2024
Annual Report

Long Duration Energy Storage Council

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Long Duration Energy Storage Council Members

Technology Providers

Innovators developing and commercializing Long Duration Energy Storage systems.

Service Providers

Law firms, EPCs, and other industry-leading organizations supporting the energy transition.

Anchor Members

Industry-leading companies or organization with a strong interest in the energy transition and Long Duration Energy Storage either as an end-user or a capital provider.

LDES Council Board Co-Presidents Statement

Upma Koul
Co-President,
Long Duration Energy Storage Council Board of Directors

Marco Ferrara
Co-President,
Long Duration Energy Storage Council Board of Directors

Recognition is growing on the value energy storage delivers to the energy transition. Yet with the stark urgency of the climate crisis in plain sight, governments and grid and regulatory authorities must move urgently to support the deployment and scaling of these vital technologies.

Through this Annual Report — the first in its history — the Long Duration Energy Storage Council seeks to demonstrate indisputably that, alongside the accelerated deployment of renewable energy, long duration energy storage must be elevated to the core of decarbonisation strategies. Coordinated and concerted actions across the stakeholder value chain are essential to push long duration energy storage over the tipping point, starting with its inclusion as a standalone lever in country and sector decarbonisation targets and as an asset in utility grid modelling and planning.

Leaders must take action to institute the necessary enabling frameworks, including supportive policies, updated regulatory and institutional structures, streamlined permitting, active government planning, and required financing, to drive LDES to scale. There is no time to waste.

Let us work together in common cause to unlock the full potential of LDES and pave the way for a cleaner, more sustainable future.

Global Renewables Alliance Statement

Bruce Douglas
Chief Executive Officer
Global Renewables Alliance

We stand at the dawn of a new era — one defined partly by the challenges we now face, but more importantly by the extraordinary opportunities before us. Renewable energy is already transforming how we power our world, and its momentum is unstoppable. As we move through 2024, the global community needs to act decisively — to build a clean, secure and just future.

Wind and solar energy now generate nearly one-third of the world's electricity, driving job creation, innovation, and economic growth. The bold commitments made at COP28, to triple renewable energy capacity and double energy efficiency by 2030, set the stage for a future of shared prosperity.

Yet our greatest achievements are still to come. We are poised to unlock the full potential of renewable energy, with the goal of reaching 11 terawatts (TW) by 2030. This transformation will not only help us meet environmental targets but will fuel growth, innovation, and cooperation on a global scale, ensuring that no one is left behind.

Central to unlocking this future is energy storage. Long duration energy storage will ensure that renewable electrons are always available, strengthening energy security and industrial competitiveness while also spurring economic development — all essential components of a just and inclusive transition.

The Global Renewables Alliance is committed to accelerating this progress and working with the Long Duration Energy Storage Council. We fully support the call for a sixfold increase in global energy storage capacity by 2030 — a target that would deliver 1.5 TW of storage to power innovation and economic resilience across the world.

We congratulate the LDES Council on their inaugural report and look forward to working to implement the seven enablers and grow the LDES marketplace.

Four Key Findings

The energy sector is undergoing a profound transformation. Power and heat systems are increasingly decarbonised, digitised, democratised and distributed, becoming vastly more complex and dynamic. Modern systems must integrate increasing supplies of variable renewable energy (VRE) and accommodate electrification strategies underway across economic sectors.

Despite this growing complexity, the global community now has a powerful tool to architect the enabling infrastructure and create the operating conditions for clean energy resources to rapidly scale and meet the challenges of our modern age: long duration energy storage (LDES) systems.

Additional benefits of LDES include grid stability, resilience and cost efficiency. Analysis[a] from the Long Duration Energy Storage Council shows up to $540 billion in annual savings globally when deploying up to 8 TW of LDES, compared to alternatives to meeting net zero. Coordinated and concerted action across the stakeholder value chain is required to scale up LDES, ranging from its inclusion as a standalone lever in country and sector decarbonisation targets to its deployment as an asset in utility grid modelling and planning, and ultimately to the development of thousands of LDES projects worldwide. Leaders must collectively take action to reap the benefits of LDES and drive it to scale in the coming years.

Key findings of this report:

1. LDES technologies are essential for the decarbonisation of energy systems, including the power system and industrial heat.

2. LDES must scale up to 50 times faster than is currently projected, from the current 0.22 terawatt (TW) deployment pipeline that is recorded in the LDES Council's project database, to as much as 8 TW of capacity that is estimated to be needed by 2040.

3. A vibrant community of scale-up technology providers, corporates and strategic partners is building momentum for the deployment of LDES solutions at scale.

4. The direction and ambition of the frontrunners will help to scale LDES deployment. Seven critical enabling strategies and actions, enablers, are identified and recommended for policymakers, regulators, technology providers and end users to accelerate the rollout of LDES.

In this inaugural Annual Report, the LDES Council presents a deployment roadmap to spur action among key stakeholders and decisionmakers. The report offers a current perspective and accounting on the global policy, regulatory and market environment for LDES, along with updated data and industry use cases.

Key reasons to build, deploy and scale LDES include the following:

Efficient integration of VRE:

Energy storage helps to smooth out the fluctuation in renewable generation, providing continuity of supply across daily, monthly and even yearly variations (time shifting), and progressively replacing the role of thermal generation to sustainably decarbonise the grid and energy systems.

Decarbonisation of energy systems:

LDES couples renewable electricity generation with round-the-clock power, heat, steam or cooling production. This allows renewable energy to be used continuously for heating, which helps to reduce dependency on fossil fuels and supports the energy transition towards net-zero emissions.

[a] LDES Council. (2022). *Net zero heat Long Duration Energy Storage to accelerate energy system decarbonization*. https://www.ldescouncil.com/assets/pdf/221108_NZH_LDES%20brochure.pdf

KEY FINDING **#1**

LDES technologies are essential for decarbonisation

Decarbonising the world's energy systems is essential to enable sustainable socioeconomic development and mitigate the effects of climate change. Variable renewable electricity (VRE) generation, such as solar photovoltaics (PV) and wind is playing an essential role – directly decarbonising the power sector and supporting the decarbonisation of certain heat and industrial applications.

The International Renewable Energy Agency (IRENA) forecasts global renewables generation capacity will increase from 3.8 TW[b] today to 11 TW by 2030[c] under its scenario limiting the global temperature increase to no more than 1.5°C. The International Energy Agency's (IEA) World Energy Outlook suggests that by 2050, installed VRE capacity will increase further to 28 TW.[d] These projections are supported by the COP28 commitment of 133 nations to triple renewable energy capacity to at least 11 TW by 2030.

The shift to renewable energy is crucial for decarbonising energy systems, supporting greater grid reliability and resilience, and strengthening energy security, but doing so necessitates new flexible energy sources. Simply increasing renewable capacity is not enough; compatible solutions are essential for a stable low-carbon energy system.

Long Duration Energy Storage (LDES) is a vital tool to enable the decarbonisation of energy systems and support governments and grid authorities in their efforts to realise their sustainability commitments on the pathway to net zero.

The term 'LDES' encompasses technologies that store energy in various forms – including electrochemical, mechanical, thermal and chemical – with a discharge duration of eight hours or more. These resources hold energy or heat for extended periods, ranging from hours to days, weeks or even seasons. LDES is critical to the decarbonisation of the energy sector.

b International Renewable Energy Agency. 2024. *Renewable Energy Highlights 2024* https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2024/Jul/Renewable_energy_highlights_FINAL_July_2024.pdf?rev=469292ef67144702b515ecb20575ec7d

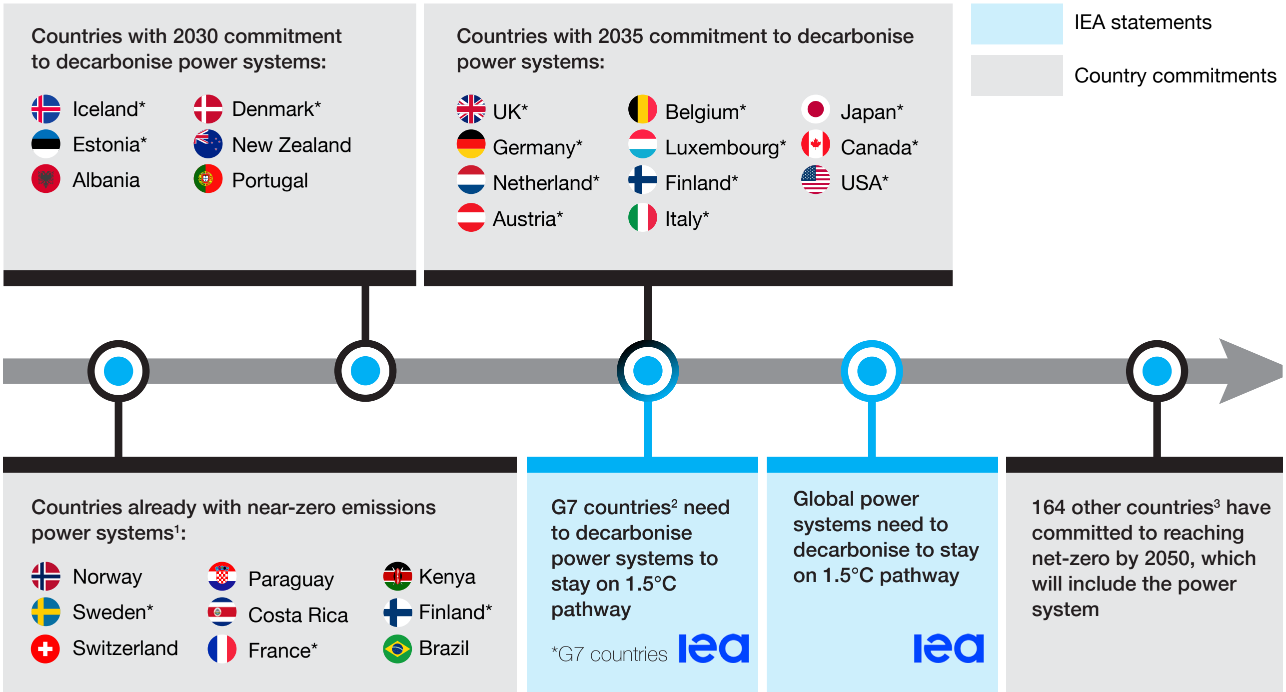
c International Renewable Energy Agency. *Tripling renewable power and doubling energy efficiency by 2030*. International Renewable Energy Agency. https://www.irena.org/Digital-Report/Tripling-renewable-power-and-doubling-energy-efficiency-by-2030

d *Assuming 85% of renewables capacity is in the form of variable wind and solar capacity. Insights are aggregated from both IRENA and IEA - Figure 3.16, page 127, STEPS, APS and NZE scenario - IEA (2023), World Energy Outlook; Table 2.1, page 77, PES and 1.5 degrees scenario highlight IRENA (2023),* World Energy Transitions Outlook 2023; IEA (2024), Renewables 2023

e COP28 UAE. 2023. *Global Renewables and Energy Efficiency Pledge*.

FIGURE 1

The decarbonisation of energy systems must increase rapidly to meet global sustainability targets



Notes: 1. Defined as emissions less than 100g/Kwhe; 2. The G7 countries are Canada, France, Germany, Italy, Japan, the United Kingdom, an he United States; 3. As of 2024, the Paris Agreement, which was adopted in December 2015, has 195 signatories. This includes 194 countrie and the European Union. If we remove the G7 countries and the EU countries, 164 signatories remain.

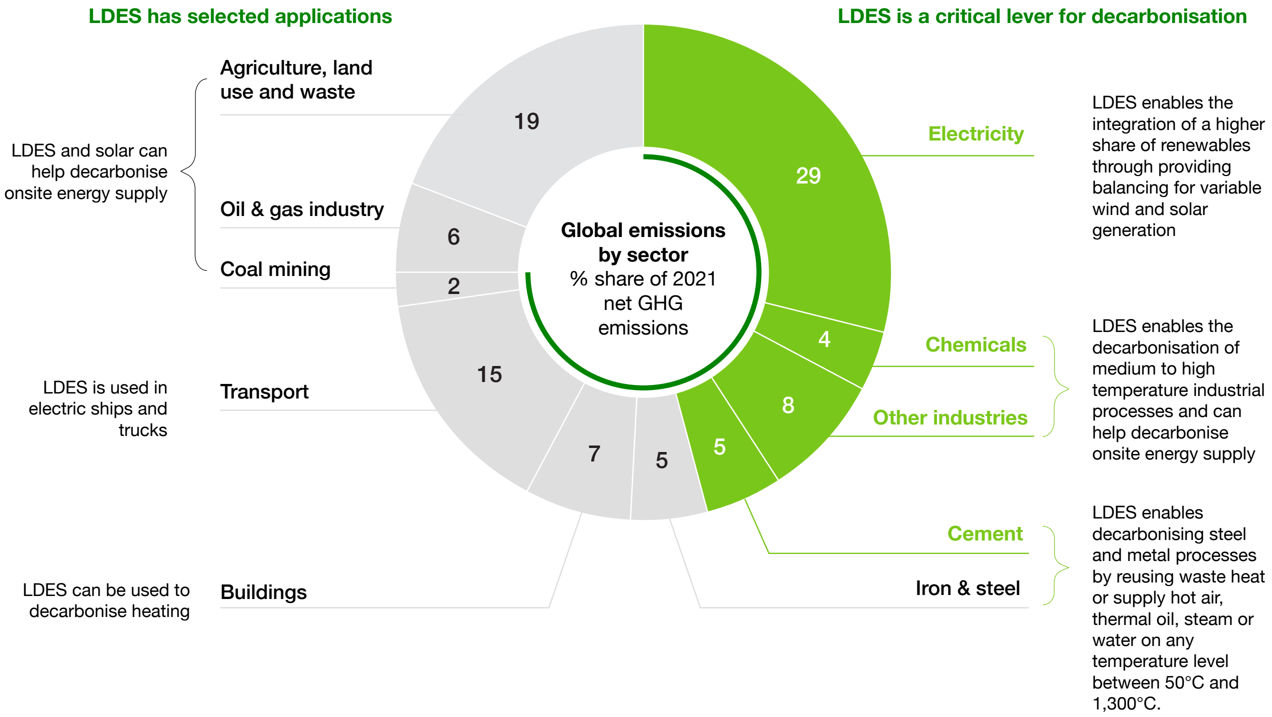
Sources: IEA; Our World in Data; UN Net-Zero coalition.

Decarbonisation efforts must also confront growing demand for power and industrial heat due to continued population growth, industrialisation and digitisation trends, and global economic development. Today, manufacturing accounts for 31% of global carbon emissions, while the electricity sector accounts for 28%.[f] Incorporating LDES can help to increase the security of supply, create new use cases for VRE like minimising curtailments, and unlock new opportunities not thoroughly addressed by shorter-duration storage solutions. Figure 2 shows the share of global emissions in 2021 of different sectors and how LDES can support their decarbonisation.

[f] LDES Council. (2022). *Net zero heat Long Duration Energy Storage to accelerate energy system decarbonization*. https://www.ldescouncil.com/assets/pdf/221108_NZH_LDES%20brochure.pdf

FIGURE 2

LDES can enable the decarbonisation of energy usage across sectors



LDES technologies provide power-to-power, power-to-heat and power-to-x services. Each supports decarbonisation strategies by enabling renewable integration on electricity grids and maximising the utilisation of this energy supply, including round-the-clock heat for industrial applications and the production of alternative fuels like hydrogen from electricity. Figure 3 provides an overview of LDES solutions by technology type and their average durations. LDES technologies can be categorised not only by their operational diversity, but also by the wide range of end uses they can serve.

> Storage durations must increase to integrate the growing volume of renewable energy expected to come online.

FIGURE 3

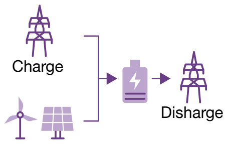
The four LDES mechanisms for storing energy

Description | Duration | LDES Council Members

Electrochemical (power-to-power)

Battery systems that can store electricity through chemical reactions

- Flow battery
- Metal anode (e.g. iron, zinc, lithium-ion battery)
- Metal air



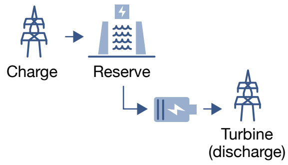
Duration: Hours to days

LDES Council Members: CATL, Invinity Energy Systems, eos, e-Zinc, Form Energy, Stryten Energy, slb, Noon Energy, Ceres, CellCube, Enervenue, Voltstorage, IBTR, ESS Inc, redflow

Mechanical (power-to-power)

Systems that use heat, water or air with compressors, turbines, & other machinery

- Pumped hydro
- Compressed air
- Liquid air/ CO_2
- Gravity



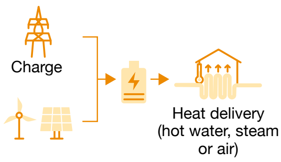
Duration: Hours to days

LDES Council Members: SENS, Hydrostor, Energy Vault, Quidnet Energy, Sage Geosystems, Sumitomo SHI FW, NEOM, Rye Development, Energy Dome, Augwind

Thermal (power-to-heat)

Systems that convert electricity to thermal energy, store in inexpensive materials & output as heat

- Sensible heat
- Latent heat
- Thermo-chemical



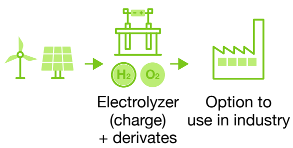
Duration: Hours to days

LDES Council Members: MGA Thermal, 1414 Degrees, Malta, Build to Zero, EnergyNest, Kraftblock, Rondo, Antora, hyme, Ice Energy, energy/intel, Kyoto, Magaldi, Echogen Power Systems, Brenmiller

Chemical (power-to-x)

High density energy carrying chemicals produced from energy sources, which can be stored, used as fuels or as chemicals feedstock

- Hydrogen
- Ammonia
- Hydrocarbons/Alcohol
- Carbons



Duration: Seasonal

LDES Council Members: Ceres, Noon Energy

Source: LDES Council data

> LDES solutions provide flexibility for a wide range of curtailment costs.

Power-to-power LDES solutions provide energy services, ancillary services and resource adequacy capacity, which help to ensure that electrical supply can meet demand 24/7. These technologies can provide significant benefits today, for example through deferred or avoided grid investments, and will also be essential in the transition towards grids dominated by very high levels of VRE-sourced generation.

Power-to-heat technologies are key enablers of industry decarbonisation and use stored energy to provide heat on demand. These technologies are commercial today and being deployed globally. Power-to-x converts electricity into energy stored in molecular (chemical) bonds in hydrogen and its derivatives, such as ammonia. All these LDES technology applications reduce emissions by replacing fossil fuels.

LDES can derisk the energy transition to renewables today. Evidence of this includes the increased renewable energy curtailment seen in many geographies that are rapidly deploying solar and wind energy. For example, in Germany, renewable curtailment cost €3.13 billion in 2023;[g] while in the United Kingdom, curtailment totalled 6.5 terawatt-hours (TWh) for wind generation and cost £1.5 billion from January 2021 to April 2023. Similarly, in Chile, 2.38 TWh – nearly 10% of solar and wind generation – was curtailed in 2023.[h] Elsewhere in South America, the Brazilian Wind Energy Association has reported that the sector lost some BRL 700 million ($128 million) in the past year; while the Brazilian Solar Association estimated a loss of BRL 50 million between April and July 2024, and Voltalia – a renewable energy producer with nearly two-thirds of its capacity in Brazil – expects that curtailment will shave some €40 million from its earnings in 2024.[i]

Curtailment costs are a result of insufficient grid infrastructure to distribute or store excess renewable generation.

> The deployment of LDES to store excess capacity and then discharge it through existing grid infrastructure materially reduces these costs.

LDES offers flexibility across power markets and industrial heat applications. Thermal energy storage takes electricity and stores it in the form of heat, and in turn provides firm heat and / or steam — transforming VRE generation into a reliable and versatile supply of process heat / or steam and electricity that is continuously available, eliminating the need for heating generation from gas and coal sources. Thermal decarbonisation is a critical strategy to reduce industrial emissions and, through district heating, to reduce emissions from other heat processes as well.

> The LDES Council has demonstrated that power-to-heat applications are already economical.[j]

g Esforin. *Grid curtailment in Germany*. Esforin. https://www.esforin.com/en/grid-curtailment-in-germany/#:~:text=At%20251.2%20terawatt%2Dhours%20(TWh,Why%20curtail%20the%20power%3F

h BNAmericas. (2024). *Chile NCRE curtailment skyrockets as renewables buildout marches on*. BNAmericas. https://www.bnamericas.com/en/news/chile-ncre-curtailment-skyrockets-as-renewables-buildout-marches-on

i Reuters. (2024, August 22). *Brazil's grid caps power from wind and solar, threatening renewable projects*. Reuters. https://www.reuters.com/business/energy/brazils-grid-caps-power-wind-solar-threatening-renewable-projects-2024-08-22/

j Long Duration Energy Storage Council. (2023, November). *Driving to net zero industry through long duration energy storage*. LDES Council. https://www.ldescouncil.com/assets/pdf/LDESIndustrialDecarbonization_May2024.pdf

This technology is commercially available, with over 40 projects in operation globally. Several detailed examples show that thermal LDES resources provide economic value to the projects they augment when they have access to wholesale electricity prices and can charge during low-price periods and discharge during periods when prices are higher.

> LDES solutions provide flexibility for a wide range of decarbonisation needs.

Several countries have a near-term target to achieve more than 50% of their electricity generation from VRE and need LDES to support an efficient, reliable grid. The IEA expects that by 2028, Chile, Denmark, Germany, Greece, Ireland, Lithuania, Luxembourg, the Netherlands, Spain and the United Kingdom will generate at least 50% of their electricity from VRE.[k,l] These countries – and others, including the United States – aim to have net-zero power systems by 2035, further amplifying the need for LDES.

Figure 4 shows the relationship between the share of total electricity generation from VRE and required storage durations for the efficient operation of electricity grids. LDES is already providing benefits today in many countries, but these efforts need to scale. The chart demonstrates that very long durations of storage resources will be necessary to support grids that rely heavily on VRE. Figure 4 also shows that even at lower levels of decarbonisation, like the levels already observed in some countries and expected soon in others, storage resources with significantly long durations are already required.

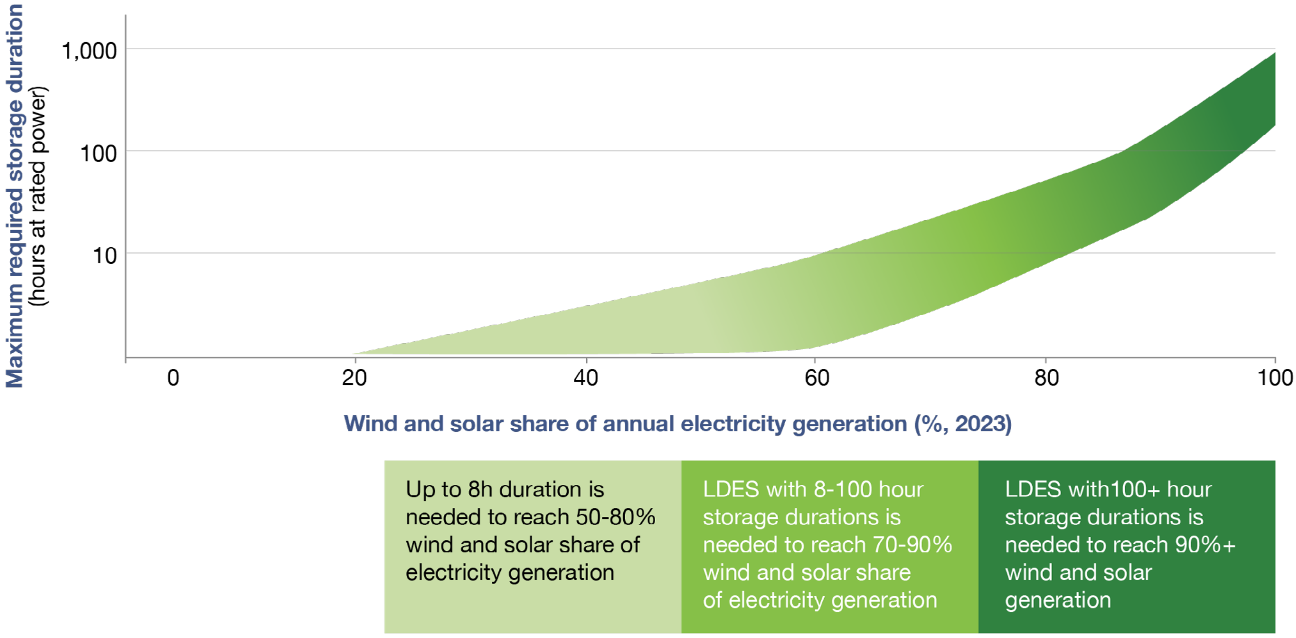
> Several countries are already planning for storage durations of eight hours and more, with a range of procurement exercises and/or policy developments underway to achieve their ambitious clean energy and decarbonisation goals.

k International Energy Agency. (2023). *Renewables 2023 (Figure: Number of countries by potential range of VRE share in annual electricity generation, p. 77)*. IEA. https://www.iea.org/reports/renewables-2023

l Ember. (2024). *Electricity data explorer*. Ember. https://ember-energy.org/data/electricity-data-explorer/

FIGURE 4

Illustration of how storage duration needs increase with greater VRE integration[m]



Source: Depicted from Albertus, P., Manser, J. S., & Litzelman, S. (2020). Long-duration electricity storage applications, economics, and technologies. Joule, 4(1), 21-32. ;

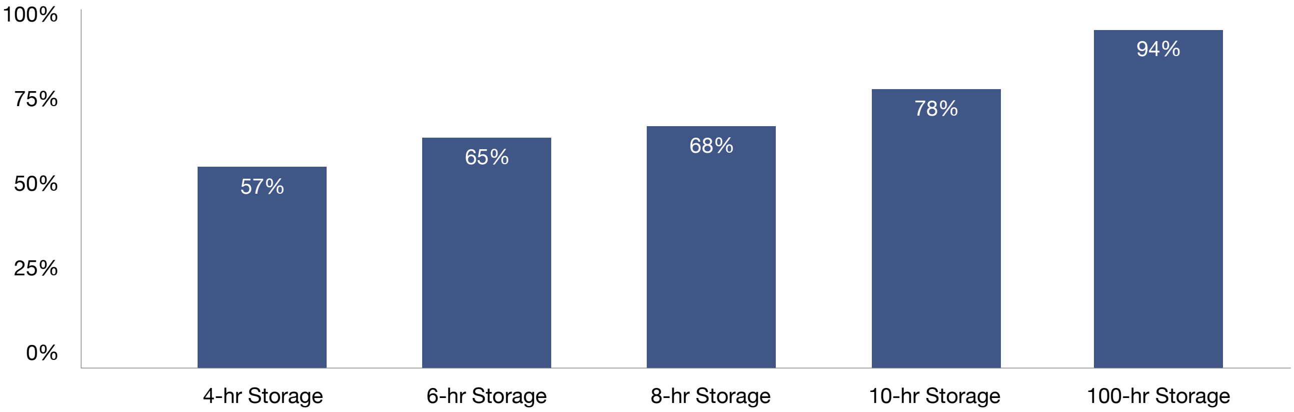
Renewable penetration is only one of the drivers of LDES demand. In practice, LDES needs are driven by a variety of factors including renewable generation patterns (wind vs solar); the availability, cost, and performance of other technologies (such as lithium ion); the state of the transmission infrastructure; and the need for clean, firm capacity, which increases with duration, as illustrated in Figure 5.

A range of LDES technologies is required to address renewable integration as well as support capacity and grid services today.

m Albertus, P., Manser, J. S., & Litzelman, S. (2020). Long duration electricity storage applications, economics, and technologies. https://doi.org/10.1016/j.joule.2019.11.009

FIGURE 5

Capacity accreditation of storage resources of various durations from recent PJM and Astrape's studies

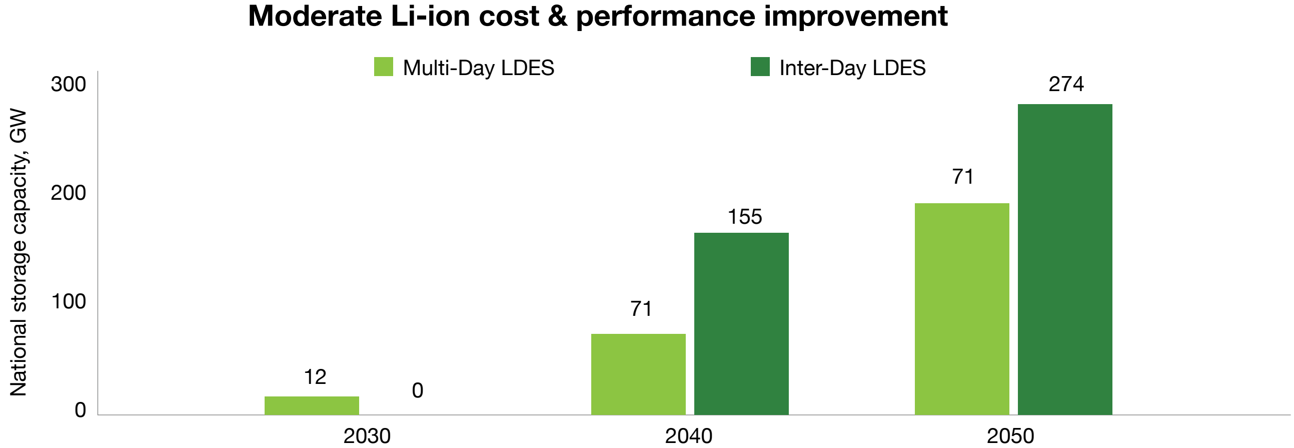


Source: Astrape Consulting. (2023). *Reserve Margin and Effective Load Carrying Capability (ELCC) Study*; PJM. (2024). Effective Load Carrying Capability (ELCC).

Ultimately, cost-effective, reliable, decarbonised power systems will include an optimal combination of LDES of various durations as determined by best system planning practices. U.S. Department of Energy's "LDES Liftoff" analysis concludes that 26-32% of 2030 storage needs are likely to be from longer duration resources due to substantial demand for clean, firm capacity. As shown in Figure 6, the study also finds that among total 2040-2050 US storage needs, a large fraction is in both inter-day and multi-day LDES.

FIGURE 6

U.S. storage capacity by year



Source: U.S. Department of Energy. (2023). *Pathways to Commercial Liftoff:* LDES.

Guiding LDES sector growth with global storage targets

Immediate action and investment to deploy LDES technologies is essential to meet future energy demands and provide dispatchable, low-carbon energy supply. Formal LDES deployment targets are key mechanisms to guide and incent investment flows and stakeholder engagement. The LDES Council strongly supports the inclusion of an energy storage target on the agenda of COP29 and is calling for a global target of 1.5 TW by 2030 as essential to support the COP28 goal of deploying 11 TW of renewables by the same year. To complement this storage target, the LDES Council envisages a need for LDES capacity – including power and thermal storage – of more than 1 TW by 2030 and up to 8 TW by 2040 to achieve net zero. To ensure energy system stability, the growth of LDES must align with the expansion of renewable energy sources. Otherwise, there is a risk of continued reliance on fossil fuels and added difficulty of achieving climate targets.

LDES targets provide clarity, direction and accountability for policymakers, industry, investors and stakeholders. Quantifiable targets can be tracked and progress measured. Storage targets provide context for the necessary enabling policy measures and send a clear signal for investment across the supply chain. Moreover, clear targets encourage collaboration among stakeholders such as governments, businesses and research institutions, fostering innovation and accelerating deployment.

In Europe alone, the revised national energy and climate plans of 11 countries quantify deployment by 2030 for pumped hydropower storage or storage technologies in general. However, in contrast to many renewable energy targets that are fixed in national laws, these goals are rarely binding, highlighting the importance of establishing a roadmap for LDES targets that is closely aligned with generation targets.

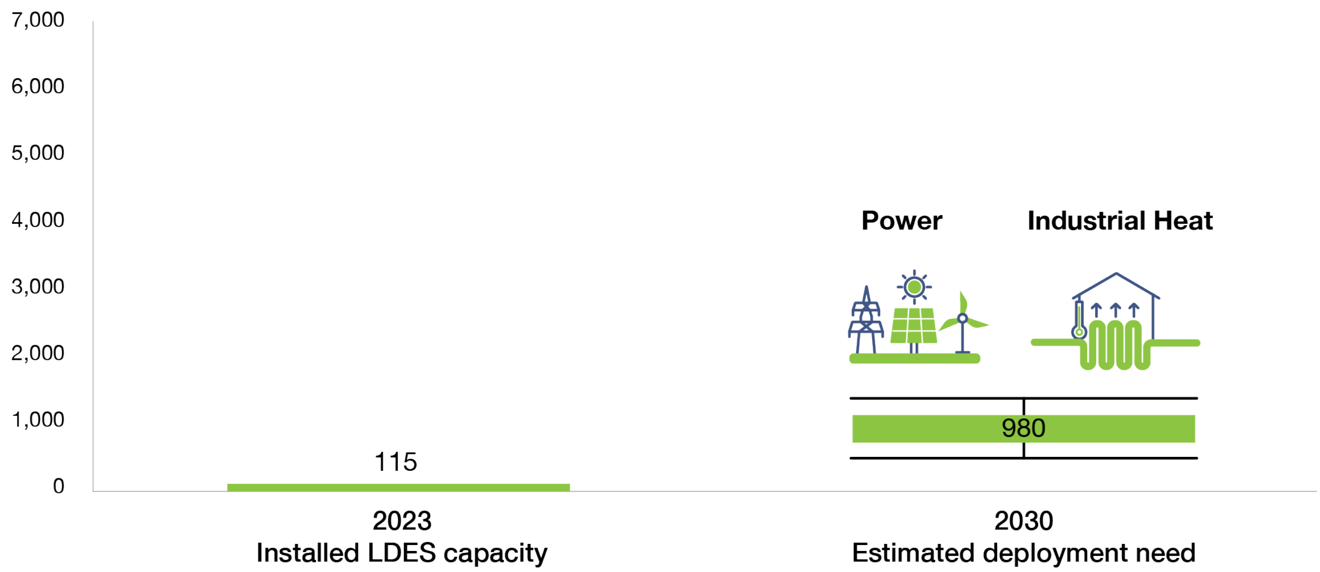
> "Long duration energy storage is one of the key technologies that the newly launched Institute for the Energy Transition is designed to focus on because LDES can play a key role in the clean energy transition. It will take close coordination with our critical partners to accelerate the commercialisation of LDES and to address the technical, economic, regulatory and policy barriers to deployment."
>
> **Tom Kuhn**, former President, Edison Electric Institute

All government signatories to the Paris Agreement must detail their plans to reduce emissions and adapt to the impacts of climate change. Known as Nationally Determined Contributions (NDCs)[n], and updated every five years, these national action climate plans embody the collective aspiration of governments to decarbonise their energy systems and speed the energy transition. The LDES Council calls for all NDCs that are to be updated in 2025 to include clear, actionable targets for LDES, as depicted in Figure 7.

The establishment of a global target for LDES would provide a framework for regulatory support and financial mechanisms for both regions and countries, ensuring that LDES can compete effectively with traditional energy sources.

FIGURE 7

Estimated annual LDES capacity needs in 2030, GW



Notes: Whisker bars represent the following ranges: 2030: 640-1,320
Sources: Systemiq analysis; *Pathway to Commercial Liftoff*: LDES.

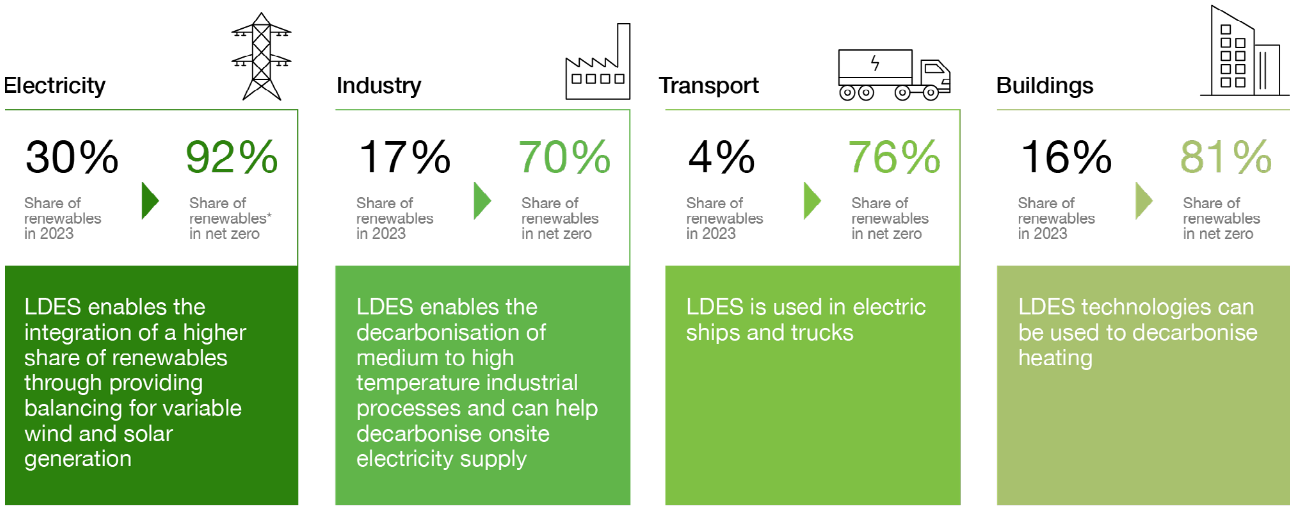
Estimated by working backwards from net-zero using historical capacity deployment rates for wind and solar between 2025 and 2050 and total addressable market estimates for industrial heat processes

Figure 8 demonstrates the decarbonisation benefits that LDES brings to the electricity, industry, transport, and buildings sectors. These benefits include enabling a higher share of renewable energy integration, supporting the decarbonisation of industrial heat processes, and facilitating clean electrification.

n Nationally determined contributions (NDCs) are at the heart of the Paris Agreement and the achievement of its long-term goals. https://unfccc.int/process-and-meetings/the-paris-agreement/nationally-determined-contributions-ndcs

FIGURE 8

LDES supports decarbonisation strategies across economic sectors



*Renewables contains biosources
Source: For electricity - IEA (2024), Renewables; IEA (2023 update) Net Zero by 2050; For Industry, Transport and Buildings 2023 values – REN21 (2024), Renewables 2024 Global Status Report Collection; For Industry, Transport and Buildings 2050 values it is assumed the total projected electricity supply in the IEA NZE scenario is supplied by renewables – IEA (2023), Net Zero by 2050 – Table A.1

It is important to note that LDES provides substantial near-term benefits such as alleviating grid congestion and curtailment, and, with thermal applications, can support the decarbonisation of industry now. The benefits of LDES include (see also Figure 9):

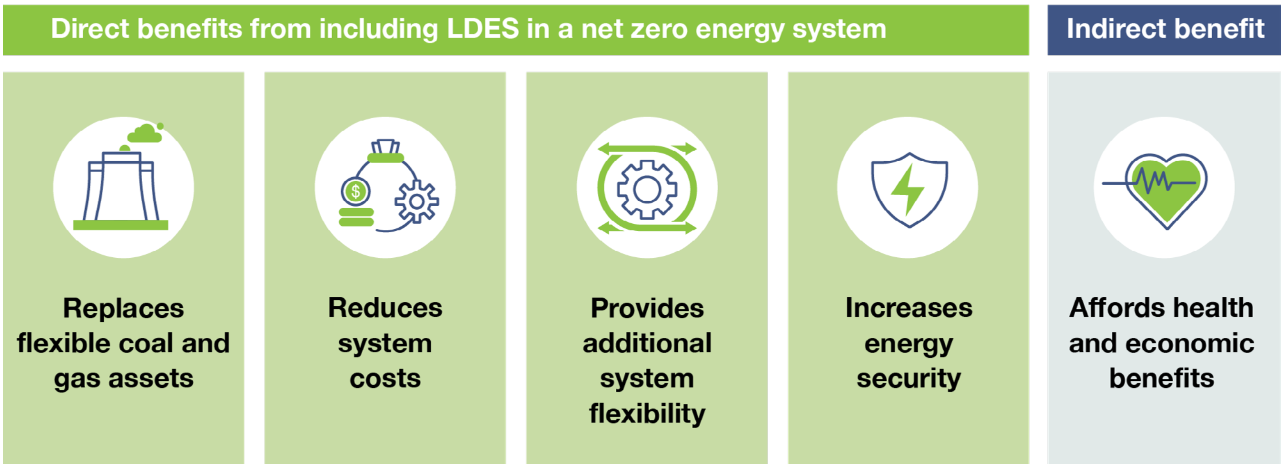
- **Faster decarbonisation of energy systems:** Existing fossil fuel assets can be retired without compromising reliability, creating headroom for more renewables and demand-side electrification – including the electrification of previously "hard to abate" sectors such as industrial heat – to help bypass grid congestion issues.
- **Reduced system costs:** Transition costs are lowered by reducing curtailment, energy wholesale prices and deferment of grid investments. The LDES Council estimates that by 2040, alongside the use of thermal energy storage for decarbonising heat, this strategy could yield global annual savings of $540 billion.[o]
- **Additional system flexibility and resource adequacy:** LDES provides benefits, including:
  - Day-ahead and real-time energy,
  - Frequency response, inertia and black start capabilities;
  - Providing additional system operation capabilities; and
  - Enabling more flexibility to address energy shifting.
- **Enhanced energy security:** LDES allows for greater integration of VRE and reducing the use of fossil fuels, which are imported in many geographies and are prone to price volatility.

o LDES Council. (2022). Net-Zero Heat: Long Duration Energy Storage to Accelerate Energy System Decarbonization. LDES Council. www.ldescouncil.com/assets/pdf/221108_NZH_LDES%20brochure.pdf

- **Health and economic benefits:**
  - Indirect benefits include improved health from reduced pollution – the Centre for Research on Energy and Clean Air estimates that $8 billion a day could be saved on the health costs of air pollution from fossil fuels,[p] and
  - The creation of new skilled jobs and the upskilling of existing jobs.

FIGURE 9

LDES technologies provide a range of social, economic and grid benefits



The overall vision is the equitable deployment of LDES worldwide to promote global energy security and climate resilience. Universal access to LDES technologies will facilitate a fair transition, helping to mitigate disparities between developed and developing nations in achieving decarbonisation goals. For example, LDES projects will help to relieve load shedding and minimise grid congestion in South Africa and reduce reliance on backup diesel generators in the Philippines.

To deploy LDES projects at pace and scale, it is vital that communities and stakeholders are engaged early and included in decision-making processes.

Following the LDES Council's global assessment of the potential benefits of deploying LDES, stakeholders have conducted more targeted assessments at the national and sub-national level (see Figure 10).

p Farrow, A., Miller, K. A., & Myllyvirta, L. (2020). *Toxic air: The price of fossil fuels*. Greenpeace Southeast Asia. https://www.greenpeace.org/static/planet4-southeastasia-stateless/2020/02/21b480fa-toxic-air-report-110220.pdf

FIGURE 10

Examples of LDES benefits across jurisdictions[q]

Geography of case study	Benefit of LDES (USD)	Description
	**16-30 billion** total electricity system cost savings NPV by 2050	The inclusion of LDES in the UK electricity system could lead to system cost savings of £13-24 billion (USD 16-30 billion) NPV to reach net zero by 2050. Widespread deployment of thermal storage could reduce carbon emissions by up to 25 million tonnes and peak electricity demand by 7%.
	**35 billion** annual system benefits by 2040	The overall cost of power systems could be reduced by around USD 35 billion annually by 2040 in the US under a 100% decarbonisation scenario. Widespread deployment of thermal energy storage could reduce 10% of US energy related greenhouse gas emissions.
	**26 billion** total electricity system cost savings by 2050	The inclusion of LDES in Germany could reduce cumulated total system costs by around € 24 billion (USD 26 billion) between 2025 and 2050 in a net zero power sector. Deployment of thermal storage at scale could help reduce the equivalent of up to 40% of Germany's gas usage today, providing significant carbon savings and energy security benefits.
	**0.4 billion**/ year system cost savings by 2030, **9 billion**/ year by 2040	Merging long duration energy storage technologies could cut New York's 2030 climate goal costs by 6% (USD 0.4 billion/year) and by nearly 30% (USD 8.7 billion/year) by 2040 compared to scenarios where only lithium-ion batteries are used in a zero emissions electric grid.

The widespread recognition of LDES by national governments underscores the urgent and vital role it plays in addressing key gaps in the electricity value chain and advancing the decarbonisation of energy systems. To meet these needs, various technologies and market readiness strategies are being prioritised, particularly focusing on LDES solutions that support long duration discharge and facilitate greater integration of VRE.

q UK Government (2022), Benefits of Long Duration Electricity Storage; Zhang, J., Guerra, O. J., Eichman, J., & Pellow, M. A. (2020). Benefit analysis of long duration energy storage in power systems with high renewable energy shares. Frontiers in Energy Research, 8, 527910; Aurora (2022), Prospects for long duration energy storage in Germany; Form Energy (2023), Modeling Multi-Day Energy Storage in New York; Systemiq (2024) Catalysing the global opportunity for Electrothermal Energy Storage; Long Duration Energy Storage Council (2021) Net-zero power: Long duration energy storage for a renewable grid

KEY FINDING #2

LDES needs to scale up to 50 times faster than is currently projected

LDES Council modelling indicates that up to 8 TW of LDES solutions are needed globally by 2040 for a net-zero energy system. However, according to the LDES Council's pipeline tracking data, only about 120 GW have been installed to-date and a further 113 GW are planned for installation, with a projected capacity of 222 GW by 2035. Global LDES capacity must scale up more rapidly to meet global renewable energy targets to combat climate change and accelerate the clean energy transition.

If energy systems do not integrate LDES at a much faster pace, decarbonisation strategies will lose momentum, perpetuating the use of fossil fuels and ensuring sustainability targets will not be met.

The LDES Council has conducted initial analysis on national deployment needs for LDES that provide an initial range for key countries (see Figure 11), broadening the understanding of how much LDES is required to meet net-zero targets.

FIGURE 11

National LDES deployment needs to meet net-zero

	Net-zero year	Low LDES (GW)	High LDES (GW)	Total Load (TWh)
United Kingdom	2035	12	61	375-450
Italy	2035	11	56	400
South Africa	2040	11	58	~400-450
USA	2035	110	150	~6,000
Australia	2040	26	30	~500
China	2050	510	785	16,500
India	2050	170	260	6,600

All types of energy infrastructure need zero-emission, dispatchable resources that can enable countries to meet their carbon reduction goals while also maintaining system reliability, and LDES is a solution providing both reliability and flexibility.

An important consideration is that LDES solutions also deliver a very valuable grid benefit in the form of capacity value. When utilities or independent system operators evaluate their capacity needs, they add up the capacity accreditation of all participating resources and strive to meet the peak demand on their system plus a planning reliability margin. If a system is only 30% renewable, the planning entity faces a capacity shortfall as demand increases and coal and other aging assets are retired. LDES can be a great resource on their portfolio if its capacity accreditation is high enough (larger at longer durations) and the cost is competitive. Furthermore, the planning entity can future-proof their portfolios if they choose LDES instead of conventional gas and prepare for a future that may incorporate a wealth of renewables supply and require more flexibility. The opportunity of LDES emerges long before deep renewable conditions materialise, underlining the multiple pathways to deploy LDES today.

Greater momentum is needed if LDES deployment and procurement is to advance at the necessary speed (i.e. to deploy up to 50 times more than currently projected). Various LDES technologies have been developed that deliver immediate, enduring benefits both to the electricity grid and to end users. Supportive policies are required to promote and accelerate development.

To enhance the LDES solutions already implemented, utilities, industrial clients, governments, and the private sector must continue to invest in and collaborate on LDES projects. Doing so will help increase capacity and ensure scalability while addressing the urgency at hand.

"Long duration energy storage is a game changer for renewable energy, enabling countries to achieve their climate goals by balancing supply and demand."

Francesco La Camera, Director-General, International Renewable Energy Agency

r Climate Impact Partners. *Fortune Global 500 climate commitments*. https://www.climateimpact.com/news-insights/fortune-global-500-climate-commitments/

KEY FINDING #3

A vibrant community of scale-up technology providers, corporates and strategic partners is building momentum for the deployment of LDES solutions at scale

LDES Council members have established projects with storage durations of eight hours or more on six continents, as shown in Figure 12. Funding for LDES solutions increased in 2023, with roughly 70% of investments consisting of grants and seed funding. The drivers for these projects are new decarbonisation initiatives by national and regional governments and sustainability commitments of large corporations.

In Western Australia, the 2023 South West Interconnected System (SWIS) Demand Assessment sets modelling to consider a 10-hour LDES option from 2030.

Energy Storage Canada finds savings of up to $4 billion in deploying storage technologies that could include longer duration energy storage solutions.

At the start of 2024, the National Energy Administration in China released a list of 56 new-type energy storage pilot demonstration projects, including 11 compressed air energy storage (CAES) projects.

The Irish TSO has highlighted an estimated 2.4GW of LDES needed for an 80% renewable grid by 2030.

Italy has a 3 GW target for LDES projects by 2030 and direct tender for large storage capacity under long-term contracts. These long-term contracts provide stability and certainty for investors and developers, reducing the cost of capital and, therefore, customer costs.

In the United States:

- California has set a target to procure 2 GW of LDES by 2030.
- New York announced a goal to deploy 6 GW of energy storage (including LDES) by 2030.
- Maine signed “An Act Relating to Energy Storage and the State’s Energy Goals” into law, directing a study into potential LDES solutions.

Alongside policymakers, the finance community is turning towards the critical role of LDES. About two-thirds of Fortune 500 companies have made significant climate commitments.[r] The LDES Council estimates that the buildout of up to 8 TW of LDES solutions by 2040 represents a $4 trillion investment opportunity that could deliver as much as $540 billion in system cost savings annually.

Several LDES Council member companies, including Ceres, Kyoto, Invinity, Energy Vault, ESS, EOS, Sens and Brenmiller, are listed on stock exchanges in Switzerland, Sweden, Finland, Israel, the United Kingdom and the United States, respectively. This has allowed these LDES companies to allow investors to buy shares in their organisations, helping to provide them funding to expand and scale their operations.

Figure 12 showcases operational long duration energy storage (LDES) projects that have storage durations of eight hours or more. These projects consist of varying technologies, including Mechanical, Thermal and Electrochemical solutions. There is an extensive geographical reach and diversity of companies with deployed long duration energy storage solutions.The LDES Council anticipates a large volume of growth in LDES project deployment across continents. Figure 13 visualizes the upcoming planned deployment of LDES projects over the next decade. LDES developers are striving to scale deployment and creating an enabling financial and policy environment is critical to the facilitation of commercial deployment across all sectors.

> "Long duration energy storage represents an opportunity to fill critical gaps in the grid and serve as a foundational platform for clean energy to power our homes, businesses and vehicles."
>
> **Dr Vanessa Z Chan**, Chief Commercialisation Officer, US Department of Energy; Director, Office of Technology Transitions

FIGURE 12

Operational LDES projects with eight-hour-plus storage durations

*This map is not indicative of exact geographical locations

FIGURE 13

Planned LDES projects with eight-hour-plus storage durations

*This map is not indicative of exact geographical locations

KEY FINDING #4

Action is needed by stakeholders such as policymakers, corporates and technology providers to realise the potential of LDES solutions

Creating an enabling environment is crucial for the large-scale deployment of LDES. Many of the bankable business cases today are dependent on very specific locations and combinations of revenue streams outside of the electricity sector, including thermal energy storage for industrial heat processes or policy incentives and support mechanisms. By leveraging the strength of advocacy, data, and thought leadership, the LDES Council creates a powerful movement for policy and financing change that is evidence-based, persuasive, and impactful.

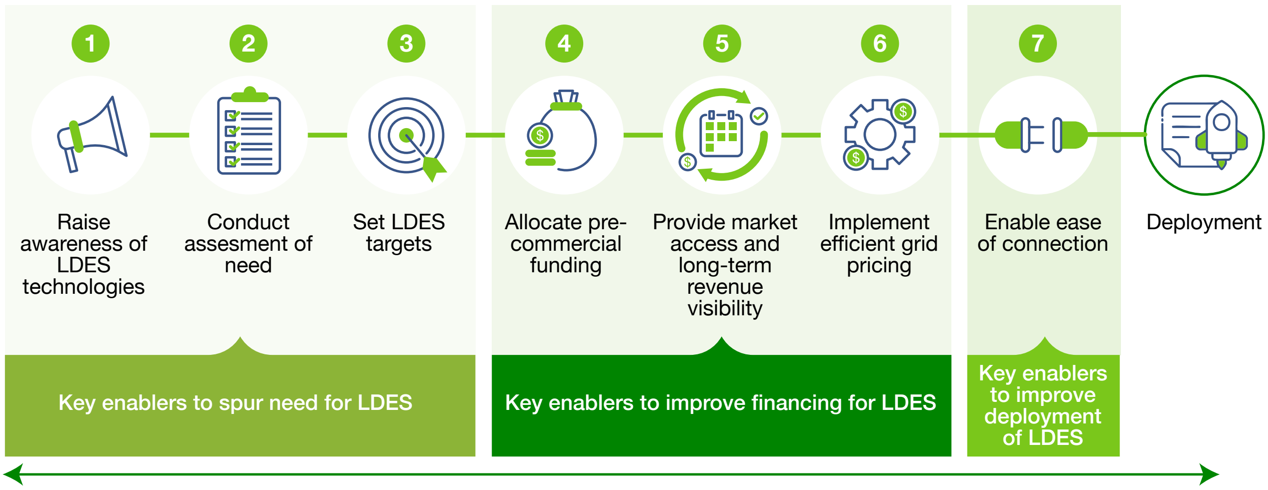
The report identifies seven enablers for a supportive environment for LDES. Multiple stakeholders will play a role in unlocking the enablers, and while some are timebound – "raising awareness," for example – others will require concerted ongoing action to fully enable LDES deployment.

> Although many countries are acting on some of the enablers, there is no country in which all seven enablers are fully in place.

Implementing enablers to scale up LDES solutions requires action from several stakeholder groups.

FIGURE 14

Seven enablers to scale LDES

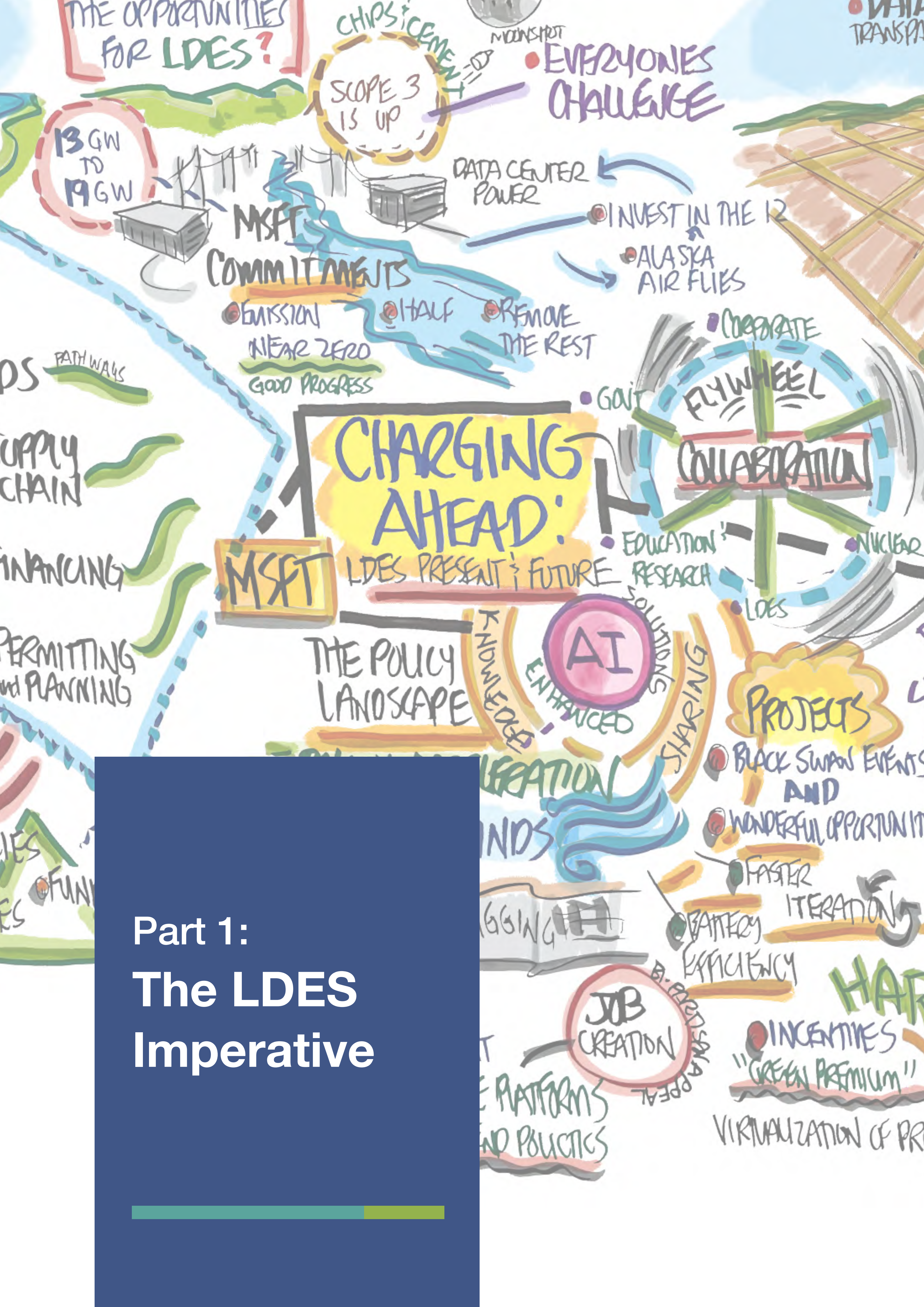


Long duration energy storage technologies are essential for a clean and just energy transition and required for the deep and durable decarbonisation of energy systems, including the power system and industrial heat. As the world shifts to meeting its energy needs with clean energy resources, LDES must play an increasingly large role in integrating this energy supply efficiently and ensuring a stable and reliable energy grid.

The deployment of LDES in all sectors must scale rapidly to meet these requirements. The commitments made by governments to accelerate the transition and rapidly develop VRE supply must be matched by efforts to deploy and scale LDES technologies. Efforts must be made to continue to build on procurement targets in New South Wales, Victoria, New York, California, Ontario, Chile and Italy. Alongside advancing policy enabling strategies, setting a specific target for energy storage deployment at COP29 will provide needed clarity, direction, and accountability for policymakers, industry, investors, and stakeholders to advance LDES deployment.

The time for action is now, and the engagement and support of policymakers and change agents around the world will guide its needed deployment. The responsibility and obligation to illuminate the needed policy enablers and market development incentives lies with all engaged citizens, making their voices heard and working together to help realise the clean energy future we owe to the generations to follow us.

> “To achieve energy independence and security in Europe, enhancing our energy storage capacity is not just an option; it is a necessity.”
>
> **Kadri Simson**, European Commissioner for Energy



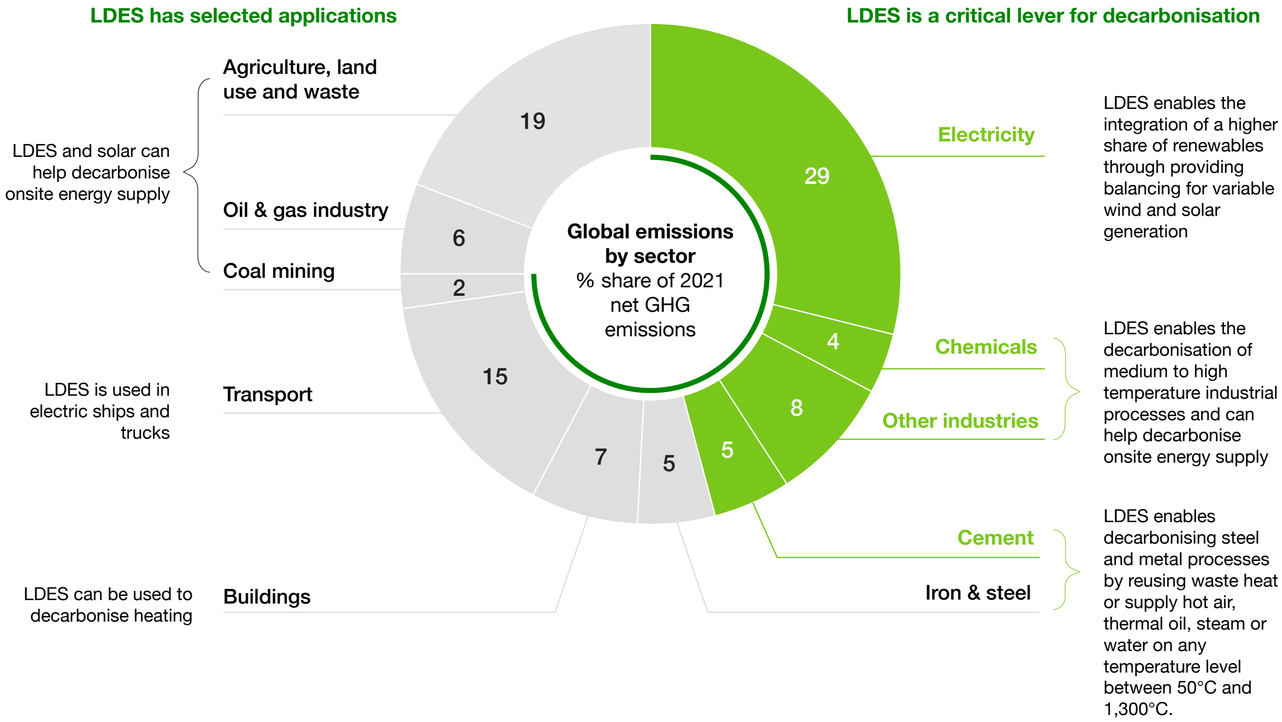
Part 1:

The LDES Imperative

The ability to store and dispatch renewable energy when needed is an essential component of the energy transition and is integral to meeting the target of tripling renewables capacity by 2030 and the Paris Agreement goals. This will only become more important as demand for power and industrial heat intensifies due to continued population growth and expanded economic development in new regions around the globe. The decarbonisation of energy systems worldwide is imperative to achieving the energy transition – as depicted in Figure 15, which shows the large number of industrial applications.

FIGURE 15

LDES can enable the decarbonisation of energy usage across sectors



The societal savings from large-scale LDES deployment can outweigh the costs of implementing policies. Incorporating LDES can help to increase the security of supply, create new use cases for renewable energy and unlock new opportunities not thoroughly addressed by shorter-duration storage solutions.

We must deploy far more low-carbon alternatives as the world moves towards net zero. The four families of LDES solutions that enable stored energy to be discharged for eight hours or more are presented in Figure 16, together with key technology characteristics.

> “Long duration energy storage will be crucial for Europe to manage its increasing reliance on variable renewable energy sources.”
>
> **Fatih Birol**, Executive Director, International Energy Agency

FIGURE 16

The four families of LDES technologies

	Description	Diagram	Charge-Discharge Period
Electrochemical (power-to-power)	Battery systems that can store electricity through chemical reactions • Flow battery • Metal anode (e.g. iron, zinc, lithium-ion battery) • Metal air	Charge → Disharge	Hours to days
Mechanical (power-to-power)	Systems that use heat, water or air with compressors, turbines, & other machinery • Pumped hydro • Compressed air • Liquid air/ CO_2 • Gravity	Charge → Reserve → Turbine (discharge)	Hours to days
Thermal (Power-to-Power)	Systems that convert electricity to thermal energy, store in inexpensive materials & output as electricity • Sensible heat • Latent heat • Thermo-chemical	Charge → Option to output power	Hours to days
Thermal (Power-to-Heat)	Systems that convert electricity to thermal energy, store in inexpensive materials & output as heat • Sensible heat • Latent heat • Thermo-chemical	Charge → Heat delivery (hot water, steam or air)	Hours to days
Chemical (power-to-power)	High density energy carrying chemicals produced from energy sources, which can be converted back to electricity • Hydrogen • Ammonia • Electrofuels	Electrolyzer (charge) + derivates (H_2, O_2) → Option to convert back to electricity	Seasonal
Chemical (power-to-x)	High density energy carrying chemicals produced from energy sources, which can be stored, used as fuels or as chemicals feedstock • Hydrogen • Ammonia • Hydrocarbons/Alcohol • Carbons	Electrolyzer (charge) + derivates (H_2, O_2) → Option to use in industry	Seasonal

Source: LDES Council data

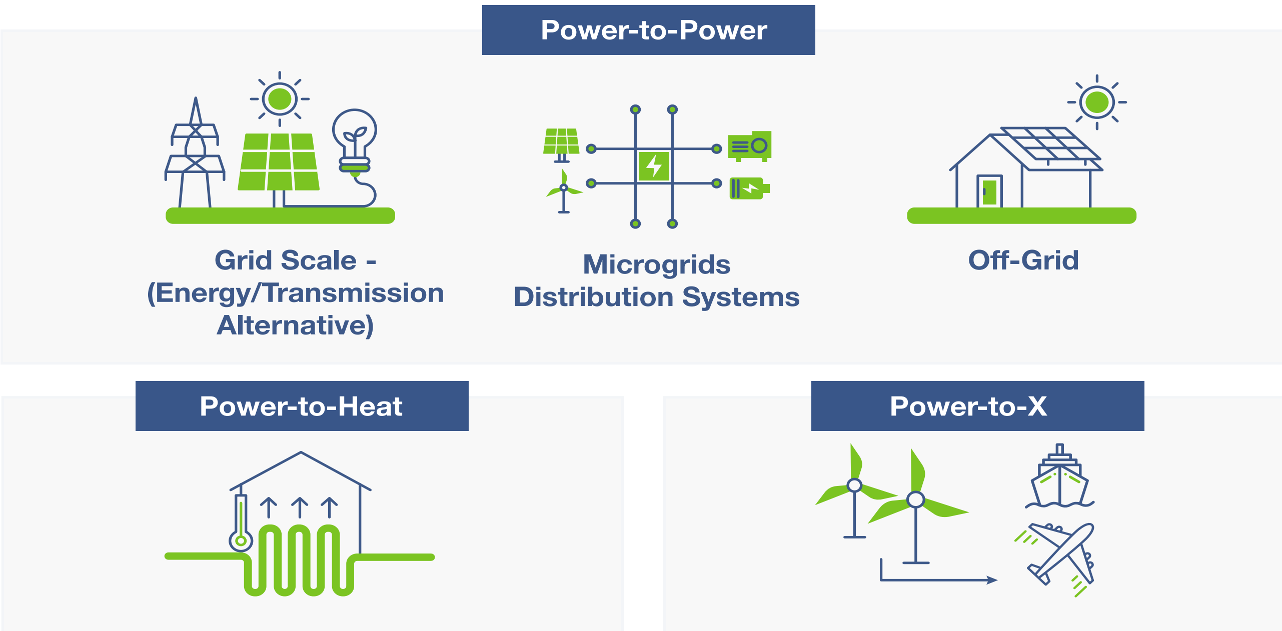
The applications of LDES are sufficiently diverse to become integrated into all aspects of our daily lives and economies. The durations of LDES are applied to different sectors. There are five applications for LDES, associated with power-to-power, power-to-heat and power-to-x functions.

Power-to-power applications include grid-scale participation, micro-grid or distribution system participation and off-grid applications. Power-to-heat provides heat for downstream processes, while power-to-x chemical resources can provide hydrogen and hydrogen derivatives. Figure 17 demonstrates the different applications for LDES. These deployment scenarios highlight the variety of ways in which LDES technologies can decarbonize key sectors.

LDES is a strategic asset that can derisk the energy transition.

FIGURE 17

Five applications for LDES



Although power-to-heat LDES technologies are already competitive in specific site locations, more can be done by key stakeholders to remove barriers to directly access wholesale electricity market prices. As market access for power-to-heat LDES increases, the benefits of LDES applications can provide response to real-time energy dispatch instructions, balancing services, and stability.

Figure 18-20 break down the various applications and use cases for each LDES technology type, by application.

FIGURE 18

Services provided by different technology mechanisms (power-to-power)

		Electrochemical (power-to-power)	Mechanical (power-to-power)	Thermal (power-to-power)	Chemical (power-to-power)
Risk Management	**Energy market participation** – buying and selling power in the futures market to manage forward risk	✓	✓	✓	✓
	Provision of balancing services – providing grid operator with a service to consume or inject electricity	✓	✓	✓	✓
Real time operation (and decarbonisation) of electricity grid	**Provision of reserve capacity** – providing grid operator with certainty that there will be enough injection power to call on	✓	✓	✓	✓
	Grid stability and power quality services – maintaining a stable supply-demand balance on the grid, and providing frequency regulation and voltage support	✓	✓	✓	✓
	Back up site power for individual sites – providing industrials, data centres with a back-up solution alternative to diesel generators	✓		✓	
	Black start services – restoring power to the grid after a complete or partial shutdown without relying on external power sources	✓	✓	✓	✓

Source: LDES Council data

FIGURE 19

Services provided by Thermal technology mechanisms (power-to-heat)

		Thermal (power-to-heat)
Decarbonisation of industry, agriculture, and transportation	**Heat** – heat generated from electricity is stored and then used as process heat or cooling when needed, or as space heating	✓
	Chemical – used as the basis for industrial processes in the manufacturing of chemicals, fertilisers and fuels	

FIGURE 20

Services provided by Chemical technology mechanisms (power-to-x)

		Chemical (power-to-x)
Decarbonisation of industry, agriculture, and transportation	**Heat** – heat generated from electricity is stored and then used as process heat or cooling when needed, or as space heating	✓
	Chemical – used as the basis for industrial processes in the manufacturing of chemicals, fertilisers and fuels	✓

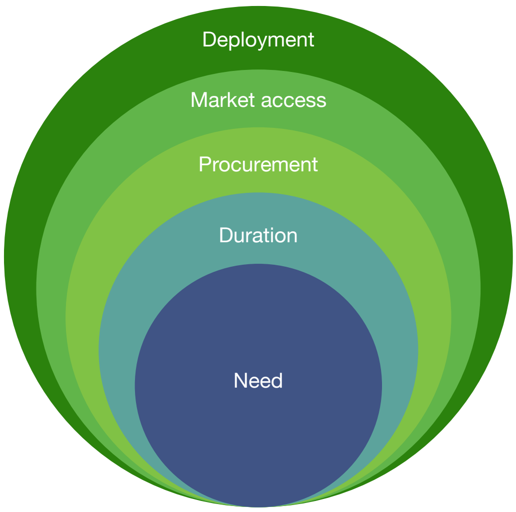
Source: LDES Council data

Many LDES technologies can provide most of the services that are compensated at market prices in organised electricity markets. These include revenues from resource adequacy capacity, energy, reserve capacity, grid stability and black start services. Developing market products that compensate services that LDES technologies provide can help to incentivise development, alongside procurement mechanisms. These levers are necessary to scale and meet the up to 8 TW need for global decarbonisation (see Figure 21). Some LDES technologies will not be in traditional markets but will rather provide off-grid and other services. Not all markets allow for full wholesale participation by LDES assets, which increases overall system costs and can weaken the business case for those LDES assets.

New procurement directives aimed at replacing coal plants can also create opportunities for market access and support the deployment of LDES.

FIGURE 21

Identifying need and building on durations to address flexibility and market access will lead to additional deployment to scale LDES solutions.



The Deployment of LDES to replace coal plant infrastructure has begun in different parts of the world.

Box 1 presents a range of LDES projects that have replaced coal plant infrastructure to provide traditional grid services.

Retrofitting Fossil Plants with Long Duration Energy Storage

Many aging gas and coal power plants can be repurposed with LDES, enabling them to transition to cleaner energy while using existing infrastructure. Instead of decommissioning, retrofitting allows these plants to keep their role in grid stabilisation by replacing turbines with energy storage systems that utilise renewable electricity.

LDES provides critical services like synchronous inertia, reactive power, and reserve power, similar to what traditional fossil plants offer. Some sites can also be adapted to supply thermal energy for industrial use, further boosting their economic value.

- Columbia Energy Storage Project: The Columbia Energy Center in Wisconsin is being retrofitted with a CO2-based LDES system by Energy Dome. When operational in 2025, it will provide 18 MW of power for 10+ hours, highlighting LDES's role in repurposing old coal plants.
- Malta's Pumped Heat Electricity Storage (PHES): Malta's utility-scale PHES system stores CO2-free variable renewable electricity and converts it into dispatchable synchronous electricity, effectively replacing gas-fired power plants. The rotating charge and discharge turbomachinery of Malta's PHES provides auxiliary services to grid operators.
- Using its own iron flow battery technology, ESS, Inc has partnered with LEAG, an operator of large-scale lignite mining and coal-fired generation in eastern Germany with a vision to transform this coal-dependent region into Germany's "Green Powerhouse." LEAG plans to develop 7–14 GW of renewable generation paired with 2–3 gigawatt-hours (GWh) of energy storage and 2 GW of green hydrogen production. Combined, these technologies will create a net-zero baseload energy system which, when fully operational, will not only replace baseload coal generation, but also use LDES to help replace natural gas for grid balancing.
- In Australia, which is renowned for its mining industry, many operations are powered by off-grid diesel generators. These mines, often located far from the national grid, rely on fossil fuel-based power systems to meet their energy needs. As the industry moves towards decarbonisation, there is growing interest in replacing diesel generators with renewable energy solutions (see the LDES Council Net Zero Heat and Industrial Decarbonisation reports at www.ldescouncil.com/reports). Renewables plus LDES help to decarbonise off-grid mining profitably, with the economics varying based on fuel cost differences (the primary driver), carbon taxes and renewables costs and resources.
- Sumitomo is developing liquid air energy storage (LAES) technology for integration with liquefied natural gas terminals and off-grid mines, among other facilities. LAES is a long duration, thermo-mechanical energy storage system that stores energy by liquefying air at cryogenic temperatures. The stored energy can then be used to provide reliable power when renewable generation is insufficient. In one case study for an off-grid nickel-cobalt mine, Sumitomo modelled a system comprising 35 MW of onshore wind, 84 MW of solar PV and a 50 MW LAES system with 25 MW discharge power and 400 megawatt-hours (MWh) of storage capacity. The analysis indicated that this set-up could meet 76% of the mine's energy demand by 2036 without the need for lithium-ion battery capacity. By integrating renewable energy with LAES, the mine could significantly reduce its reliance on fossil fuels, thereby cutting its carbon emissions and transitioning to a more sustainable energy system.

According to the International Monetary Fund, "It's sound economic logic to pay for the replacement of coal with renewables to reap a net social gain measuring in the tens of trillions of dollars." And LDES can bring even more savings by charging during excess renewable production, decreasing curtailments and providing flexibility services to address load shifting as well as providing heat and reliable services for grid capacity.

LDES technologies can also help to strengthen energy system security around the world. Among other things, they play a key role in enabling island nations and countries with limited fossil fuel resources to reduce their reliance on fossil fuel imports and support greater integration of VRE, affording a variety of benefits to local economies by mitigating fossil fuel use, lowering customer costs and promoting clean air quality.

Beyond isolated energy systems such as off-grid and microgrid systems, smaller island nations are implementing cost-effective decarbonisation pathways, especially for their electric power systems. Doing so helps to avoid blackouts during off-peak seasons for onshore wind or solar PV systems, while also accelerating the energy transition and strengthening system resilience and reliability.

LDES will unlock new value from clean energy resources, helping to meet the challenges of our modern age by addressing risk mitigation, improving grid operations in a changing world and decarbonising industries.

"Solar, already the most economical source of new electricity globally, will further strengthen its competitive advantage. Combined with long duration energy storage, solar becomes a continuous, reliable 24/7 energy source."

Dr. Ajay Mathur, Director General, International Solar Alliance

Part 2:
LDES Market Readiness

LDES resources store energy through four different mechanisms: electrochemical, mechanical, thermal and chemical. Figures 22 to 29 present some examples of LDES projects and further detail including specific technology, market readiness, round-trip efficiencies, and geographic footprint. This section examines the technological readiness of the four mechanisms and provides insights on the work and cost data of LDES Council technology members.

FIGURE 22

Market readiness of Electrochemical (power-to-power) LDES technologies

Category	Technology	Market readiness	Storage duration (hours)	Round-trip efficiency (%)	Geographical footprint (kWh/m²)
Electrochemical (power-to-power)	Vanadium Flow batteries	Early commercial	4-24+	60-80%	20-50
	Lithium-Ion (LFP, NMC)	Commercial	2-10	85-96%	90-95
	Sodium-Ion	Early commercial	4-20	60-85%	2-43
	Zinc Air	Early commercial	10-100	40-45%	2-43
	Zinc Bromine Flow	Early commercial	4-12	60-70%	2-43
	Iron Air	Early commercial	100	40-45%	2-100
	Non-Metal chemical storage	Emerging	0-200	40-50%	300-1500

Source: Long Duration Energy Storage Council. Data collected from members.

FIGURE 23

Electrochemical LDES projects - deployment updates

Electrochemical

i-Battery Energy Technology launched their first all-vanadium flow battery production line, which is expected to reach an annual capacity of 1000 MWh/ year in 2024

In March 2023, i-Battery accomplished the angel round investment financing by three top venture capitals. Simultaneously, it has carried out exploration research for four generation battery paths and signed 9 strategic cooperation agreements in the global market. In October 2023, the first all-vanadium flow battery intelligent production line was officially put into operation, with the capacity reaching 300 MWh/year, and the annual capacity in 2024 will reach 1000MWh/year. i-Battery utilizes its unique stack hybrid sealing technology to achieve 0 leakage. Its products can achieve 100% zero attenuation deep filling and discharging. They also just closed Series Pre-A find raising with 6M USD.

Electrochemical

redflow	**Redflow announced AUD $50 Million in Global Long duration Energy Storage Projects**	Redflow has seen significant global growth in the long duration energy storage market and this year have announced over AUD$50 million of awarded projects. These projects include a 4 MWh Energy Queensland project, a 34.3 MWh energy storage project for US Department of Energy and two Departent of Defense projects for 1.2-1.4 MWh microgrid in New York State and 400 kWh Sigonella Naval Air Station in Italy, 6.6 MWh Barona Community LDES Project and the California Energy Commission funded 15 MWh Paskenta Microgrid project. Redflow has delivered more than 3.2 GWh of storage capacity to over 250 active global deployments.
cellcube BUILDING ENERGY STORAGE INFRASTRUCTURE	**CellCube evaluated their Commercial Vanadium Flow Battery System, quantifying its financial benefits in the last 14 years**	The Journal of Energy Storage published the article "Long Term Performance Evaluation of a Commercial Vanadium Flow Battery System" by Yifeng Li et al highlighting a CellCube FB10-100 system. The CellCube system has been in operation for 14 years. The system required four minor maintenance operations. A 5% capacity loss was proven to be reversible, and the system restored to 100% capacity by electrolyte rebalancing. The study concluded the CellCube system and electrolyte exhibited "stable performance and very little capacity loss". CellCube's current 4th generation commercial products incorporate significant advances in stack technology, electrolyte chemistry, and battery management systems.
STRYTEN ENERGY	**Stryten Energy has won funding to build a vanadium electrolyte manufacturing plant**	Stryten Energy commemorated the installation of its advanced vanadium redox flow battery (VRFB) at Snapping Shoals EMC, a utility provider in metro Atlanta, to demonstrate VRFB's energy storage capabilities and evaluate new utility use cases for the cutting-edge, long duration technology. Stryten has also been awarded DOE MAKE IT Prize funding to build a vanadium electrolyte manufacturing plant, a critical first step to establishing a scalable and vertically integrated domestic supply chain to support the growing VRFB energy storage commercial and industrial base.
eos	**Eos Energy Secures $398 Million Loan for Groundbreaking 8 GWh LDES Manufacturing Line**	Eos Energy Enterprises has achieved a significant milestone with the conditional approval of a $398 million loan from the U.S. Department of Energy's Loan Programs Office (LPO) for Project AMAZE, an 8 GWh manufacturing line. This is the first LPO loan granted for LDES technology, marking a pivotal moment in the industry's development. The funding will support the expansion of Eos' manufacturing capabilities to meet the growing demand for long duration energy storage solutions, reinforcing their commitment to innovation and sustainability in the energy sector.
ENERVENUE	**EnerVenue has delivered pilot projects in the US, Europe, India, China, the Caribbean and South America**	In the last year, EnerVenue has delivered pilot projects with major commercial energy users, independent power producers, and utilities in the U.S., Europe, India, China, the Caribbean, and South America. The company is currently developing its fourth-generation Energy Storage Vessel, which is the unit that will be produced at scale in 2025 and will be shipped in the company's plug-and-play Energy Rack building block solution for integration in an Energy Venue. The company is delivering a differentiated solution and has been recognized by Time Magazine as one of America's Top Greentech Companies in 2024.
noon ENERGY	**Noon Energy has been awarded $8.8 million for the deployment of a 100-kW/10-MWh storage system**	This funding will enable the demonstration and deployment of a 100-kW/10-MWh system aimed toward improving grid reliability and resilience for disadvantaged and low-income communities. The system will balance seasonal variability to enable 100% solar power available 24/7.

FIGURE 24

Market readiness of Mechanical (power-to-power) LDES technologies

Category	Technology	Market readiness	Storage duration (hours)	Round-trip efficiency (%)	Geographical footprint (kWh/m²)
Mechanical (power-to-power)	Compressed-air energy storage	Early commercial	6-100	40-70%	12.5
	Liquid Air	Commercial	10-72	60-75%	59-74
	Liquid CO_2	Commercial	4-24	75-80%	4-5
	Gravity-based	Emerging	0-15	70-90%	7
	Pumped Hydro Storage (PHS)	Commercial	0-10	70-85%	5-12
	Closed loop PHS and run of river	Commercial	0-15	50-80%	4-5

Source: Long Duration Energy Storage Council. Data collected from members.

FIGURE 25

Mechanical LDES projects - deployment updates

Mechanical

SAGE GEOSYSTEMS

Sage Geosystems has raised USD 18 million for its first commercial 3 MW storage facility using Geopressured Geothermal System (GGS) technology

Sage Geosystems was successful in closing the first $18 million in their Series A funding led by Chesapeake Energy and joined by technology investor Arch Meredith, Helium-3 Ventures and with continued support from existing investors Virya, Nabors, and Ignis Energy. The proceeds will fully fund Sage's first commercial 3MW energy storage facility using their proprietary Geopressured Geothermal System (GGS) technology. Sage's energy storage technology (called EarthStore™), is a mechanical system with the resource being subsurface pumped storage hydropower. It has a round-trip efficiency (RTE) of 70-75% AC-to-AC with a duration of 4 to 24+ hours, and water losses less than 2%. Storage capacity per well is 3MW using 9-5/8" casing and 5MW with 13-3/8" casing. Sage Geosystems is building a high-pressure Pelton turbine (5,000 psi and 3MW) for this first commercial facility.

ENERGYDOME
Our WORLD can't wait.

Energy Dome began construction on the first 20 MW/ 200 MWh CO2 battery, and have received funding for a CO2 battery repurposing a retiring coal facility in Wisconsin

Energy Dome has begun the construction on the first standard-frame 20MW/200MWh CO2 Battery in Sardinia, Italy. This project, funded by Breakthrough Energy Catalyst and the European Investment Bank, is slated for commercial operation in 2024. Moreover, Energy Dome and US Utility Alliant Energy have received funding from the Department of Energy's Office for Clean Energy Demonstrations for a standard-frame CO2 Battery in Wisconsin. The Wisconsin project, expected to be operational by 2026, will repurpose a retiring coal facility in Columbia County, WI.

Mechanical

Sumitomo SHI/FW	**Sumitomo SHI FW Advances Liquid Air Energy Storage Projects in Japan and UK**	Sumitomo SHI FW (SFWHI) is actively advancing its energy storage projects. SHI, parent company of SFW is constructing a 5MW/20MWh Liquid Air Energy Storage Plant in Hiroshima, Japan, with commercial operation expected by May 2025. This plant is a commercial pilot project funded entirely by SHI's investment. Additionally, SHI is an investor and the sole technology partner of High View Power (HP). HP has closed £300 million in funding and is now building the world's first commercial Liquid Air Storage plant in Carrington, United Kingdom. The 50MW/300MWh plant, with main investors including Goldman Sachs, Centrica, UKIB, and Rio Tinto, is slated for commercial operation by early 2026.
AUGWIND	**Augwind announces improved RTE**	In Q2 2024, Augwind announced an improved round trip efficiency (RTE) of 47.3% at their 0.5MW/1MWh demonstration facility. This significant milestone substantiates Augwind's capability to achieve a 60% RTE in their next demonstration, showcasing their commitment to advancing energy storage technology.
HYDROSTOR	**Hydrostor Advances A-CAES with Key Projects in Canada, California, and Australia**	Hydrostor's Advanced Compressed Air Energy Storage (A-CAES) technology offers low-cost, emissions-free, long duration energy storage. Validated by a $250 million investment from Goldman Sachs and the Canada Pension Plan, Hydrostor has two facilities in Canada and 700 MW in late-stage development. The Willow Rock Energy Storage Center in California will provide 500 MW of storage, supported by a 25-year PPA with Central Coast Community Energy. Additionally, the 200 MW Silver City project in Australia has secured a Long-Term Service Agreement with the NSW government and a reliability agreement for backup power in Broken Hill.
SENS	**SENS is developing UPHS projects in abandoned mines**	SENS recently secured full ownership of two of the key sub-projects within the energy storage project in Pyhäsalmi, Finland: An 85 MW battery storage system (BESS) and a 75 MW underground pumped storage facility (UPHS). Both projects have ready-to-build status and will move towards completion with the help of several investors. The UPHS power plant will utilize the existing Pyhäsalmi mine structure and its synchronized energy storage system. With a storage capacity of 530 MWh and a maximum output of 75 MW, it is designed to balance energy supply and demand. SENS is also developing two solar projects adjacent to the energy storage cluster, one FPV 40 MW solar park and one land based 40 MW solar park (PV).
Rye Development	**Rye Development awarded $81 million for Lewis Ridge Pumped Storage project**	Rye Development, a U.S. leader in pumped storage hydropower, was awarded $81 million from the U.S. Department of Energy Office of Clean Energy Demonstrations to support the Lewis Ridge Pumped Storage project in Bell County, Kentucky. The project will create around 1,500 construction jobs and provide 287 MW of capacity and eight hours of storage. Upon completion, it will be one of the first pumped storage hydropower facilities built in the U.S. in over 30 years and the first located on former coal mine land, contributing to the region's energy legacy and workforce.

FIGURE 26

Market readiness of Thermal projects and LDES technologies

Category	Technology	Market readiness	Storage duration (hours)	Round-trip efficiency (%)	Geographical footprint (kWh/m²)
Thermal (power-to-power)	Sensible heat	Early commercial	200	55-90%	30-800
	Latent heat	Emerging to commercial	25-100	20-50%	30-450
	Thermo-chemical	R&D/Emerging	Not available	Not available	Not available
Thermal (power-to-heat)	Sensible heat	Early commercial	200	55-97%	30-800
	Latent heat	Emerging to commercial	25-100	20-93%	350-1644
	Thermo-chemical	R&D/Emerging	Not available	Not available	Not available

Source: Long Duration Energy Storage Council. Data collected from members.

FIGURE 27

Thermal LDES projects - deployment updates

Thermal

ANTORA	**Antora Energy announced its first large-scale thermal battery manufacturing facility in California**	Antora Energy raised a $150 million Series B funding round led by Decarbonization Partners, a partnership between BlackRock and Temasek. This financing round will enable Antora to ramp production of its factory-made thermal batteries to deliver billions of dollars of zero-emissions energy to industrial customers. Last year, Antora announced its first large-scale thermal battery manufacturing facility, located in San Jose, California.
MGA THERMAL	**MGA Thermal raised USD 14 million, whichwill be used to prove the scale and industrial capabilities of their technology**	MGA Thermal is pleased to close their Pre-B funding round at approximately $14 million, with the recent installment of $5.7 million announced in April 2024. The funding will be used to prove the scale and industrial capabilities of MGA's thermal energy storage systems. This round was supported by returning investors including Main Sequence, Melt Ventures and new investor JEKARA. The funding brings its total funds and grants raised to date to approximately $28.8 million.
ALFA LAVAL	**Alfa Laval is working on validating a new path in Power-to-Heat-to-Power energy storage solutions**	Alfa Laval is to be the heat exchanger partner for the EU-funded development project SCO2OP-TES, where together with its 13 partners from 10 countries it will validate the use of super-critical CO2 as part of a Thermally Integrated-Pumped Thermal Energy Storage project. Alfa Laval aims to validate a new path in Power-to-Heat-to-Power energy storage solutions using this novel technology.
KRAFT BLOCK	**Kraftblock has raised EUR 20 million, which will be used to accelerate their mission to decarbonise process heat in industry**	Kraftblock raised a total of €20 million in a Series B financing round led by Shell Ventures. The VC arms of Techint Group and ArcelorMittal, as well as the largest private bank in Spain, a US investor and the European arm of SBI Holdings, invested in the high-temperature energy storage company as well. Kraftblock will use the funds to further expand its staff and project activities in Europe and worldwide. It will accelerate the mission to decarbonize process heat in the industry.

Thermal

Shell	**Shell has deployed a thermal energy storage system in one of their plants, expecting to reduce diesel use by 300 tons and reduce emissions by 900 tons a year**	At Shell's Zhuhai plant in China, which produces lubricants and greases, a thermal energy storage system has been introduced. This system replaces diesel fuel with renewable electricity to generate the process steam required for manufacturing lubricants. The storage system will optimise steam production and is expected to reduce the use of diesel by 300 tonnes and CO2 emissions by more than 900 tonnes a year.
RONDO	**Rondo Energy Secures €75 Million for Industrial Decarbonization Projects in Europe**	Rondo Energy has secured €75 million in financing from Breakthrough Energy Catalyst and the European Investment Bank to fund three pioneering industrial decarbonization projects in Europe. These projects will deploy Rondo Heat Batteries (RHBs), which convert intermittent renewable electricity into continuous, high-temperature heat and power. The installations will serve the food & beverage, chemical production, and clean fuel sectors, providing cost-effective, zero-carbon energy solutions.
ENERGYNEST	**ENERGYNEST's ThermalBattery Commissioned at Avery Dennison's Belgian Plant**	ENERGYNEST's ThermalBattery has been commissioned at Avery Dennison's plant in Belgium, in collaboration with Campina Energie and Azteq. This project, combining Concentrated Solar Thermal (CST) and thermal storage, will save 2.3 GWh of natural gas annually. Additionally, last year saw the start of construction for another ENERGYNEST ThermalBattery at ENI in Italy, further expanding their innovative energy storage solutions in Europe.
MALTA	**Malta's Pumped Heat Energy Storage (PHES)**	Malta's PHES technology is a synchronous long duration energy storage system designed to replace fossil and nuclear power plants by providing essential grid reliability services such as inertia, reactive power, and short circuit current. Utilizing a heat pump and thermal storage, Malta PHES generates over 100 MW of clean, dispatchable power and heat, maintaining grid stability even as traditional power plants retire. This technology supports the reliable deployment of renewable energy by filling the critical gap left by the loss of conventional power plants, ensuring a stable transition to a carbon-free energy future.
KYOTO™	**Kyoto Group launched their first at-scale 'Heatcube' in Denmark**	The Kyoto Group marked a significant milestone on the journey to electrify the huge, and currently fossil-based, market for process heat. Their first full-scale Heatcube at Norbis Park in Denmark became operational and was connected to a AI-powered DataOps platform. Kyoto was honored with the prestigious Energy Transition Changemakers award at COP28. Among a number of highlights last year, another key one was their strategic partnerships with, and investments from, leading utility Iberdrola and thermal energy leader Spirax Group and the commercial order for Heatcube delivering Heat-as-a-Service to KALL Ingredients.
BRENMILLER THERMAL ENERGY STORAGE	**Brenmiller Energy is installing 2 thermal energy storage units, one of these is projected to reduce energy costs by USD 7.5 million over 15 years**	Over the past year, Brenmiller Energy has signed two innovative projects to advance heat decarbonization in the food and beverage and public healthcare sectors. A 32-MWh Thermal Energy Storage (TES) unit, soon to be installed at a manufacturing plant partially owned by the global giant Heineken, is projected to reduce energy costs by $7.5 million over 15 years using solar energy and off-peak electricity. Simultaneously, the public Wolfson Hospital has signed on to save up to $1.3 million annually with Brenmiller's bGen™ ZERO system, aiming to reduce emissions by 3900 tons per year. These initiatives showcase Brenmiller's cutting-edge technology and highlight a global shift towards sustainable, cost-effective energy solutions with significant economic and environmental benefits.
BUILD TO ZERO	**Build to Zero and Dekitra Partner for Europe's First Net Zero Chlorine Factory**	Build to Zero has signed a commercial contract with the chemical company Dekitra to install a First-Of-A-Kind (FOAK) ThermalBox® unit. Build to Zero manufactures the Electrothermal Energy Storage (ETES) equipment known as ThermalBox® available in standard sizes of 2.5 MWp(th) with 14 MWh(th) storage, and 5 MWp(th) with 28 MWh(th) storage. This equipment is designed to decarbonise steam up to 20 barg, catering to the chemical, food & beverage, and paper industries. With this installation, Dekitra will become the first chlorine products factory in Europe to achieve net zero emissions by 2026.

FIGURE 28

Market readiness of Chemical LDES technologies

Category	Technology	Market readiness	Storage duration (hours)	Round-trip efficiency (%)	Geographical footprint (kWh/m²)
Chemical (power-to-power)	Hydrogen	Emerging	500-1000	28-40%	5-50
	Ammonia	Emerging	170-350	35-40%	98
	Methanol	Emerging	170-350	Not available	Not available
Chemical (power-to-x)	Hydrogen	Early commercial	500-1000	40-70%	5-50
	Ammonia	Early commercial	170-350	35-40%	98
	Methanol	Early commercial	170-350	Not available	Not available

Source: Long Duration Energy Storage Council. Data collected from members.

FIGURE 29

Chemical LDES technologies - deployment updates

Chemical

ENERGY VAULT Enabling a Renewable World	**Energy Vault began construction on the largest green hydrogen long duration energy storage system in the US**	Energy Vault began construction of the largest green hydrogen long duration energy storage system in the U.S. The hybrid green hydrogen plus battery energy storage system will be capable of powering approximately 2,000 electric customers within PG&E's Calistoga microgrid for up to 48 hours (293 MWh of carbon-free energy). The project is supported by a 10.5-year tolling agreement; with commercial operation expected in the summer of 2024, solidifying Energy Vault's global leadership role in technologies for long duration energy storage.
NEOM نيوم	**NEOM Hydrogen Company Secures $8.4 Billion for World's Largest Green Hydrogen Plant**	In major yearly achievements for Chemical Energy Storage, NEOM Hydrogen activity stands out prominently. The NEOM Green Hydrogen Company (NGHC) has completed financial close with a total investment value of USD 8.4 billion for the world's largest carbon-free green hydrogen plant. Located in Saudi Arabia, the NGHC facility will have an initial production capacity of up to 600 tons of green hydrogen per day, saving 5 million tons of CO2 annually. This project includes a SAR 31.5 billion investment, with SAR 22.9 billion from financing providers. Additionally, the facility features a 600 MWh Battery Energy Storage System, highlighting significant advancements in both chemical and electrochemical energy storage.

Market trends point to significant growth across the LDES sector, fueled by the growing recognition of their fit in decarbonisation strategies and supported by increased Series A and B funding from both public and private entities, improved technological performance, and successful pilot projects. The rise in commercial contracts and advanced project planning further underscores the expanding demand for LDES solutions.

Technology cost data

Cost remains a factor in the widespread deployment of long duration energy storage, as achieving economic viability is essential for scaling these technologies and ensuring their integration into global energy systems. The LDES Council conducted a survey of current and future technology costs. This section presents that data, supplemented by other, previously unpublished, cost information.

Survey data indicates that LDES technology costs will fall significantly in the coming years as technologies develop and LDES deployment increases. The LDES Council projects reductions of as much as 60% in installation costs for electrochemical and mechanical solutions, and up to 50% for thermal technologies between 2025 and 2030, respectively.

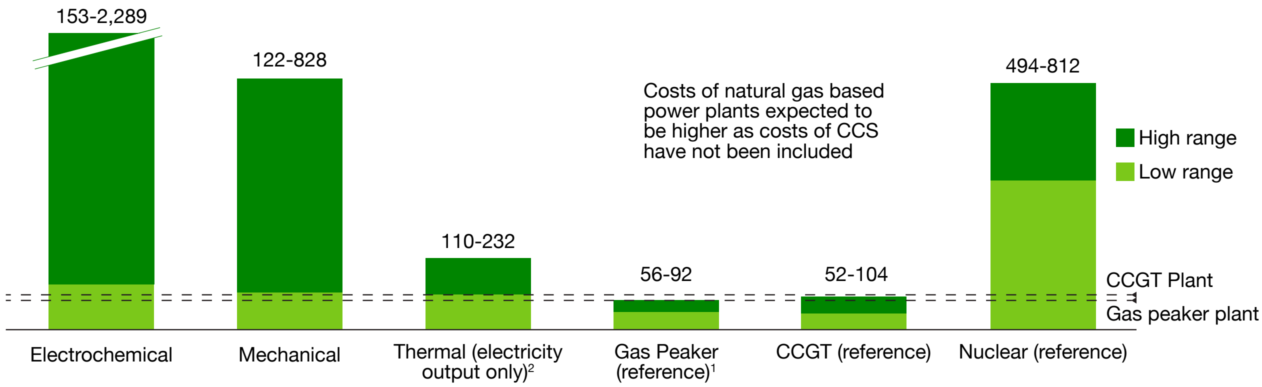
LDES operations and maintenance costs are expected to remain stable between 2025 and 2030. These costs are already low, typically accounting for less than 2% overall annualized project costs.

The lowest total installation costs for electrochemical, mechanical and thermal technologies are expected to be close to competitive with gas generation by 2030. These results are illustrated in Figure 30.

> Some thermal energy storage applications are already competitive with gas generation.

FIGURE 30

Total installed cost of 100 MW systems (eight-hour storage), 2030 (power-to-power), USD/kWh-year



Please note

- Gas generation is included as a common reference for costs
- This comparison does not consider operating cost differentials
- This view is informative for site specific investment but not for a system least cost perspective
- We avoid levelized cost of storage (LCOS) throughout this section because, although LCOS can be a useful metric, it makes assumptions about use cases for resource operation which are unlikely to hold true for long duration storage for a renewable grid

[1] Install cost includes all equipment, system install and integration, grid connection and project development, discount rate used of 5% over lifetime of the plant. Plant size is ~500MW [2] Thermal systems have ~2x efficiency when output is heat, relevant for decarbonizing industrial processes. Source for electrochemical and mechanical - LDES Council (2024), Benchmarking analysis; Source for thermal (as data was not available in the benchmarking analysis)- PNNL (2023), Cost and performance estimates; For Gas Peaker, CCGT and Nuclear - Lazard (2023), 2023 Levelized Cost Of Energy+.

Power-to-heat storage costs are best measured by the levelised cost of heat, to compare technologies that can deliver the same output, such as fossil fuel boilers, heat pumps and electric boilers.

Unlike power-to-power applications, power-to-heat services provide heat for industrial applications such as food, beverage or chemical manufacturing, and cooling for cold storage and district heating. With further commercial development, these services can also provide heat for high-temperature manufacturing processes (e.g., steelmaking and cement making). Access to wholesale markets can improve the business case for power-to-heat and help to reduce overall system costs.

Today, many heat services for industrial applications are provided by natural gas-fired boilers. For industrial applications to adopt power-to-heat LDES solutions, the all-in costs will need to be comparable to natural gas boiler solutions today. These include the costs of LDES technology, coupled with future electricity prices, compared to the costs of natural gas boiler technology coupled with natural gas prices. Cost competitiveness is a complex relationship between these different components. Carbon pricing programs and direct access to wholesale market prices can help to drive the adoption of power-to-heat LDES solutions.

LDES technologies also have a different cost profile compared to fossil fuel technologies. LDES, like other low-carbon technologies, as well as infrastructure including transmission grids and offshore wind, requires more upfront capital expenditure but has relatively low ongoing operational costs. One practical implication is that investors need to have long-term revenue visibility before committing. A wide range of mechanisms are available to address these challenges, including contracts for difference (used for offshore wind), feed-in tariffs (used for solar) and the regulated asset base model (for transmission and other basic infrastructure).[t] To mitigate this challenge for LDES, several policy frameworks are being proposed or introduced by policymakers around the globe. For more detail on several of these initiatives, please see the LDES Council's "Deploying LDES: Implementation Best Practices" analysis provided alongside this report.

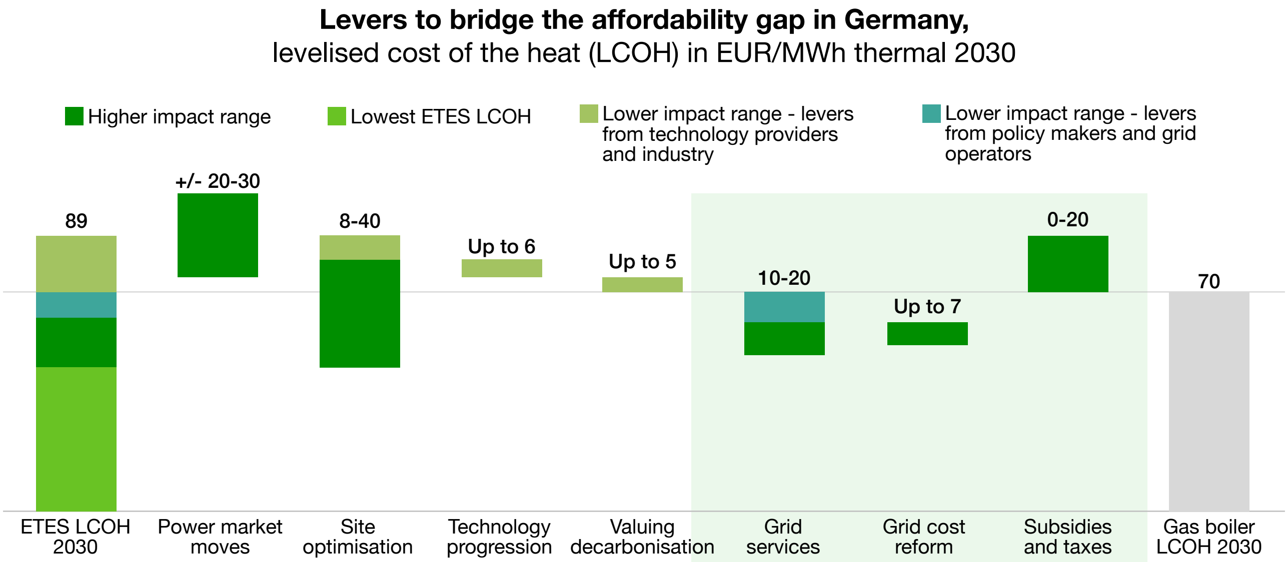
LDES consists of technologies that stores energy in various forms – including electrochemical, mechanical, thermal and chemical – with a discharge duration of eight hours or more. These resources hold energy or heat for extended periods of time, ranging from hours to days, weeks or even seasons. LDES is critical to the decarbonisation of the energy sector.

s [1] Install cost includes all equipment, system installation and integration, grid connection and project development, discount rate used of 5% over lifetime of the plant. Plant size is ~500 MW [2] Thermal systems have ~2x efficiency when output is heat, relevant for decarbonising industrial processes. Source for electrochemical and mechanical: Benchmarking Analysis, LDES Council, 2024. Source for thermal: Cost and Performance Estimates, Pacific Northwest National Laboratory, 2023, https://www.pnnl.gov/cost-and-performance-estimates. Source for Peaker, combined cycle and nuclear: Levelised Cost of Energy+, Lazard, 2023, https://www.lazard.com/research-insights/2023-levelized-cost-of-energyplus/.

t LDES Council. (2022). *The Journey to Net-Zero: An Action Plan to Unlock a Secure, Net-Zero Power System.*

FIGURE 31

Mechanisms to impact cost of power-to-heat solutions[u]



Parties involved	**Market participants**	**Industry, tech providers**	**Tech providers**	**Industry**	**Regulators, grid operators**	**Regulators, grid operators**	**Policymaker and regulator**
Examples	• Change in power purchasing agreement cost • Change in wholesale power prices • Change in discount for off- peak power	• Optimised charging • On-site power supply • Gas boiler as backup • Combined heat and power setup	• Further capital expenditure reductions	• Green premium • Other environmental opportunity cost	• Payment for services to balance electricity grid (discounted at 50% for market risk)	• Further decrease in grid fees and taxes in line with other EU countries	• Maximum financial support of up to 90 EUR/t CO_2 if no other levers are actioned

← **Actions by regulators and policymakers** →

Source: Systemiq and Breakthrough Energy. (2024). *Catalysing the global opportunity for Electrothermal Energy Storage.*

The three largest cost components of power-to-heat LDES are wholesale power prices, grid costs and capital expenses, and fixed operation and maintenance costs (see Figure 31). The key indicator of power-to-heat solution competitiveness is the ratio of wholesale electricity prices to wholesale gas prices, which are used by conventional boilers.

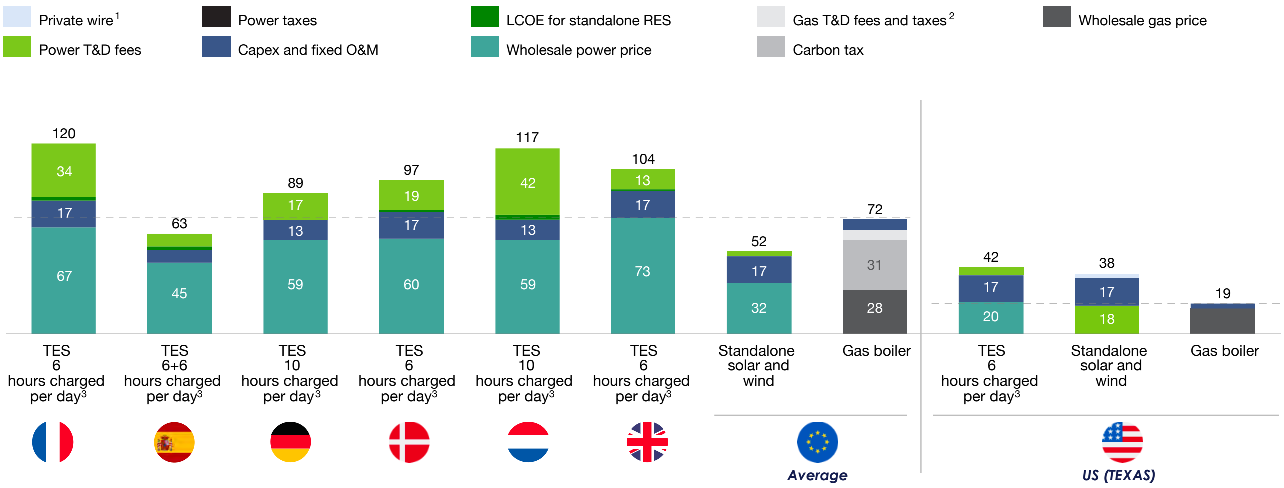
u Systemiq and Breakthrough Energy. (2024). *Catalysing the global opportunity for Electrothermal Energy Storage*. https://www.systemiq.earth/wp-content/uploads/2024/02/Global-ETES-Opportunity.pdf

FIGURE 32

Levelised cost of heat of power-to-heat storage in selected countries[v]

Generalised 2030 LCOH of Power to Heat in selected countries

2030 projected levelised cost of heat of power to heat in selected countries
EUR/MWh thermal



2030 (Generic setup before optimisation — please see figure 10 for LCOH in optimised set up)

[1] Private wire estimated at 15% of capital expenditures

[2] Private wire estimated at 15% of CAPEX

[3] Commercially available solid state thermal energy storage, 6- to 12-hour charge and 24-hour discharge; wholesale power price is for the least expensive 6 to 12 hours

Note: Does not include current subsidies schemes, changes in T&D fees, taxes, and balancing costs; power prices are based on CCC projections for a decarbonised grid

Sources: Catalysing the global opportunity for electrothermal energy storage, Systemiq and Breakthrough Energy, 2024

Response times also differ by technology. Electrochemical and chemical solutions generally have the quickest response times. This is important for resources that participate in electricity grids and provide services requiring fast response times, such as frequency response.

Some LDES technologies are subject to locational restrictions in terms of where they can be deployed. For example, pumped hydropower, compressed air energy storage and hydrogen storage need specific geological conditions to be cost effective, benefiting from large water reservoirs, underground caverns and cavern geologies, respectively. In addition, the use of green hydrogen and ammonia as fuels may depend on the availability of additional infrastructure, such as pipelines and storage facilities.

Market mechanisms in various countries are increasingly supporting the deployment of long duration energy storage.

[v] Systemiq and Breakthrough Energy. (2024). *Catalysing the global opportunity for Electrothermal Energy Storage*. https://www.systemiq.earth/wp-content/uploads/2024/02/Global-ETES-Opportunity.pdf

Market Mechanism to Support LDES Deployment: The UK's Cap and Floor

A critical LDES deployment enabler is the provision of market access and long-term revenue visibility. LDES, like other low-carbon technologies and infrastructure, can require large upfront capital expenditure but has far lower operational costs. One practical implication is that investors need to have long-term revenue visibility before committing funds to support these projects.

There are a number of policy interventions available to provide such visibility, including Contracts for Difference, Feed in Tariffs and the Regulated Asset Base model. One such intervention is the Cap and Floor mechanism that the UK government is introducing for Great Britain's electricity market.

A Cap and Floor mechanism provides a multi-year contract with a defined minimum (the "floor") and maximum (the "cap") level of revenues over a specified period.

Should revenue received by the asset fall below the floor, revenues will be topped up to reach the floor. Similar dynamics apply for the cap, except in reverse, with a "hard" cap representing the maximum revenue that can be received, with excesses returned to the counterparty (and ultimately to consumers).

The intent of these caps is to limit societal exposure over the course of the policy support while also providing investors with confidence that they will receive a minimum return.

Like a Contract for Difference, a Cap and Floor is typically administered and funded by a government vehicle, supported from taxes and/or electricity bills. If implemented with a "soft" cap, a portion of the capture value above the cap can be shared with the asset owner (e.g., in pre-set diminishing portions as revenues increase above the cap) to efficiently transfer price signals and reward assets for participation at times of greatest system need. The floor price can be set such that it enables competitive debt financing for the asset, and average payouts between cap and floor price would nominally offer returns sufficiently attractive to drive project investment. Such a mechanism is already used for interconnector transmission lines in the UK.

In the UK, the Department for Energy Security and Net Zero has confirmed[w] it will introduce a Cap and Floor scheme for long duration electricity storage in the electricity market of Great Britain.

The initial proposal provides support for electricity storage technologies with durations of 6 hours or longer, however a final decision on duration is expected in early 2025. The proposed scheme is intended for electricity storage only. The proposal excludes technologies that are already capable of commercial deployment, such as Lithium-ion, and technologies that already have significant support programmes in place, such as green hydrogen. The UK is not currently planning to set a target for the scheme but will provide an indicative range for each allocation round.

The consultation proposed a minimum project size of 100 MW for well-established technologies and a 50 MW minimum for less well-established technologies. A final decision on the minimum project size is expected in early 2025. The mechanism will be administered by the British energy regulator Ofgem. Initial contracts are likely to be administratively allocated – assessed against a range of criteria – rather than through a simple price competition.

The LDES Council responded positively to the consultation, welcoming the UK Government's proactive steps to address the barriers faced by long duration energy storage technologies. The LDES Council made several recommendations, including:

- To increase the minimum duration to 8 hours;
- To set an ambitious capacity target for the scheme to send a clear signal to the market;
- To open the scheme to thermal technologies, or alternatively to ensure those technologies have a clear route to market;
- To allow for smaller project sizes for less established technologies in particular; and
- To closely monitor the market to ensure longer duration services are properly valued, avoiding reliance of operators on cap payments.
- The UK government will publish a final detailed response in winter 2024/25 and intends for the first contracts to be signed in 2025.

w United Kingdom Long duration electricity storage: proposals to enable investment. https://www.gov.uk/government/consultations/long duration-electricity-storage-proposals-to-enable-investment

Australia

In Australia, under its Electricity Infrastructure Roadmap, the New South Wales (NSW) government is targeting 2 GW of LDES by 2030 to address decarbonisation and reliability needs as the state decommissions its coal power plants. Projects can bid in competitive tenders for long-term energy service agreements, which provide an option to access competitively set minimum prices for eligible projects, affording long-term certainty to incentivise investment. The minimum duration of such projects is set at 8 hours. The NSW government recently consulted on whether this criterion should be relaxed to allow shorter-duration projects access to the same contracts.

The LDES Council recommended maintaining a minimum eight-hour duration as more coal assets will be withdrawn from the NSW grid during the 2030s and the need for LDES assets will increase significantly, and the NSW government has now confirmed it will maintain the 8-hour minimum. The Australian government also has a national support programme – the Capacity Investment Scheme – that is broadly similar in approach, although it has a lower minimum duration requirement.

Chile

The Chilean government in 2022 created a law (Law No 21.505 of 2022) encouraging the participation of renewable energy in the electricity matrix by promoting storage technologies. This Law is the result of a cross-cutting state policy, demonstrating Chile's commitment to the promotion of renewable energy sources and the decarbonisation of the electricity system and to allow storage systems to participate in energy and power transfers. In June 2024, Chile announced an "Amendment to the Capacity Regulation" under its Directive DS 70, aimed at promoting the development of energy storage systems[x] in Chile for a period of 10 years. The proposal initiates process for modification with 100% recognition for storage hours greater than 5 hours. The Chilean Ministry of Energy expects to initiative updates with directives that focus on the following: (a) Incorporation of storage into the regulation; (b) Review of connection costs; (c) Network services and tariff signals; (d) Review of connection procedures, and disputes, among others, and (e) congestion management.

x Chilean DS No. 70 published in the Official Gazette https://www.bcn.cl/leychile/navegar?i=1204012

Part 3: Project Tracker and Deployment Map

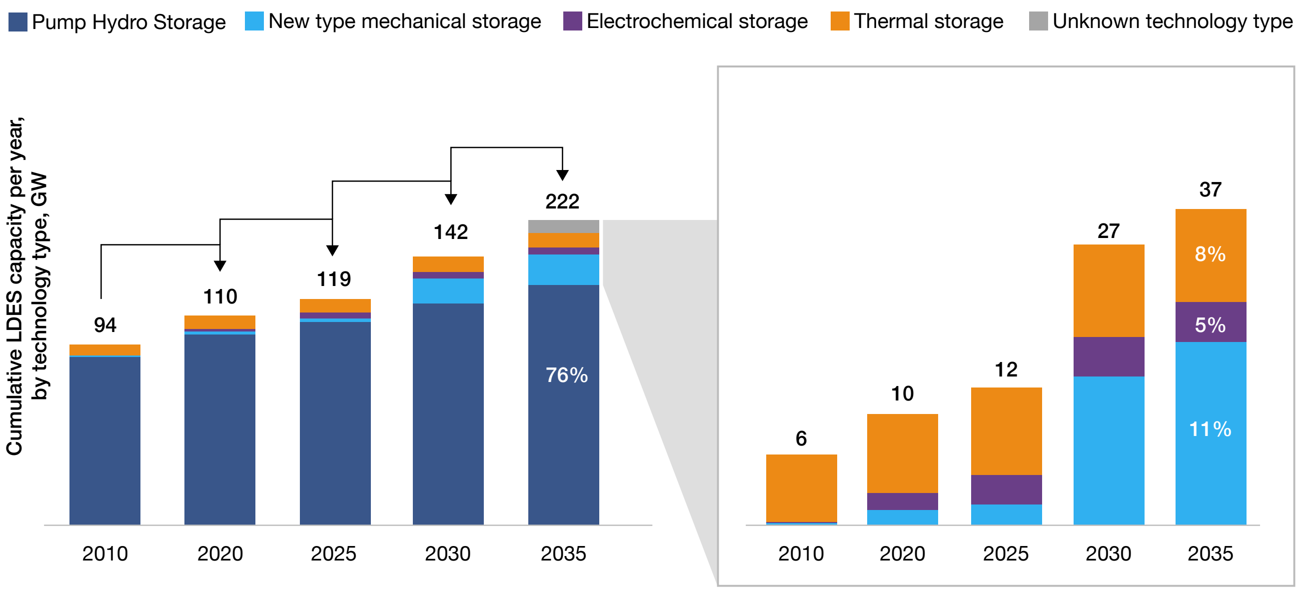
The LDES Council has collected data from members and other sources to compile a robust dataset illustrating the extent of planned and installed LDES capacity around the globe.[y]

This dataset consists of approximately 520 projects with duration 8 hours and up, deployed and in the pipeline. The LDES Council anticipates rapid deployment of LDES solutions by 2035. The data collected reveals that LDES capacity has grown steadily since 2010 and is expected to increase by about 40% over the next decade, from 115 GW in 2023 to about 222 GW in 2035 (see Figure 33).

However, this is still significantly below the potential 8 TW of storage projected for the upper bound of LDES capacity needed for global decarbonisation by 2040, as well as the target of 1 TW by 2030. Barriers to development include inadequate funding, a lack of clear targets, regulatory challenges and the slow adoption of new technologies. About 90% of deployed LDES capacity today is pumped hydropower; by 2035, this figure is projected to fall to about 76% (see Figure 33).

FIGURE 33

Cumulative LDES capacity per year up to 2035 (GW)



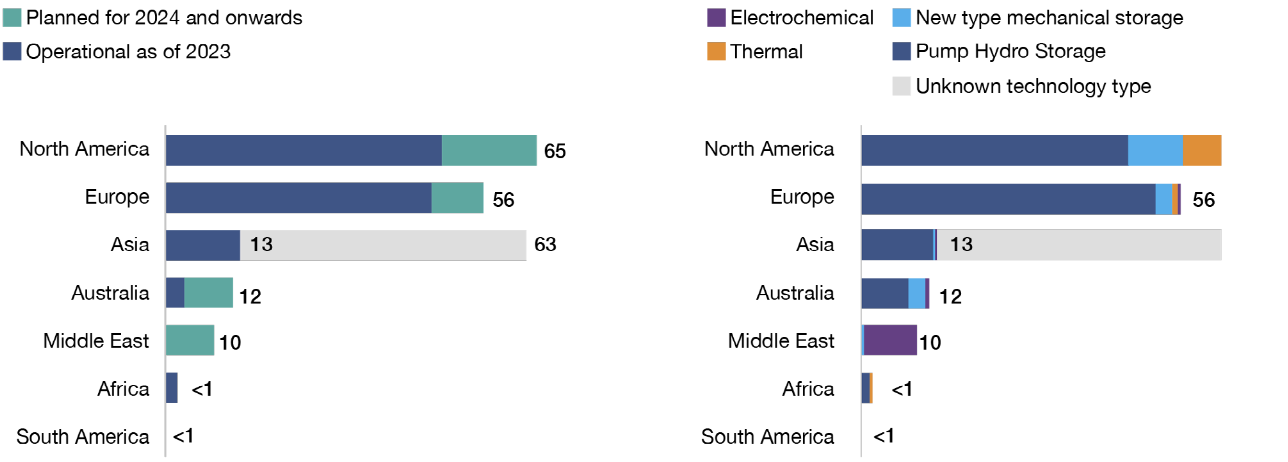
y This data set may not be exhaustive. Chemical storage projects are not currently included in the database. LDES project estimates from China are difficult to obtain and these datasets include limited data on projects in China.

FIGURE 34

Current and projected LDES capacity by region and technology (GW)

Cumulative operational and planned LDES capacity per region from LDES Council database[1], [GW]

Cumulative operational and planned LDES capacity per region and technology from LDES Council database[1], [GW]



Total all regions 222 GW

This overview is not exhaustive. **Data from China is an estimated due to data being less readily available.** Totals do not add up due to rounding. Based on BNEF projections it is assumed China covers ~40% of total installed. LDES capacity in 2035. BNEF (2023), 2H 2023 Energy Storage Market Outlook.

Both North America and Europe are characterised by their large existing pumped hydropower storage capacity, with many projects of 100 MW and over. Other new types of LDES storage technology projects are concentrated in North America, the Middle East, Europe and Australia, with North America and Europe the leaders in this regard – not least thanks to new supportive policies and funding opportunities. Expected deployment in North America is largely driven by procurement targets in California and New York; while in Europe, the drivers include renewable energy targets (under the Renewables Energy Directive, the aim is to increase the share of renewable energy in overall EU energy consumption to at least 42.5% by 2030, with a target of 45%), and a commitment to reduce net greenhouse gas emissions by 90% by 2040.[z] In doing so, LDES procurement must grow to capture the value of an integrated VRE and LDES system, so that the round-the-clock needs of customers can be met.

LDES solutions are key to satisfying energy demand in varying geographies and use cases. In the Middle East, new LDES capacity is expected to be electrochemical; whereas the projections for Australia and North America anticipate about 80% and 50% mechanical technology, respectively. China is developing large LDES projects, including compressed air and flow battery technologies; and in 2022 and 2023, it broke size records for new LDES projects.[aa]

The following maps provide a current snapshot of LDES deployments.

z EESC. 2024. The Eu's 2040 climate target sets the course to net zero by 2050. https://www.eesc.europa.eu/en/news-media/news/eus-2040-climate-target-sets-course-net-zero-2050

aa BNEF. 2024. Lithium-Ion Batteries are set to Face Competition from Novel Tech for Long duration Storage: Bloomberg NEF Research. https://about.bnef.com/blog/lithium-ion-batteries-are-set-to-face-competition-from-novel-tech-for-long duration-storage-bloombergnef-research/

FIGURE 35

Geographic deployment of LDES projects (excluding pumped hydro storage)

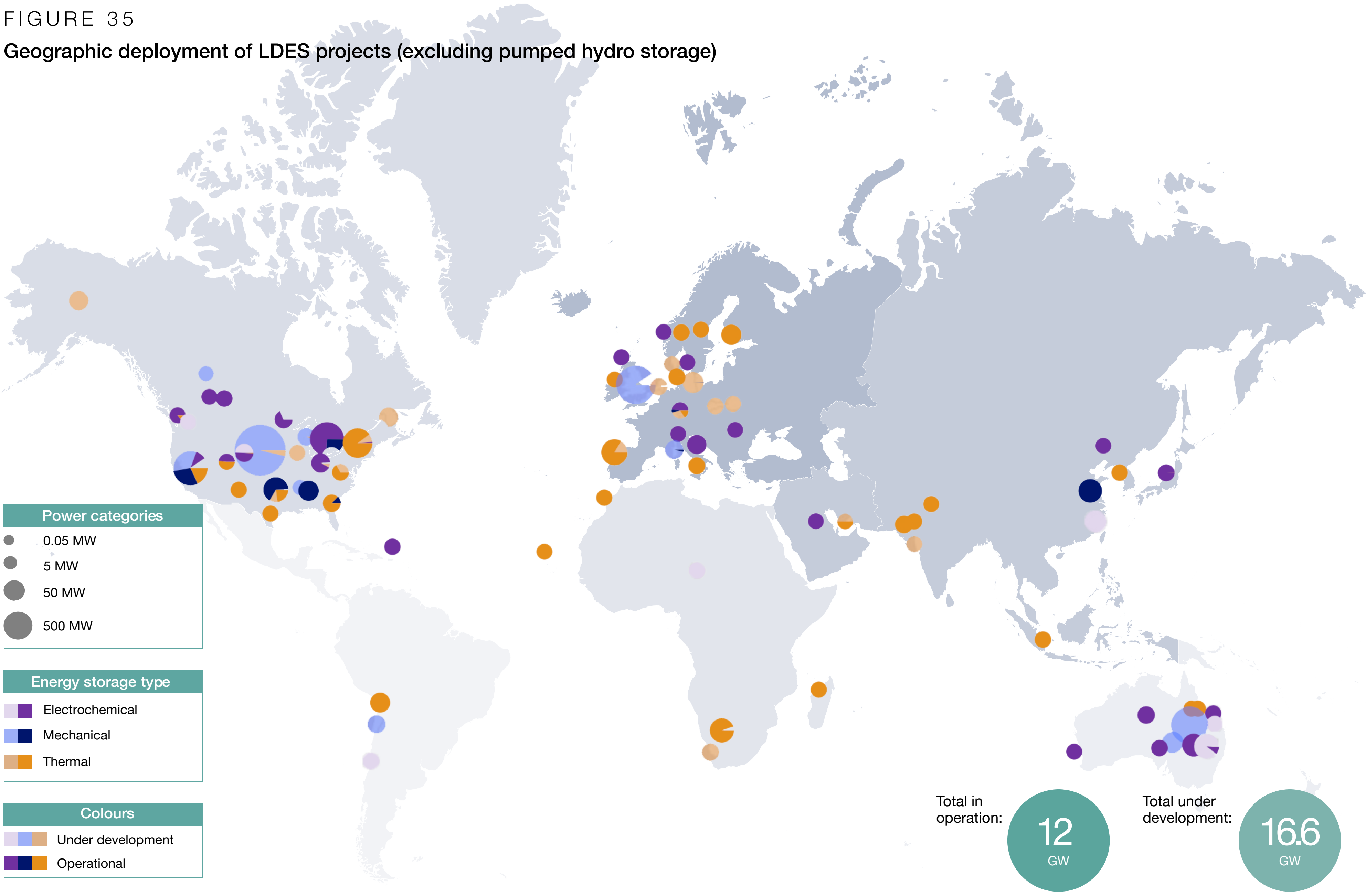


FIGURE 36

Geographic deployment of pumped hydro storage LDES projects

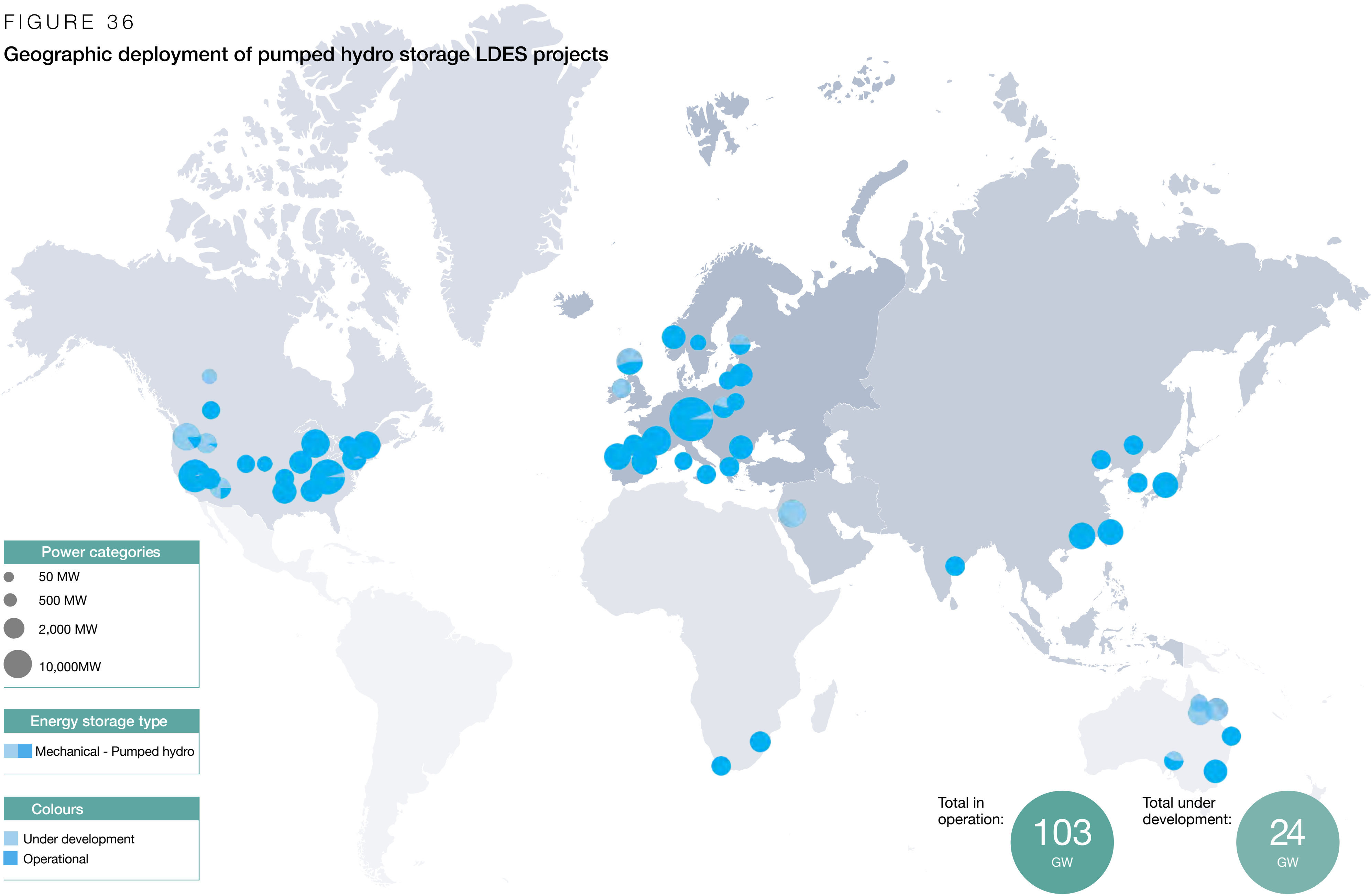
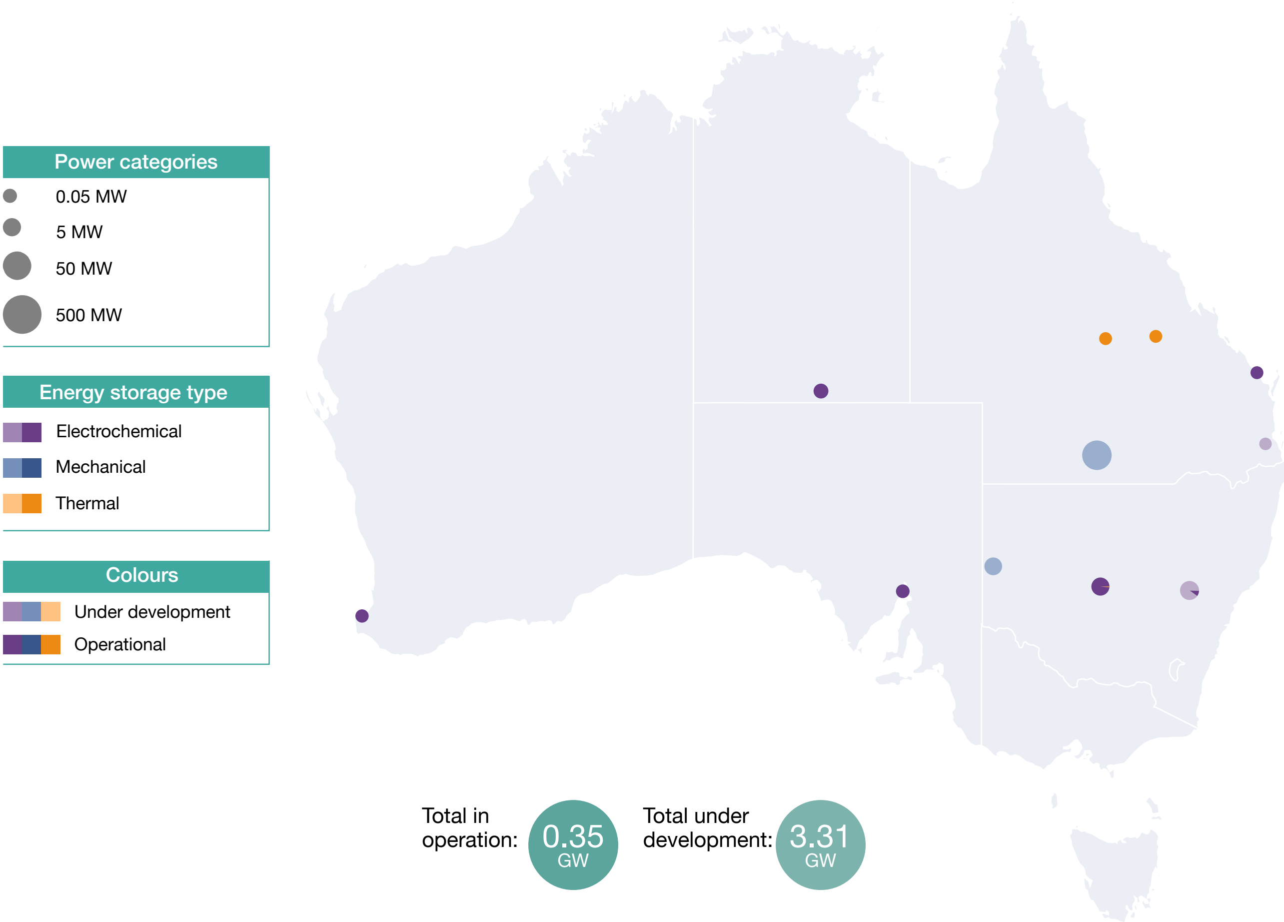


FIGURE 37

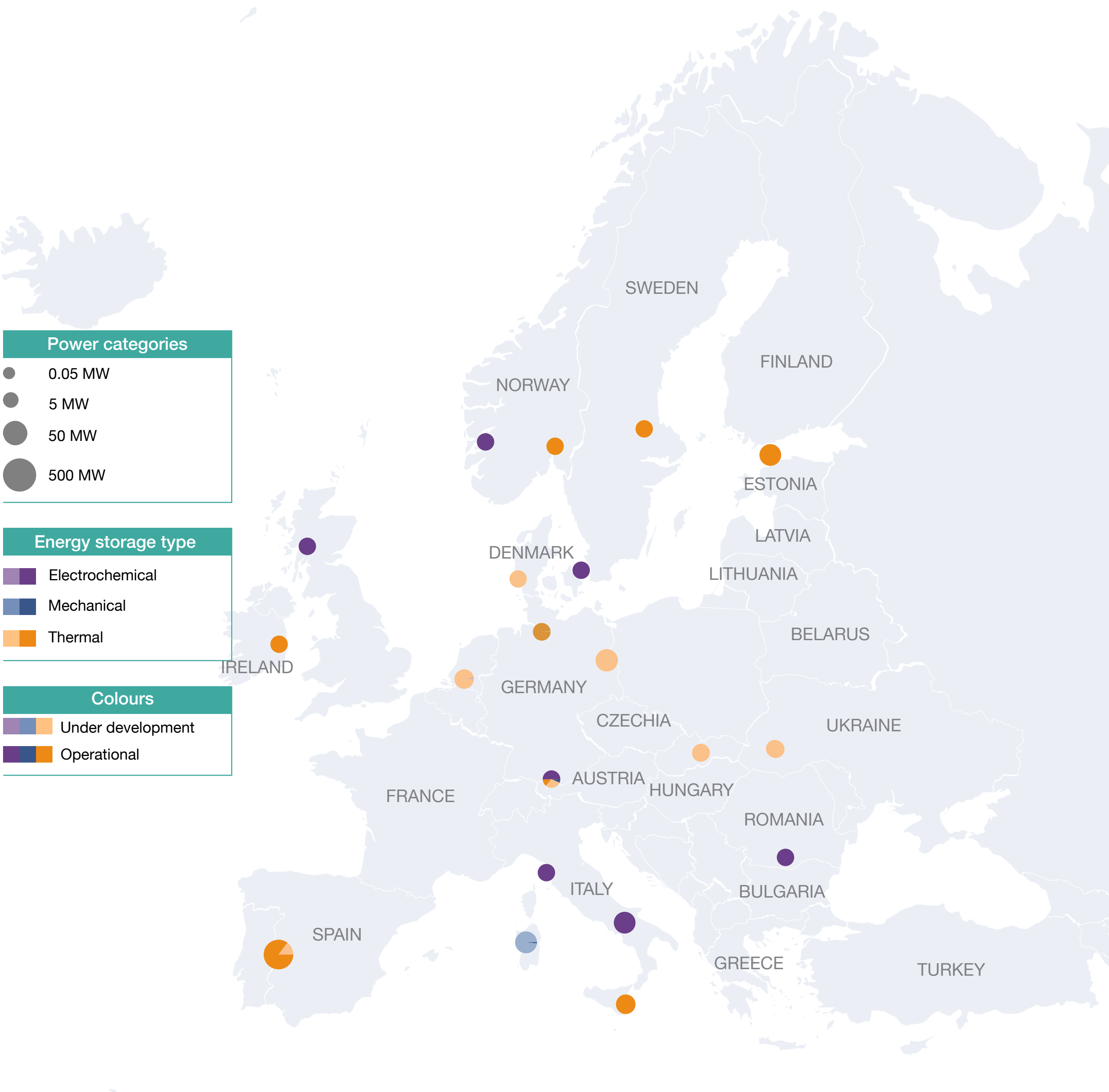
Geographic deployment of LDES projects (excluding pumped hydro storage) in Australia



> "We need 'long duration' energy storage to feed the grid. It needs to be affordable. And effective. And reliable. And we need it soon."
>
> Arshad Mansoor, Chief Executive Officer, Electric Power Research Institute

FIGURE 38

Geographic deployment of LDES projects (excluding pumped hydroelectric) in Europe

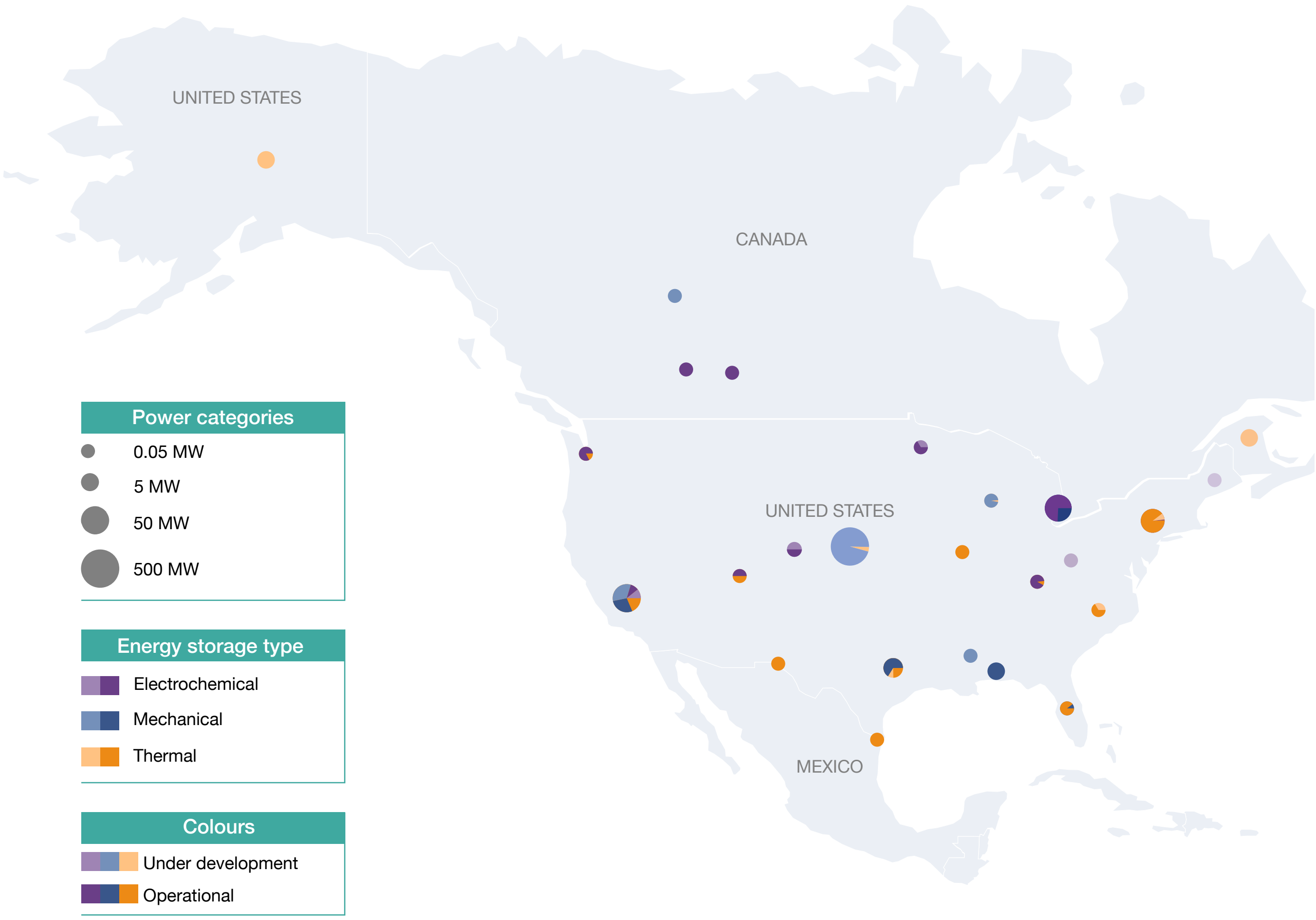


Total in operation: 0.78 GW

Total under development: 3.72 GW

FIGURE 39

Geographic deployment of LDES projects (excluding pumped hydropower) in North America



Total in operation: 9 GW

Total under development: 9 GW

> "The key is to fully utilise the transmission we have already paid for with solar and wind. That means long duration energy storage near generation and then more storage near distribution."
>
> Jigar Shah, Director, Loan Programs Office, US Department of Energy

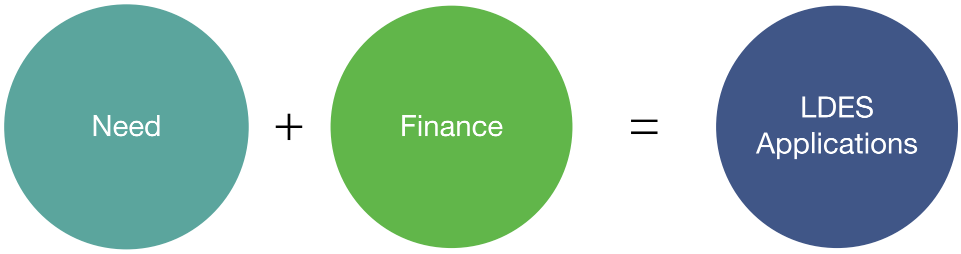
Part 4:

Seven Enablers to Deploy and Scale LDES

Creating an enabling environment is crucial for the large-scale deployment and scaling of LDES. As highlighted in the previous section, some LDES projects have already been deployed or planned, but many more must be deployed to decarbonise energy systems and meet global sustainability targets.

Many of the bankable business cases today are dependent on very specific locations and combinations of revenue streams outside of the electricity sector, including thermal energy storage for industrial heat processes, as well as support through policy incentives and support mechanisms.

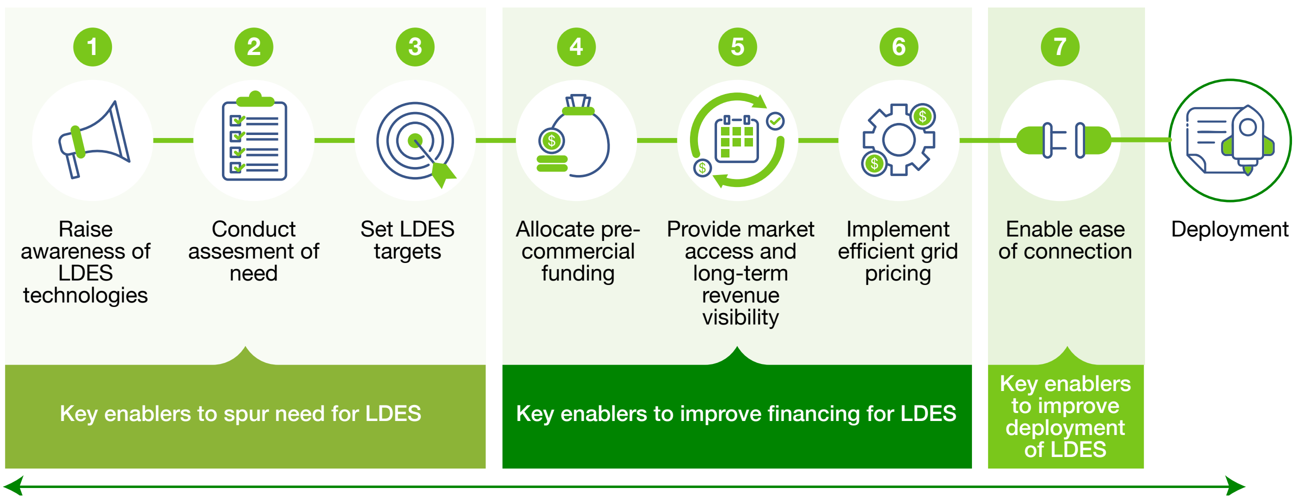
An enabling environment includes the clear applicability of LDES (“**need**”); the development of investable business cases (“**finance**”); and the efficient deployment of LDES projects (“**deployment**”).



This report identifies seven enablers for a supportive environment for LDES. categorised under these three groupings (see Figure 40). While some are timebound – for example, “raising awareness” – others require concerted ongoing action to fully enable LDES deployment. Each enabler is applicable at a high level to power-to-power, power-to-heat and power-to-x LDES applications. Further detail on the enablers can be found in “Deploying LDES: Implementation Best Practices” analysis provided alongside this report.

FIGURE 40

Seven enablers to scale LDES



Although many countries are already acting on some of the enablers, there is no country in which all seven are fully in place. Figure 41 provides a snapshot of the seven enablers across a range of different countries and regions.

FIGURE 41

Examples of the seven enablers to scale LDES across regions

India's largest power utility, NTPC,[bb] is exploring novel LDES solutions to help promote the energy transition and low-carbon electricity markets in India. Indian utilities now also include LDES in tender criteria.

Spain has approved resource adequacy targets in line with the EU Agency for Cooperation of Energy Regulators (ACER) to ensure that there is enough generation to meet demand and reliability. This alignment with ACER's recommendations, with European Commission approval, will help Spain to implement robust resource adequacy mechanisms.

California (United States), New York (United States), Victoria (Australia) and NSW (Australia) all have LDES targets. California has a goal of 100% renewable energy on the grid by 2045,[cc] with a proposed procurement of over 10 GW of new energy resources, including 2 GW of LDES.[dd]

In the United Kingdom, over £69 million of capital funding has been made available under the LDES Demonstration Programme, including funding tranches for power-to-power, power-to-thermal and power-to-x technologies.[ee] The programme aims to accelerate the commercialisation of first-of-a-kind LDES technologies through demonstrations.

The Chinese National Energy Administration has released a list of 56 new-type energy storage pilot demonstration projects, including 11 compressed air energy storage projects. Demonstrations at this scale enable fast learning and quicker deployment of the best technologies, leading to lower costs overall.

Google, Microsoft and Nucor Corporation are seeking to accelerate innovative and early commercial projects to include LDES. They will pilot demand aggregation and procurement models, focusing on offtake agreements, influencing policy and developing new tariff structures.

Chile's energy regulator introduced bidding rules that require developers to include storage technologies to their renewable energy projects, entitling them to secure a 20-year power purchase agreement (PPA).

The Moroccan Agency for Solar Energy will enter into a 30-year PPA[ff] for the Noor Midelt III project – a 150 MW solar power plant with up to eight hours' storage duration.

German law exempts energy storage assets from grid fees if they go online before August 2029, providing a near-term incentive for LDES and other storage technologies.

Spain has implemented time-variable grid fees, allowing LDES facilities to charge at times with low fees. These arrangements are more reflective of the impact of LDES on the grid and thus support the deployment of LDES as flexible assets.

The Netherlands and Denmark are in the process of approving non-firm (or interruptible) grid connections in locations where these would benefit the grid. This allows LDES to utilise grid connection when there is available capacity.

The Danish Energy Authority has also implemented a 'single window agency' to address grid congestion, which should streamline the approval process for grid connection, facilitating faster connections and supporting the growing demand for renewables.

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bb NTPC. (2022). Long duration energy storage. NTPC. https://ntpc.co.in/about-us/corporate-functions/et-pr/project-initiative/long duration-energy-storage-ldes

cc Energy Storage News. (n.d.). California: 'Energy storage revolution is here,' says governor as US leader state surpasses 10GW. Energy Storage News. https://www.energy-storage.news/morocco-launches-400mwh-solar-plus-storage-tender/

dd Energy Storage News. California eyes central procurement of 2GW of LDES to help scale novel technologies. Energy Storage News. https://www.energy-storage.news/morocco-launches-400mwh-solar-plus-storage-tender/

ee UK Government. Longer duration energy storage demonstration (LODES) competition. UK Government. https://www.gov.uk/government/collections/longer-duration-energy-storage-demonstration-lodes-competition

ff Energy Storage News. Morocco launches 400MWh solar-plus-storage tender. Energy Storage News. https://www.energy-storage.news/morocco-launches-400mwh-solar-plus-storage-tender/

Significant and sustained action from a range of stakeholders is needed to unlock these enablers and ensure that LDES is developed at scale to provide reliability, security and flexibility alongside energy system decarbonisation. Accelerated deployment will help technologies to reach scale faster through quicker realisation of cost reductions and improved efficiencies.

While all the enablers are needed, the relative contribution over time from different stakeholders will vary. Raising awareness of the need for LDES is a critical first step, but one that is relatively straightforward and timebound. Including LDES in planning assumptions and modelling will be an ongoing effort; but again, it should not require significant effort on the part of relevant stakeholders. Conversely, acting on other enablers —such as reforming grid access fees, facilitating full market participation for LDES and providing long-term revenue visibility— will involve more complex, coordinated multi-stakeholder initiatives.

The commitments made by governments to accelerate the energy transition and rapidly develop VRE supply must be matched by efforts to deploy and scale LDES technologies. Efforts must be made to continue building on procurement targets in the Australian states of New South Wales (NSW) and Victoria, the US states of New York and California, the Canadian province of Ontario, and in Chile and Italy. Alongside advancing policy enabling strategies, setting a specific target for energy storage deployment at COP29 will provide the necessary clarity, direction and accountability for policymakers, industry, investors and stakeholders to accelerate the deployment and scaling of LDES.

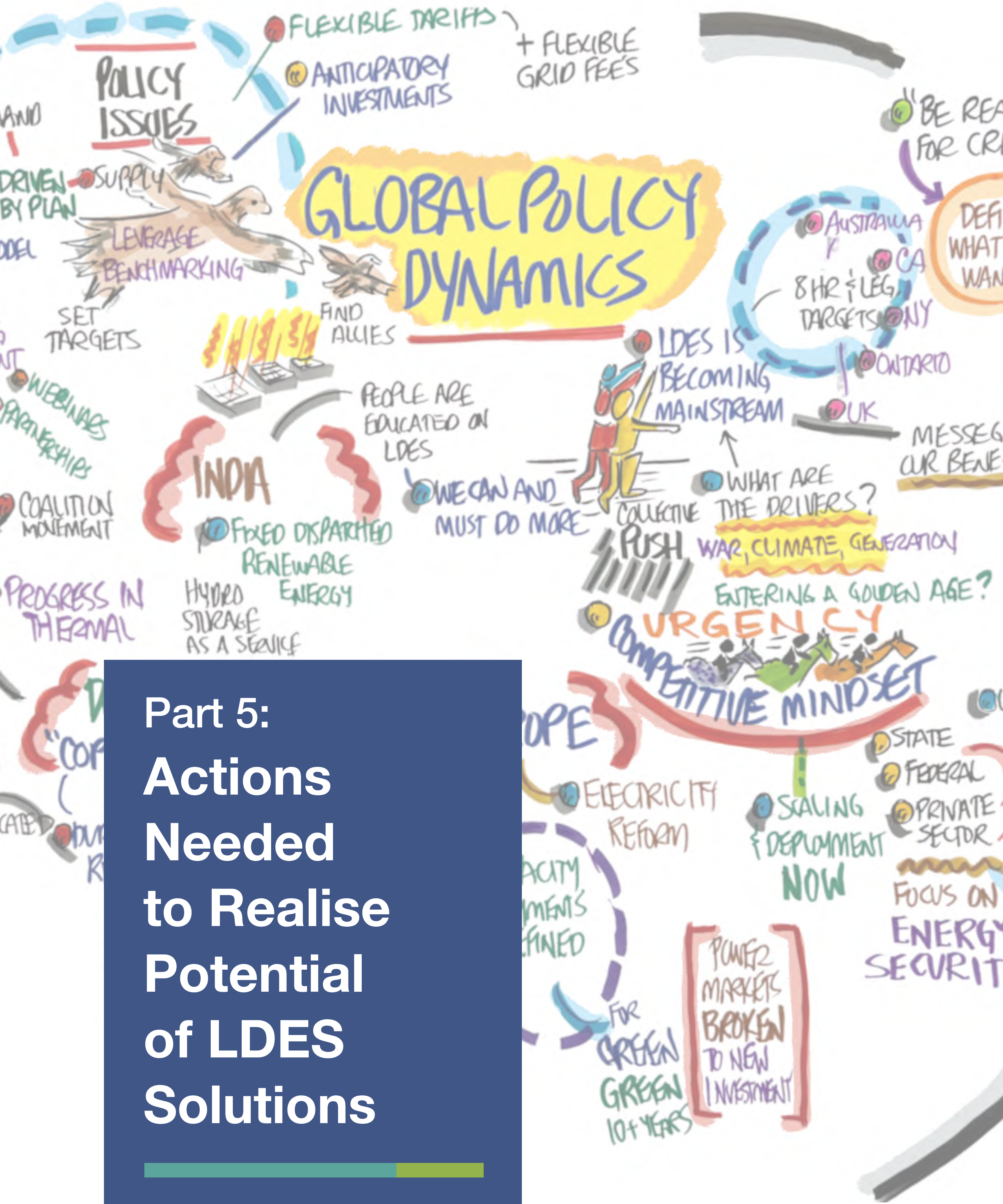
However, wider market and policy structures are still limiting LDES deployment, resulting in missed opportunities. Beyond direct enabling actions, there are frameworks that play an important role in creating a positive environment for LDES and decarbonisation more generally.

Examples of these wider signals include:

- **Ambitious greenhouse gas reduction targets:** Countries with ambitious greenhouse gas reduction targets will need LDES technology earlier, and at a larger scale, than those with more modest goals.
- **Ambitious renewables targets:** Countries with ambitious renewables targets will need LDES technology to ensure that electricity supply and demand are in balance and that emissions are minimised. The EU target of generating 42.5% of energy from renewable sources by 2030 is one example of how major economies can drive the accelerated deployment of renewables.
- **Removal of fossil fuel subsidies:** Reducing and removing fossil fuel subsidies will make these fuels more expensive compared to low-carbon alternatives like LDES.
- **Carbon pricing**: Carbon pricing reflects the real cost of carbon emissions, including externalities. It increases the price of high-emissions technologies and benefits low-carbon alternatives like LDES.

With only around 222 GW in the development pipeline, the global community is far from being on track to meet the 8 TW needed to achieve net zero. Therefore, LDES must scale up to 50 times faster than is forecast by the current pipeline.

The time for action is now, and the engagement and support of policymakers and change agents around the world are needed to guide LDES deployment. Responsibility for advocating for the necessary policy enablers and market development incentives lies with all engaged citizens, making their voices heard and working together to help secure the clean energy future that we owe to the generations that follow us.



Part 5:

Actions Needed to Realise Potential of LDES Solutions

Action is needed by policymakers, utilities, regulators, corporates, technology providers, investors and key stakeholders to realise the abundant potential of LDES solutions.

Key action checklist to deploy and scale LDES solutions

Policy Makers

Need | Finance | Deployment

Need	• Include long duration energy storage technologies in decarbonisation pathway modelling and reports across all relevant applications (electricity, heat, industry and transport) • Ensure that support mechanisms cover all long duration energy storage applications and technologies • Model the long duration energy storage capacity needed within their energy systems including power, heat and power-to-X application. • Set long duration energy storage targets based on the electricity system's need for flexibility and ensure this is tied into revenue support mechanisms and system transition pathways • Set ambitious targets for decarbonisation of industry and transport and ensure this is tied into heat and chemical storage technologies • Support parallel research and development efforts in industry and academia to further reduce the cost of LDES
Finance	• Introduce mechanisms that provide long term revenue stability e.g., Cap and Floor schemes, long term capacity payments, long term fixed revenue schemes. • Evaluate where LDES can be treated as national critical infrastructure • Support early-stage projects through de-risking mechanisms and grants e.g., public backed financing
Deployment	• Allow LDES developers to co-locate storage with renewable generation for self consumption benefits

Key action checklist to deploy and scale LDES solutions

Regulators

Need | Finance | Deployment

Need

- Ensure that support mechanisms cover all long duration energy storage applications and technologies
- Model the long duration energy storage capacity needed within an electricity system
- Require robust modeling requirements that take full account of variable renewable generation throughout the year at a granular level and feed these into grid planning and procurement policies
- Where appropriate, allow grid operators to own LDES assets
- Introduce discounted fees for non-firm grid connections

Finance

- Reform electricity market structures to signal the value of flexibility and enable revenue stacking
- Allow thermal storage to access wholesale prices to take advantage of technology capacity to be scheduled to utilise only lowest value renewable energy generation
- Ensure adherence to strict cost causation principles to ensure thermal storage doesn't pay for capacity, reliability (or in some cases transmission/distribution) system costs that are not impacted by thermal storage
- Introduce and / or permit long term offtake agreements for storage
- Introduce discounted fees for non-firm grid connections

Deployment

- Introduce non-firm grid connections to allow flexibility assets to skip the queue
- Allow LDES developers to co-locate storage with renewable generation for self consumption benefits

Grid Operators

Need | Finance | Deployment

Need

- Ensure LDES technologies are assessed or procured in grid applications through usage of the latest modelling techniques and data

Finance

- Evaluate system benefits from thermal storage for increasing renewable energy penetration at lower cost
- Use the latest LDES technology cost in assessments

NGO and Academics

Need | Finance | Deployment

Need

- Continue educating on the latest benefits of LDES and include LDES technologies in all pathway modelling

Key action checklist to deploy and scale LDES solutions

Corporates and Other Market Participants

Need | Finance | Deployment

Need
- Regularly assess business cases for technologies to decarbonise industrial process heat and energy
- Consider how power purchase agreements can drive uptake of LDES technologies

Utilities and Investors

Need | Finance | Deployment

Need
- Regularly assess potential investments in LDES technologies using the latest insights on costs, revenues, market dynamics and regulation

Finance

Need | Finance | Deployment

Need
- Remain informed on different types of LDES business case
- International financial bodies need to increase support for LDES as a reliable system for power

Finance
- To create instruments to reduce the cost of financing in development economies
- Private capital to keep business cases up-to-date

LDES Technology Providers

Need | Finance | Deployment

Need
- Share latest information on LDES use cases and technology specifications
- Improve performance of LDES technologies to match market needs (e.g., improving the round-trip efficiency and working lifetime of LDES technologies)

Finance
- Show and quantify benefits of specific LDES technologies
- Strive to beat the up to ~60% reduction in capex costs between 2025 and 2030
- Modularise and standardise technology designs to maximise cost reduction potential

Deployment
- Standardise the construction of LDES technologies where possible, making product development more attractive, reducing quality issues through in-field learning, and enabling factories to benefit from economies of scale

Key action checklist to deploy and scale LDES solutions

LDES Council

Need Finance Deployment

Need

- Increase knowledge sharing between different sets of stakeholders
- Recalibrate LDES targets for external communication purposes
- Support target setting and provide the fact base needed to create capacity target setting (e.g., for implementation of the EU Electricity Market Design)
- Continue helping educate on the latest economics and benefits for LDES (in collaboration with organisations such as the IEA and IRENA)

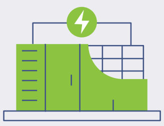
Finance

- Support technology providers in showing the benefits of their specific technology
- Continue conversations with specific governments on the support needed to scale LDES implementation
- Support standardisation process by bringing together the right players

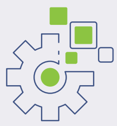
About the Long Duration Energy Storage Council

The LDES Council is a global organisation advancing decarbonisation by facilitating the accelerated deployment of LDES solutions. The LDES Council provides fact-based guidance on the deployment of long duration energy storage. The LDES Council's members span a spectrum of innovation, including mechanical, thermal, electrochemical and chemical solutions. The world will need to deploy up to 8 TW of LDES by 2040 with a market potential of $4 trillion.

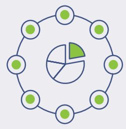
To fully realise the transformative potential of LDES solutions and achieve a decarbonised energy system, deployments must ramp up significantly. The LDES Council remains steadfast in its commitment to advancing these essential technologies. By working with members, partners and key decision leaders in governments, regulatory agencies, financial institutions and civil society, the full spectrum of benefits that LDES offers can be unlocked, accelerating the clean energy transition and helping to ensure a resilient, sustainable and decarbonised energy future for all.



Development and testing of LDES for faster innovation

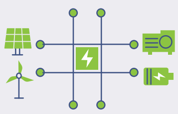


Level the playing field for diverse LDES technologies



Market creation for stronger incentives for investments and open markets for LDES implementation

Deployment of LDES to see larger economies of scale



Infrastructure deployment for more connections and interoperability

International relationship building

A global partnership network

The LDES Council greatly values its work with its global partnership network to educate stakeholders, enable supporting policy structures and market development, and advance LDES deployment worldwide.

The Global Renewables Alliance (GRA) was established by the Global Wind Energy Council, Global Solar Council, International Hydropower Association, Green Hydrogen Organisation, Long-Duration Energy Storage Council and the International Geothermal Association to unify the global bodies representing the clean technologies required for a net zero world by 2050.

The LDES Council also partners with a wide range of organisations playing a vital enabling role in the development of LDES globally.

LDES Council strategic partners

- Argonne National Laboratory
- ARENA – Australian Government, Australian Renewable Energy Agency
- BloombergNEF
- The Business Council for Sustainable Energy
- C2ES – Center for Climate and Energy Solutions
- CEBI – Clean Energy Buyers Institute
- ClearPath
- The Climate Registry
- CATF – Clean Air Task Force
- Clean Energy Business Network
- Clean Energy Council
- Clean Energy Business Council – Middle East & North Africa
- CSIRO – Australia's National Science Agency
- Department of Defense – United States of America
- Dii
- EASE – European Association for Storage of Energy
- Energy Storage Canada
- EEI – Edison Electric Institute
- EPRI
- ESMAP – Energy Sector Management Assistance Program
- The Electricity Storage Network
- eurelectric
- European Investment Bank
- FCA – Future Cleantech Architects
- giz – Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
- Global Renewables Alliance
- Greening the Islands Foundation
- Gujarat Power Corporation Ltd.
- GUVNL
- GWNET – Global Women's Network for the Energy Transition
- iea – International Energy Agency
- IECDS
- IESA – India Energy Storage Alliance
- IREC
- IRENA Coalition for Action
- isa – International Solar Alliance
- Island Innovation
- Ministry of New and Renewable Energy
- NEAR
- NREL – National Renewable Energy Laboratory
- OTT – Office of Technology Transitions
- Pacific Northwest National Laboratory
- PSSEA – Philippine Solar and Storage Energy Alliance
- RE+ Events
- REN21 – Renewables Now
- Renewable Thermal Collaborative
- RMI – Energy. Transformed.
- SAESA – South African Energy Storage Association
- Smart Energy Council
- Sustainable Energy for All
- Energy Climate Development
- TESTA – Thailand Energy Storage Technology Association
- U.S. Department of Energy
- UNFCCC
- USEA – United States Energy Association
- We Mean Business Coalition
- World Resources Institute
- The World Bank

How to get in touch with LDES Council?

Please contact the LDES Council through the below channels if you have questions about the LDES Council Annual Report, would like to share feedback, or simply wish to start a conversation.

info@ldescouncil.com

https://ldescouncil.com/

www.linkedin.com/company/ldes-council/

https://x.com/LDESCouncil

About the Long Duration Energy Storage Council

The Long Duration Energy Storage Council is a global organisation advancing decarbonisation by facilitating the accelerated deployment of LDES solutions. The LDES Council's global industry organisation provides fact-based guidance on the deployment of LDES. The LDES Council covers a wide range of LDES technologies, and its members operating in 22 countries span a spectrum of innovation, including mechanical, thermal, electrochemical and chemical solutions.

To fully realise the transformative potential of LDES solutions and achieve a decarbonised energy system, deployments must ramp up significantly. The LDES Council remains steadfast in its commitment to advancing these essential technologies. By working with members, partners and key decision leaders in governments, regulatory agencies, financial institutions and civil society, the full spectrum of benefits that LDES offers can be unlocked, accelerating the clean energy transition, and helping to ensure a resilient, sustainable and decarbonised energy future for all.

www.ldescouncil.com