Net-zero power

Long duration energy storage for a renewable grid

Introduction prior to panel

March 2022

LDES Long Duration Energy Storage Council

McKinsey & Company

The LDES Council was founded in 2021 to address some of the big questions on the role of energy storage to achieve net zero

Technology providers

Highview Power, AZELIO, Form energy, ENERGYDOME, VOLTSTORAGE, ENERVENUE, ALUMINA ENERGY, ceres, e-zinc, Quidnet Energy, SaltX Technology, ENLIGHTEN, TORC, eos, Stiesdal, ESS INC, INVINITY ENERGY SYSTEMS, MALTA, ECHOGEN power systems, redflow, MAGALDI, Ambri, KRAFTBLOCK, cellcube, EnergyNest

Anchors

Industry and services customers

RioTinto, Google, Microsoft, COMPASS datacenters

Capital providers

Breakthrough Energy

Equipment manufacturers

ALFA LAVAL, INNIO, SIEMENS energy, Baker Hughes, Sumitomo SHI FW, VOITH

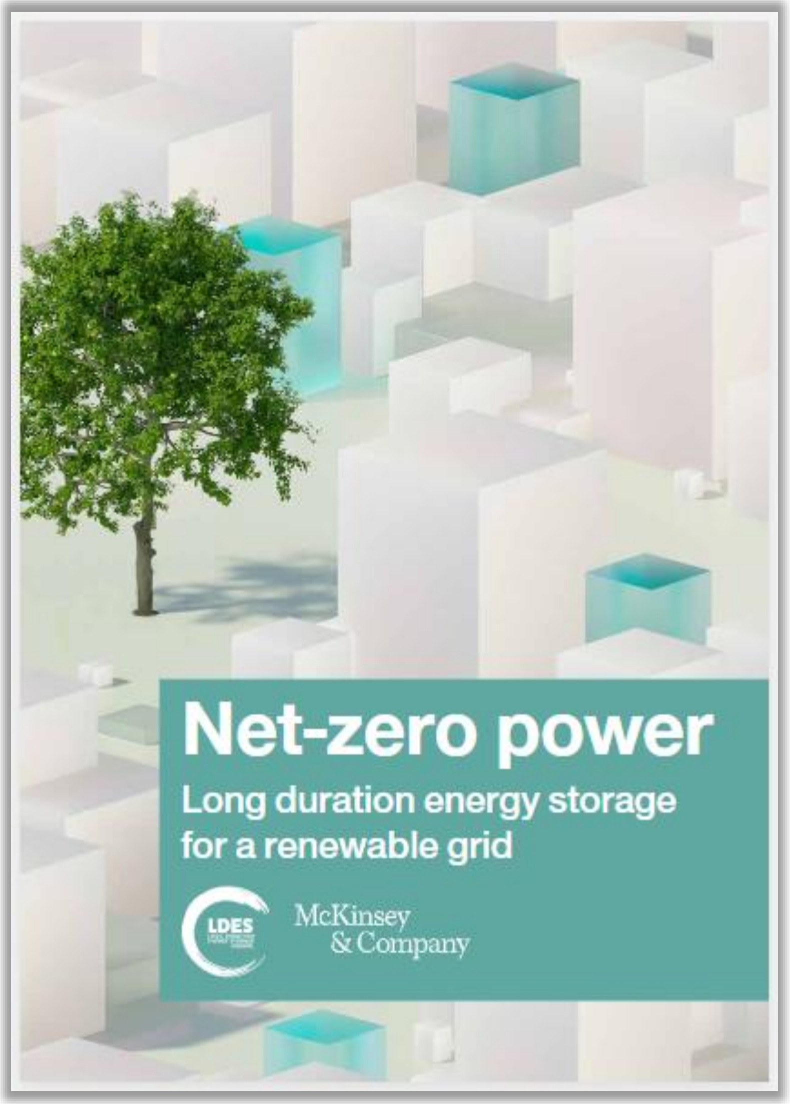
Low-carbon energy system integrators & developers

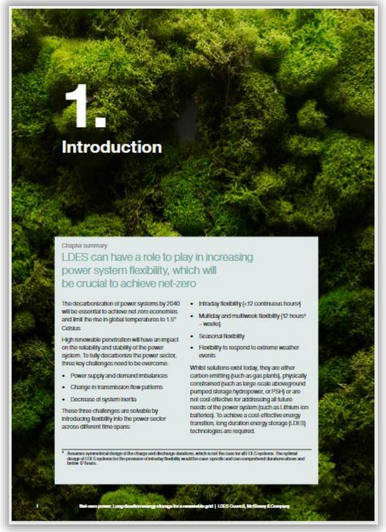
bp, Greenko, NEOM, TotalEnergies, corre energy, Ørsted, Shell, Reliance Industries Limited

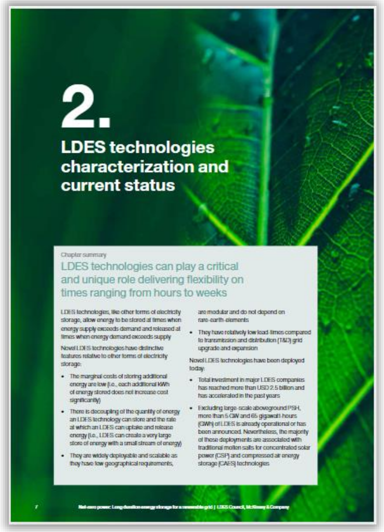
Key principles of the LDES Council

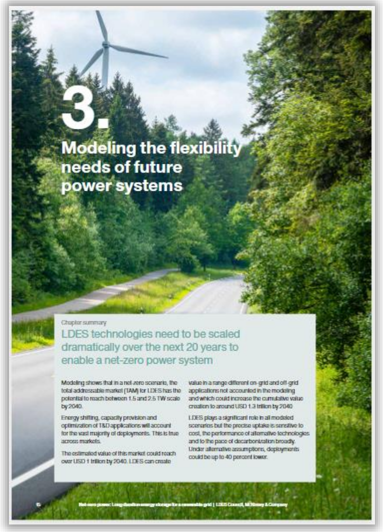
- CEO-led
- Global
- Fact-based
- For societal benefit
- All types of energy storage, not just electrochemical

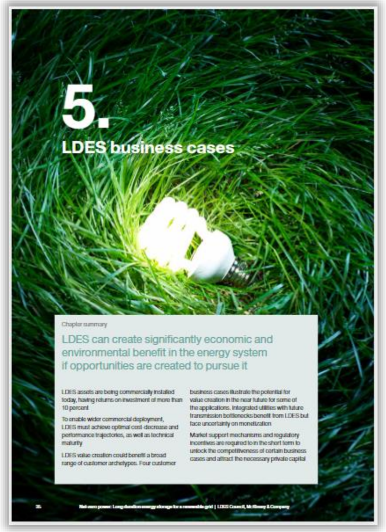
The inaugural report of the LDES Council was launched at COP26











Findings: LDES will play a major role in net-zero power systems

Renewable penetration and LDES cost-down potential…

… leads to widescale LDES deployment and positive business cases

60-70%

% renewables of overall capacity for widespread LDES deployment

1.5-2.5 TW

Total deployed LDES by 2040

USD 1.5-3 tr

Total investment in LDES capex required by 2040

~60%

LDES cost reduction expected by 2040, driven by scale, innovation and supply chain improvements

3-15%

IRR range for example modelled LDES applications[1]

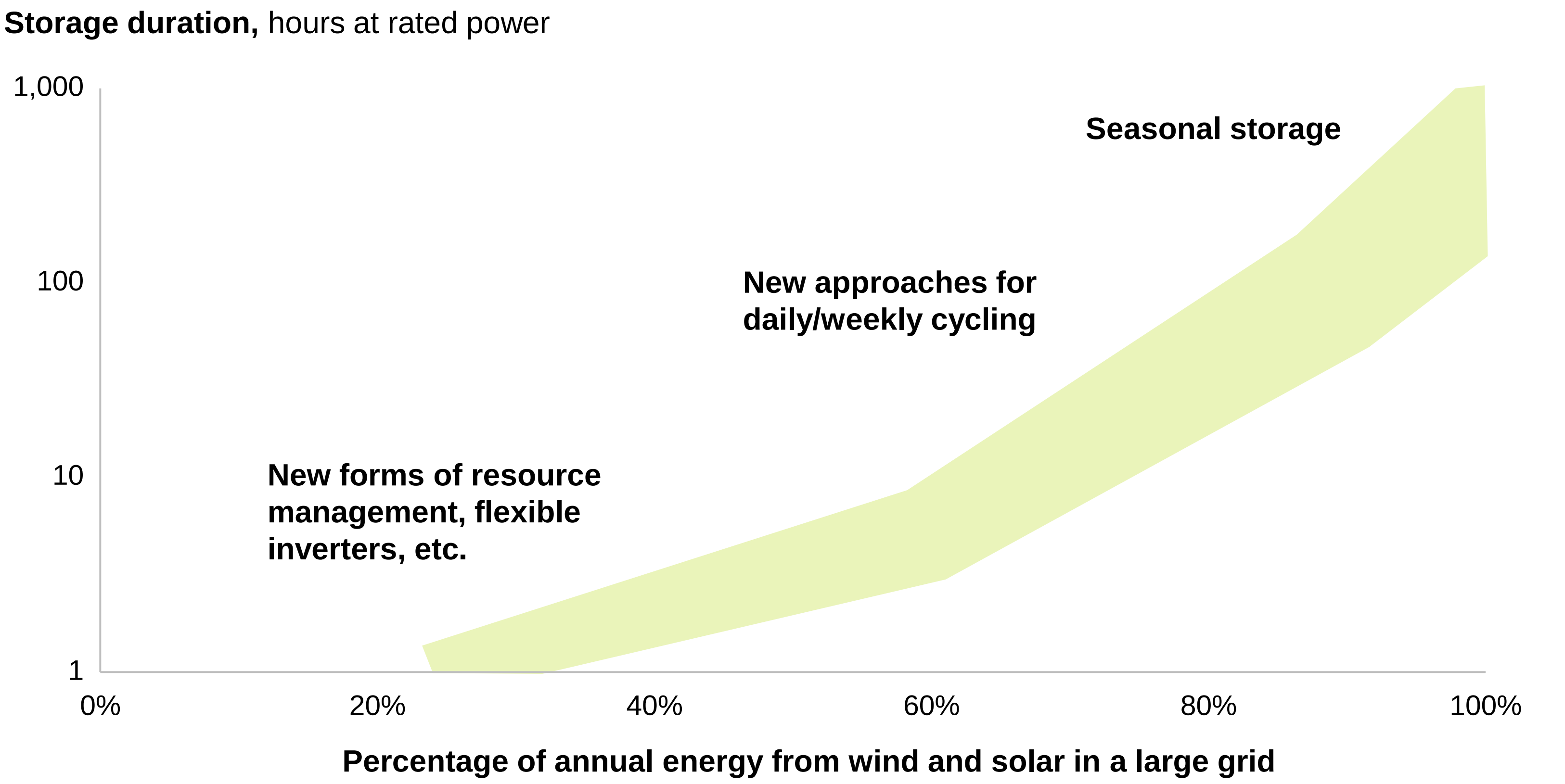
>50%

LDES as portion of all installed power flexibility capacity in 2040

1. Excluding potential improvement from implementing market mechanisms, regulatory adjustments, and carbon prices

Flexibility is critical for decarbonisation of power systems

Adoption curve of longer flexibility durations accelerates at 60-70% RE penetration



RES integration leads to new system challenges

- Power supply and demand not always in balance
- Transmission flow changes potentially require costly and lengthy transmission upgrades
- Retirement of conventional, synchronous generators creates need for new sources of grid support services, e.g., reactive power, inertia

Source: Advanced Research Projects Agency–Energy

LDES typically offers two major value propositions

Energy shifting

Time horizon	Role of storage	Typical solution
Intraday	Balance variable daily generation with load	**8-24 hours LDES**
Multiday, multiweek	Support multi-day imbalances Absorb surplus generation to avoid grid congestion	**24+ hours LDES**
Seasonal duration	Support during seasonal imbalances Mitigate extreme weather events	**Hydrogen**

+

Grid services

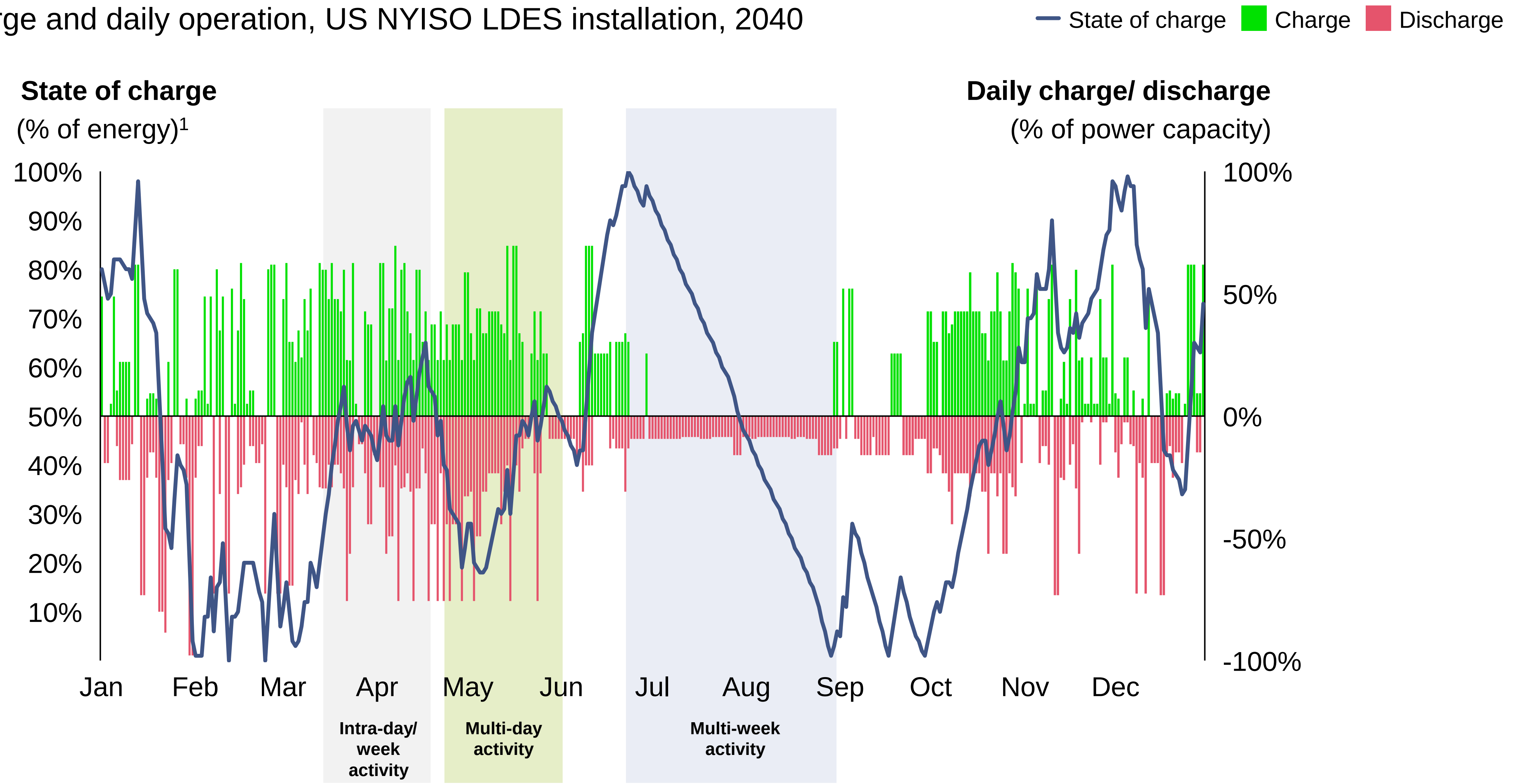
Grid services offered by LDES

- **Inertia**
- **Fast frequency response (FFR)**
- **Primary/secondary/tertiary reserve**
- **Reactive power/voltage control**
- **Short circuit level improvement**
- **System restoration/ black start**

Note: services are technology-specific

We observe LDES playing multiple roles across intra-day, multi-day and multi-week cycling

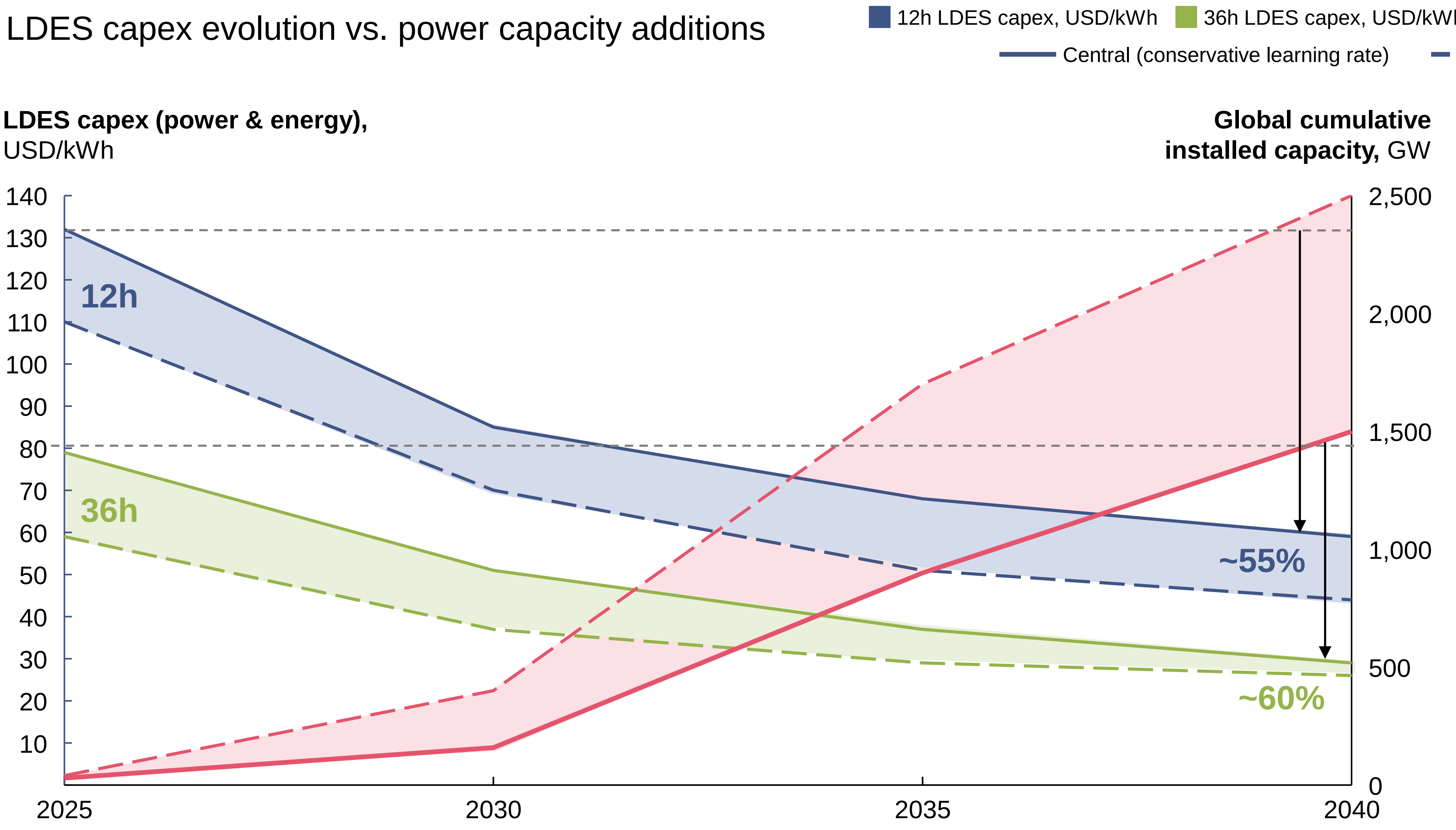
State of Charge and daily operation, US NYISO LDES installation, 2040



Source: McKinsey Power Model, 2040 US results

Cost performance is expected improve sharply (-60% by 2040), boosting capacity deployment

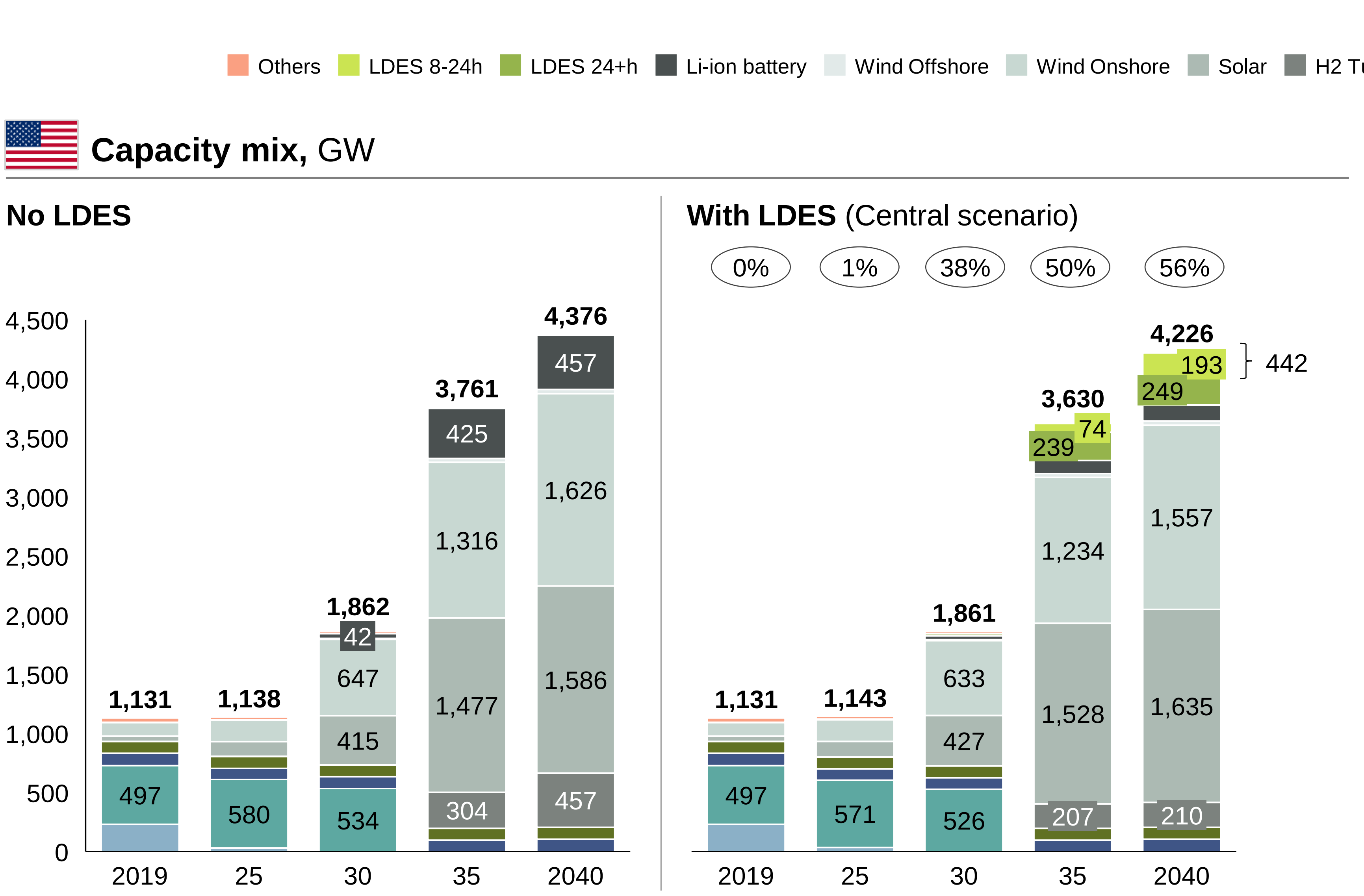
LDES capex evolution vs. power capacity additions



Insights

Cost reduction driven by
- Scale effects
- Technology advancements
- Increasing supply chain efficiency

In the US, LDES could make up ~56% of new flexible capacity



Insights

LDES archetypes expected to play major role within "new flexible capacity" (i.e. Li-ion, H2 turbines, LDES)

Until 2030, existing gas limits LDES

By 2040, >50% of new flexible capacity might be LDES systems

Source: McKinsey Power Model

LCOS used to compare cost competitiveness of LDES in realistic operating conditions

Capex of LDES solution, construction, balance of system

O&M opex costs

Replacement intervals and costs

Round-trip efficiency (RTE)

Ancillary consumption, self-discharge

Cost of charging energy

$$\text{LCOS} = \frac{\text{Installation cost} + \text{Lifetime discounted O\&M cost} + \text{Lifetime discounted charging cost}}{\text{Total lifetime discounted electricity discharged}}$$

Throughput

- Discount rate
- Nameplate capacity
- Nominal duration
- Utilization

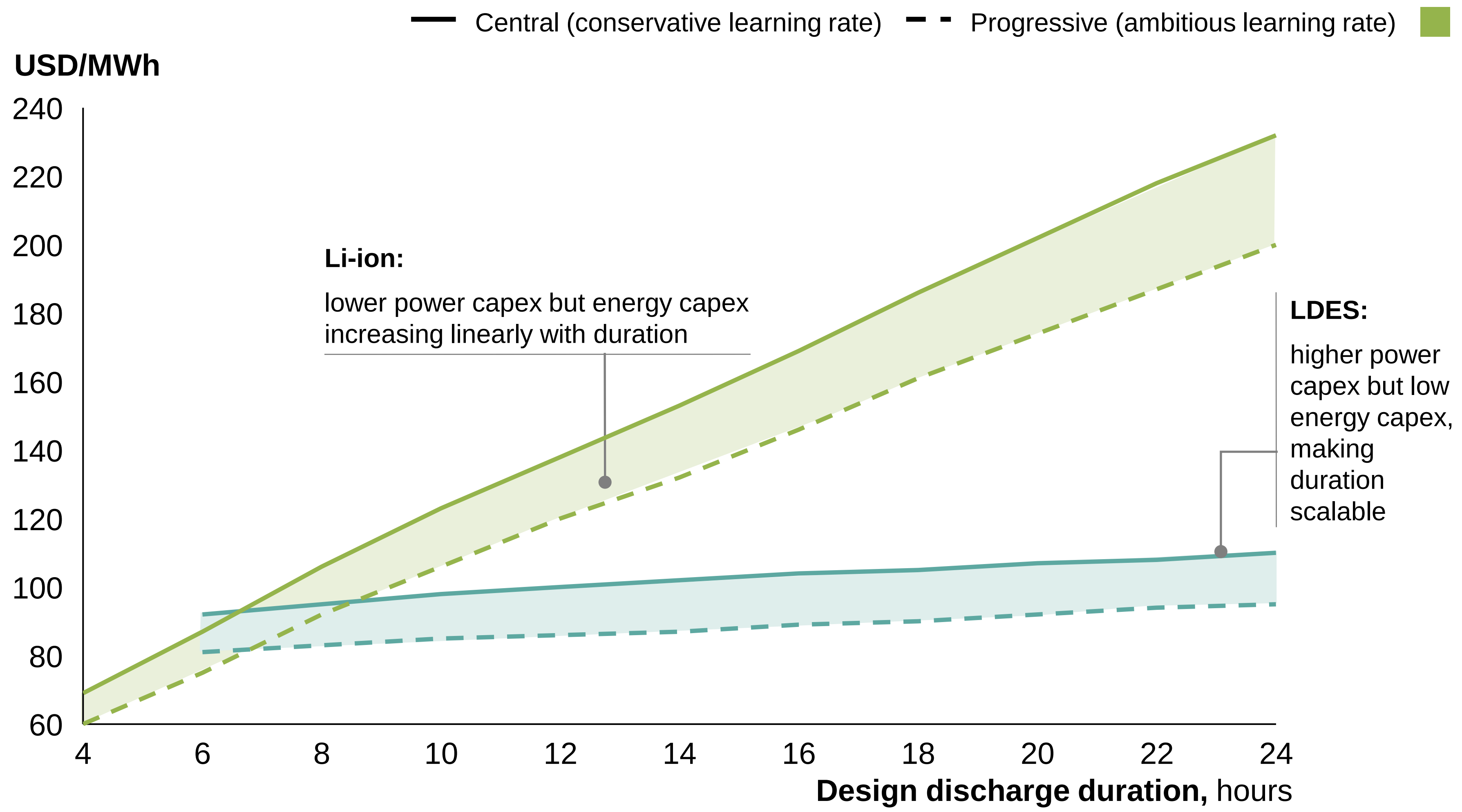
Insights

LCOS is comparable to LCOE and represents a tool for cost comparison of electricity storage

LCOS depends heavily on the operations of the system but allows a like-for-like comparison

LDES likely cost-competitive for durations >6-8 hours

2030 energy storage LCOS competitiveness by duration for selected technologies (USD/MWh)



Insights

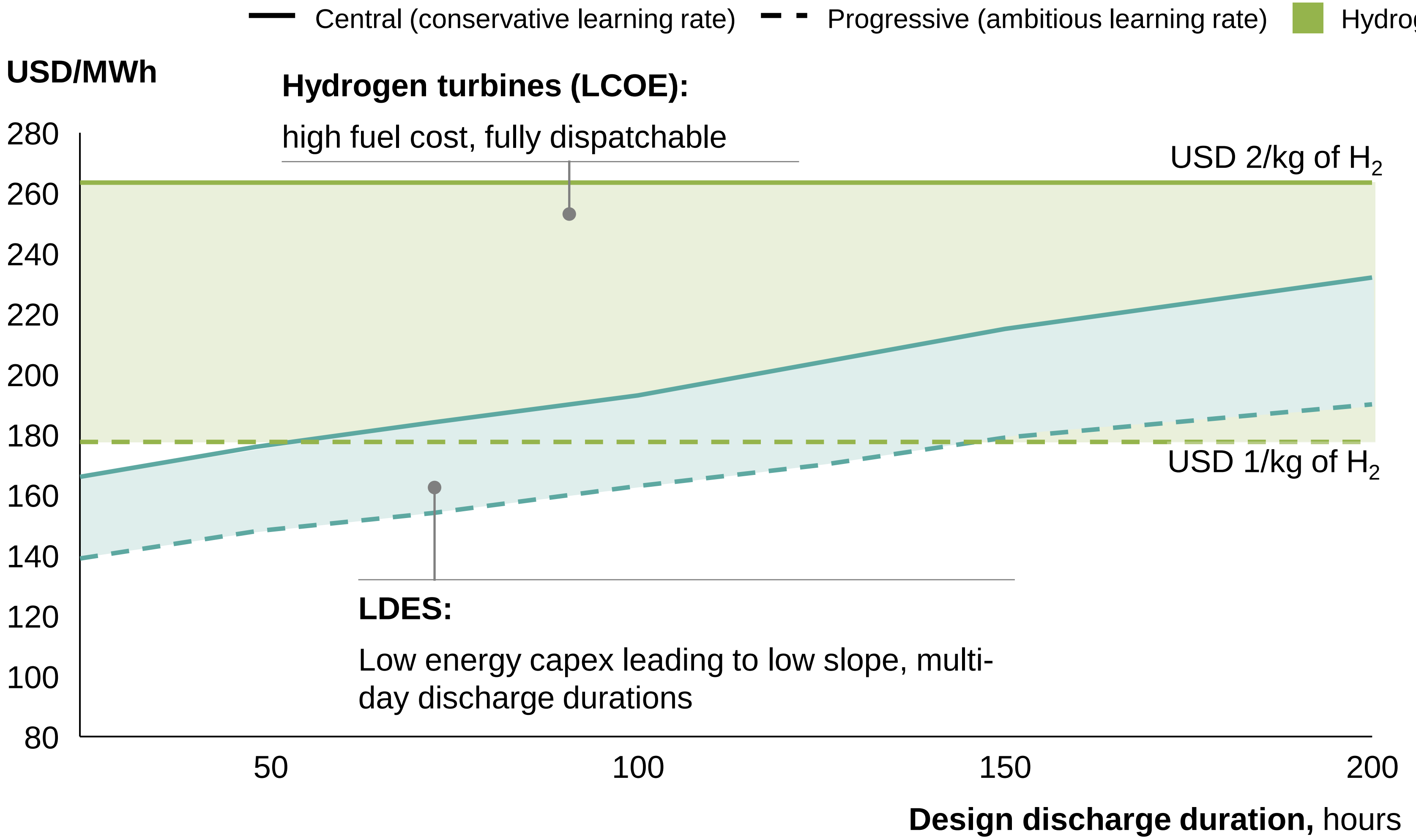
>8 hours duration, due to low energy capex, LDES offers lower LCOS

Source: LDES Council member technology benchmarking

McKinsey & Company

LDES likely cost-competitive for discharge durations <100-150 hours

2030 energy storage LCOS competitiveness by duration for selected technologies (USD/MWh)



Insights

Hydrogen turbines are likely competitive above 150 hours duration

Source: LDES Council member technology benchmarking

Seven drivers of potential value for LDES assets – note that only a subset of these will apply depending on the application

T&D optimi-zation

Savings from replacing costly transmission build-out with relatively more cost-efficient investment in storage[1]

Capacity provision

Capacity payments for availability of dispatchable power

RE curtailment reduction

Revenues from storing and discharging otherwise curtailed renewable energy,[1] under limited transmission capacity

Grid support

Compensation for offering grid stability services[2] as conventional generation plants (e.g., coal) – which traditionally offer stability – are phased out

Firmed PPA premiums

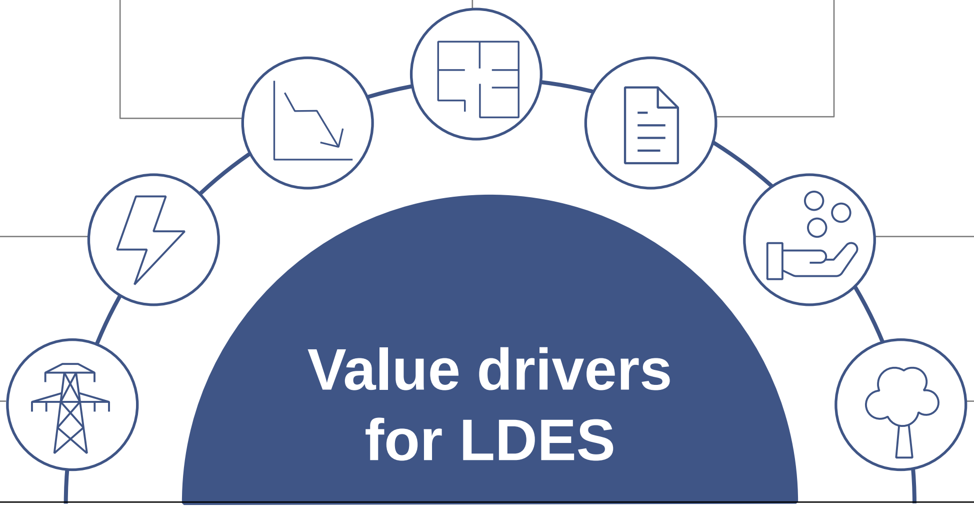
Premiums paid by customers with targets on 100% RE looking to, e.g., decarbonize operations, hedge market volatilities

Production cost savings

Electricity production cost savings, e.g., from replacing onsite diesel generation

CO_2e cost savings

CO_2e cost savings originating from reducing/displacing existing fossil generation and not having to pay a carbon price for the associated emissions



1. Including cost savings on compensation paid to curtailed RE suppliers and redispatched power suppliers (depending on local regulatory regime)
2. Stability services include: short circuit, dynamic voltage control, inertia

Business cases for diverse LDES use cases explored

Value drivers for LDES

Applies to case study | Does not apply

Customer example	IRR 2025 (potential improvement)	T&D optimi-zation	Capacity provision	RE cur-tailment reduction	Grid support	Firmed PPA premiums	Produc-tion cost savings	CO_2e cost savings
Integrated utilities with significant RE build-out and transmission bottlenecks	**~3%** (+11%)	Applies to case study	Applies to case study	Applies to case study	Applies to case study	Does not apply	Does not apply	Applies to case study
RE developers or owners selling corporate RE PPAs with firmed capacity	**~7%**	Does not apply	Does not apply	Does not apply	Does not apply	Applies to case study	Does not apply	Does not apply
Isolated island power systems	**~7%** (+5%)	Does not apply	Does not apply	Does not apply	*May apply for larger systems*	Does not apply	Applies to case study	Applies to case study
Industrial customers (e.g. mine)	**~15%** (+4%)	Does not apply	Does not apply	Does not apply	*May apply for larger systems*	Does not apply	Applies to case study	Applies to case study

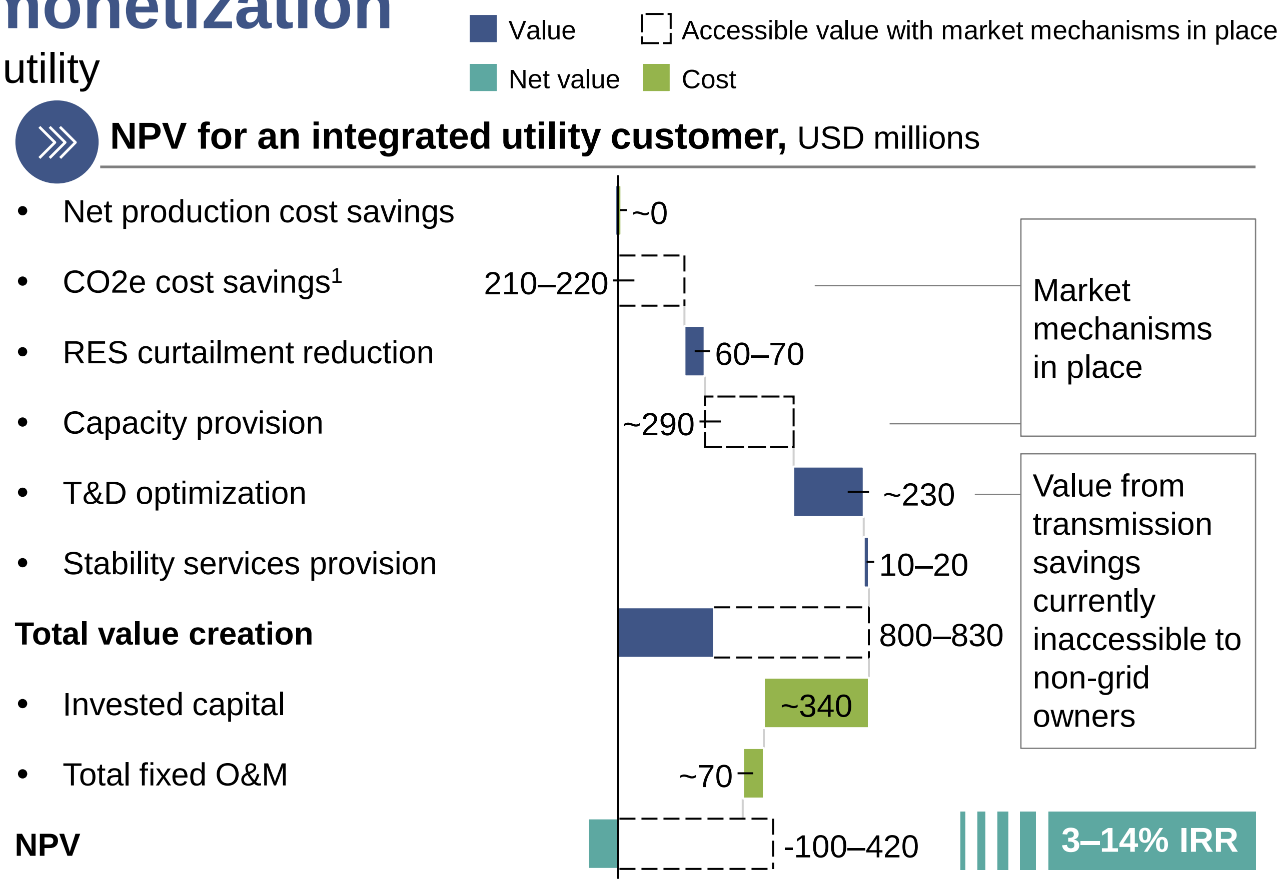
1| A US case study shows how integrated utilities can benefit from multiple LDES applications but face uncertainty on monetization

Case example: US-based utility

Customer profile

- Integrated utility in the US that depends on gas-peaking plants for reliability
- Geographic divide between generation and demand with transmission bottlenecks
- Challenges building new transmission
- LDES assets to displace gas-peaker plants and improve RE utilization
- Potential LDES system: 200 MW/2,000 MWh (10 hours); systems of longer durations are also seeing demand driven by utilities' long-term needs

NPV for an integrated utility customer, USD millions



Assumptions

Final investment decision date	Commercial operation date	CO_2e price scenario	WACC
2023	*2025*	*Base case*	*6%*

1. CO2e cost savings originate from the opportunity of replacing a gas peaking plant with LDES

Key unlocks

Range of NPV is USD 100 mn to 420 mn, of which most comes from transmission optimization, capacity provision, and CO_2e cost savings

To access the higher end of this range, market mechanisms would have to be fully in place to ensure the benefits can be captured, e.g., for transmission owners not permitted to own storage assets

LDES
LONG DURATION ENERGY STORAGE COUNCIL

McKinsey & Company

The analysis uses the McKinsey Power Model and 10,000+ data points from tech providers

Country requirements and constraints (electrification, CO2, RPS, policy)

Exogenous fuel demand (e.g., H2, EV charging)

Asset cost and technology performance

Assumptions from other sources (e.g., NREL, BNEF, H2 Council)

NREL NATIONAL RENEWABLE ENERGY LABORATORY

BloombergNEF

Hydrogen Council

MPM Model optimization

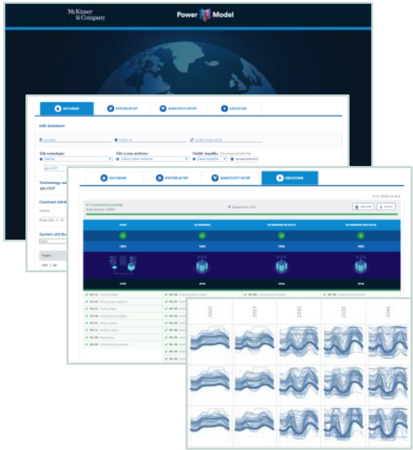
Lowest cost pathway for net zero power system

Total addressable market for LDES

Capacity and generation mix, incl. flexibility

Societal cost savings

Investment required



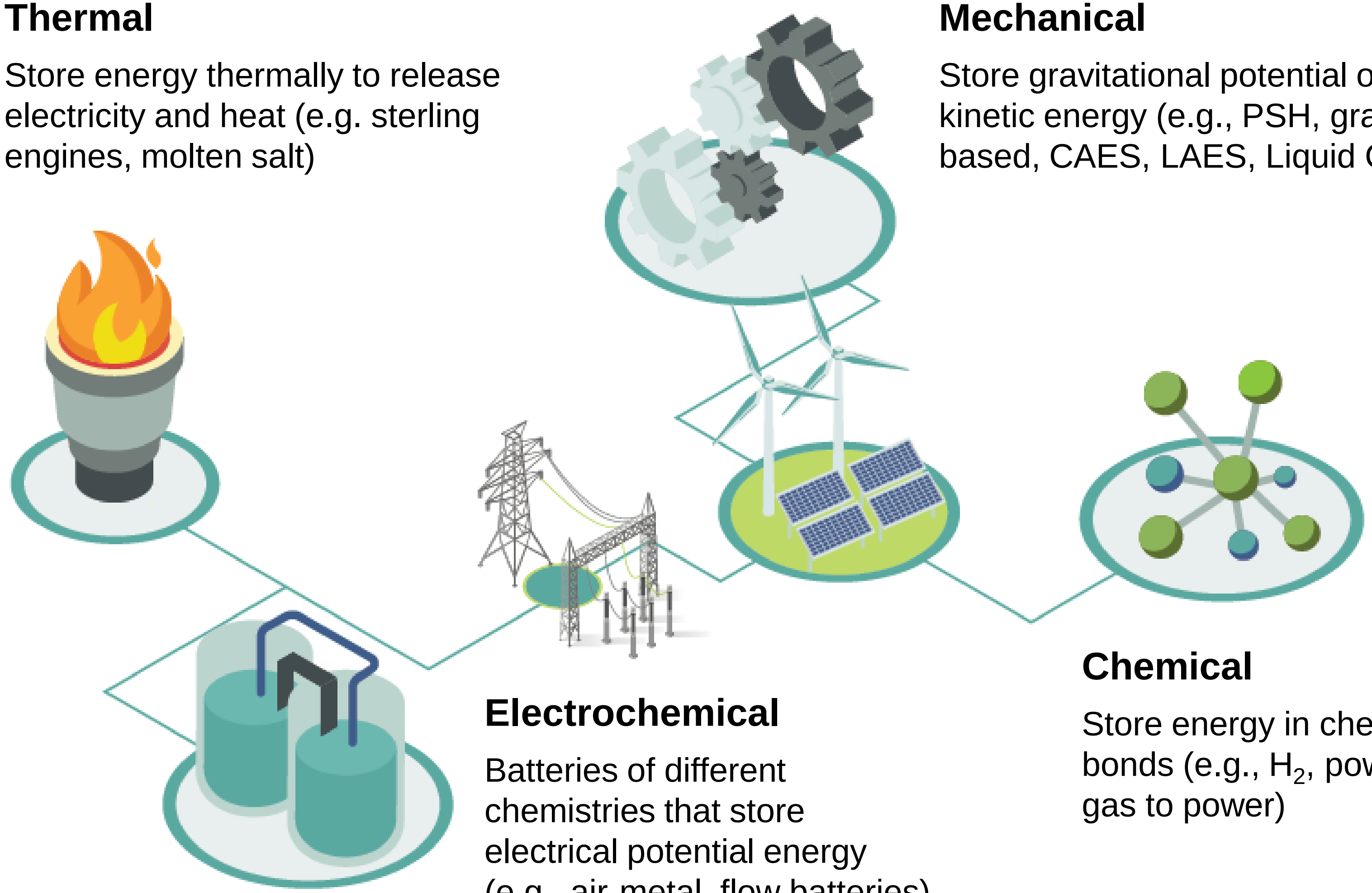
MPM determines which **investments and operating decisions minimize costs** to meet net zero targets

10,000+ data points from members processed by independent clean team

Coupled with deep insights from Council members, McKinsey, external experts

Respected public sources leveraged

Many technological approaches tackle the same fundamental need



Thermal

Store energy thermally to release electricity and heat (e.g. sterling engines, molten salt)

Mechanical

Store gravitational potential or kinetic energy (e.g., PSH, gravity based, CAES, LAES, Liquid CO_2)

Electrochemical

Batteries of different chemistries that store electrical potential energy (e.g., air-metal, flow batteries)

Chemical

Store energy in chemical bonds (e.g., H_2, power to gas to power)

Significant opportunity for LDES across major power markets

Summary of bulk power modeling results in key regions

Before 2030 | 2030–40

Modeled markets	Cumulative LDES installed power capacity, GW	Cumulative LDES installed energy capacity, TWh	Average installed duration, hours 2030	Average installed duration, hours 2040
US	440–600	30–40	15–20	70–75
Europe	140–290	5–20	20–30	50–60
India	125-250	15-25	8–10	95–130
Japan	40–80	1–5	14	35–90
Australia	20–40	0.5–1	15	25
Chile	10–15	0–0.5	10–15	18
Extrapolation to RoW	1–230 490–840	0–5 20–40	14	63
Total	1,300–2,300	80–135	14	64

Source: McKinsey Power Model