Long duration energy storage for the power system: a diverse field of technologies eager for deployment

- Decarbonizing electricity will require large amounts of wind and solar energy. However, energy from these sources fluctuates and does not generally align with load patterns.
- Scaling up a portfolio of Long duration energy storage (LDES) technologies is urgently needed to decarbonize grids and provide energy security.
- Employing a wide-ranging array of LDES technologies ensures a diversified supply chain not reliant on one fought-over resource and instead based on elements that are abundant and safe.
- Chemical LDES technologies, which are the ones best suited for seasonal storage, are still in demonstration or early development stages.

Storage technologies are considered as long duration energy storage (LDES) if they can continuously supply energy, at rated power, for at least 10 hours in a row. They enable the integration of large shares of wind and solar into the power grid (necessary to decarbonize electricity generation) by storing clean electricity when available and supplying it back when needed. By doing this, LDES balances supply and demand, reduces congestion and curtailment, provides grid stability, and improves energy security during times of low supply.

LDES is not merely optional, but rather **a critical tool for the energy transition**. In the EU, a goal of 1.2 TW of renewable capacity has been set for 2030. However, this must be combined with significant increases in energy storage to ensure European energy systems can perform effectively. To meet this increase in renewables, the LDES Council has estimated Europe will require over 200 GW of energy storage by 2030. Additionally, the European Association for the Storage of Energy, EASE, estimates that Europe will need at least 600 GW of energy storage capacity by 2050 to meet its climate targets. This represents a tenfold increase from the approximately 60 GW available today and a dramatic rise in historic deployment rates from 1 GW/year to 14 GW/year. Similar challenges are encountered in most other world regions, where the majority of the electricity still comes from coal- and gas-fired power plants and where solar and wind energy are the cheapest and most viable alternative.

LDES technologies are extremely diverse but can generally be grouped into four families: electrochemical, thermal, mechanical, and chemical. Some LDES technologies are suited for intra-day applications, while others can supply energy consistently for several weeks or even months.

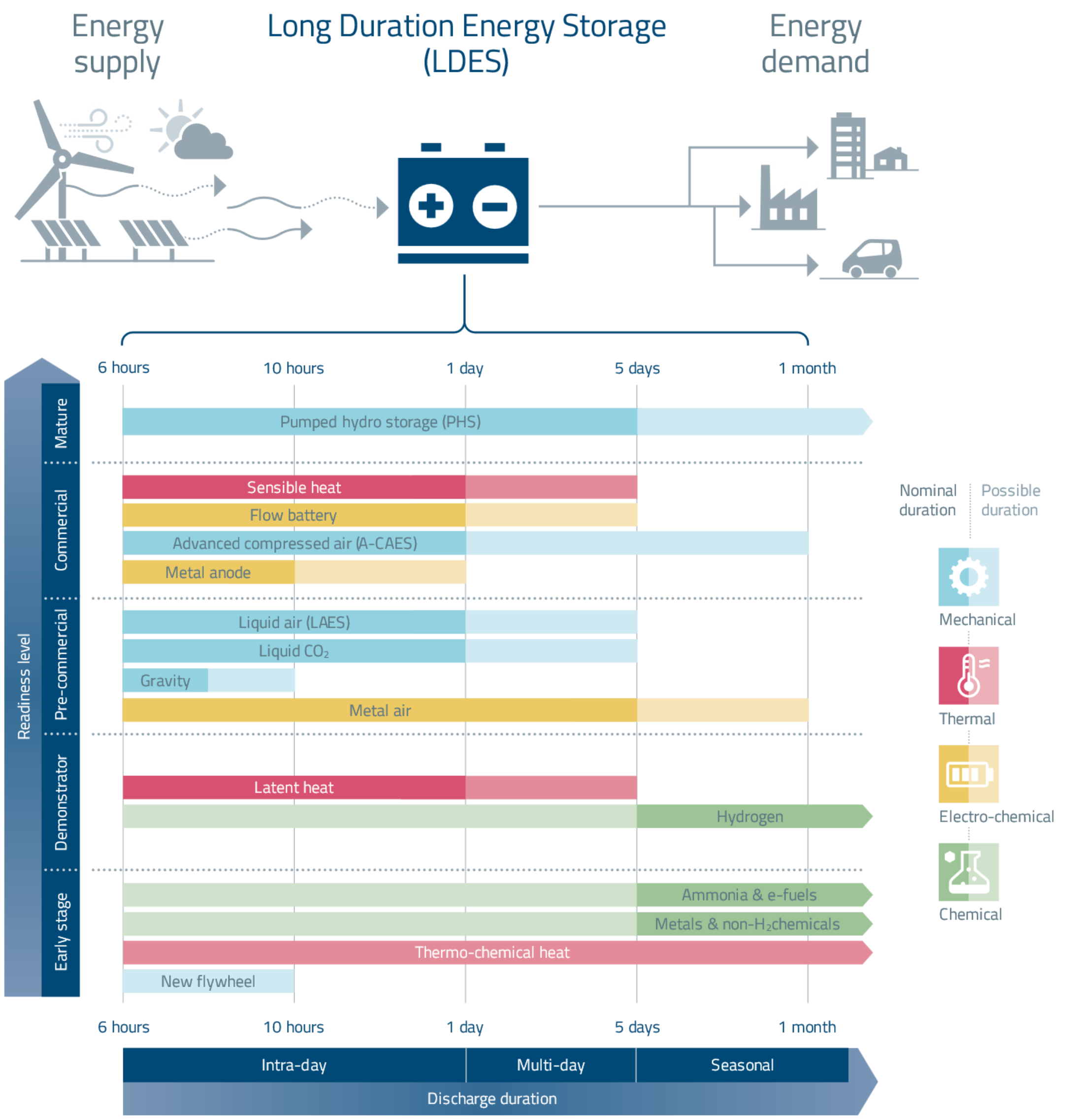

Figure 1 – Long duration energy storage (LDES) balances supply and demand, enabling the integration of large shares of wind and solar energy into the power grid. The graph shows a non-exhaustive list of LDES technologies, grouped according to readiness level and discharge duration. Nominal duration indicates the typical or optimal discharge duration for each technology category, while possible duration indicates a less common or sub-optimal application.

Most LDES technologies are free from geographical constraints, are highly scalable, rely on modular designs, and use relatively inexpensive and abundant materials. However, several are still in early stages of development and commercialization, which has an impact on their cost. Figure 1 shows a list of LDES technologies grouped according to their approximate discharge duration and deployment readiness[1].

The graph focuses on LDES technologies that can be used to supply electricity. While some of them can be designed to supply heat instead (or even to supply both), some of their characteristics might change (e.g. sensible heat storage can supply heat at low temperatures for seasonal applications, but is restricted to the intra-day and multi-day range when used to supply electricity, as it requires operating at very high temperatures). While the focus of this publication is on electricity storage, heat storage is also immensely important and is the focus of ongoing work by both Future Cleantech Architects and the LDES Council.

The most mature and widely implemented LDES technology is pumped hydro storage (PHS), which constitutes well over 90% of all energy storage capacity worldwide. The vast majority of new PHS installations are closed-loop, which greatly minimize the environmental footprint associated with historic on-river systems. However, large-scale PHS still typically faces decade-long development cycles and is not suitable for some geographies. Other LDES technologies (including innovative PHS schemes with faster development times and smaller constraints) are urgently needed to help accelerate storage deployment.

As shown in Figure 1, **several technologies have reached the commercial and pre-commercial stages and are slowly scaling up**. These technologies include some of the **best candidates to accelerate LDES growth for intra-day and multi-day applications** alongside pumped hydro. However, as shown in Figure 2, flexibility is needed from daily to seasonal timescales, and LDES technologies optimal for seasonal applications are in less advanced stages.

In particular, most **chemical LDES technologies best suited for seasonal applications are still in demonstration or early development stages**. Within the chemical family, hydrogen is the most advanced technology. However, hydrogen and its derivates are currently produced using fossil fuels, and nascent green hydrogen production faces both significant logistical challenges and strong competing demands from several decarbonizing sectors, such as the fertilizer and chemical industries. This means that rapid progress is particularly needed from non-hydrogen-based chemical LDES to enable sufficient deployment of seasonal storage.

[1] As there are dozens of technologies within each LDES family, an exhaustive list would surpass the scope of this publication. The figure only includes some of the most prominent and representative categories. Noticeably, it does not include lithium-ion battery systems, which are the second most widely implemented grid-scale storage technology after pumped hydro. Most lithium-ion systems, however, are designed to operate at or below 4 hours of discharge duration, thereby being better suited for power quality and peak shaving applications rather than energy management, which does not qualify as LDES.

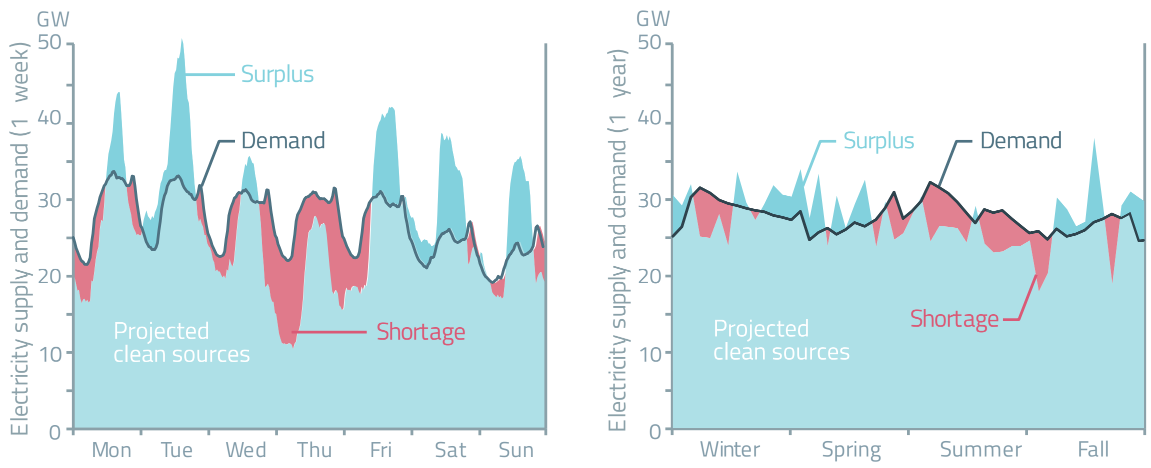

Figure 2 – Wind and solar energy production fluctuate over time, resulting in an imbalance between supply and demand. ***Energy storage is needed*** *to compensate for these fluctuations,* ***from daily to seasonal timescales****. The graph shows projected electricity generation in a developed economy under a net-zero scenario. Left: fluctuations over a week. Right: fluctuations over a year. Source: [Future Cleantech Architects' LDES factsheet](#).*

The LDES industry is in the lift-off phase of the developmental curve, proving the technologies work and are readily available for commercial use at the utility level. Furthermore, **the wide array of LDES technologies ensures a diversified supply chain**, supported by a variety of elements that are abundant and safe, instead of relying on a small number of fought-over resources prone to creating supply bottlenecks.

LDES does not only provide flexibility and energy security, it also offers a variety of other valuable services (such as reducing curtailment and grid congestion, dealing with fast changes in demand, restarting the grid after a blackout, and improving power quality) that provide additional reliability. Current transmission and distribution planning often neglects these advantages and should be updated to reflect the multiple benefits that LDES brings to markets and the power system as a whole.

Most climate targets and current policies have targets for 2030, which is less than seven years away. To truly decarbonize economies and reduce emissions, policies must change today to address tomorrow's needs: scaling up the LDES value and supply chain must start now in order to harvest savings in a near future. Decision-makers must consider setting LDES targets to spur market growth as soon as possible.

There are three notable types of policy support that can drive action towards net zero: long-term market signals, revenue mechanisms, and direct technology support.

Long-term market signals critically provide a more secure investment case for LDES, as they provide certainty and transparency, while more strategic planning for storage capacity targets and clearer procurement targets will aid the incorporation of LDES into inclusive grid planning. Carbon pricing and the removal of fossil fuel subsidies will help to level the playing field, while streamlining and simplifying permitting processes will be key in accelerating implementation.

Revenue mechanisms are necessary for improving project financial viability for both customers and investors. Contracts for Difference, Caps, & Floors, and 24/7 clean Purchase Power Agreements (PPAs) can all also be leveraged to achieve this. These tools provide mechanisms for ensuring the multiple value streams LDES provides are compensated and provide financial certainty.

Compared to traditional pay-as-produced renewable PPAs, 24/7 clean PPAs offer a more precise means of matching supply and demand as renewables contribute an increasing share of global generation capacity, while LDES can be leveraged to provide the required flexibility, security, and reliability.

Finally, **direct technology support** is needed to fast-track growth in public-private partnerships and accelerate innovation and delivery. Targeted R&D is needed to increase readiness levels of the least developed technologies and support for large-scale demonstrators is required to de-risk pre-commercial technologies, help expand supply chains for a growing demand, and boost investor confidence.

The value of long duration energy storage is clear, and the diversity of technologies available makes it not only an attractive solution for various geographic regions, but a practical solution for energy leaders to achieve net-zero emissions goals.