost of storage deployments evolve.

In addition, modeling toolkits and the ability to handle increased computational complexity will continue to progress. These improved capabilities will create the potential for more comprehensive modeling that will provide new insights. However, while there are limitations due to computational power, simplified modeling approaches can still yield valuable insights.

PNNL's modeling assessment of the LA Basin demonstrates the value of directional insights. The researchers considered a variety of scenarios to create the optimal combinations of energy storage resources to replace all local fossil fuel generation. Although the researchers applied simplifications of simulating "representative days" instead of a full, 8760 hourly model to perfectly represent California's power system, their findings helped show that between 80-120 GW of storage is needed to fully decarbonize the LA grid. While additional research is needed to refine this analysis, planners can confidently begin the procurement process to add more storage to the region.

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[30] Learn more about PowerSIMM here: https://www.ascendanalytics.com/solutions/powersimm-suite.

IMPLEMENTATION & PROCUREMENT

Modeling exercises should be used to identify grid needs and begin procurement activities but are not a substitute for evaluating the cost-effectiveness & value proposition of specific projects.

As utilities and regulators perform modeling activities to identify long-term resource needs, these entities should consider that their results will show a directional snapshot at a particular moment in time. This is especially true in the rapidly evolving area of LDES technologies. As a result, the scoping of these analytical exercises should be narrow enough to shed light on investments that can spur procurement activities. To do so, it is fundamental to keep in mind that the array of technologies that can meet the need identified in the modeling is much wider and more diverse than the specific solution or solutions modeled. As such, when translating modeling results into procurement directives and targets, utilities and regulators should ensure their procurement constructs allow for all resources that can meet the modeled need to participate in the related request for offers (RFO).

This approach has been pursued by the CPUC, which, within its IRP proceedings, has directed all its jurisdictional load-serving entities to collectively procure 1,000 MW of LDES by 2028. To ensure that this procurement directive incented the development of all types of LDES assets and not just the procurement of 4-hour storage built in blocks, the CPUC noted that LDES must be “able to deliver at maximum capacity for at least eight hours from a single resource.”[31] Ultimately, the translation of results into procurement targets that are certain to provide value is critical to develop the LDES market and to allow operators, buyers, and regulators to develop the needed contractual, regulatory, and operational experience to fully integrate LDES into the grid.

From the utility perspective, community choice aggregator PCE has set its mission to deliver 100% renewable energy on an annual basis by 2025 and for 99% of the hours in the year by 2027.[32] This rapid timeline informed their modeling activities, and the results of their analysis have guided their procurement process. So far, PCE has procured both 8-hour and 4-hour storage, along with solar+storage, as immediately beneficial resources. They continue to explore resource options through their modeling activities and will adjust their procurement strategy as they gain new insights to achieve their clean energy goals.

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[31] “Decision 21-06-035.” California Public Service Commission, June 24, 2021, https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M389/K603/389603637.PDF.

[32] “Strategic Plan 2020-2025.” Peninsula Clean Energy, June 2020, https://www.peninsulacleanenergy.com/wp-content/uploads/2020/06/PCE-Strategic-Guide-Online-W.pdf.

4. RECOMMENDATIONS FOR AGENCIES, REGULATORS, AND POLICYMAKERS

Require Utilities to Engage in Long-Term Planning Modeling and Consider LDES in their Analyses

While IRP processes that include long-term modeling are increasingly common across the U.S., there is significant variance regarding the methods, inputs, assumptions, and candidate resources considered therein. In this context, state energy agencies should deepen their collaboration with legislatures and key authorities, such as regulatory bodies, to establish the appropriate requirements for regular, long-term modeling processes. Once set up, policymakers and planners then must ensure that LDES technologies are included in all IRP modeling processes. To do so, it will be critical to select a means to characterize LDES candidate resources, either through an exploration of the available technologies or through the construction of storage archetypes, that capture the wide array of available solutions. These decisions will require utilities to first develop a well-defined scope to inform modeling scope, priorities, and trade-offs.

Strategen encourages the exploration of technology-neutral modeling since it is unclear which specific storage technologies will achieve the most significant cost and performance improvements in a market currently confronting supply-chain issues and interconnection challenges while seeking to leverage policy incentives for clean energy deployments codified in the federal Inflation Reduction Act. Ultimately, this approach can provide important insights for both public and private investments regarding the price points technologies like LDES should strive for in the coming years.

Enforce the Use of Modeling Tools that Accurately Represent LDES Value

In addition to including LDES technologies, IRP processes should utilize modeling tools that can appropriately model the technical characteristics and dispatch of LDES. Here, the temporal granularity and horizon of the model are essential factors. Research from UC Merced found that “the number of consecutive days for energy arbitrage changes the operation of storage.”[33] Researchers found that modeling longer time horizons in capacity expansion models changes the role of low-cost LDES: their modeling analysis selected storage assets with up to 10 hours of duration when allowed to optimize over 7 consecutive days. When researchers increased the time horizon to 60 consecutive days, storage duration jumped to 200 hours. A time horizon of 365 consecutive days (8,760 hours) yielded storage selections of up to 630 hours in duration. Given these findings, expanding the time horizon of capacity expansion models to model 365 conservative days will be essential to properly identify the need for and value of LDES.

In addition to accurately modeling dispatch that is sufficient for the range of storage durations, the production cost models used by utilities should incorporate all relevant value streams for LDES, such as capacity, energy, ancillary services, and resilience. Models also must be able to assess the uncertainty and risk in the potential future portfolios to understand how future conditions may impact the need for LDES.

Develop Load and Supply Forecasts and Scenarios that Capture Extreme Weather Events

Modeling exercises that seek to identify cost-effective and reliable portfolios must, by definition, compare all available candidate resources in terms of cost and contribution to meet energy and capacity needs. As such, the valuation of each resource class is only as accurate as the accuracy of its relative value with regard to another technology. Thus, it is not enough to accurately estimate the contributions of LDES to assess the value of this resource class, the reliability contributions of other resources must also be accurately measured to understand the benefits and relevance of LDES in proper context.

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[33] “Long Duration Energy Storage Public Workshop #3.” UC Merced, July 2022, https://efiling.energy.ca.gov/GetDocument.aspx?tn=244120.

Conventional resources are often represented in the planning process as examples of firm or perfect capacity. This means that summer-rating or nameplate capacity is used as the proxy for the reliability contributions of these conventional assets, an assumption that is overly generous given observed performance. This overestimation has significant effects in most modeling exercises, as it skews the apparent cost-effectiveness of certain solutions at the expense of others, ultimately hindering reliability and affordability. Given the fact that LDES is more likely to serve as a firm capacity resource, the overestimation of conventional resources in terms of reliability can significantly affect the perceived need and opportunity for LDES. For these reasons, it is important for state agencies, regulators, and utilities to coordinate to develop methodologies that, ad minima, consider the forced outage rates of conventional assets. This modification is desirable as it would provide a more accurate representation of a resource's capabilities. This type of analysis is particularly impactful for aging, inefficient, and unreliable fossil-fueled assets whose operational realities are far from what can be inferred based only on their nameplate capacity. Overall, the development of these values is desirable, as it would alleviate regulatory risks associated with counting practices that overestimate the reliability value provided by fossil-fueled resources.

Support Stakeholder Engagement Regarding Model Development

Once the scope and tools have been developed, regulators, operators, and utilities must commit to open and transparent stakeholder processes within their IRPs to allow for greater visibility and collaboration in updating modeling inputs. Doing so will be particularly important for LDES, given that LDES are emerging technologies with significant space to grow and evolve. In this context, it will be critical to encourage stakeholders, including industry and environmental groups, to offer feedback and be involved in these processes.

Application to Procurement Activities

When translating modeling results into procurement directives and targets, utilities and regulators should ensure their procurement constructs allow for all resources that can meet the modeled need to count toward the requirement or to participate in the related RFO. This translation of results into no- and least-regrets procurement targets is critical to spur the LDES market because it will allow operators, buyers, and regulators to develop the needed contractual, regulatory, and operational experience to fully integrate LDES into the grid.

Identify Needs and Procurement Opportunities that Can Be Leveraged as Pilots or Demonstrations for Emerging Technologies

As utilities and regulatory agencies work on improving modeling and planning tools to effectively coordinate the decarbonization of their jurisdictions, the work of other state agencies will also include easing the path to market of LDES technologies to build operational experience and confidence in emerging technologies. In this context, the identification of specific cases and needs that could serve as pilots and demonstrations for these technologies will be critical. LDES assets are uniquely positioned to serve roles beyond reliability, including local and critical facility resiliency. As such, these resources can capably meet specific goals that other assets may not, given land use, emissions, noise, or other limitations. Deployment of these assets could also bolster the reliability of areas that have suffered historic underinvestment, as well as enhance the resiliency of community facilities such as hospitals and shelters. Moreover, these initial procurement and deployment forays can defer or even nullify the need for future investments if adequately targeted. For these reasons, state energy agencies should coordinate with utilities and communities to identify potential pilot and demonstration cases that can ease a path to market for LDES assets.

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34 "Getting Capacity Right: How Current Methods Overvalue Conventional Power Sources." Advanced Energy United, March 2022, https://info.aee.net/hubfs/2022%20Folders/2022%20Reports%20With%20Stickers/STICKER%20Getting%20Capacity%20Right%20-%20How%20Current%20Methods%20Overvalue%20Conventional%20Power%20Sources.pdf.

GREEN
HYDROGEN
COALITION

The Green Hydrogen Coalition, a 501(c)(3) educational nonprofit organization, is dedicated to facilitating practices and policies to advance the production and use of green hydrogen in all sectors where it will accelerate a carbon-free energy future.

HyBuild™ North America is the GHC's platform to architect low-cost, mass-scale green hydrogen hubs throughout the continent. The first regional focus of the platform, HyBuild Los Angeles, was launched in 2020 and has identified a pathway to achieve $2.05/kg delivered green hydrogen costs in the Los Angeles Basin to serve multi-sectoral offtakers, reduce air pollution, and create diversely skilled local jobs.

The GHC's second platform, the *Western Green Hydrogen Initiative*, is a public-private partnership to assist interested states and partners in advancing and accelerating deployment of green hydrogen infrastructure in the Western region for the benefit of the region's economy and environment.

For more information on the GHC, visit ghcoalition.org.