Sandia National Laboratories

LONG-DURATION ENERGY STORAGE (LDES)

Prepared for the CESA Members Only Meeting

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U.S. DEPARTMENT OF ENERGY NNSA

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WHAT I WILL DISCUSS TODAY

- Decarbonization and the role of energy storage.
- The need for new technologies
- What is LDES—technologies and applications.
- Introducing the LDES National Consortium
- Commercialization challenges & recommendations
- Q&A

What is Decarbonization?

- The shift away from fossil fuel generation (e.g., coal, natural gas) toward renewable energy (e.g., solar, wind) and/or clean energy (inclusive of nuclear).
- 19 states have adopted Decarbonization goals.
- Nationally, more than 80 cities representing an estimated total population of 40 million people have also established goals.
- **Decarbonization requires an unprecedented level of new clean energy / renewable projects.**
- More than 11,000 projects comprising over 2TW of generating capacity and storage were actively seeking interconnection in the US in 2023. (Source: DOE)
- This is nearly three-times greater than the 700GW of projects that were seeking interconnection at the start of 2022. The vast majority of the planned projects are solar, storage and wind.

The following states have adopted decarbonization / clean energy / renewable goals.

	STATE	DEADLINE	GOAL	CLEAR ROLE FOR ES/LDES
1	CA	2045	100% carbon-free electricity	YES
2	CO	2050	100% carbon free electricity	Somewhat
3	CT	2040	100% carbon-free electricity	NO
4	HI	2045	100% renewable energy	Somewhat
5	IL	2050	100% carbon-free electricity	Emerging
6	LA	2050	Net zero greenhouse gas emissions	NO
7	ME	2050	100% clean energy	NO
8	MA	2050	Net-zero greenhouse gas emissions	NO
9	MD	2045	Net-zero greenhouse gas emissions by 2045	
10	MI	2050	Economy-wide carbon neutrality	NO
11	NJ	2050	100% carbon-free electricity	Somewhat
12	NM	2045	100% carbon-free electricity	NO
13	NV	2050	100% carbon-free electricity	Somewhat
14	NY	2040	100% carbon-free electricity	Somewhat
15	OR	2040	Greenhouse gas emissions reduced 100 percent below baseline emissions	Somewhat
16	RI	2030	100% renewable energy	NO
17	VA	2045	100% carbon-free electricity	NO
18	WA	2045	100% zero-emissions electricity	Somewhat
19	WI	2050	100% carbon-free electricity	NO

The role of energy storage / LDES

- Solar and wind are (of course) intermittent and non-dispatchable resources.
  - ✓ Intermittent—the sun does not always shine and the wind does not always blow in predictable patterns.
  - ✓ Non-dispatchable—these renewable energy sources cannot be controlled by operators.
  - ✓ Its electricity generation does not match with the peak demand hours.

- Lithium-ion battery storage is already playing an important role in grid operations.
  - ✓ Managing peak loads for up to four hours;
  - ✓ Can replace gas-fired power plants;
  - ✓ Helps to smooth out power fluctuations on the electrical grid, which create reliability issues.

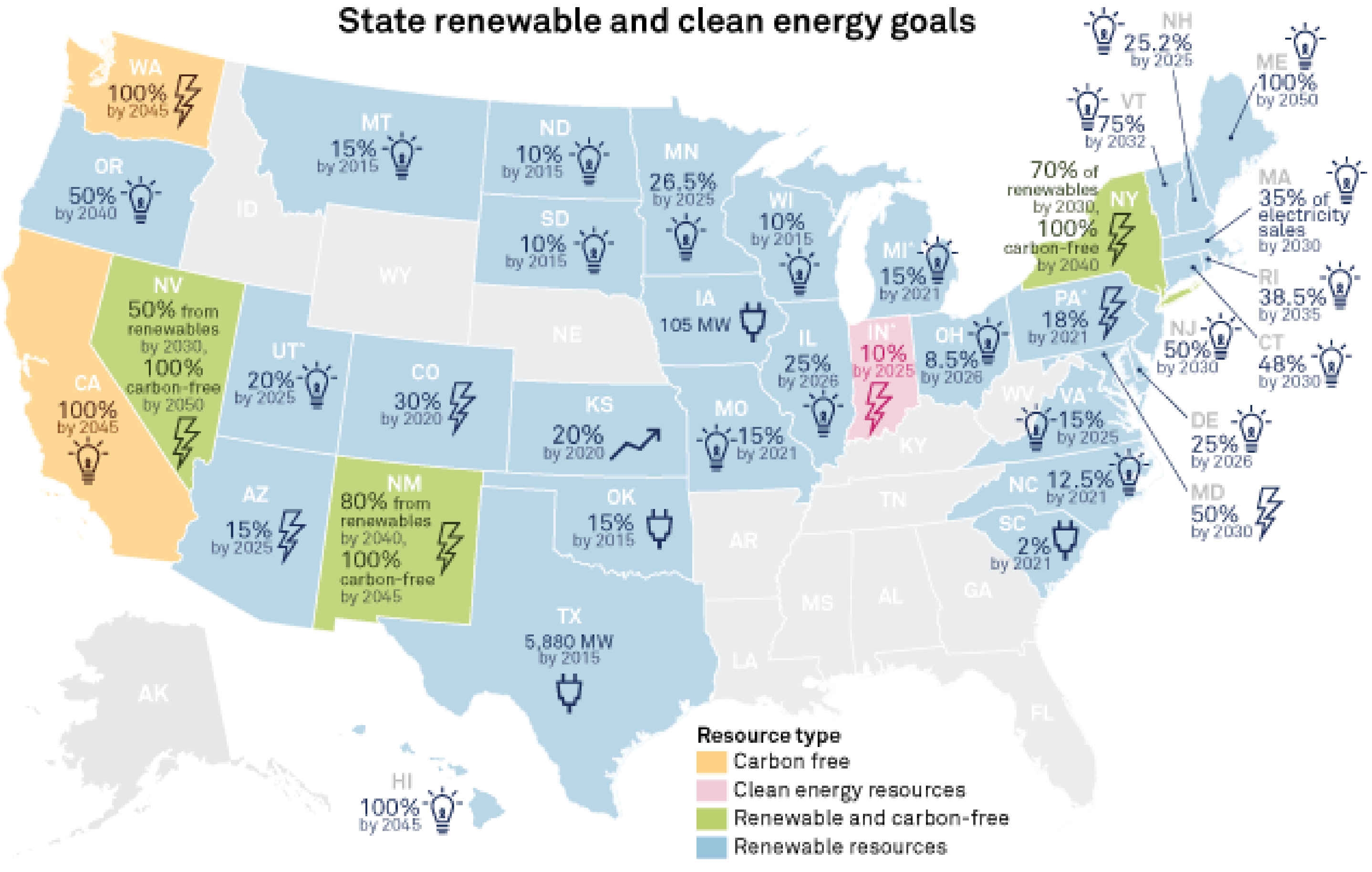
Energy Storage Policy—Current Status

- About 15 states have adopted some form of energy storage policy, which in all cases exists along with a renewables policy.
- Energy storage activity still driven mostly in states that have the following policies:
  - Utility **procurement mandates, targets or goals** (11 states);
  - Financial **incentives / subsidies** (CA, MD, NJ, NY);
  - State-funded **demonstration projects** (MA, MD, NY, UT, WA)
- Requiring storage in **utility IRPs** is also becoming more common. (NV, NM)

***Deployment*:**

- Installation has been mostly concentrated in CA-ISO and PJM, and ERCOT regions, and in states that have developed enabling policy frameworks. Texas is an exception, where business incentives & wholesale opportunities have driven ES development.

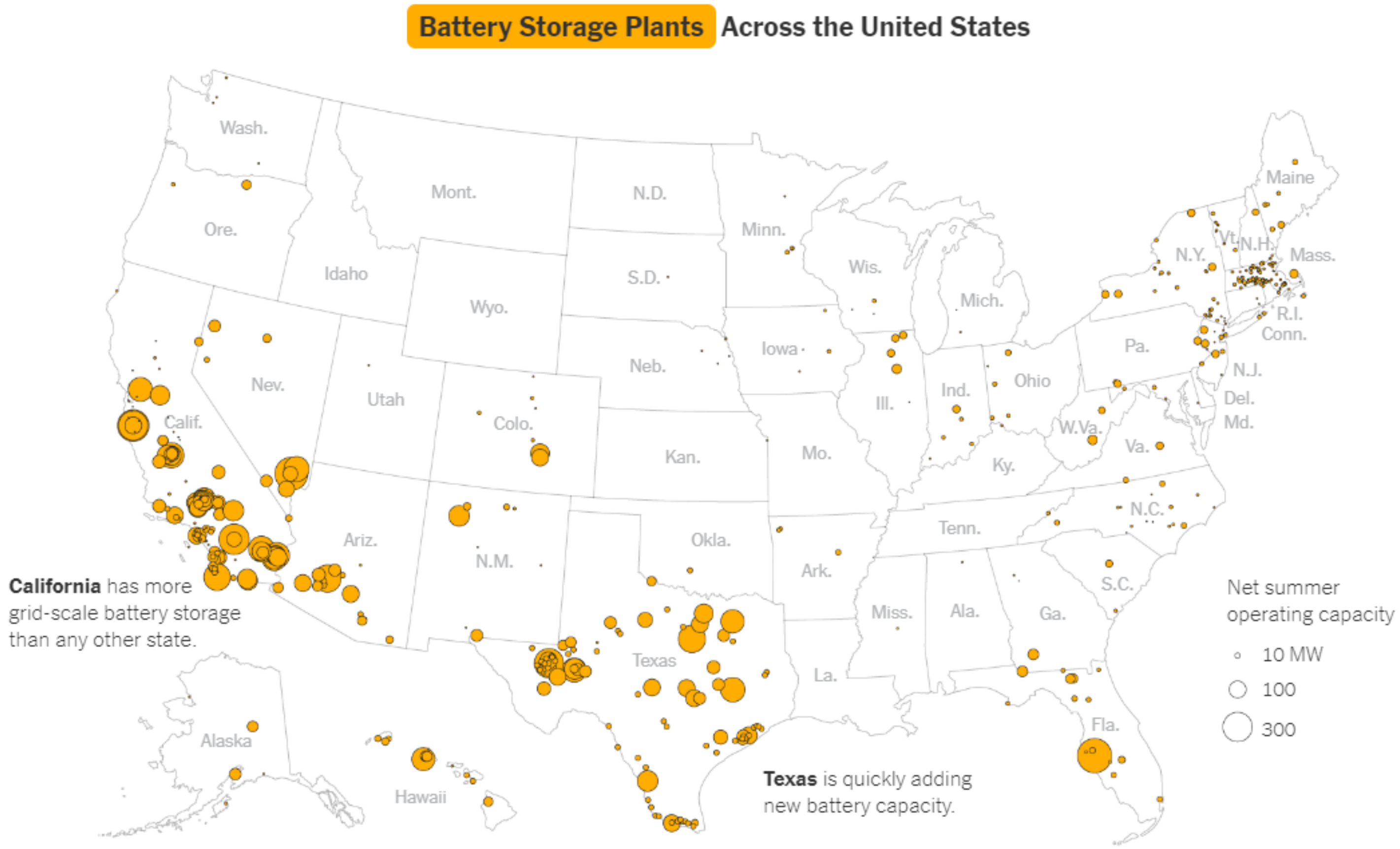
The role of LDES in a decarbonized future.



Source: EIA

- As renewables penetration exceeds 60%, this creates critical operational needs and market opportunities for LDES.
- Increase of "grid stress events"—extended periods of under-generation.
- Extreme weather events are also increasing…a rise in "winter peaking" scenarios with longer extended peaks.

The need for new technologies.



Battery Storage Plants Across the United States

California has more grid-scale battery storage than any other state.

Texas is quickly adding new battery capacity.

Source: EIA

- ➢ But depending solely on lithium-ion batteries is not an option.
  - ✓ By 2040, Demand will be twice the available Supply!
  - ✓ Li-ion batteries are arguably better suited for electric cars and portable electronics, and not as good for stationary storage. Plus there is not enough of it to accommodate grid-scale storage.
  - ✓ 4-hour duration limitations, fire hazards.
- ➢ For true LDES, 10 hours to 3 days, we will have to turn to Thermal, Gravity, or Chemical Storage.

Identifying key markets for LDES.

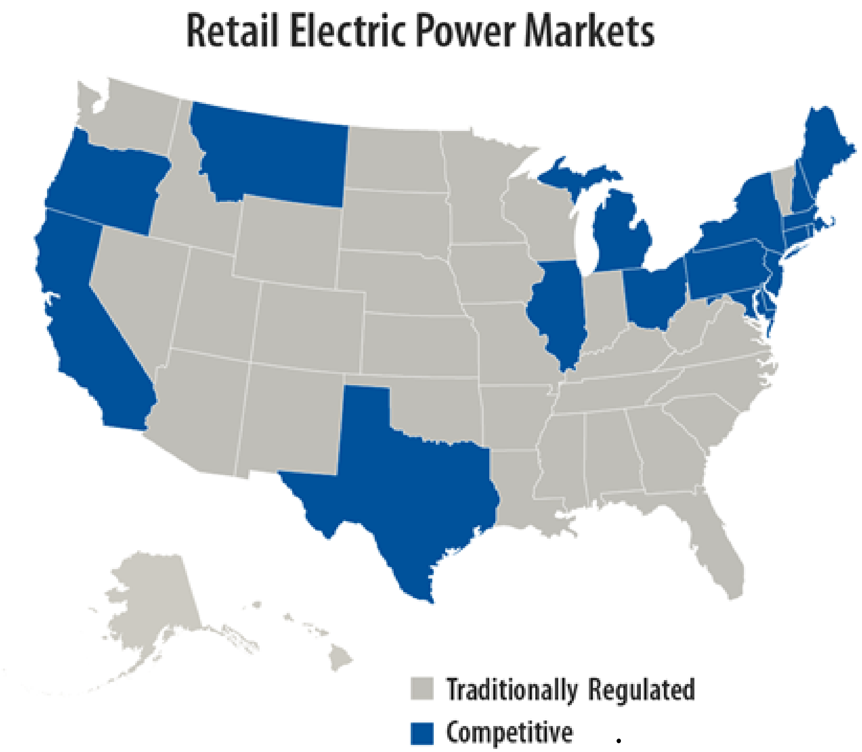
Regulated Markets

"Vertically integrated" utility **owns or controls** generation, transmission, and distribution

Regulated by states (public utility commissions)
Cost recovery via rates charged to customers

LDES needs to solve grid problem and be reliable, low-risk

Electricity markets are not homogenous.



https://www.epa.gov/repowertoolbox/understanding-electricity-market-frameworks-policies

Restructured Markets

Market is **competitive**

Utilities usually prohibited from owning G&T assets.

RTOS/ISOs responsible for inter-/intra-state T, D and O&M with oversight from FERC

LDES needs to make money

- Most states have not developed an LDES policy (CA is an exception)
- Little agreement about where, how and why LDES will be deployed.

Defining LDES—starting points.

- Presently definitions of LDES have focused on **duration**…defined as the length of time a storage system can sustain power output at its maximum discharge rate.

- DOE definition is by duration with a minimum of 10 hours.
  - ✓ Most states have no duration-based definition at all.

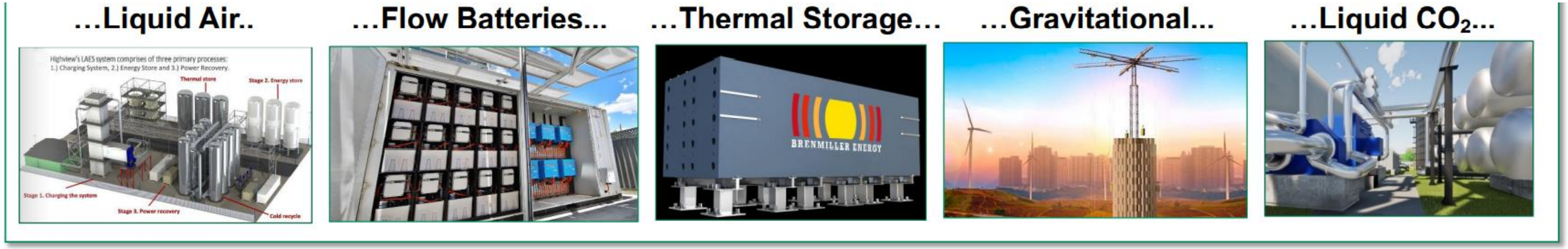
- Dozens of LDES chemistries in development with hundreds of companies in competition.

- Diversity across LDES technologies will be key…no “one size fits all” solution…different technologies for different applications.

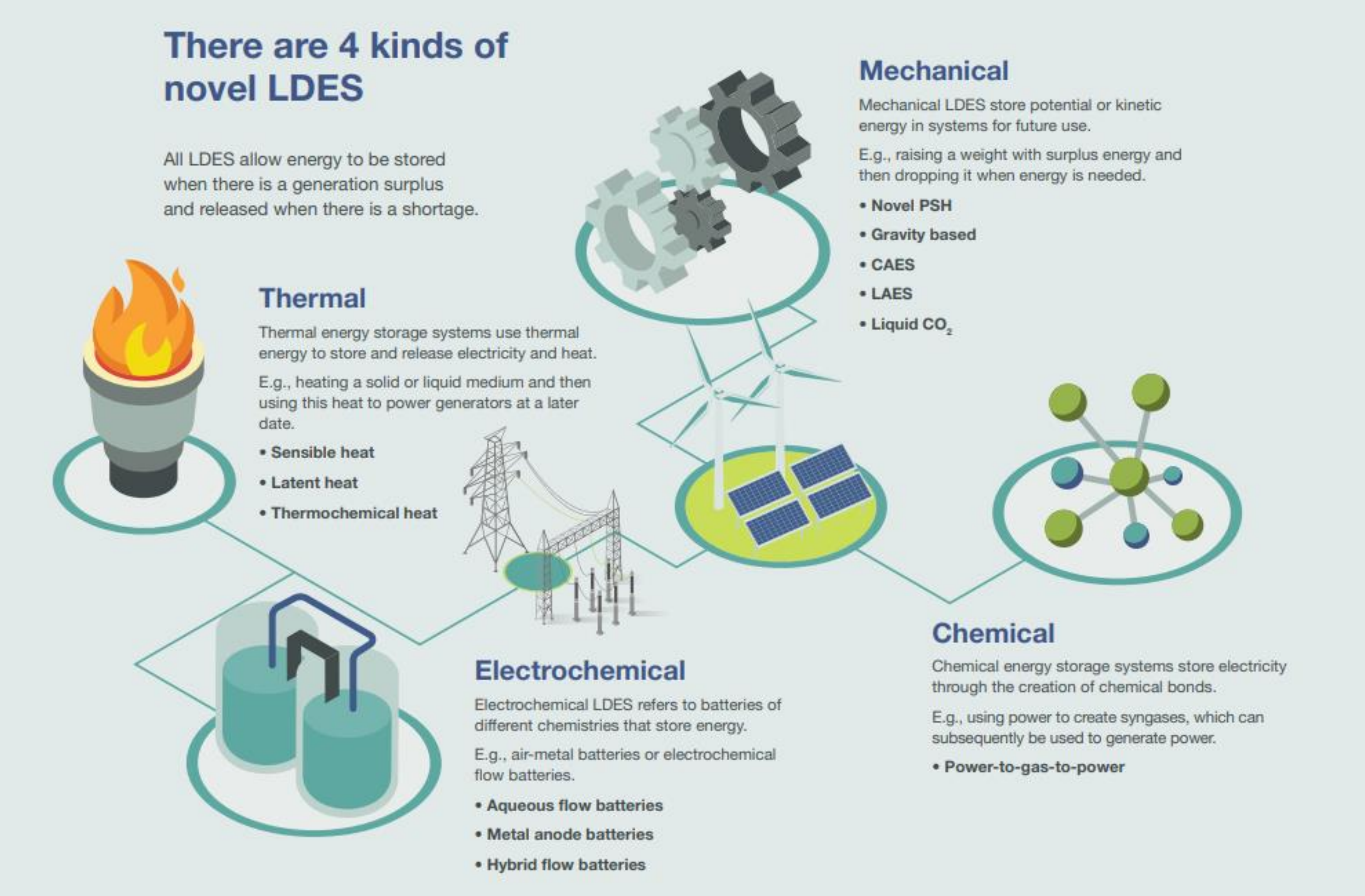
- Thus, increasingly, LDES technologies will be defined by the applications / use cases they serve.

The good news about LDES.

- For true Long Duration Energy Storage, 10 hours to 3 days, we will have to turn to Thermal, Gravity, or Chemical Storage
- The good news: LDES comprises a wide family of technologies with differing technological maturities and market readiness…any technology that can be deployed competitively to storage energy for prolonged periods (hours, days, weeks).



- Lab experiments, commercial developments and new market needs support the development of a portfolio of LDES solutions necessary to meet decarb goals.



There are 4 kinds of novel LDES

All LDES allow energy to be stored when there is a generation surplus and released when there is a shortage.

Mechanical

Mechanical LDES store potential or kinetic energy in systems for future use.

E.g., raising a weight with surplus energy and then dropping it when energy is needed.

- **Novel PSH**
- **Gravity based**
- **CAES**
- **LAES**
- **Liquid CO_2**

Thermal

Thermal energy storage systems use thermal energy to store and release electricity and heat.

E.g., heating a solid or liquid medium and then using this heat to power generators at a later date.

- **Sensible heat**
- **Latent heat**
- **Thermochemical heat**

Electrochemical

Electrochemical LDES refers to batteries of different chemistries that store energy.

E.g., air-metal batteries or electrochemical flow batteries.

- **Aqueous flow batteries**
- **Metal anode batteries**
- **Hybrid flow batteries**

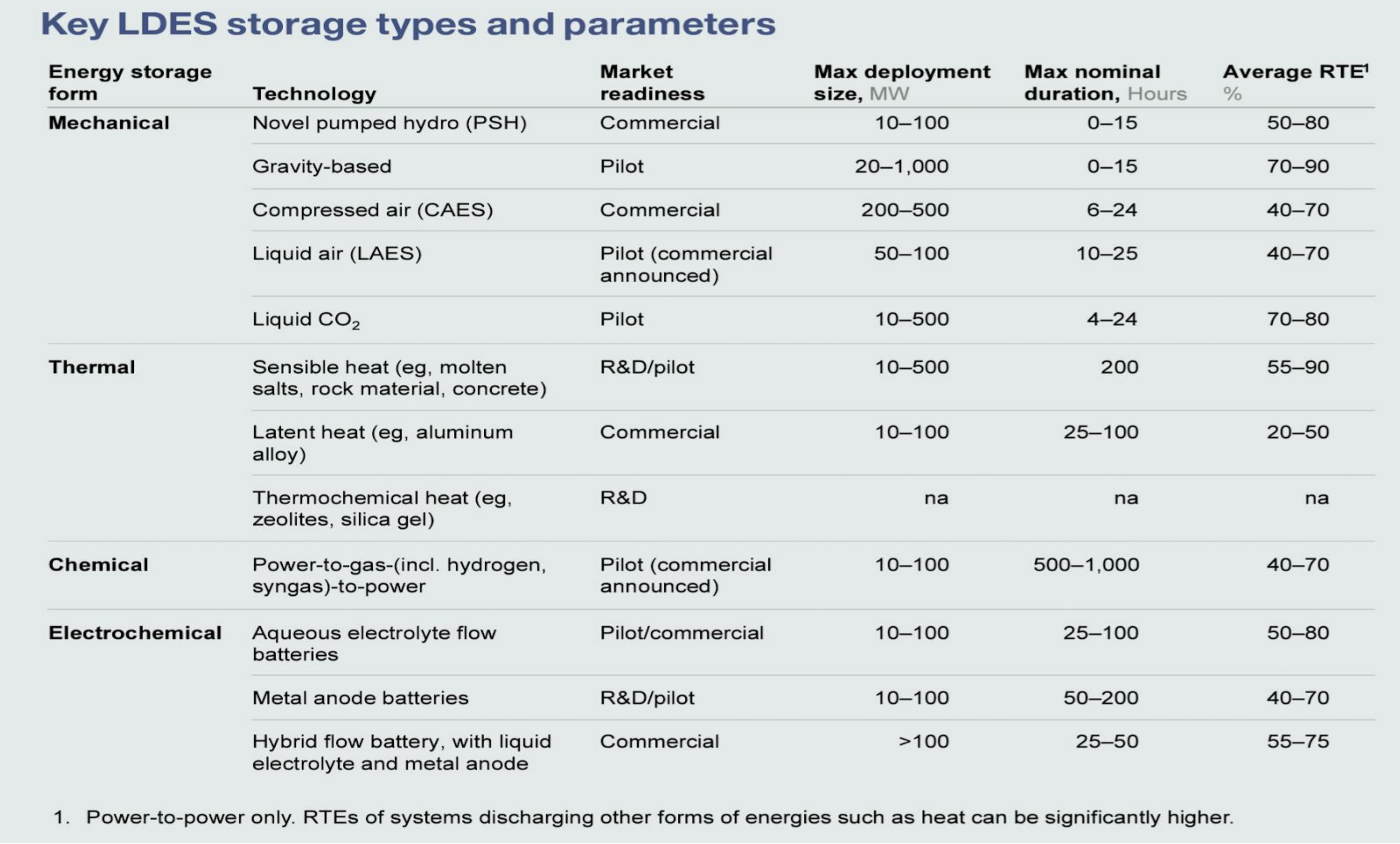
Chemical

Chemical energy storage systems store electricity through the creation of chemical bonds.

E.g., using power to create syngases, which can subsequently be used to generate power.

- **Power-to-gas-to-power**

Source: Pathways to Commercial Liftoff: Long Duration Energy Storage, DOE



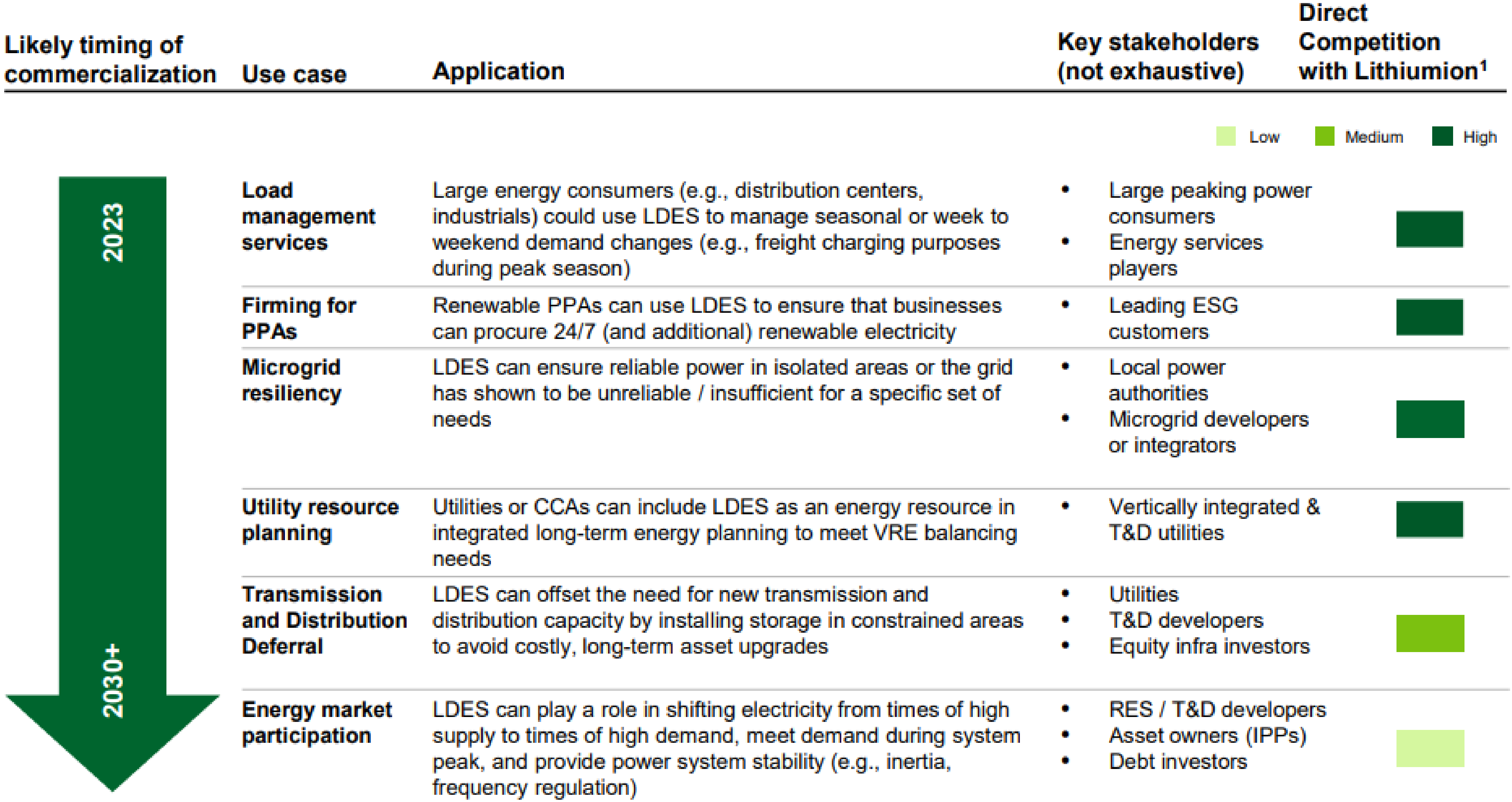
Key LDES storage types and parameters

Energy storage form	Technology	Market readiness	Max deployment size, MW	Max nominal duration, Hours	Average RTE[1] %
Mechanical	Novel pumped hydro (PSH)	Commercial	10–100	0–15	50–80
	Gravity-based	Pilot	20–1,000	0–15	70–90
	Compressed air (CAES)	Commercial	200–500	6–24	40–70
	Liquid air (LAES)	Pilot (commercial announced)	50–100	10–25	40–70
	Liquid CO_2	Pilot	10–500	4–24	70–80
Thermal	Sensible heat (eg, molten salts, rock material, concrete)	R&D/pilot	10–500	200	55–90
	Latent heat (eg, aluminum alloy)	Commercial	10–100	25–100	20–50
	Thermochemical heat (eg, zeolites, silica gel)	R&D	na	na	na
Chemical	Power-to-gas-(incl. hydrogen, syngas)-to-power	Pilot (commercial announced)	10–100	500–1,000	40–70
Electrochemical	Aqueous electrolyte flow batteries	Pilot/commercial	10–100	25–100	50–80
	Metal anode batteries	R&D/pilot	10–100	50–200	40–70
	Hybrid flow battery, with liquid electrolyte and metal anode	Commercial	>100	25–50	55–75

1. Power-to-power only. RTEs of systems discharging other forms of energies such as heat can be significantly higher.

Source: Pathways to Commercial Liftoff: Long Duration Energy Storage, DOE

Use case and application opportunities will likely have different timelines.

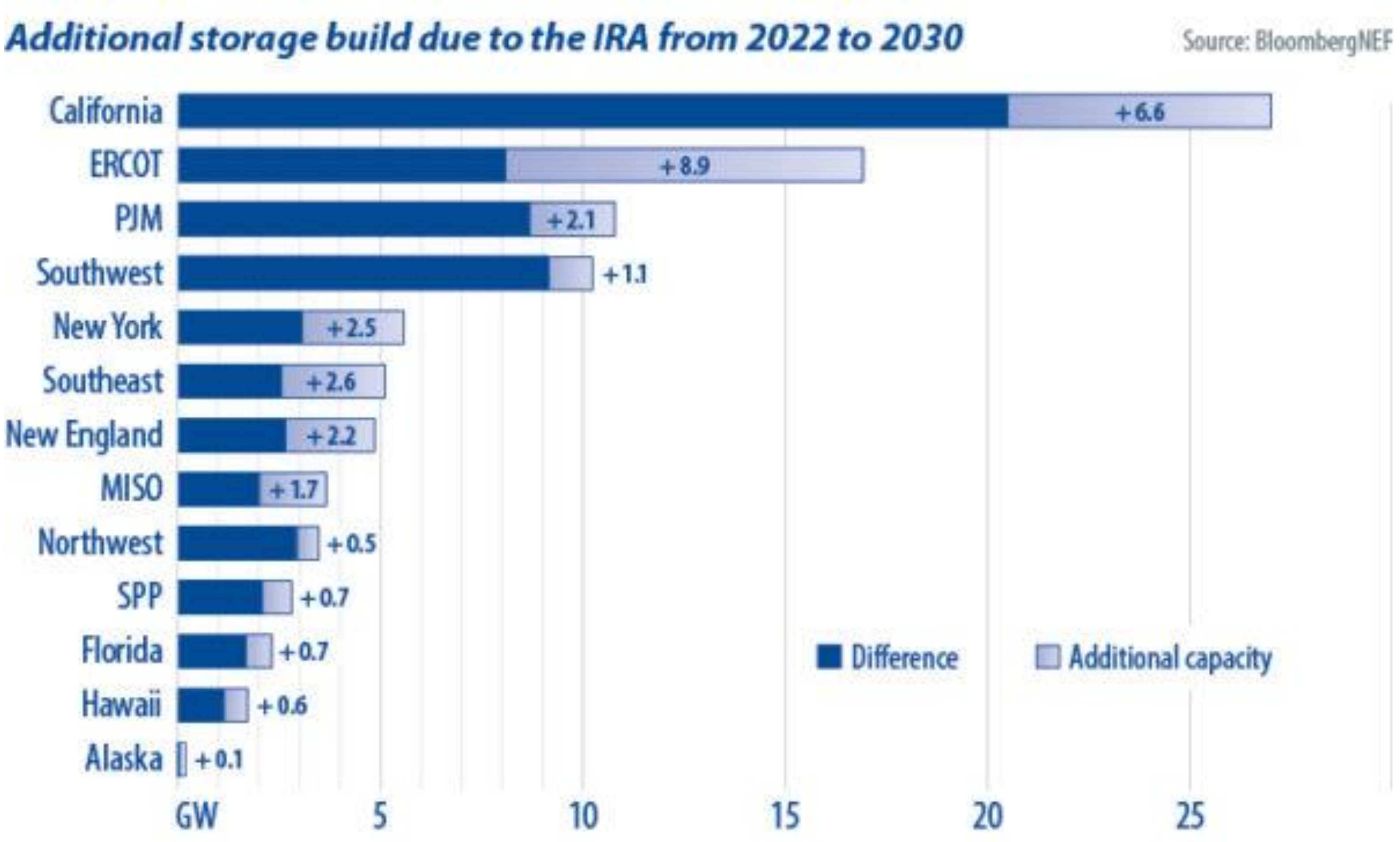


▢ Low ▨ Medium ■ High

Likely timing of commercialization	Use case	Application	Key stakeholders (not exhaustive)	Direct Competition with Lithiumion[1]
2023	**Load management services**	Large energy consumers (e.g., distribution centers, industrials) could use LDES to manage seasonal or week to weekend demand changes (e.g., freight charging purposes during peak season)	• Large peaking power consumers • Energy services players	■
	Firming for PPAs	Renewable PPAs can use LDES to ensure that businesses can procure 24/7 (and additional) renewable electricity	• Leading ESG customers	■
	Microgrid resiliency	LDES can ensure reliable power in isolated areas or the grid has shown to be unreliable / insufficient for a specific set of needs	• Local power authorities • Microgrid developers or integrators	■
	Utility resource planning	Utilities or CCAs can include LDES as an energy resource in integrated long-term energy planning to meet VRE balancing needs	• Vertically integrated & T&D utilities	■
	Transmission and Distribution Deferral	LDES can offset the need for new transmission and distribution capacity by installing storage in constrained areas to avoid costly, long-term asset upgrades	• Utilities • T&D developers • Equity infra investors	▨
2030+	**Energy market participation**	LDES can play a role in shifting electricity from times of high supply to times of high demand, meet demand during system peak, and provide power system stability (e.g., inertia, frequency regulation)	• RES / T&D developers • Asset owners (IPPs) • Debt investors	▢

Source: Pathways to Commercial Liftoff: Long Duration Energy Storage, DOE

Federal funding in particular is driving development.



IRA, BIL subsidies + DOE demonstrations grants are driving investments and project development for clean energy.

Research from Stanford University suggests that the cost of LDES projects will need to fall to $5/kWh to be viable in the long run, and this depends heavily on the blend of renewable sources available.

Challenges—High-level perspectives.

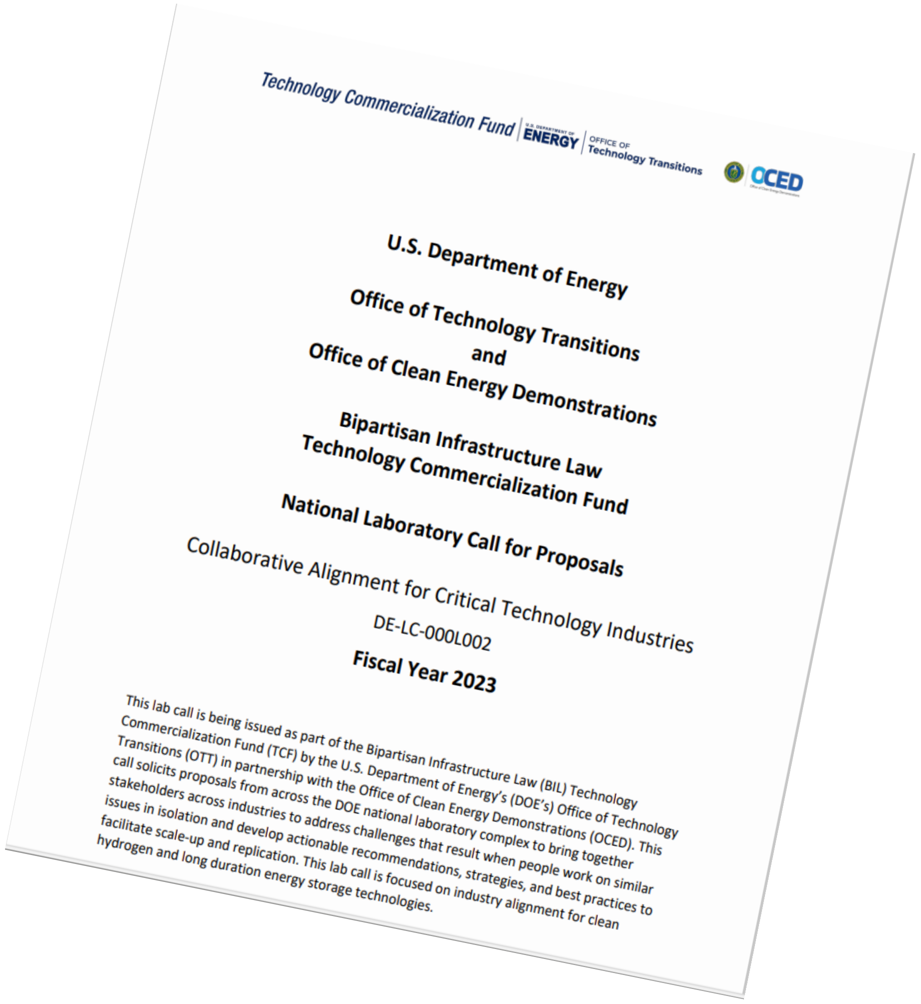
- ***Challenge #1:*** Lack of policy consistency
  - ✓ Most states have not developed an LDES policy (CA is an exception)
  - ✓ Little agreement about where, how and why LDES will be deployed.

- ***Challenge #2:*** It's unclear what LDES should do, and where.
  - ✓ Most regions have only adopted a 4 hour-or-less energy storage requirement
  - ✓ Currently little need or value beyond 4 hours

- ***Challenge #3:*** Little consensus on how LDES should be valued or compensated.
  - ✓ In restructured markets, LDES needs to make money.
  - ✓ Efforts to define ISO/RTO, utility and customer services remain incomplete.

All of this led to the DOE’s Lab-only Proposal Call.

- Released in the summer of 2023.
- U.S. DOE Office of Technology Transitions and Office of Clean Energy Demonstrations
- Funding provided by Bipartisan Infrastructure Law Technology Commercialization Fund
- Intended to address commercialization challenges that arise when many entities working in similar areas work in isolation.
- 50% cost-sharing requirement due to the opportunity being defined as a demonstration project.
- Sandia applied as lead lab with five lab partners.



Technology Commercialization Fund | ENERGY | Office of Technology Transitions | OCED

U.S. Department of Energy

Office of Technology Transitions
and
Office of Clean Energy Demonstrations

Bipartisan Infrastructure Law
Technology Commercialization Fund

National Laboratory Call for Proposals

Collaborative Alignment for Critical Technology Industries

DE-LC-000L002

Fiscal Year 2023

This lab call is being issued as part of the Bipartisan Infrastructure Law (BIL) Technology Commercialization Fund (TCF) by the U.S. Department of Energy’s (DOE’s) Office of Technology Transitions (OTT) in partnership with the Office of Clean Energy Demonstrations (OCED). This call solicits proposals from across the DOE national laboratory complex to bring together stakeholders across industries to address challenges that result when people work on similar issues in isolation and develop actionable recommendations, strategies, and best practices to facilitate scale-up and replication. This lab call is focused on industry alignment for clean hydrogen and long duration energy storage technologies.

LDES NATIONAL CONSORTIUM

The National Consortium for the Advancement of LDES Technologies

Will McNamara
Sandia National Laboratories
Principal Investigator

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525 SAND2024-00410PE.

This project is funded by the Infrastructure Investment and Jobs Act, also known as the Bipartisan Infrastructure Law (BIL), as part of the DOE Technology Commercialization Fund (TCF), administered by the Office of Technology Transitions in collaboration with the Office of Clean Energy Demonstrations.

THE NATIONAL CONSORTIUM FOR THE ADVANCEMENT OF LDES TECHNOLOGIES

The LDES National Consortium provides a forum through which stakeholders across the LDES ecosystem can convene to **identify barriers, determine potential synergies, and collaboratively develop and implement strategies necessary to achieve LDES technology commercialization** within the next decade.

MAJOR DELIVERABLES OVER NEXT THREE YEARS:

- LDES Demonstrations & Deployments Tracking System
- LDES Technology Maturity Evaluation Framework
- Assessment of Utility Needs for LDES
- Geographical Readiness Assessments
- Evaluation of US Wholesale Markets
- Evaluation of US Retail Markets
- Full Set of Commercial Pathways Recommendations
- Networking and Community Outreach

National Launch: January 2024

Lab Leadership

Lead by Sandia Labs partnering with ANL, INL, NREL, ORNL, & PNNL

160+ Teaming Partners

LDES National Consortium will be comprised of U.S. industry and community stakeholders, known as "Teaming Partners."

Website

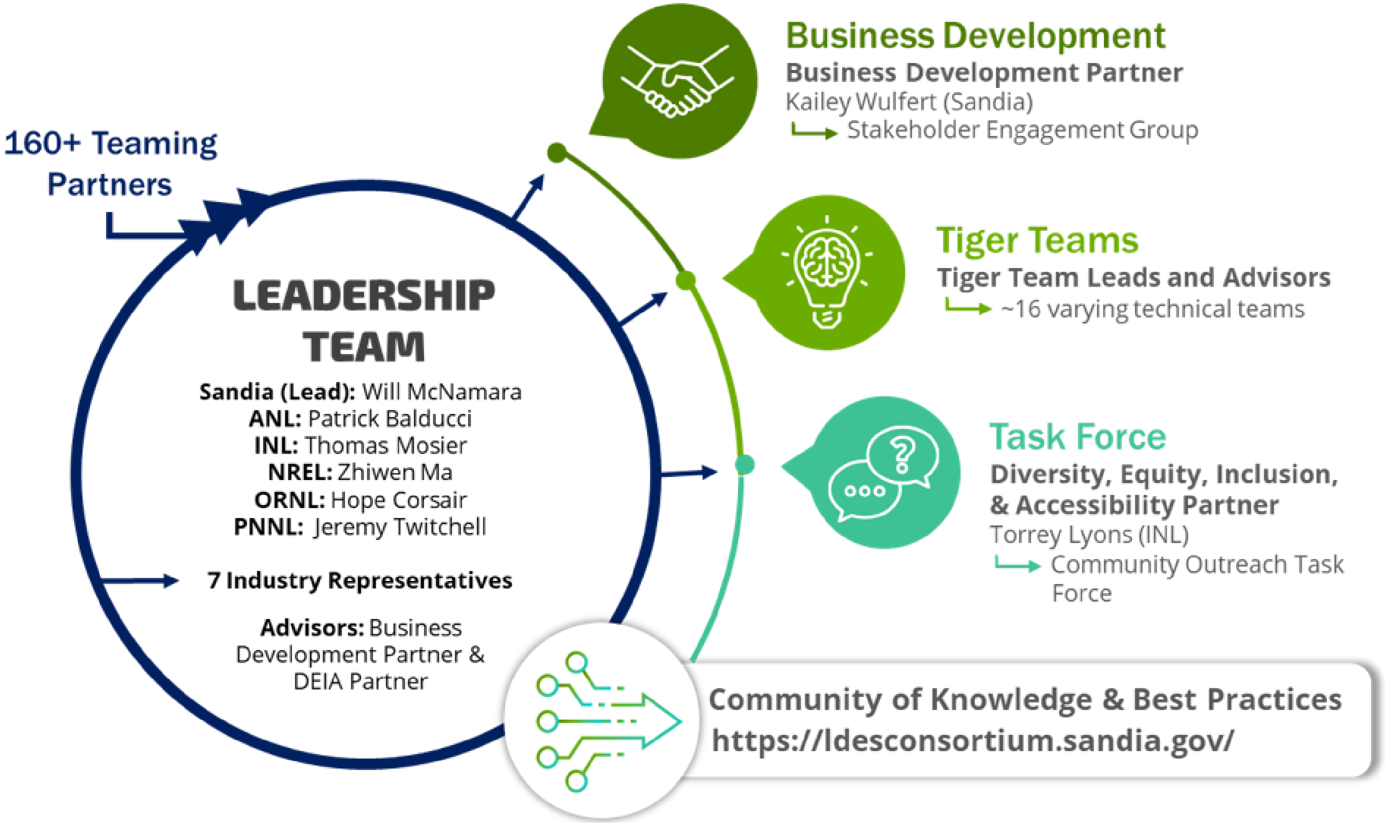
Community of Knowledge and Best Practices ensuring findings are easily accessible

3 Years
$7M Federal Funds + Cost Share

16 Tiger Teams

Topical working groups to evaluate challenges.

Organizational Structure



160+ Teaming Partners

LEADERSHIP TEAM

Sandia (Lead): Will McNamara
ANL: Patrick Balducci
INL: Thomas Mosier
NREL: Zhiwen Ma
ORNL: Hope Corsair
PNNL: Jeremy Twitchell

7 Industry Representatives

Advisors: Business Development Partner & DEIA Partner

Business Development
Business Development Partner
Kailey Wulfert (Sandia)
↳ Stakeholder Engagement Group

Tiger Teams
Tiger Team Leads and Advisors
↳ ~16 varying technical teams

Task Force
Diversity, Equity, Inclusion, & Accessibility Partner
Torrey Lyons (INL)
↳ Community Outreach Task Force

Community of Knowledge & Best Practices
https://ldesconsortium.sandia.gov/

TIGER TEAMS

- Customer Adoption
- Demonstrations & Deployments
- Economics & Valuation
- Equity
- Grid Infrastructure
- Interconnection, Standards & Permitting
- Investor Confidence / Finance
- Market Planning
- Policy & Regulations
- Reliability & Resilience
- Safety & Grid Security
- Supply Chain & Manufacturing Efficiencies
- Technology Development, Evaluation & Testing
- Use Case Development
- Utility Resource Planning
- Workforce Development

Tiger Teams will develop what ultimately will become the public stakeholder recommendations for these specific focus areas.

11 Challenges—Pulled directly from the DOE's Lift-Off Report.

1. Cost of an LDES system needs to come down by 2030
2. LDES technologies must achieve 7-15% improvement in roundtrip efficiency to compete with Li-ion storage and hydrogen.
3. The specific needs related to LDES workforce training (i.e., skills and training) are presently not well defined.
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).
5. A comprehensive assessment of necessary supply chain improvements specific to LDES technologies does not presently exist.
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
7. Presently, there is no publicly available evaluation of LDES technologies against primary competitive factors.
8. LDES is not included in most utility grid firming plans.
9. LDES use cases require market changes.
10. ISO and RTO markets will need to develop support mechanisms.
11. State-level policymaking specific to LDES has been very limited.

#4—Resource adequacy compensation

- Further assessment is needed to determine how Regional State Committees (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.
- Alternatives to the Effective Load Carrying Capability (ELCC) should be developed as a means to developed as a means to evaluating the contributions that LDES can made toward resource adequacy requirements.
- Approaches 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 should be assessed for the potential to be offered as a standardized approach to other states.
- Further analysis of whether the approach that California is taking to monetize resource adequacy (its "Slice of Day" policy) should be conducted to determine the viability of offering this as a standardized approach for other states to adopt.

#6—How to evaluate grid upgrades.

- A research entity should be tasked with conducting an interconnection standards gap analysis that is specific to LDES technologies and their unique requirements.
- Initiate a docket to investigate proactive interconnection planning processes and increased sharing of upgrade costs across multiple developers.
- The authorization process of scheduled interconnection agreements within RTO/ISO markets should be streamlined.
- Improve the capabilities of existing modeling software tools currently available to grid planners to capture the full value of LDES resources.

#11—State level policymaking.

- States that have adopted an energy storage procurement target, goal or mandate should be encouraged to take a further step and specifically identify the amount of LDES that is to be procured at where renewable energy mix is high and the storage gap is large.
- Compile/develop LDES policy recommendations for states.
- Develop an LDES benefit/cost model, to use in utility regulatory dockets.
- States should be encouraged 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.

Website Information

The Community of Knowledge & Best Practices Website is the official name for the LDES National Consortium's public facing Website.

- **The Website will be the primary repository for the output of the LDES National Consortium, along with knowledge-sharing information that seeks to enhance the public's understanding of LDES and the role it will play in the energy future of the US.**
- **It is anticipated that the Website will include, but is not limited to:**
    - A list of participating Teaming Partners that includes organization name, URL, primary point of contact name and title, and contact information (after approval from the Teaming Partner organization).
    - Commercialization recommendations developed by Tiger Teams.
    - A glossary of "LDES common terminology" with suggestions on how key terms should be defined.
    - A library of previously published LDES materials developed by our national Lab Partners and DOE offices.

ldesconsortium.sandia.gov

The LDES marketplace is still nascent.

We are in the midst of a full convergence of industry forces… technology, manufacturing, supplies, investors, policymakers and customers are all coming together to move the energy sector forward!

- From now through 2030, we will likely remain in a phase of **demonstrations and solution development**, spurred largely by federal subsidies.
- Literally billions of dollars being injected into this space driving what is nothing less than an industry transformation!
- Now is the time to define end-use applications and how LDES technologies can be used!
- Ultimately, a diverse set of LDES technologies will be needed for different applications in different locations.

Acknowledgements

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THANK YOU!

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