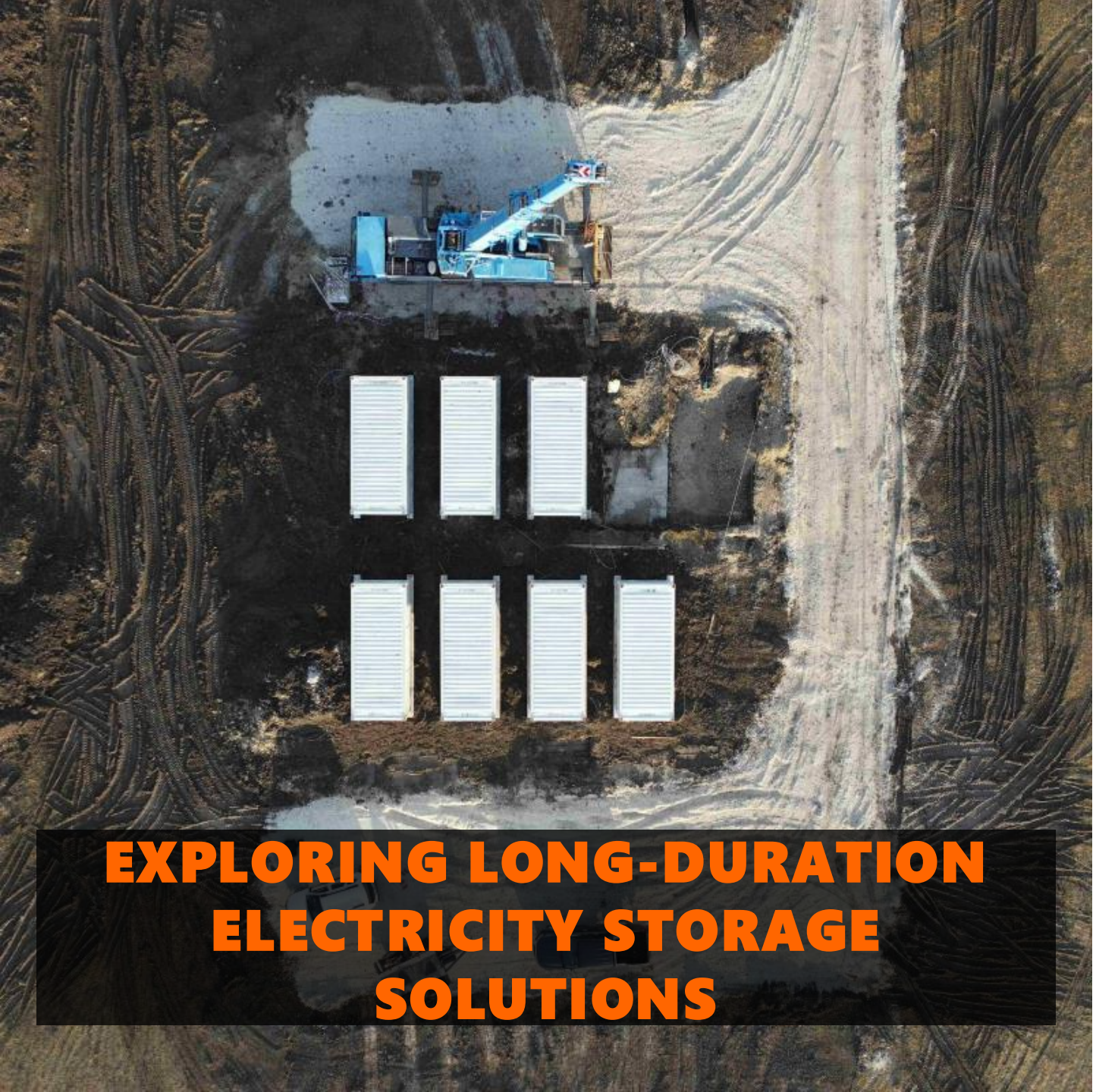

EXPLORING LONG-DURATION ELECTRICITY STORAGE SOLUTIONS

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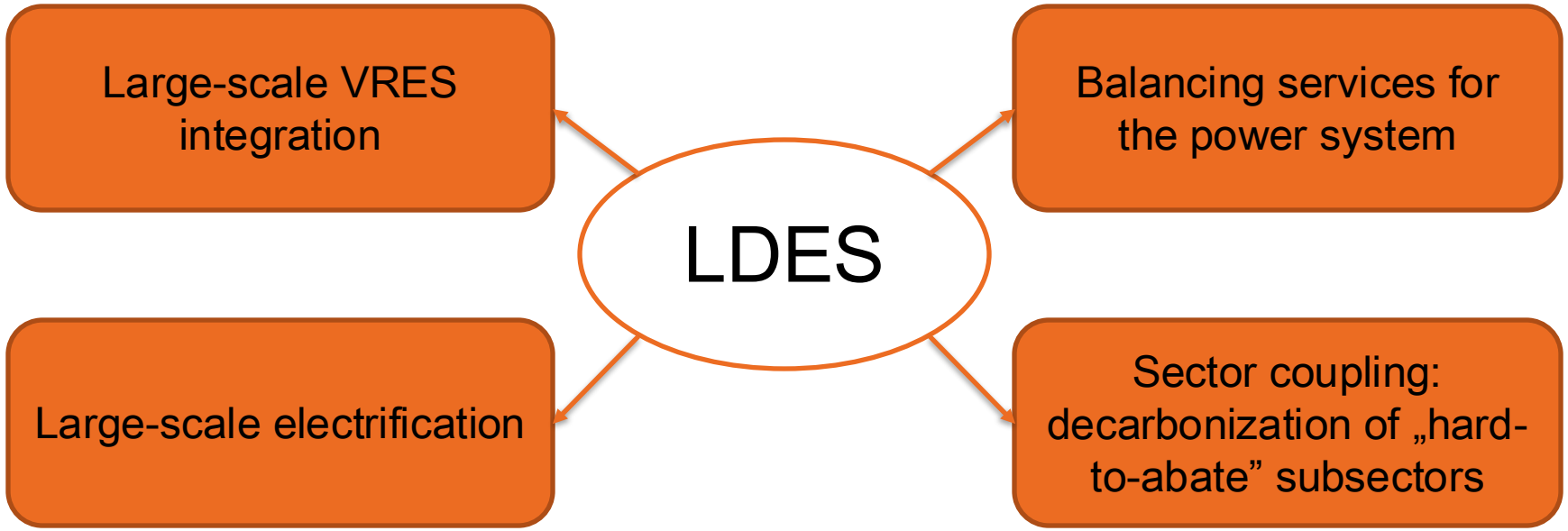
Relevance and definition of LDES



A technology that is capable to accept electricity generated by the power system, to convert it into a suitable form for storage, to keep it for a certain time and to return energy back in a form that is usable when it is needed.
(Ter-Gazarian, 2011)

LDES Technology:

- „Can stably discharge electricity at rated power for no less than **8 hours**" (California Public Utilities Commission)
- „At minimum can provide **inter-day application**" (Shan et al.(2022))
- „stores energy (…) with a discharge duration of **8 hours or more**, (…) hold energy for **extended periods**, ranging from hours to days, weeks or even seasons." (LDES Council, 2024)
- „supply duration of **at least 6 hours** at a minimum capacity of **100 MW**" (Department of Energy Security & Net Zero, UK Government, 2024)

LDES technologies

Mechanical (P-t-P)

- **Pumped Hydro**: composed of two reservoirs with elevation difference and at least one powerhouse.
- **Compressed Air Energy Storage**: uses energy to compress air into a large underground cavern.
- **Liquid Air:** Air is cooled to cryogenic temperature using a cycle of compression, cooling and expansion with associated hot and cold storage tanks.
- **Gravity-Based Systems:** replacing part of the water with a heavy piston, water pushed through the penstock to move the turbine and generate electricity.

Thermal (P-t-H)

- **Sensible Heat Storage** (e.g., molten salts, rocks, concrete): Stores energy in the temperature of material.
- **Phase Change Materials**: Utilizes a phase-transition of its storage medium.
- **Thermochemical Storage:** Employs chemical reactions (reversible endothermic/exothermic): splitting a molecular substance into products that are stored separately and rein troduced to reverse the reaction and release heat.

Electrochemical (P-t-P)

- **Flow Batteries** (Vanadium redox, Zinc-bromine): Store energy in liquid electrolytes held in tanks, scalable by adding more electrolyte volume.
- **Next-Generation Batteries** (metal-air, sodium-based, high-temperature batteries). Aim to reduce costs and longer discharge times compared to typical Li-ion.

Chemical (P-t-X)

- **Hydrogen and Synthetic Fuels**: Excess renewable electricity used to produce hydrogen (via electrolysis) or synthetic hydrocarbons, which can be stored (often in geological formations) and later converted back to electricity or used directly in industrial heat processes. Seasonal storage, sector-coupling purposes.

Characteristics of LDES technologies

Category	Technology	Technology readiness	Discharging duration (h)	Response time	Energy Capacity (MWh)	Lifetime (yrs)	Roundtrip efficiency (%)	Average capital cost ($/kW)
Mechanical	A-CAES	Early commercial	6-100	3-10 min	10-10000	20-30	40-70	700-1100
	Liquid Air	Commercial	10-72	5-10 min	10-10000	20-40	60-75	900-4500
	Gravity-based	Emerging	0-15	Seconds	4-10000 (20000)	~40	70-90	~1300
	PHS	Commercial	0-10	Seconds-5 min	100-20000	25-100	70-85	1800-3400
Thermal	Sensible heat	Early commercial	200	Min	0.1-2000		55-97%	
	Latent heat	Emerging to commercial	25-100	Min	0.1-2000		20-93%	
	Thermochemical	R&D/Emerging	n.a.	Min	0.1-2000		n.a.	
Electro-chemical	Vanadium flow	Early commercial	4-24+	Milliseconds	0.1-100	5-20	60-80%	600-1500
	Zinc bromine flow	Early commercial	4-12	Milliseconds	0.1-100	5-20	60-70%	700-2700
	Non-metal chemical	Emerging	0-200				40-50%	
Chemical (P-t-X)	Hydrogen	Early commercial	500-1000				5-50%	
	Ammonia	Early commercial	170-350				98%	
	Methanol	Early commercial	170-350				n.a.	

Source: LDES Council (2024); Shan_etal(2022), EASE (2024)

Energy system services and storage technologies according to their discharging power capacity and timescales for discharging

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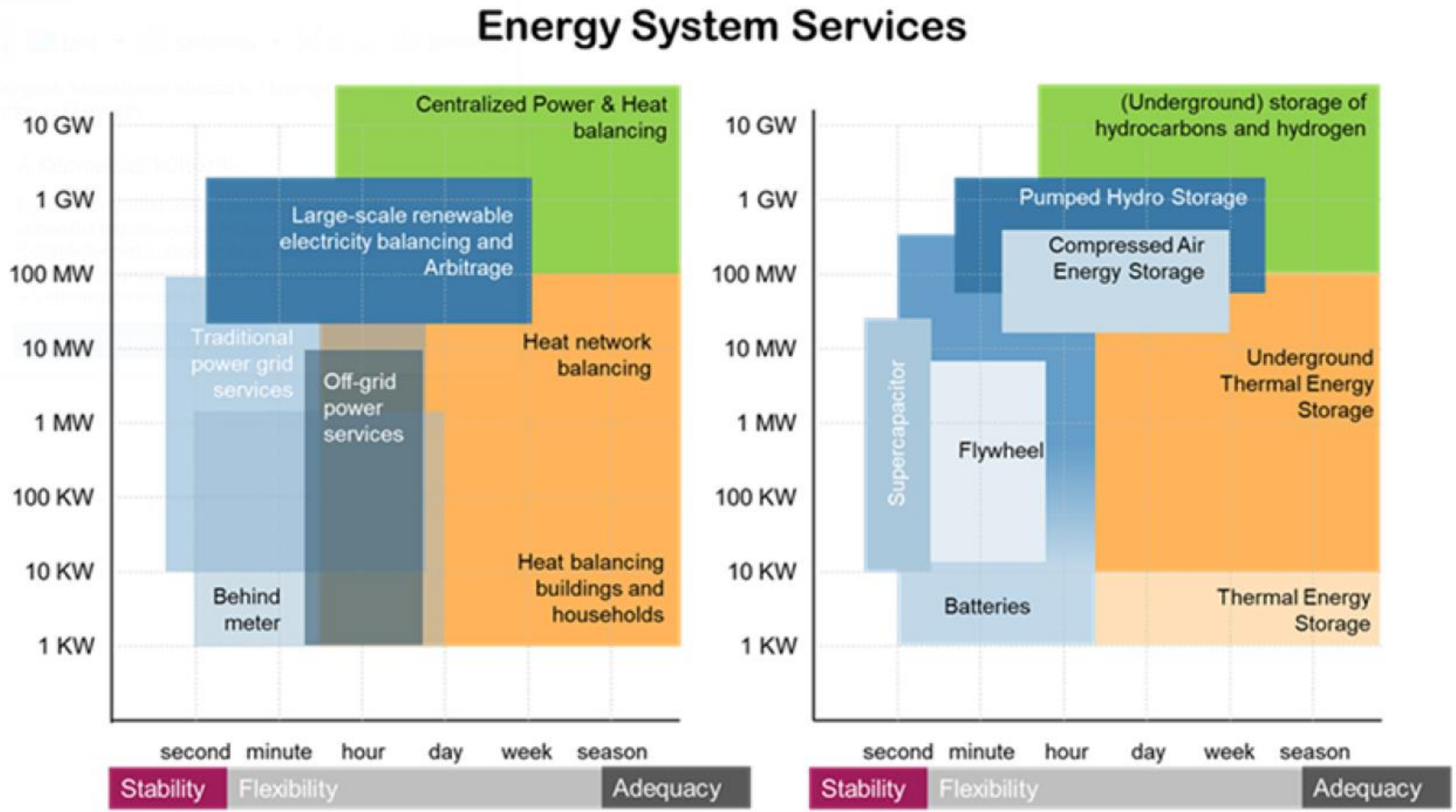

Source: EASE (2022)

LDES capacity projections

- The European Association for Storage of Energy's (EASE) estimation about energy storage targets for 2030 and 2050 (EASE):
  - Assumptions for **2030 targets**: 187 GW in total:
    - 67 GW batteries and other short duration solutions
    - **65 GW PHS** (new and existing)
    - **55 GW energy storage** (Power-to-X-to-Power) to replace a portion of gas turbine flexibility in 2030 (short and long duration ES)
      - (**40 GW electrolyser** target as stated in the European Hydrogen Strategy is taken into account)
  - Assumptions for **2050 targets**: 600 GW total:
    - **65 GW PHS** (new and existing)
    - Long duration energy storage technologies are expected to reach **between 128 GW and 264 GW**. An average of 200 GW LDES is considered.
    - 120 GW of V2G based on scenario of European EV deployment
    - An additional 50 GW of stationary batteries are assumed.
    - To meet the total energy storage flexibility needs in 2050 as much as 165GW, could be filled by P2X solutions
- Long Duration Energy Storage Council's (LDES) project tracker data (worldwide):
  - Estimates for LDES (8hrs+) cumulative capacity by **2035**: 222 GW, compared to 110 GW level by 2020. Of which:
    - In Europe: **56 GW**, North America: 65 GW, Asia: 63 GW
    - 76% PHS (90% today), 11% new type mechanical, 5% electrochemical, 8% thermal.

Horizon calls on LDES

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- Mechanical LDES:
  - 2 calls, €21 million in total, TRL: 4-5;
  - Development of new pumped-hydro storage; Supporting power grid stability, where hydro and CAES are listed.
- Thermal LDES:
  - 2 calls, €33 million in total, TRL: 6-7;
  - Underground thermal energy storage in urban areas; Thermal energy storage solutions for solar thermal plants.
- Electrochemical:
  - 1 call, €15 million, TRL: 4-5;
  - Cost-effective next-generation batteries for long-duration stationary storage.
- Technology independent:
  - 1 call, €14 million, TRL: 7-8;
  - Cross-regional network and market model for optimisation of long duration storage

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Thank you for your attention!

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