LDES
LONG DURATION ENERGY STORAGE COUNCIL

Deploying LDES: Implementation Best Practices

Accelerating Deployment and Scale-up of LDES through Seven Enablers

The global energy system is undergoing a profound transformation. The mass deployment of variable sources of renewable energy like solar PV and wind is essential for decarbonisation but will in turn require investment in flexibility to ensure firm, clean, power and heat. A suite of long duration energy storage (LDES) technologies store energy in various forms including chemical, thermal, mechanical and electrochemical. These resources dispatch energy or heat for extended periods of time ranging from 8 hours, to days, weeks, or seasons. Deploying up to 8 TW of LDES will be essential if we are to transition to Net Zero.[1]

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 storage for industrial heat processes, or policy incentives and support mechanisms. There are also still market and policy obstacles to LDES deployment, resulting in missed opportunities.

Beyond direct enabling actions, wider policy and market frameworks play an important role in creating a positive environment for LDES — and indeed decarbonisation more generally. Examples of these wider signals include the following:

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.

Removal of fossil fuel subsidies:

Reducing and removing fossil fuel subsidies will make these fuels more expensive compared to low-carbon alternatives such as LDES.

Ambitious variable renewable deployment 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[2] is one example of how major economies can drive the accelerated deployment of renewables.

Carbon pricing:

Carbon pricing reflects the real cost of carbon emissions, including externalities. It increases the price of high-carbon technologies and benefits low-carbon alternatives such as LDES.

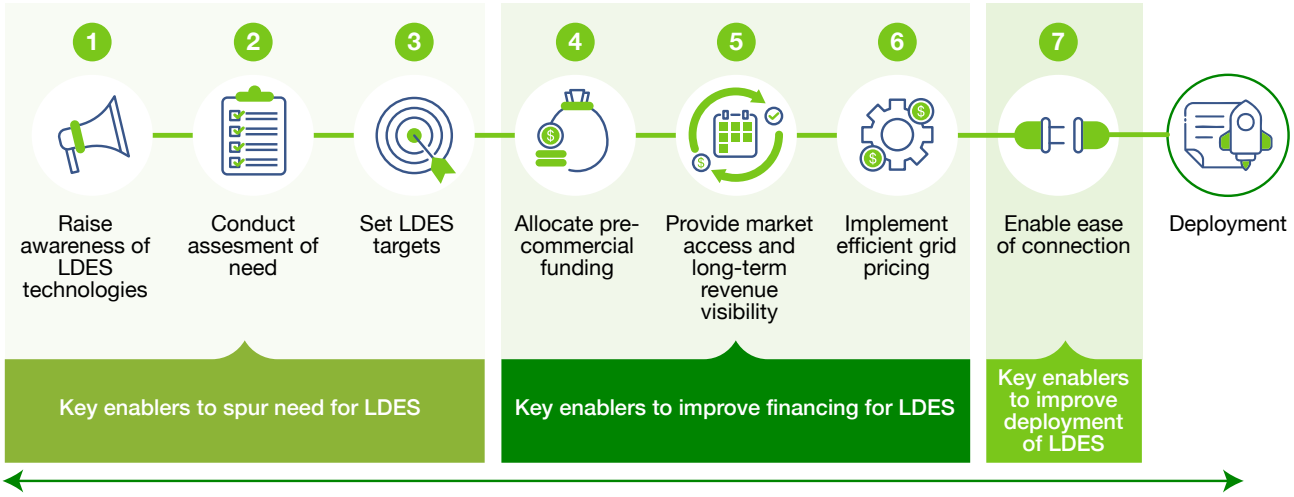
[1] Long Duration Energy Storage Council (2024). 2024 Annual Report.
[2] European Commission. (2023). Renewable energy targets: The revised Renewable Energy Directive, adopted in 2023, raises the EU's binding renewable energy target for 2030 to a minimum of 42.5%.

Significant and sustained action from a range of stakeholders is needed to 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 efficiencies.

An enabling environment includes clear applicability of LDES ('**need**'), the development of investable business cases ('**finance**') and the efficient deployment of LDES projects ('**deployment**'). Seven enablers of LDES have been identified, which are categorised under these three headings (see Figure 1). Each enabler is applicable at a high level to the three key LDES applications: power-to-power, power-to-heat and power-to-X. Although many countries are acting on some of the enablers, there is no country in which all seven enablers are fully in place.

FIGURE 1

Seven enablers to scale LDES



1. Raise awareness of LDES technologies

Stakeholders such as policymakers, manufacturers, utilities, financiers and industrial energy users must understand the benefits and operational characteristics of LDES to increase demand for and reap the benefits of these solutions.

At present, these stakeholders are insufficiently aware of the operational characteristics and capabilities of LDES, leading to a lack of deployment at scale. LDES solutions remain underutilised and are rarely considered for applications in electricity, industrial or corporate-site level decarbonisation plans. Figure 2 illustrates the limited progress on this enabler that has been made thus far.

FIGURE 2

Progress on Enabler 1[3]

Enabler 1: Raise awareness of LDES technologies	
Geographies	**Description of progress in 2023/2024**
Globally	Globally, a variety of stakeholders have published reports and hosted webinars and other events on long duration energy storage. Examples include the campaign by Future Cleantech Architects and publications by the World Bank Energy Storage Partnership, International Energy Agency (IEA) and the International Renewable Energy Agency (IRENA). These raise awareness of the need for and benefits of long duration energy storage.
ARENA Australian Government Australian Renewable Energy Agency	The Australian Renewable Energy Agency (ARENA) has published multiple knowledge pieces on long duration energy storage, including "Long Duration Energy Storage Trials in Remote Microgrids" and "Pioneering underground hydrogen storage". Such reports provide stakeholders with focused information to enable them to take forward long duration energy storage deployment.
IESA India Energy Storage Alliance	The India Energy Storage Alliance (IESA) organises the annual World Energy Storage Day, raising awareness of the critical importance of all forms of energy storage, including LDES, with a global audience. India's largest power utility NTPC took initiative to explore novel long duration energy storage solutions under development across the globe, increasing its awareness and understanding and enabling it to better plan for its own energy transition. Utilities in India are now changing their tender criteria to include LDES.
	The US Department of Energy (DoE) has published a report and organised webinars specifically on LDES in 2023 as part of its Pathways to Commercial Liftoffs Reports series. The goal of the series is to "provide a common fact base and a tool for ongoing dialogue with the private sector". By providing a common set of facts, more consistent decision-making is enabled across the public and private sectors. Maine signed "An Act Relating to Energy Storage and the State's Energy Goals" into law, directing a study into potential long duration energy storage solutions
EASE European Association for Storage of Energy	The European Association for Storage of Energy (EASE) has published multiple knowledge pieces on long duration energy storage, including a policy paper on Thermal Energy Storage. This raises awareness and understanding of long duration energy storage, especially in a European context, and so increases the likelihood of future policy being informed by the latest understanding on LDES.
ENERGY STORAGE CANADA	The trade association Energy Storage Canada has launched a "LDES Working Group" for their members, aiming to "focus on securing the immediate support of decision makers to incorporate LDES in their plans and actions". Initiatives such as these enable LDES stakeholders to target key decision makers in a consistent and coherent way, leading to better informed policy.

[3] FCA (2024). FCA starts information campaign on LDES; World Bank. (2023). Unlocking the Energy Transition | Guidelines for Planning Solar-Plus-Storage Projects ESMAP; IRENA. (2020). Innovation Outlook – Thermal Energy Storage; Australian Renewable Energy Agency. (2024). Knowledge Bank; Energy Storage Canada. (2023). Taking Action on Long Duration Energy Storage; US DoE Pathways to Commercial Liftoff. (2023). Long Duration Energy Storage Commercial LiftOff; Energy Storage Canada. (2024). Long Duration Energy Storage Opportunity Assessment; EASE. (2023). Thermal Energy Storage

2. Conduct an assessment of needs

LDES must be incorporated into energy system designs and decarbonisation planning to ensure that the least-cost mix of assets is deployed in the right place at the right time.

Region-specific reliability studies on energy system planning optimise the mix of generation and storage — including LDES — for a particular power or heat system. Modelling methodologies should include up-to-date costs for generating technologies; robust sets of technologies to choose from; sophisticated future weather profiles, including extreme weather scenarios; and load profiles including hourly load for a full year. These planning processes should directly inform goals for resource procurement.

While approximately 10 countries have calculated and published LDES needs for their electricity and heat systems thus far, almost none have incorporated LDES technologies into their industrial decarbonisation strategies (a number have looked at hydrogen, but not the full range of LDES technologies). Failure to use appropriate models for decarbonisation pathways will drive up the overall costs of decarbonisation if LDES is not included.

FIGURE 3

Progress on Enabler 2

Enabler 2: Conducted assessement of need	
Geographies	**Description of progress in 2023/2024**
Globally	Some countries are incorporating long duration energy storage technologies into industry decarbonisation strategies. By January 2023, 32 governments, such as Egypt, Brazil, Colombia, and Uruguay, have released hydrogen strategies, all underscoring the necessity of hydrogen energy storage in various capacities. However, very few countries have explicitly included thermal energy storage in their (industry) decarbonisation strategies.
	The EU Electricity Market Design asks EU Member States to assess their flexibility needs (see Box) – once each Member State has conducted its assessment the need for LDES across the EU will be firmly established.
	Ireland's two transmission grid operators published a call for evidence on Market Procurement Options for long duration energy storage. This call recommended that a Long Term System Service contract had the best strategic fit and was easiest to deploy in the country. The TSO intends to complete the procurement process for such contracts. They aim to award the first contracts by January 2025, securing connection by 2029.
	The UK government consultation on a cap and floor mechanism for long duration electricity storage highlights an analysis which concluded "a low regrets deployment of 2.5-3 GW as long duration energy storage could mitigate some of the deployment uncertainty for emerging, innovative, novel solutions (like hydrogen) in the 2030-2040 period". This sends a clear signal to the market of the minimum need for LDES.
	Italy, California and Australia have also conducted analyses on the need for LDES in their electricity systems, providing clear evidence to policy makers, investors and wider stakeholders on the need for LDES that can now be turned into action such as setting targets (enabler 3) and introducing long term revenue visibility schemes (enabler 4).
	Spain approved Resource Adequacy Targets in line with the EU Agency for Cooperation of Energy Regulators (ACER) to ensure enough generation to meet demand and reliability. This alignment with ACER's recommendations, upon EU commission approval will allow Spain to advocate to robust resource adequacy mechanisms in line with EU competition and state aid rules, potentially providing additional revenue streams for LDES.
	The US DOE has taken steps towards finding Strategies to Decarbonize America's Industrial Sector. It has issued an RFI focused on 'Pathways for U.S. Industrial Transformations: Unlocking American Innovation' with 4 pathways to reduce industrial emissions through innovation in US manufacturing including through thermal energy storage.

Sources: EirGrid, SONI (2023), Shaping Our Electricity Future Roadmap Version 1.1; CEC (2023), Long Duration Energy Storage Program; Dunsky (2024), Long Duration Energy Storage (LDES) Opportunity Assessment ; NSW (2023), Electricity Infrastructure Roadmap; Victoria State Government (2024), Victorian renewable energy and storage targets; Recharge (2023), China's $1bn bet on gravity to store massive amounts of green energy West Australia SWIS Demand Assessment 2023 to 2042

EU assesses flexibility needs in the revised Electricity Market Design

Grid operators and regulators play a crucial role in assessing and planning the amount and type of energy storage needed in an energy system through analysis and modelling. These studies help to inform the amount of LDES needed and deployment timelines, balancing system needs with longer-term cost optimisation. In the EU, the revised Electricity Market Design (EMD) came into force in June 2024. The EMD requires member states to assess their flexibility needs and specify how they will meet those needs, with an emphasis on non-fossil fuel solutions. The first such assessments are expected to begin in Q3 2025 and are likely to take up to 12 months, using a methodology that will be developed by the European Network of Transmission System Operators and approved by the European Union Agency for the Cooperation of Energy Regulators.

To ensure that planning models are accurate and effective, it is recommended that grid operators integrate the latest data inputs on available technologies and associated costs. Moreover, there is a need to develop and integrate enhancements for weather assumptions to fortify system resilience against the impacts of climate change.

3. Set LDES 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 up to 11 countries quantify deployment by 2030 for pumped hydropower storage or storage technologies in general. However, in contrast to many renewable energy targets which are fixed in national laws, these goals are rarely binding, which highlights the importance of establishing a roadmap for LDES that includes binding targets.

> The establishment of a global target for LDES provides a framework for regulatory support and financial mechanisms for both regions and countries, ensuring that LDES can compete effectively with traditional energy sources and thus fulfil its pivotal role in the transition to a sustainable energy future.

Decarbonisation targets should also accelerate the rollout of LDES alongside other clean energy generation, forming a glide path to enable decarbonisation. Targets should include specific delivery dates and be revised over time. Effective targets for LDES should also specify power (megawatt (MW)), energy (megawatt-hours (MWh)) and duration; and the timespan should be aligned with renewables goals.

Countries have made limited progress on setting LDES targets for power-to-power applications, but very few targets have been set for power-to-heat applications. While roughly 30 countries or regions have specific storage targets, only five have LDES targets. More jurisdictions must set targets for progress if the goal of deploying up to 8 TW of LDES to achieve net zero by 2040 is to be met.

FIGURE 4

Progress on Enabler 3[4]

Enabler 3: Set LDES targets	
Geographies	**Description of progress in 2023/2024**
 Globally	Across several countries, energy storage targets have continued to be announced meeting decarbonisation ambitions. Beyond battery storage, many of these countries have also signalled their progress in establishing LDES targets.
	Irish TSO highlights **~2.8 GW** of LDES1 is needed for an 80% renewable grid by 2030. This is expected to feed through into direct procurement of LDES assets in Ireland.
	Italy has a 3 GW target for LDES projects by 2030. Procurement against this target is now under way.
	A procurement programme in California is underway to deliver 1 GW of 12 hour + LDES and 1 GW multi-day LDES by 2031-2037. Such targets send a strong signal to investors that long duration storage will be supported in the relevant jurisdiction.
	Analysis in Ontario concluded the province needs 6 GW of LDES (defining LDES as resources with a minimum 10-hour duration).
	The New South Wales government has a target of 2 GW of new long duration storage (8+ hours duration) by 2030 as part of its broader Electricity Infrastructure Roadmap. In Western Australia, the 2023 South West Interconnected System (SWIS) Demand Assessment sets modelling to consider a 10 -hour LDES option from 2030. Victoria's legislated energy storage targets include at least 2.6 GW of energy storage capacity by 2030, and at least 6.3 GW by 2035.
	Chinese rules require renewable plants to integrate storage equivalent to 20% of their generation capacity, with at least a 2–4 hour duration (LDES can therefore also be included here, and requirements for shorter durations may be increased to longer durations over time, as the need for LDES becomes more urgent). Additionally, a pumped storage target of 120 GW was set by 2030. The pumped storage target in particular provides a strong signal to the supply chain and motivates action across a wide range of stakeholders.

[4] Sources: EirGrid, SONI. (2023). Shaping Our Electricity Future Roadmap Version 1.1; CEC. (2023). Long Duration Energy Storage Program; Dunsky. (2024). Long Duration Energy Storage (LDES) Opportunity Assessment; NSW. (2023). Electricity Infrastructure Roadmap; Victoria State Government. (2024). Victorian renewable energy and storage targets.

4. Allocate pre-commercial funding

Public funding is important to help LDES and other technologies advance from the demonstration and pre-commercial stages to commercial deployment. Historically, support for emerging infrastructure has enhanced economies of scale and accelerated deployment. Funds and grants provide greater revenue certainty to investors, enabling them to finance the upfront costs of projects, including pre-commercial LDES projects with novel technology. When market participants such as utilities invest in pilot LDES projects, they help to scale new technology and gain experience in operating and connecting LDES resources to the grid, which makes subsequent investments more effective.

Sandboxes offer a relaxed regulatory environment and can reduce the permitting hurdles for deployment and serve as a space for experimentation, facilitating the innovation that is critical for cost-effective grid evolution.

Furthermore, mechanisms such as loan guarantees from publicly financed institutions can help to derisk private investment — something which is particularly important in the early stages of commercial deployment, when financiers may be less comfortable investing in new technology. Such arrangements have parallels, in, for example, export credit facilities.

Funds and grants are available to scale LDES technologies — primarily in China, the US, Australia, Chile and Europe.[5] These catalyse the development of such technologies and foster novel collaborations for efficient and economic deployment within integrated energy systems. More effort is needed on innovative financial arrangements to bridge the gap between demonstration, pilot and commercial projects.

[5] This conclusion is based on desktop research, stakeholder interviews and the International Energy Agency's (IEA) Policy Database IEA. (2024). IEA Policy Database.

FIGURE 5
Progress on Enabler 4[6, 7]

Enabler 4: Allocate pre-commercial funding	
Geographies	**Description of progress in 2023/2024**
Globally	Funds and Grants can provide a catalyst for new long duration energy technologies to scale while fostering novel collaborations for efficient and economic deployment within integrated energy systems. Many countries recognise the need for financing to activate the long duration energy storage marketplace.
	At the start of 2024, the National Energy Administration (NEA) 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 eventually quicker deployment of the best technologies, leading to lower costs overall.
Google Microsoft NUCOR	Arizona's Salt River Project utility launched a request for proposals for demonstration projects for, non-lithium long duration energy storage with 10-hour discharge rate. Google, Microsoft, and Nucor Corporation aim to accelerate first-of-a-kind and early commercial projects to include long duration energy storage. They will pilot demand aggregation and procurement models, focusing on offtake agreements, influencing policy, and developing new tariff structures. Specifically, the organisations highlight that for energy projects they are looking for discharge durations of 8 hours or greater (with >12 hours preferred). Private sector investment such as this complements public sector grants, enabling private users to test technologies with real world applications that fit with their business need.
	The Western Australia Government and ARENA will each provide USD 2.85 million to trial two LDES batteries by Horizon Power. Such trials help to demonstrate LDES technologies in challenging environments (in this case the Australian outback, with consistent, high temperatures.
	USD 310 million in grants for standalone energy storage projects, thermal energy storage and reversible pumped hydro. Launched in 2023, online by 2026. Such grants enable developers to test and deploy technologies ahead of grid scale deployment, bringing forward the time at which they can deploy without subsidy.
	USD 38 million for the UK Battery Industrialisation Centre development facilities. USD 32 million direct equity investment towards commercial development of vanadium flow batteries (focused on 4-12 hours). Nearly USD 90 million invested through LDES demonstration programme under the Department for Business, Energy and Industrial Strategy.
	USD 325 million grant from the US Department of Energy (DOE) for advancing long duration energy storage[1] deployment. This funding targets both the scaling up of commercial technologies and the advancement of pre-commercial technologies, with nine projects receiving a total of USD 286 million from the long duration energy storage Funding Opportunity and another six projects securing USD 39 million under the "LDES Demonstrations Lab Call" for deployment at national labs.
	Australia, Germany, Italy, the UK, Ontario (Canada) and California (US) all have regulatory sandbox programmes.

[6] [1] The DOE defines LDES differently from the LDES Council, only assuming technologies that provide 10 or more hours of energy storage discharge at full power. Australian Renewable Energy Agency (ARENA). (2024). New battery technologies tested at regional WA microgrids; Tamarindo. (2023). Chile: A 'showcase' for storage and the energy transition; China Daily. (2024). China's energy storage capacity expands to support low-carbon goals; Energy Storage News. (2023). Spain launches €280 million grants for standalone energy storage, thermal and PHES; UK Parliament (2024). Batteries for electric vehicle manufacturing: Government Response to the Committee's First Report of Session 2023-24; Energy Storage News. (2023). Energy Dome, Invinity, Form, Redflow projects among DOE's US$325 million LDES winners;

[7] International Smart Grid Action Network. (2019). Implementing Agreement for a Co-operative Programme on Smart Grids; International Smart Grid Action Network (ISGAN). (2019). Innovative Regulatory Approaches with Focus on Experimental Sandboxes; California Energy Commission. (2024). Long Duration Energy Storage Programme (2024); Decentralised Energy Canada. (2021). Getting to Deployment: Bridging the Gaps in Energy Innovation in Canada.

Over the years, the gap in finance for LDES has been bridged by governments through funding or incubators and by private catalyst initiatives. For example, the US and the UK introduced nationwide funding for demonstration (to-scale) facilities with up to eight hours of storage duration across various technology applications. Examples from the US exist under the Office of Clean Energy Demonstrations 'Long Duration Energy Storage Demonstration Initiative and Joint Program' which is prescribed under the Bipartisan Infrastructure Law, and within the UK, the Longer Duration Energy Storage Innovation Programme (part of UK Net Zero Innovation Portfolio) towards the Ten Point for a green Industrial revolution[8]. These funding programmes and private catalyst initiatives increasingly feature priority forgovernment-level interventions to scale-up LDES technologies under grant streams and innovation demonstrations.

Examples of Pre-Commercial Funding Across Regions

A strong indicator for advancement in technologies can be public sector financing at pre-commercial stage. Long Duration Energy Storage Council technology provider members have been recipient to a significant proportion of available funding. Project examples of successful grants from the Long Duration Energy Storage Council members are listed below. These funding examples are not exhaustive but demonstrate existing activities by LDES Council members across regions and technology applications

US State-level Funding

The Office of Clean Energy Demonstrations (under the Bipartisan Infrastructure Law) has made available $350 million in funding grants for the development of LDES solutions to support a low-cost, reliable, carbon-free electricity grid. LDES projects with storage durations of 10 hours or more have been awarded grants across 17 states:

- **Pumped thermal energy storage in Alaska Railbelt:** Alaska relies on two coal-fired generation units, one of which is slated for retirement. Awards of up to $50 million will be directed towards supplying residents in remote locations and those living in areas with extreme weather conditions. **Echogen Power Systems** will develop and deploy a pumped thermal energy storage system with a 1,200 MWh capacity, capable of a minimum continuous output of 50 MW for 24 hours, at the Healy Power Plant.
- **Children's Hospital Resilient Grid with Energy Storage (CHARGES):** Technology provider **Redflow** is installing a 34 MWh behind-the-meter zinc bromide flow battery system for the Valley Children's Hospital in California. CHARGES demonstrates the ability of LDES to provide critical power backup for medical and acute care facilities and enhance system resilience in regions that are increasingly at risk of major power outages due to extreme weather events such as fires, storm surges, floods, heatwaves and earthquakes.

Under the US Department of Energy, Advanced Research Projects Agency-Energy (ARPA-E) the Seeding *Critical Advances for Leading Energy Technologies with Untapped Potential Programme* awards include:

- **Geo-mechanical pumped storage project for San Antonio-based CPS Energy:** Engineered by **Quidnet Energy**, this project demonstrates the benefits of using pumped hydropower technology to create an LDES resource that does not require mountainous terrain. The project will scale to provide a storage duration of 10 hours, supporting CPS Energy's 'Flexible Path' Resource Plan.

[8] The Net Zero Innovation Portfolio provides funding for low carbon technologies and systems to help enable the UK to end its contribution to climate change.

US State-level Funding

- **ESS Tech, Inc:** The State of California under its California Energy Commission (CEC) awarded the Sacramento Municipal Utility District (SMUD) a $10 million grant to demonstrate a groundbreaking 4 MW, 8-hour iron flow battery project. The project, developed by technology provider **ESS Inc**, is in its early phases at SMUD's Sacramento Power Academy. Additionally, through the CEC grant, SMUD has committed approximately $19.5 million in cost-sharing for labour and material expenses.

- **Form Energy:** Additionally, CEC awarded technology provider **Form Energy** a $30 million grant to develop a 5 MW, 100-hour iron-air battery storage project in Mendocino County. This project aims to connect to the California grid and provide energy services and is expected to be operational by the end of 2025. Further, the US Department of Energy has awarded the state of Maine a $147 million grant to develop an 85 MW storage facility with a discharge duration of up to 100 hours, to be built by Form Energy.

EU

- **Rondo Energy:** Rondo Energy has received €75 million from Breakthrough Energy Catalyst and the European Commission through the European Investment Bank to develop a heat battery based on thermal energy storage technology, which combines century-old materials with advanced automation. The technology uses brick batteries to store energy and provide continuous uninterrupted heat. Three projects have been signed in Europe.

- **Malta Inc:** Through its German subsidiary, Malta Inc has received €9 million from the German Federal Ministry for Economic Affairs and Climate Protection. The project involves collaboration with the German Aerospace Centre, Alfa Laval and Siemens Energy, and will facilitate the expansion of research institute DLR's TESIS facility to validate an innovative heat exchanger developed by Alfa Laval.

- **Energy Dome:** Announced at COP28 under the EU Breakthrough Energy Catalyst Partnership, Energy Dome received a total of €60 million – with up to €35 million in the form of a project-level grant commitment and €25 million as a venture debt financing commitment – from the European Investment Bank. The project will employ an innovative carbon dioxide-based thermal-mechanical energy system. Located in Sardinia, Italy, it will supply energy to the grid with a 10-hour discharge duration.

UK

In 2021, the UK announced £69 million of capital funding under the LDES Demonstration Programme, which includes funding tranches for power-to-power, power-to-thermal and power-to-X technologies. The programme aims to accelerate the commercialisation of innovative LDES projects through demonstrations. Projects include the following:

- **Vanadium flow battery longer-duration energy asset demonstrator:** Invinity has received £11 million to fund a 40 MWh demonstration vanadium flow battery that will be connected to the national grid in Scotland. The project is expected to go live in early 2025.

- **e-Zinc energy storage system:** e-Zinc has received about £145,000 to accelerate the commercialisation of LDES systems in the UK based on its zinc energy storage technology.

5. Promote market access and long-term revenue visibility

LDES assets should be able to participate in a wide range of energy markets, including ancillary services and wholesale markets. This will both strengthen the business case for LDES and reduce overall system costs.

Resource adequacy markets ensure that there is sufficient capacity and reserves for the system operator to maintain balanced supply and demand. This is achieved through the execution of contracts between power producers and the system operator. **Real-time wholesale energy markets** enable consumers, companies and energy distribution businesses to buy and sell energy in small time increments. This is usually done an hour before delivery.

In common with many other forms of low-carbon infrastructure, LDES assets have long payback times, making it vital for investors to have a good understanding of revenue flows over time. Energy markets are dynamic and revenues that are forecast to be available in, for example, 10 years' time may not materialise, due to factors such as policy and regulatory changes, technological developments and geopolitical events.

Mechanisms that provide long-term revenue visibility and stability can reduce risk for investors and help to overcome insufficient resource adequacy and energy market revenues. Examples of such mechanisms include contracts for difference (CfDs), feed-in tariffs, cap and floor mechanisms, capacity payments and government-backed financial guarantees. These mechanisms can improve or guarantee revenue streams beyond typical expectations for energy market and resource adequacy revenues.

As an example of the importance to investors of long-term revenue visibility in respect of low-carbon infrastructure, the UK implemented a CfD scheme that guarantees offshore wind developers a fixed price per MWh generated for a 15-year period.[9] This gave investors' confidence in future returns and has spurred significant offshore wind deployment.

Countries can also consider whether LDES is an asset of national importance that could be compensated under national infrastructure public funding, as opposed to energy market revenues, or included as part of a regulated asset base. Examples could include treating LDES as part of the electricity grid system or providing compensation through national funding schemes.

Some countries are establishing contract structures or guarantees to reduce revenue risk in relation to LDES. As these mechanisms are implemented, the LDES Council expects to see other countries review and implement similar schemes, drawing on the experience of the frontrunners.

[9] UK Government. (2017). Electricity Market Reform: Contracts for Difference.

FIGURE 6

Progress on Enabler 5[10]

Enabler 5: Provide long-term revenue visibility	
Geographies	**Description of progress in 2023/2024**
 Globally	Recognizing mechanisms that support the deployment of LDES will require long term revenue stability and reducing risk associated with investments in technologies globally. Several Governments are identifying financial incentives, through long-term contracts, low interest to attract investments and support development and deployment for energy storage.
	Energy storage was embedded into German ancillary services and balancing markets, enabling participation of LDES in these markets, and so providing greater visibility of, and access to, revenue. The nation currently has 85 energy storage projects in various stages of development that total 6.4GW.
	Europe took legislative action through Renewable Energy Directive (EU) 2018 / 2001 to remove double charging of energy storage assets. Additionally, the renewable Energy Directive (EU) 2019/944 also calls for energy storage to be able to participate in ancillary services markets. The new Electricity Market Design also allows for Members States to introduce support mechanisms for storage.
	Italy has introduced direct tenders for large storage capacity under long-term contracts (12-14 years). System operator TERNA is predominantly offering these contracts for battery storage systems, pumped storage hydropower and other technologies. These long-term contracts provide stability and certainty for investors and developers, reducing the cost of capital and therefore costs to consumers.
	The UK has consulted on a Cap-and-floor mechanism for long duration electricity storage with 6+ hour duration. If implemented this will provide investors with a minimum 'floor' revenue.
	Significant investment and manufacturing tax credits for standalone storage projects, made available through the Inflation Reduction Act. These increase the attractiveness of such assets to investors, resulting in more deployment and further synergies such as economies of scale.
	Australian Capacity Investment Scheme has a rolling programme of auctions securing storage with 4hr+ duration Additionally, The New South Wales (NSW) government initiated a tender for long duration energy storage projects to secure 1GW of 8-hour storage capacity. Under Long-Term Energy Service Agreements LDES projects in NSW may receive a 14 year contract (40 years for pumped storage hydro) with a series of 2 year options to receive an annuity payment, giving clear visibility of minimum revenues over time.
	Chile's energy regulator (Comisión Nacional de Energía) introduced new bidding rules in 2023 that allow developers to add storage technologies to their projects, entitling them to secure a 20-year Power Purchase Agreement (PPA). Chile announced in 2023 the allocation of USD 2 billion for large-scale storage auctions.
	Japan held its first-ever competitive auction for low-carbon energy capacity with a total of 1.67GW of projects under the bids for energy storage. Of this total, 3 pumped hydro storage projects were recipients for award for 20-year fixed revenue capacity market contracts.
	Moroccan Agency for Solar Energy (MASEN) Morocco's state-funded renewable energy development organisation will enter a 30-year PPA for Noor Midelt III project tender awardee acting as shareholder and land provider. The NOOR III project is a 150 MW solar tower-plant with up to 8 hours storage duration.
	The Irish transmission system operators are considering stand-alone storage auctions and a fixed term system services contract with central control as procurement options.

[10] NSW. (2024). NSW powers ahead with biggest energy storage tender; European Parliament. (2024). EU energy policy; EirGrid, Soni. (2023). A Call for Evidence on the Market Procurement Options for Long Duration Energy Storage (LDES); TIMERA. (2023). Italian battery investment is about to surge; Energy Storage News. (2023). US' tax credit incentives for standalone energy storage begin new era; Energy Storage News. (2024). Google, Microsoft seek technologies including LDES, geothermal, nuclear in 'several US regions.'

6. Implement efficient grid pricing

Regulators should ensure that grid prices reflect supply and demand principles, to drive efficient markets that send better pricing signals to participants. Where possible, these signals should not include unnecessary or distortionary fees.

Efficient wholesale market signals incentivise the siting of new projects at locations that are optimal for the grid, to enhance future congestion relief and promote the most effective use of existing grid infrastructure. These signals also help to optimise the use of resources in real-time and day-ahead markets, leading to lower retail rates and overall costs of electricity.

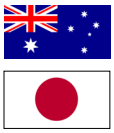
Efficient retail market signals provide demand-side benefits that incentivise customers to curb use when there is greatest pressure on the grid and to shift use from stressed periods to periods of abundant supply. This helps grid operators by partially shaping load around grid capabilities, instead of operating the grid to satisfy a fixed demand.

Similarly, markets should send wholesale price signals for large loads and new technology such as power-to-heat LDES that can respond to grid dispatch instructions. Large electricity consumers with the capability to respond to dispatch instructions can provide valuable services to grid operators, similar to those provided by traditional generation. This affords grid operators additional levers to maintain reliability during extreme conditions and reduces overall electricity prices. Unnecessary or distortionary fees, including high fees related to transmission charges, can impede these signals.

Most grid cost charging structures do not reflect the benefits of LDES to the electricity system, such as through time-variable grid fees or non-firm grid connections. Significant progress in this regard is needed, which would support grid infrastructure development more broadly.

FIGURE 7

Progress on Enabler 6[11]

Enabler 6: Implement efficient grid pricing	
Geographies	**Description of progress in 2023/2024**
	Spain implemented time-variable grid fees, allowing long duration energy storage to charge at times with low fees. Such arrangements are more reflective of the impact of LDES on the grid and so support the deployment of LDES as flexible assets.
	Current German legislation exempts energy storage assets from grid fees if they go online before August 2029, providing a near term incentive to LDES and other storage technologies.
	The Netherlands is introducing 'non-firm agreement' (NFA) connections and time-weighted rates, which Aurora Energy Research estimates could reduce grid fees up to 67%, providing a strong additional incentive to deploy LDES which does not require firm connections.
	Denmark introduced discounted grid fees for interruptible connections, enabling more efficient grid operations and providing a cost benefit to flexible sources of demand such as LDES.
	Chile, the Philippines and the United States use the nodal pricing model.
	Australia and Japan use zonal pricing.

[11] Smart Energy International. (2024). Norgesnett and Volue partner on 'grid aware' EV charging programme; Systemiq. (2024). Catalysing the global opportunity for electrothermal energy storage; BVES. (2023). BVES Welcomes Extended Grid Fees Exemption for Energy Storage and Calls for Long-term Legislative Certainty; Murray. (2024). Netherlands' 'non-firm' grid connections and lower fees could double BESS deployments;

7. Enable ease of connection

Efficient planning, permitting and connection will avoid bottlenecks in resource and infrastructure deployment, including LDES. Delays increase costs for investors and reduce overall system benefits. Some regions are introducing accelerated approval processes for non-firm grid connection projects.[12] Faster approvals can facilitate the additional deployment of other generating assets, including renewable energy.

Many developers cite connection times as the biggest challenge they face. Improvements to connection processes so that flexible assets – such as LDES resources – can connect more quickly are important to achieve decarbonisation and accommodate rapidly changing grids. In September 2023, the Global Renewables Alliance, the Planning for Climate Commission and the Green Hydrogen Organisation published a nine-point plan for fast and fair permitting to address some of these concerns.[13]

A 9-point plan for fast and fair permitting, recommendations from the Planning for Climate Commission

1. Innovate to shorten permitting timeframes.
2. Streamline permitting processes in a transparent and predictable manner.
3. Engage communities from the outset.
4. Deploy carefully designed and regulated benefit-sharing mechanisms.
5. Put in place strong policies and safeguards to limit environmental impacts.
6. Accelerate grid infrastructure build-out and integration.
7. Allocate land appropriately and strategically.
8. Strengthen and optimise institutional capacity at central and local levels.
9. Avert technological risks by adopting rigorous standards.

FIGURE 8

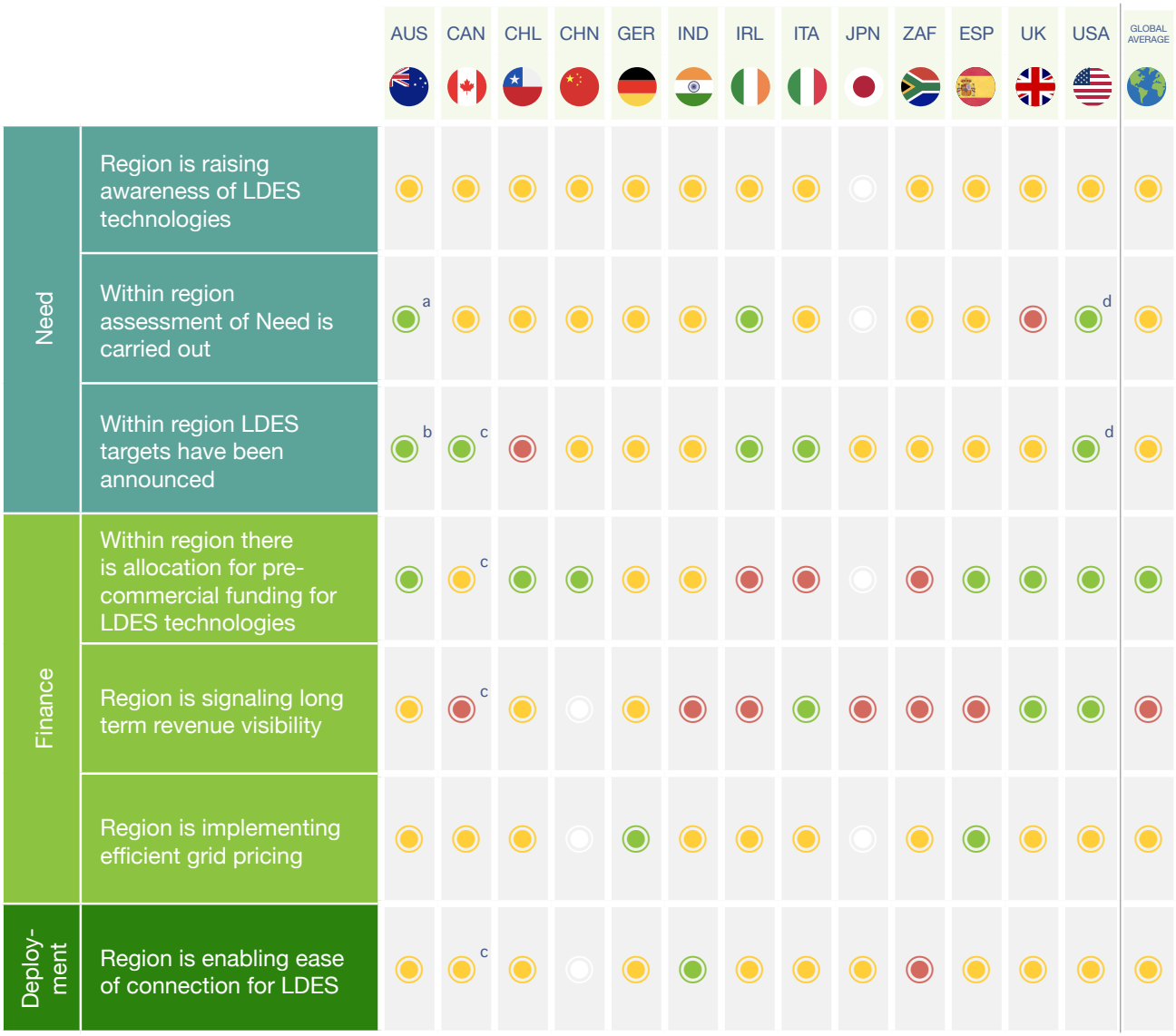
Progress on Enabler 7[14, 15]

Enabler 7: Enable ease of connection	
Geographies	**Description of progress in 2023/2024**
Globally	An efficient planning, permitting and connection process avoids the bottlenecking of long-term storage infrastructure deployment. Select countries are increasing the pace for connectivity with providing the substantial benefits of long duration energy storage. Increasing the pace of grid connections will provide substantial benefits beyond LDES, enabling the deployment of a wide range of low carbon technologies.
	The Netherlands and Denmark are in the process of approving non-firm (or interruptible) grid connections in locations where these benefit the grid. Under this special contract, grid operators will have the authority to disconnect grid connections during peak times, offering a discount on grid fees in return. This arrangement allows LDES to utilise the grid connection when there is available capacity. The Danish Energy Authority has also implemented a 'single window agency' to address grid congestion, this should benefit LDES by streamlining the approval process for grid connections, facilitating faster connections and supporting the growing demand for renewables.
	India has a single window portal designed to streamline permitting for statutory clearance to support the hydrogen ecosystem and facilitate the green corridor for renewable energy transfer. This could benefit deployment of LDES by enhancing the efficiency of regulatory processes for low carbon technologies.

[12] Systemiq. (2024). Catalysing the global opportunity for electrothermal energy storage;
[13] Planning for Climate Commission. (2023). Tackling climate change through fast and fair permitting for renewable energy and hydrogen: recommendations from the Planning for Climate Commission.
[14] Sources: Systemiq. (2024). Catalysing the global opportunity for electrothermal energy storage;
[15] EY. (2024). India's Green Hydrogen Revolution.

FIGURE 9

LDES policy progress on the seven enablers



[a] Although no federal target has been set, energy storage targets to include LDES have been set in the states Victoria and New South Wales. [b] Limited progress made in states Victoria and New South Wales. [c] No progress on a federal level, but limited progress in the state of Ontario. [d] Little progress on a federal level, but some progress on a state level, e.g., in Maine, California and New York.

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/

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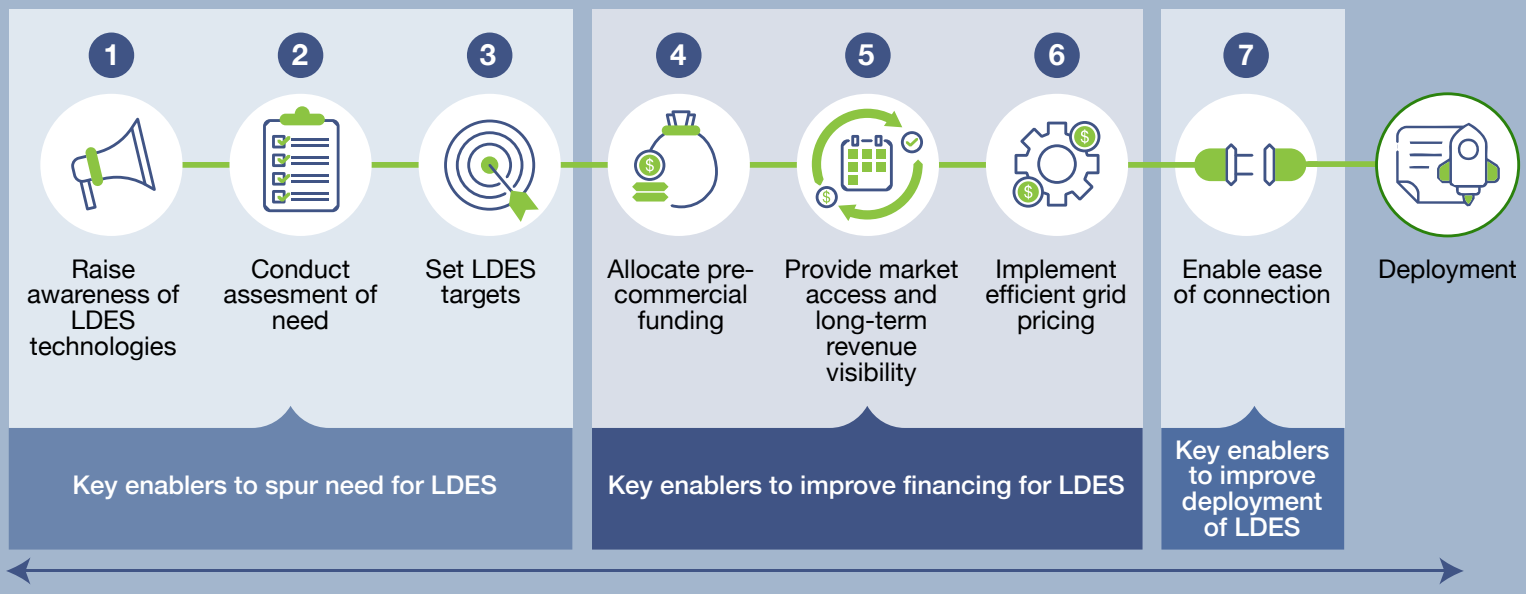

About the Long Duration Energy Storage Council

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