Pennsylvania’s Energy Future: Long Duration Energy Storage for Scalable Deployment

EnergyPath 2026

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ldescouncil.com

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LDES Council – Decarbonising the Global Energy Sector

Any long duration technology storing energy in various forms – chemical, thermal, mechanical, or electrochemical – and able to dispatch energy or heat for **8+ hours** to days, weeks, or seasons.

www.ldescouncil.com

The LDES Council forges **powerful partnerships** with stakeholders, amplifying awareness of the **critical need for LDES** to ensure flexibility, resilience, reliability, security, and affordability across all industrial sectors.

Vision for 2040

8 TW Deployed

Total potential LDES capacity including power (3 TW) and heat (5 TW)

$4 Trillion Invested

Total capex required to deploy LDES by 2040, in USD

$540B Annual Savings

Realized across the entire energy system, in USD

LDES
LONG DURATION ENERGY STORAGE COUNCIL

LDES Council Global Membership

Membership Details

ANCHOR MEMBERS

Alfa Laval, aws, ExxonMobil, Google, Microsoft, MN, Ørsted, Rio Tinto, Shell, slb

SERVICE PROVIDERS

ESB, ReNew, Baringa (Brighter together), Sumitomo SHI FW

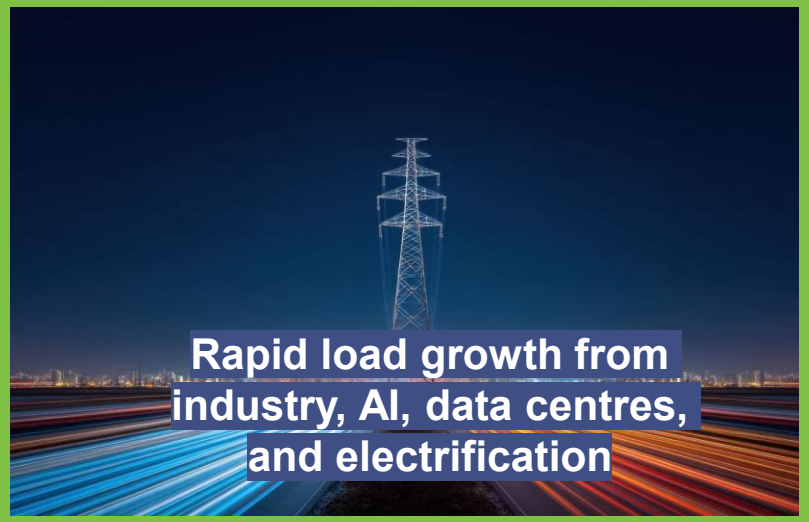
START-UPS

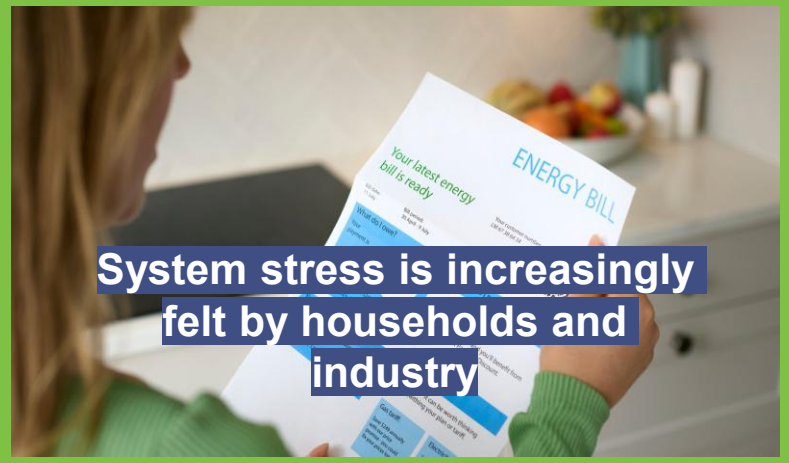
REDOX, Arkle, cmblu, OFFGRID ENERGY LABS

TECHNOLOGY PROVIDERS

14 CLEAN SCALABLE ENERGY STORAGE, ANTORA, BRENMILLER THERMAL ENERGY STORAGE, CATL, cellcube Energy Storage Systems Inc., ECHOGEN power systems, energyintel, ENERGY VAULT Enabling a Renewable World, ENERVENUE, eZinc, eos, HiTHIUM, HYDROSTOR, i2tr i-battery 艾博特瑞, INVINITY ENERGY SYSTEMS, KRAFT BLOCK, Mainspring, MALTA, MAGALDI dependable energy storage, MGA THERMAL, noon ENERGY, Quidnet Energy, XL Batteries, RKP, RONDO, Sumitomo SHI FW, SUMITOMO ELECTRIC, TERRAFLOW ENERGY, SIZABLE ENERGY, STOLECT, STORION ENERGY, GREENROCK ENERGY BUILT FOR RESILIENT POWER

Energy systems are struggling to keep pace with change





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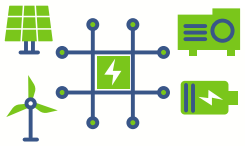
LDES offers a diverse suite of solutions that are “fit for purpose”

LDES can:

- Shift clean energy across hours, days, and seasons
- Extend grid services that traditional resources provide
- Provide 24x7 heat for chemical, food and beverage manufacturing, and heavy industrial needs
- Meet off-grid and microgrid electrical needs during peak demand
- Keep the energy system supplied during long gaps in generation
- Remove excess generation avoiding curtailment costs

POWER-TO-POWER

Grid Scale
(Energy/
Transmission Alternative)

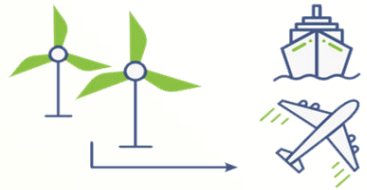


Microgrids Distribution Systems

Off-grid

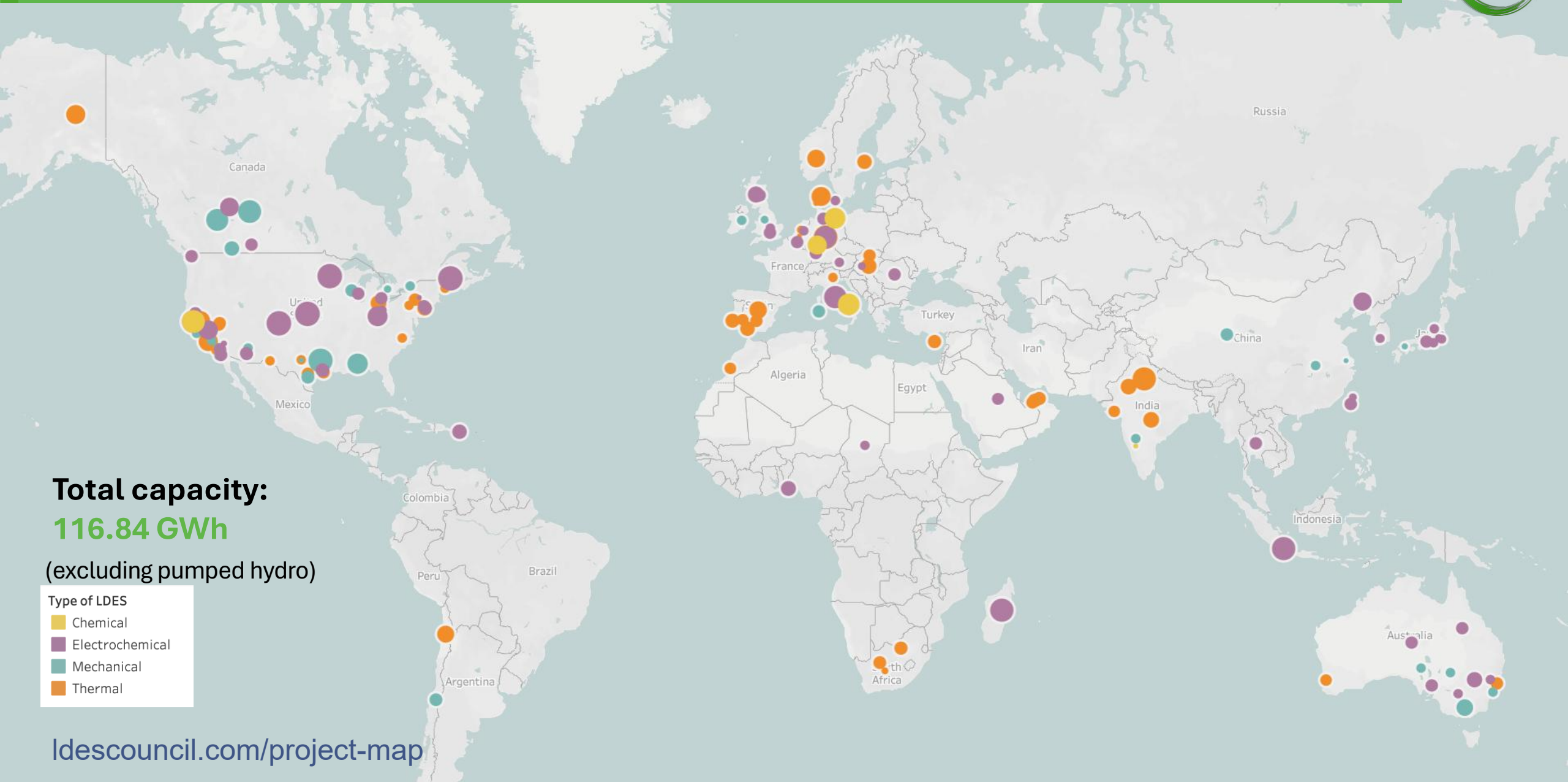
POWER-TO-HEAT

POWER-TO-X



Thermal / TES	Electrochemical	Mechanical	Chemical
Stores heat or cold in materials like **molten salt, sand, bricks or rocks**, and releases it later as heat, cooling, or electricity.	Stores energy in batteries using chemistries such as **flow, metal-air, zinc, sodium or lithium**, and discharges it later as electricity.	Stores energy using systems like **pumped hydro, gravity, flywheels, compressed air (CAES) or liquid air (LAES)**, and releases it later as mechanical power or electricity.	Stores energy in **chemical fuels such as hydrogen or ammonia**, which can be held long-term and used later for power, heat, or industrial processes.

Long duration energy storage is scaling worldwide

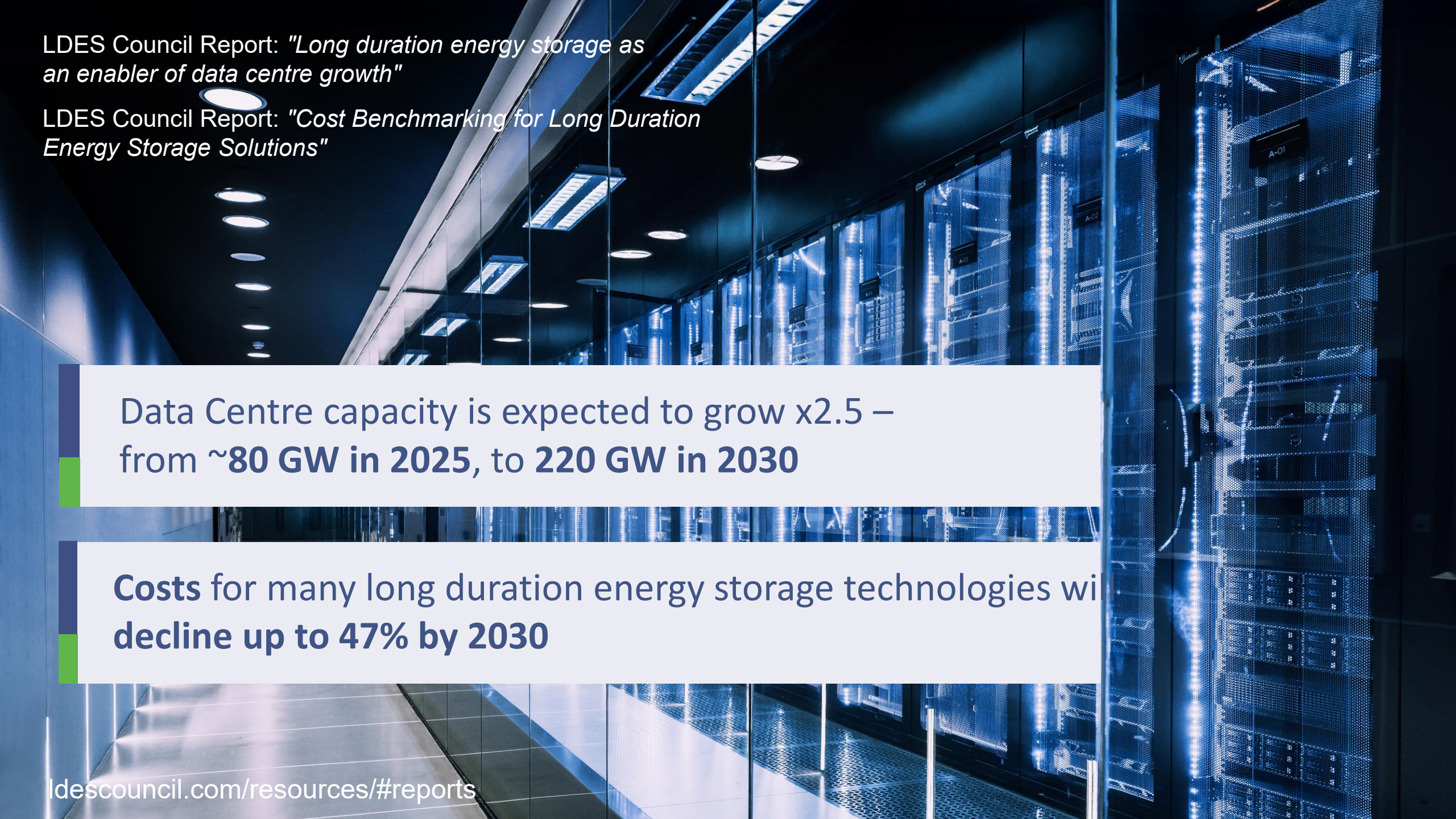


Total capacity:

116.84 GWh

(excluding pumped hydro)

ldescouncil.com/project-map



LDES Council Report: *"Long duration energy storage as an enabler of data centre growth"*

LDES Council Report: *"Cost Benchmarking for Long Duration Energy Storage Solutions"*

Data Centre capacity is expected to grow x2.5 – from ~**80 GW in 2025**, to **220 GW in 2030**

Costs for many long duration energy storage technologies wi **decline up to 47% by 2030**

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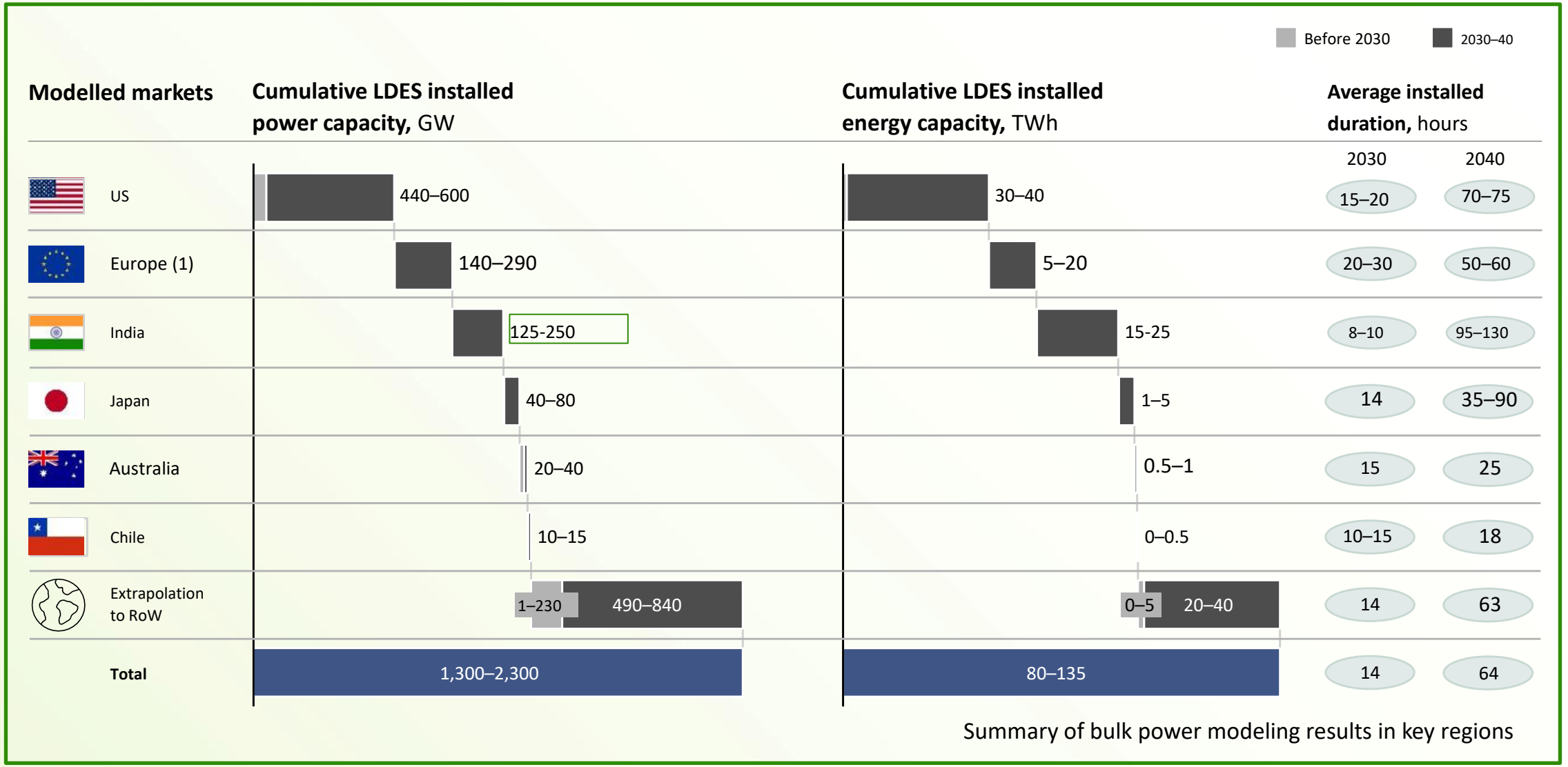
A Significant LDES Opportunity is Emerging in Power Markets

Modelled LDES capacity and duration across major global markets



Summary of bulk power modeling results in key regions

1. Europe incl. UK

Source: McKinsey Power Model

What's holding LDES back today?

LDES represents a **$4 trillion investment** opportunity by 2040, with the potential to deliver up to **$540 billion** in annual system cost **savings.**

Yet large-scale deployment is still slowed by a few critical gaps:

- Policy frameworks don't yet fully value what LDES delivers
- System planning hasn't caught up with long duration needs
- Investment lacks stable, long-term signals

PA LDES Legislation Introduced: HB 2380

Pennsylvania would create one of the few dedicated LDES procurement programs, creating a long-term pathway that improves **investment certainty**.

Procurement

- **1000 MW (10-24 hours)**
- **500 MW (24+ hours)**
- Contracts by 2033

Purpose

- Reliability
- Meet growing demand

Preference

- Benefits to PA workforce and businesses
- U.S. material sourcing

Status

- Passed House Energy Committee
- Senate introduction next
- Bi-partisan support

Progress for LDES in Pennsylvania

Why HB 2380 Matters:

- Reliability
  - Improve grid reliability through additional firm capacity.
  - Strengthen winter reliability and resilience during extended grid stress events
- Economic Growth
  - Supports AI, manufacturing, and data centers
  - Attracts private investment and jobs
- Lower Costs
  - Defers transmission upgrades
  - Reduces long-term grid system costs

Advocacy: On June 23, the LDES Council brought LDES technology developers to PA state legislators to share about their technologies and support for procurement targets.

LDES Council Report: Accelerating LDES Bankability

Bankability Report

- LDES is not being deployed at the scale required to meet global and national decarbonisation, energy security and affordability goals.
- The LDES Council estimates that ~2 GW will be required by 2030 and up to 8 TW by 2040, implying a 50x scale-up from today's pace.
- A significant barrier is a lack of **Bankability**.

To understand the core issues around bankability, the LDES Council, in collaboration with Teneo, conducted two workshops in 2025, (London and New York City during Climate Weeks), with investors and technology providers to identify best practices for addressing bankability challenges.

The white paper was released in Dec 2025.

Leading LDES Technology Companies & Investors Participated

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Bankability Challenges to be Addressed

Like other early-stage energy transition technologies, LDES faces a combination of hurdles often associated with emerging technologies that influence investor confidence and risk.

Market Design

Today, energy and capacity markets are optimized for short-duration resources, failing to capture LDES's full value

Missing Mandates

- Few U.S. states have state-level carve-outs for LDES (California, Virginia)
- Limited alignment between regulatory frameworks and the LDES value stack

Missing / Uncertain Subsidies

Inconsistent grants and unpredictable availability of subsidies like ITC

Technology Risk

- Varies by technology and use case
- Need for guaranteed performance over multi-year cycles (e.g., degradation, round-trip efficiency)

Manufacturing & Construction Risk

Limited EPC contractors with experience in LDES deployment at scale

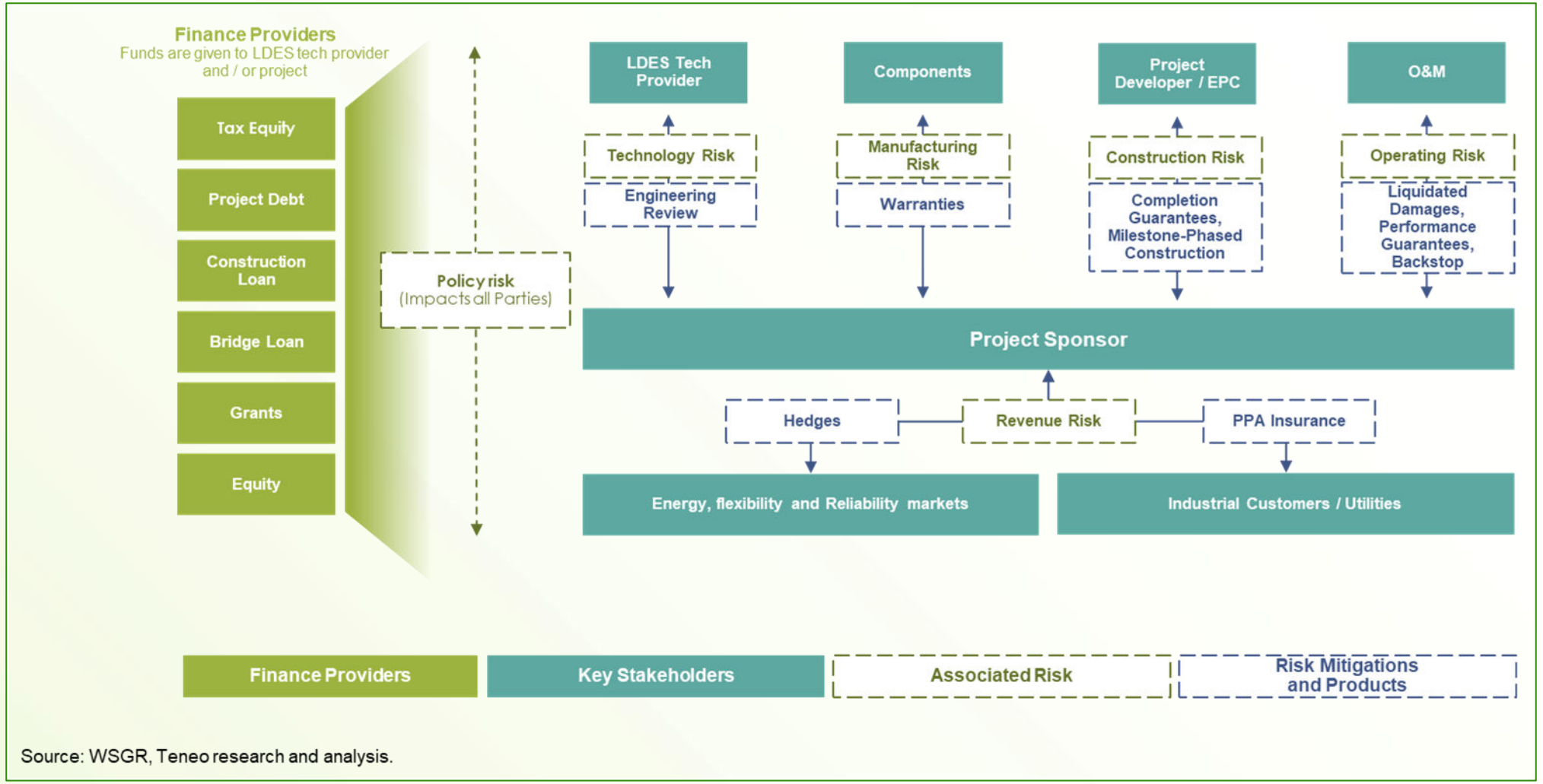
Operating Risk

Need clear allocation of maintenance and O&M responsibilities / costs

Source(s): Clean Tech Group, CEC, Teneo research and analysis.

Understanding and Managing LDES Risk

Clear and efficient allocation of risk across all the stakeholders in an LDES project is critical.



Source: WSGR, Teneo research and analysis.

Bankability Assessment Checklist for Funders of LDES

The white paper includes a structured framework that reflects how investors, lenders and independent advisors evaluate the bankability of LDES projects. The framework builds on the findings from the workshops and synthesises methodologies used by financial institutions, multilaterals and technical advisors.

The framework can be grouped into five key pillars, each containing specific evaluation criteria and checklists that investors and lenders typically apply:

1. Technology and Technical Maturity
2. Commercial Maturity and Vendor Strength
3. Market and Revenue Model
4. Project Structure and Risk Allocation
5. Financial and Economic Viability

Supplementary Evaluation Tools are also outlined.

Bankability Scoring or Rating (Indicative Example)

Category	Weight	Score Range
Technology Maturity	25%	1-5
Commercial Track Record	20%	1-5
Market & Revenue	25%	1-5
Project Structure	15%	1-5
Financial Viability	15%	1-5
Weighted Average ≥ 3.5 → Generally "Bankable"		

If a project going through this checklist process receives a score of 3.5 or greater, it can be considered "bankable."

LDES Projects around the world

Early projects, public de-risking, and private capital are converging to enable scale

What we're seeing

- Public capital is de-risking first deployments, private capital is following
- Industrial heat and non-grid use cases expanding the LDES market
- Policy support increasingly focused on flexibility and system value
- Early projects transitioning from demonstration to commercial operation

What this means

- LDES is now reaching investable scale across multiple technologies
- Blended finance is becoming the standard pathway, not the exception
- First movers are setting bankability benchmarks for the sector
- Projects are increasingly replicable across regions and portfolios

Examples:

Rondo x Heineken

Portugal: 100 MWh industrial heat battery replacing gas boilers for industrial decarbonisation, backed by EDP.

Energy Dome x Google

Italy: 20 MW / 200 MWh CO_2 battery entering commercial phase with ENGIE offtake. First-of-a-kind technology moving to scale.

UK National Wealth Fund / UKIB

UK: Public match-funding and risk-sharing to unlock private capital for early LDES assets.

NATIONAL WEALTH FUND

CASE STUDY

LDES Deploying Globally

Snapshot

Form Energy **Iron-air battery | up to 100-hour duration**
Partners: Great River Energy (MN), Xcel Energy (MN), Georgia Power (GA), PG&E (CA), Dominion (VA), NYSERDA (NY), Puget Sound Energy (WA)
14 GWh announced | $405M raised | Manufacturing: Weirton, WV

Energy Dome **CO2 Battery | 10-hour duration**
20 MW / 200 MWh with Alliant Energy, Wisconsin (state-approved; construction 2026; DOE $30M; WEC Energy, Shell co-investors)
Google data centre partnership (US, Europe, APAC) | Texas data centre MOU signed 2026

Noon Energy, Antora Energy...

New projects announced every single week.

A Clean Energy Accelerator Charge (CEAC) will provide for 1,400 MW of wind, 200 MW of solar and 300 MW of long-duration energy storage, along with a $50 million investment towards Xcel Energy's Capacity*Connect Program, which will help drive reliability on the grid. The additional generation will help advance Xcel Energy beyond its current energy mix of 70% carbon-free electricity.

Impact

20 MW / 200 MWh
First US CO2 Battery
Alliant Energy, Wisconsin

VA, CA, NY, WI
State + federal policy supporting deployment

14 GWh
Form Energy US pipeline across 7 utility partners

CASE STUDY

Eos Energy Enterprises: PA Manufacturing Facility for Zinc-based LDES

Snapshot

A U.S. domestic **manufacturing facility** to produce batteries, helping achieve Eos's goal of **4 GWh** of annual manufacturing capacity by the end of 2026.

Turtle Creek, Pennsylvania

Zinc-based Long Duration Energy Storage

Impact

Received $400 million federal credit

300+ construction jobs created

Automated battery production

CASE STUDY

Hydrostor's Willow Rock A-CAES: Powering California's path to a carbon-free grid

Snapshot

A **500 MW A-CAES facility** that will deliver **4,000** 8**MWh** of LDES to support **California's shift to a carbon-free grid.**

Kern County, California

Advanced Compressed Air Energy Storage

Impact

$500 million local economic benefits

700+ construction jobs created

50 years lifespan

CASE STUDY

Calistoga Resiliency Center: powered by **Energy Vault**'s hybrid hydrogen–battery storage technology

Snapshot

A **293 MWh hybrid hydrogen–battery** system delivering **48 hours of clean power** to keep Calistoga's microgrid running during wildfire shutoffs.

Calistoga, Napa County, California

B-VAULT™ DC battery

Impact

200-400 tons of CO2 avoided per year

8.5 MW Peak Power Output

20 years operational lifetime

CASE STUDY

Energy Superhub Oxford: **Invinity**'s flow battery at the heart of the UK's largest hybrid energy storage project

Snapshot

Invinity's **5 MWh flow battery** underpins **Energy Superhub Oxford**, a world-first urban decarbonisation project integrating EV charging, low–carbon heat and grid services. The system has already helped save over **2,300 tonnes of CO_2** while showing how LDES can support large-scale electrification in cities.

Oxford, UK

VS3 Flow battery technology

Impact

2 – 10 hour charge/discharge durations

2 MW / 5 MWh battery

Select Investments in Larger OEMs

There have been numerous funding successes for LDES OEMs at the enterprise level.

Company	Description	Latest Round	Total Raised*	Funding Types	Key Investors
ANTORA	Developer of thermal batteries for industrial operations	2024	~$200M	VC / PE	Decarbonization Partners, Emerson Collective, GS Futures, Breakthrough Energy Ventures
ENERGY VAULT Enabling a Renewable World	Developer of gravity-based LDES and BESS	2025	~$788M	VC, SPAC / PIPE, Project Financing	SB Investment Advisers, SailingStone Capital, BlackRock
Form energy	Developer of iron-air battery up to 100 hours duration	2024	~$1.4B	Grants, VC / PE	Capricorn, Eni, Breakthrough, Macquarie, CPP Investments
Highview Power	Developer of liquid air energy storage	2024	~$580M	Grants, VC, Corporates	UK Infrastructure Bank, Centrica, Goldman
融科储能 RONGKE POWER	Developer of vanadium flow batteries	2023	~$145M	VC / PE	Legend Capital
HYDROSTOR	Developer of compressed air energy storage	2025	~$330M	VC / PE, Debt, Project Financing	Something Good Ventures, CPP, Goldman
MALTA	Developer of electro-thermal energy storage solutions	2024	~$100M	VC, Grants	Alfa Laval, Chevron Technology Ventures, Piva Capital

Source(s): Company websites, Pitchbook, Teneo research and analysis.
Note(s): *Pitchbook as of September 2025.

How LDES Translates into Investment

Capital, policy and performance are aligning around LDES.

LDES as infrastructure	Scale enablers	Investment Outcomes
Long-life, low-volatility assets	Proven performance & revenues	**Lower cost of capital**
Reliability & revenue driven	Blended finance for FOAK projects	**Scalable portfolios**
Venture > Project Finance > Institutional investors	Policy & public capital support	**Stable, long-term returns**

Accelerating LDES Bankability – Moving forward

LDES is essential to deliver secure, affordable and clean energy.

But without long-term, low-cost capital, deployment cannot scale at the pace required.

LDES market has moved from…

Revenues are uncertain and short-term

No shared performance standards or transparent data

Limited early-stage de-risking mechanisms

High cost of capital dominated by venture equity

Policy frameworks don't consistently reward duration

…to Foundations of Scalable Capital

- ✓ **Business Models**
  Long-term offtake contracts (15-25 yrs)
- ✓ **Technology Maturity**
  Proven, verified performance
- ✓ **Financial Structure**
  Layered risk protection (equity, insurance, guarantees)
- ✓ **Standards & Transparency**
  Shared definitions, warranties, metrics
- ✓ **Policy Frameworks**
  Market reforms valuing flexibility, reliability, duration

Long duration energy storage is reliable, affordable, and **bankable**, with clearer pathways for investment than ever before.

Thank You.

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