Net-zero power
Long duration energy storage for a renewable grid

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Thermal-Mechanical-Chemical Energy Storage Workshop
Washington, August 3-4th 2022

MALTA

LDES LONG DURATION ENERGY STORAGE COUNCIL

The Long Duration Energy Storage (LDES) Council was launched at COP26

Signing of statements of intent and launch ceremony

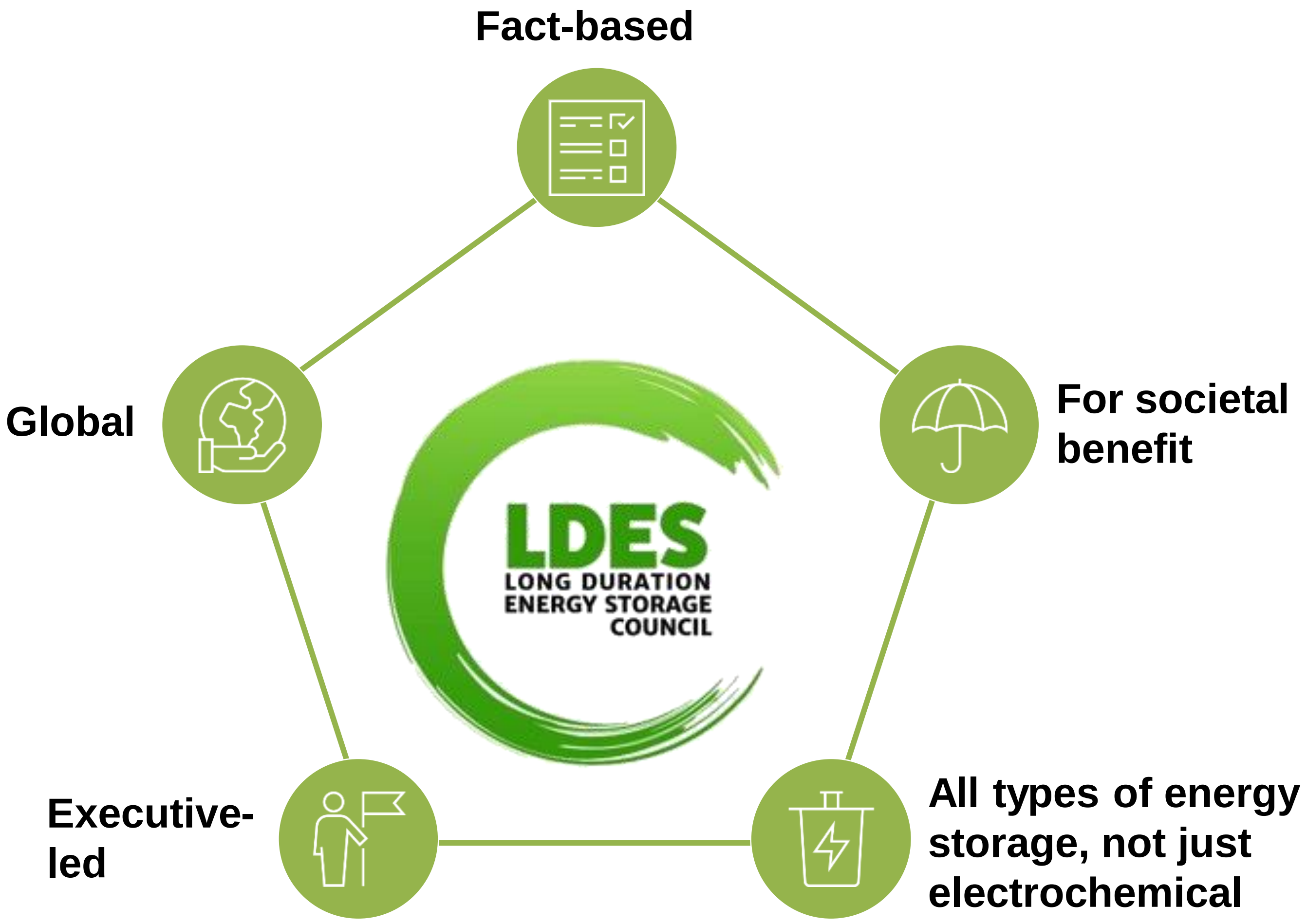
Introduction to the Council

Networking lunch

Source: LDES Council 2021

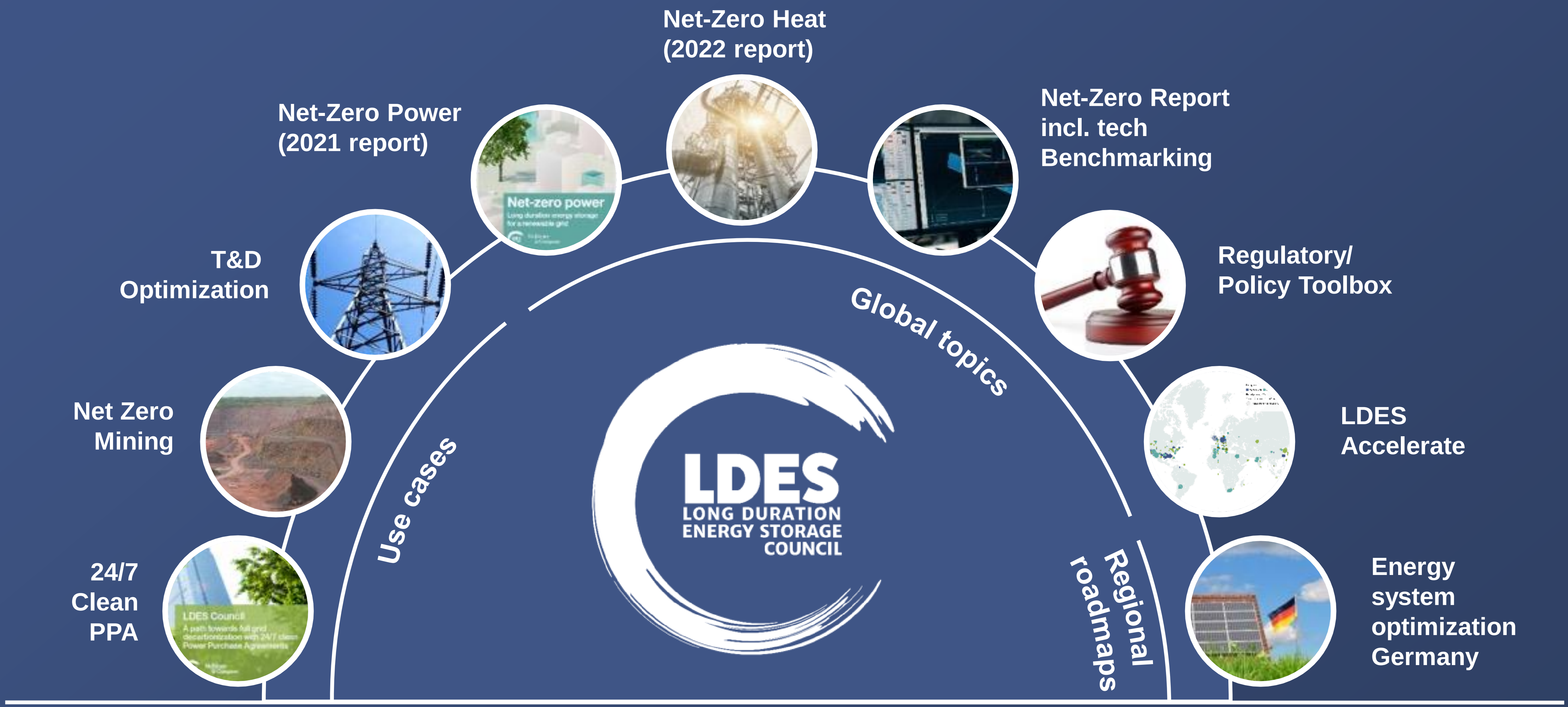
50+ Leading Companies Have Joined the LDES Council to Accelerate Decarbonization

Key Principles of the LDES Council



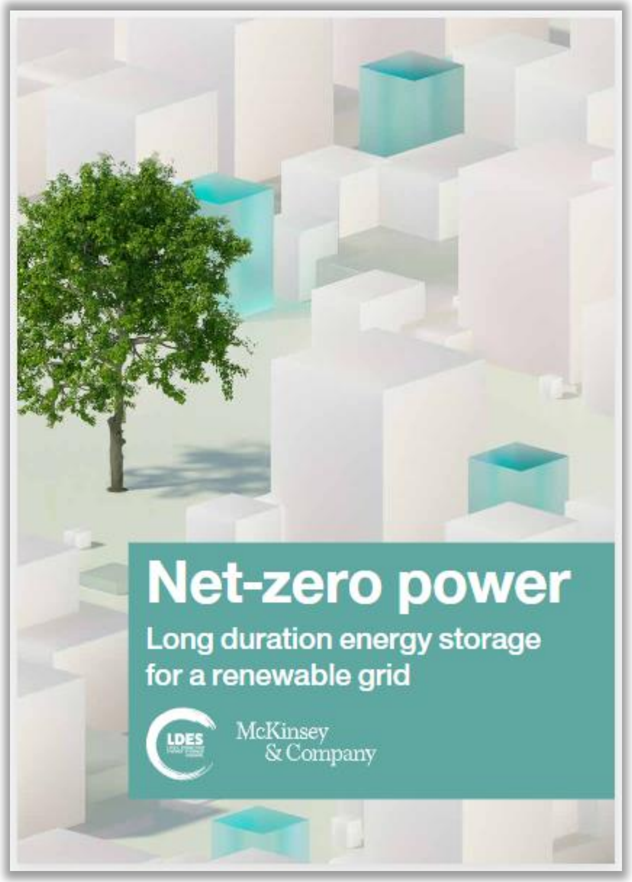
The LDES Council is an independent body with its own governance structure, with the mission to accelerate energy decarbonization through the scale-up of LDES

In 2022, the Council will build upon 2021 insights supported by the expertise and engagement of its growing membership



Inaugural analytical report released in November 2021

Net-zero power: *Long duration energy storage for a renewable grid*



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

Renewable penetration and LDES cost-down potential…

60-70%

% renewables of overall capacity for widespread LDES deployment

~60%

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

… leads to widescale LDES deployment and positive business cases

1.5-2.5 TW

Total deployed LDES by 2040

USD 1.5-3 tr

Total investment in LDES capex required by 2040

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

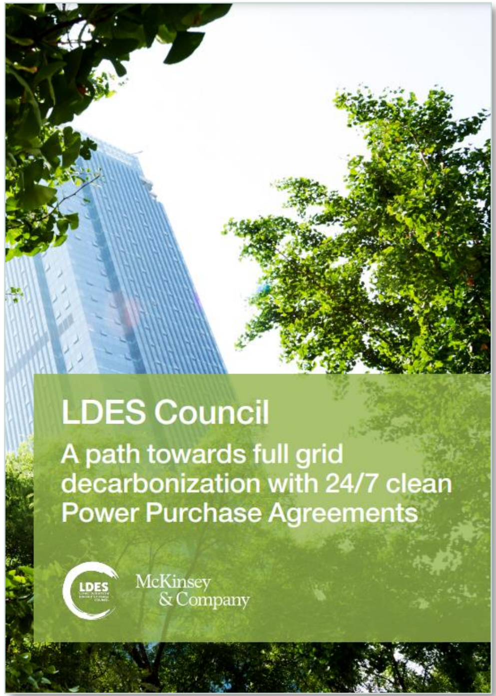
https://www.mckinsey.com/business-functions/sustainability/our-insights/net-zero-power-long-duration-energy-storage-for-a-renewable-grid#

The LDES Council leverages the deep expertise of its member base to publish insights on the topic of energy flexibility

Flagship 2021 net-zero power report (November 2021)

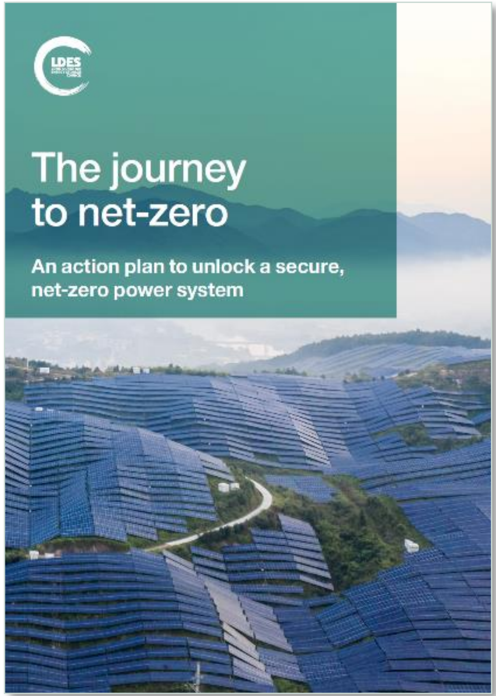
https://ldescouncil.com/assets/pdf/LDES-brochure-F3-HighRes.pdf

A path toward full grid decarbonization with 24/7 clean power purchase agreements (May 2022)



https://ldescouncil.com/assets/pdf/2205_ldes-report_247-ppas.pdf

Policy toolbox report (June 2022)

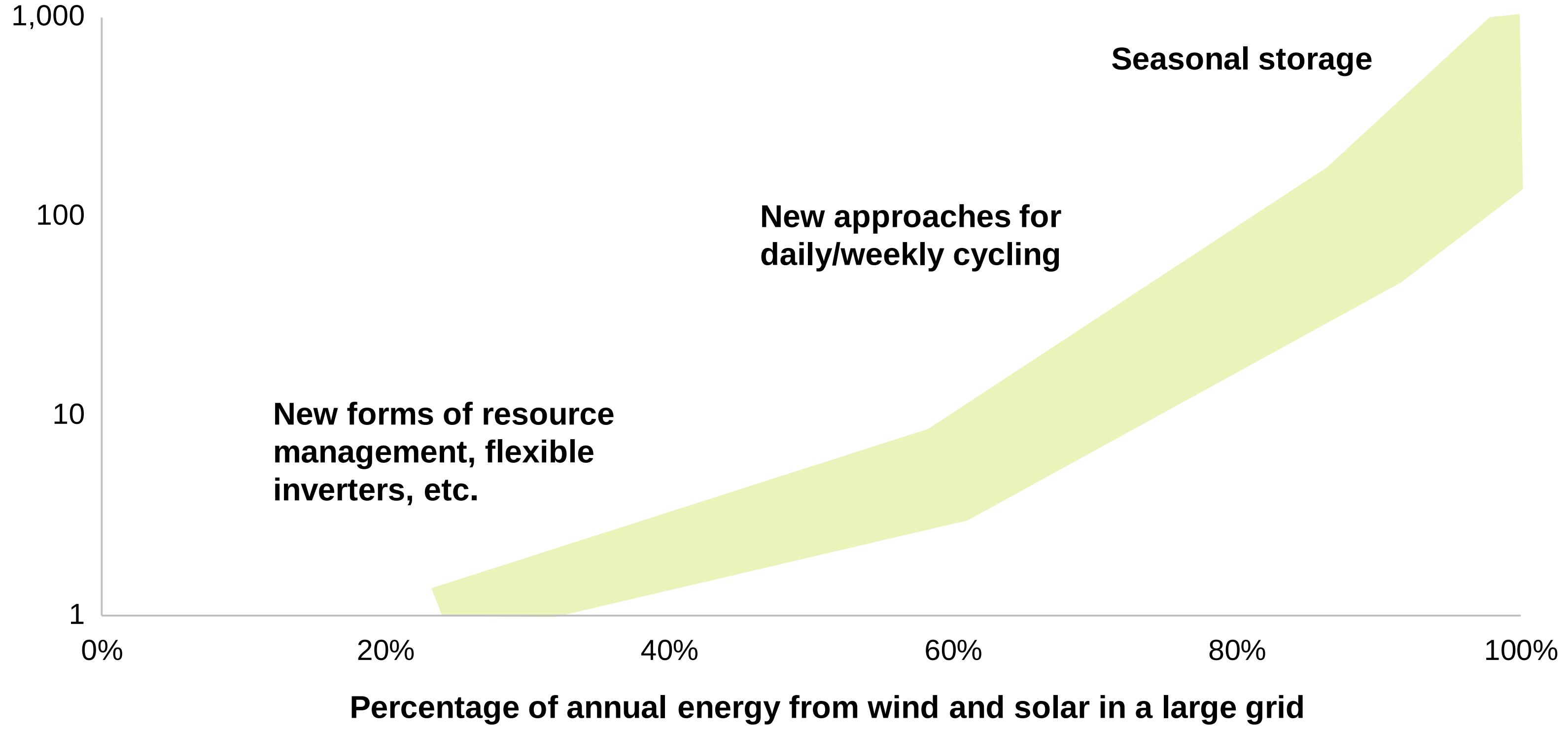


To be published June 21, 2022

Flexibility is critical for decarbonisation of power systems

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

Storage duration, hours at rated power



Source: Advanced Research Projects Agency–Energy

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

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

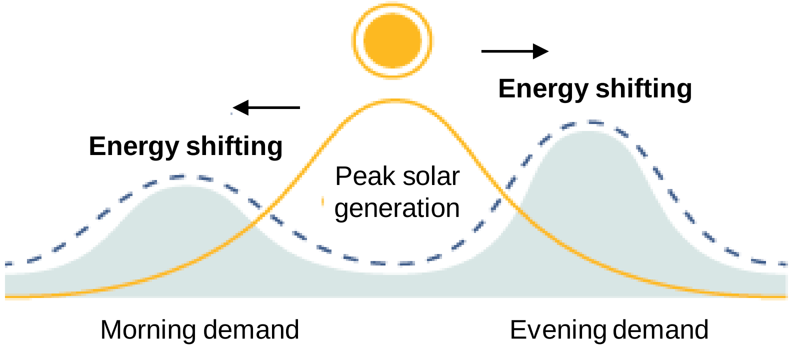
Grid services offered by LDES

- **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

Long Duration Energy Storage deployed in different contexts

LDES unlock many different use cases

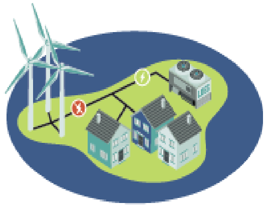


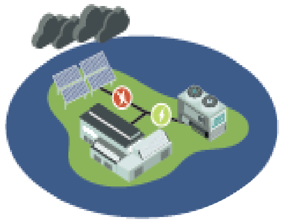
Energy shifting

+

Grid services

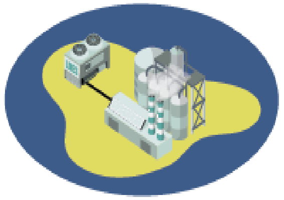
Optimising transmission & distribution investment





Firming renewable PPAs

Supporting island grids



Supporting industries with remote and unreliable grids

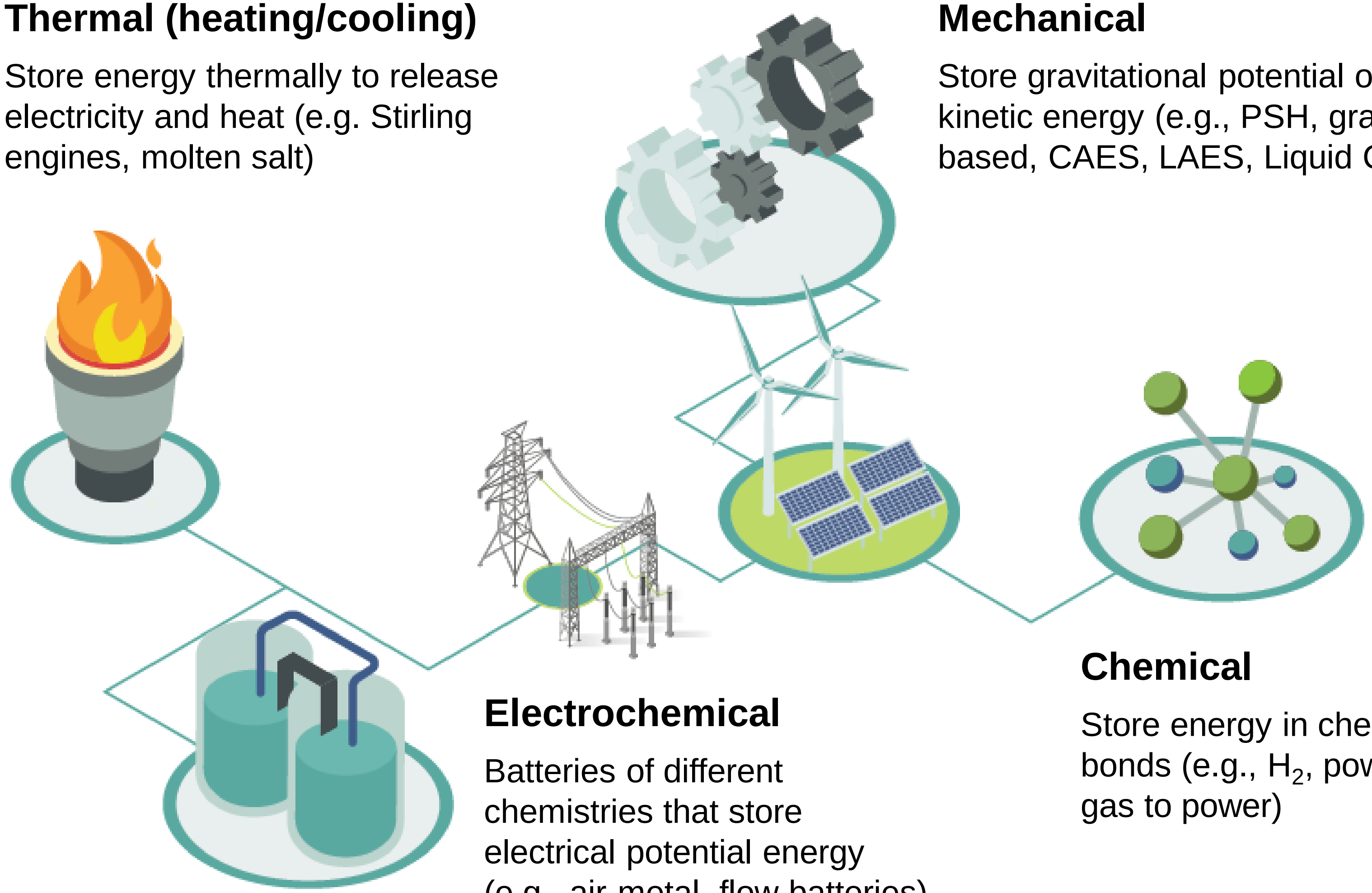
Many technological approaches tackle the same fundamental need

Thermal (heating/cooling)

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

Mechanical

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



Electrochemical

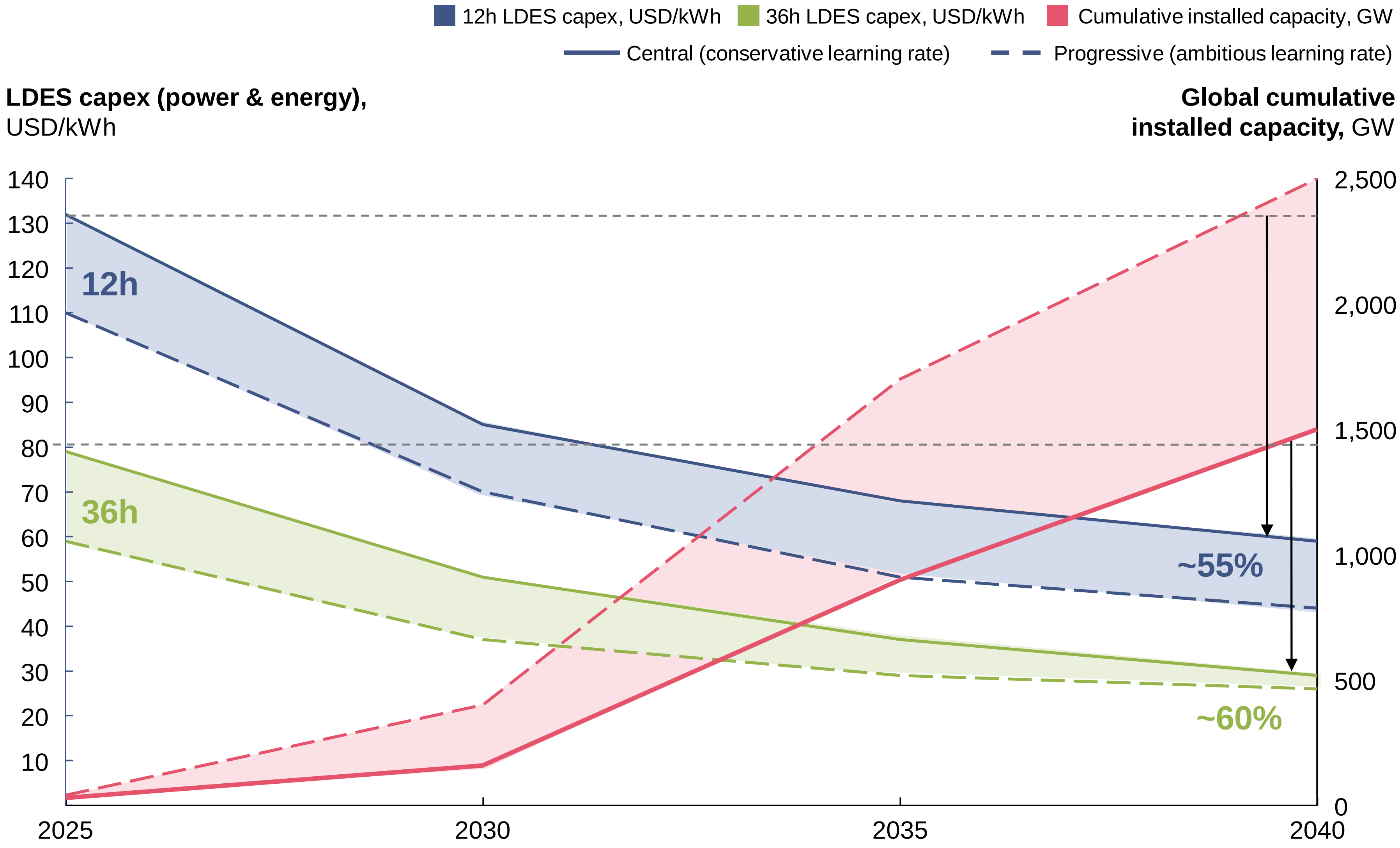
Batteries of different chemistries that store electrical potential energy (e.g., air-metal, flow batteries)

Chemical

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

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

LDES capex evolution vs. power capacity additions



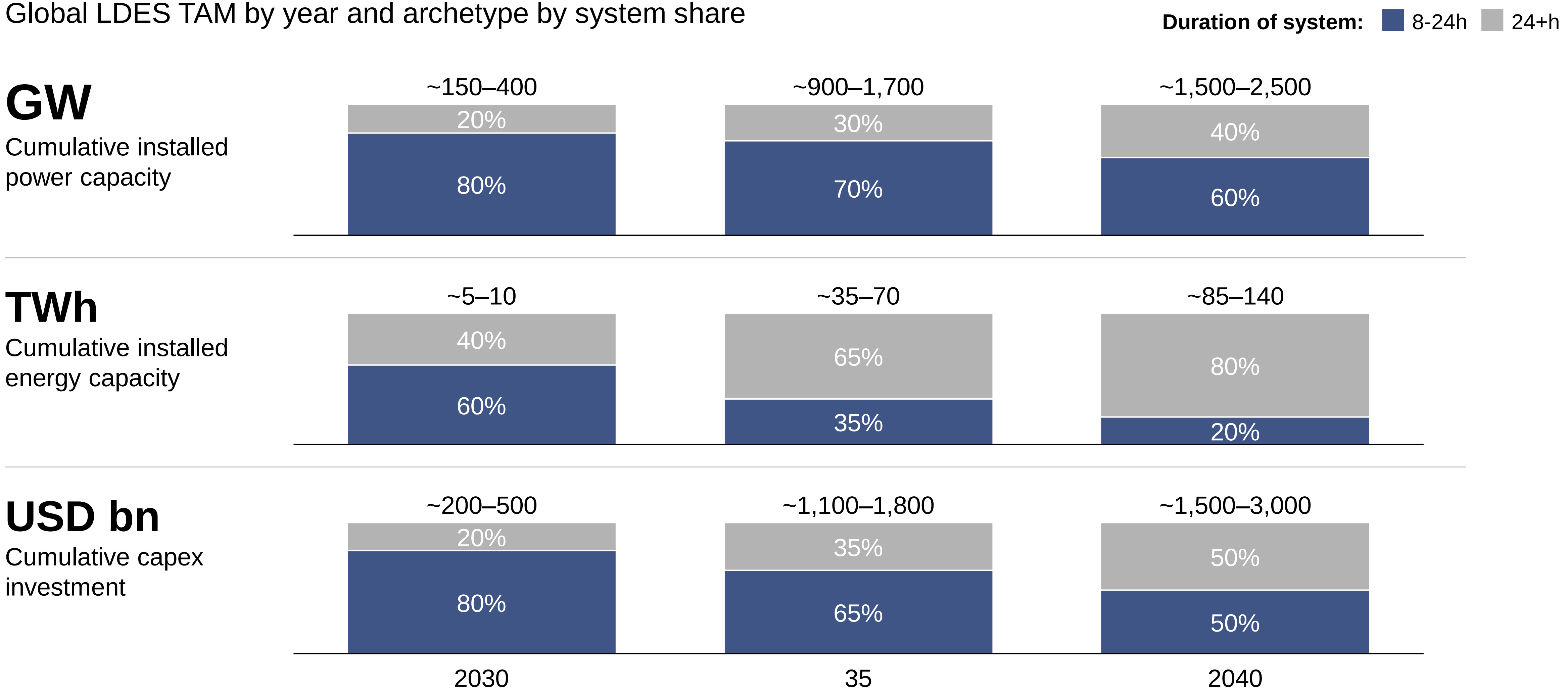
Insights

Cost reduction driven by

- Scale effects
- Technology advancements
- Increasing supply chain efficiency

Average system duration increases over time

Global LDES TAM by year and archetype by system share



Significant opportunity for LDES across major power markets

Summary of bulk power modeling results in key regions

Before 2030 | 2030–40

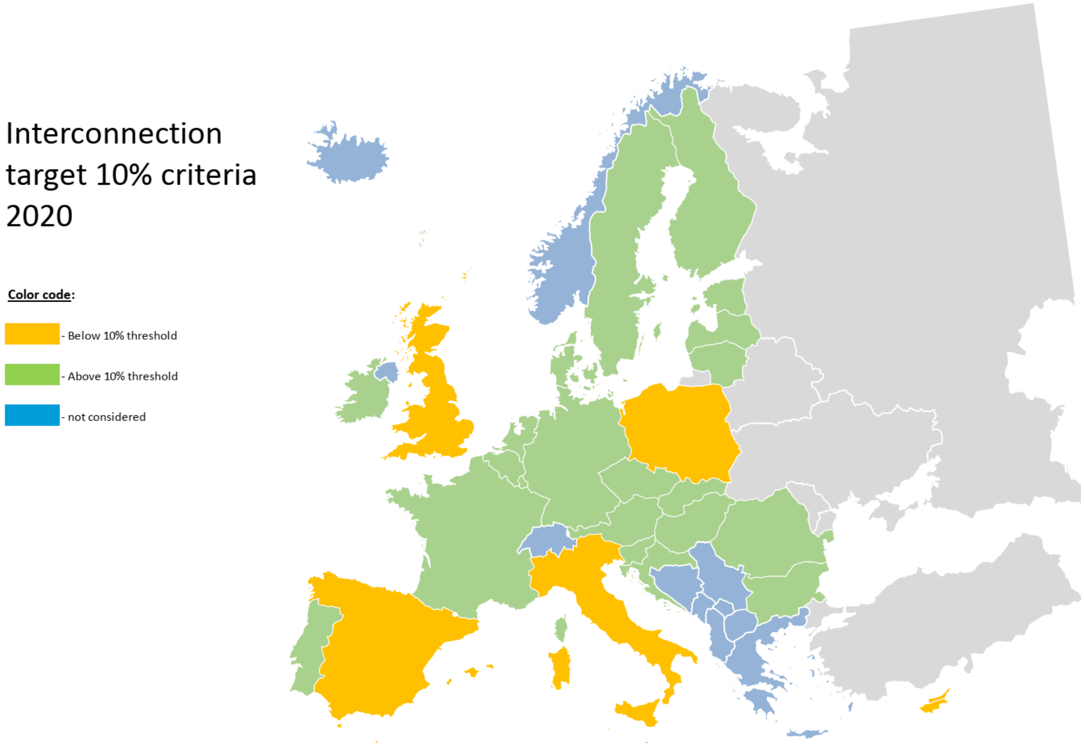
Modeled markets	**Cumulative LDES installed power capacity,** GW	**Cumulative LDES installed energy capacity,** TWh	**Average installed duration,** hours 2030	2040
US	440–600	30–40	15–20	70–75
Europe[1]	140–290	5–20	20–30	50–60
India	125-250	15-25	8–10	95–130
Japan	40–80	1–5	14	35–90
Australia	20–40	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

1. Europe incl. UK

Source: McKinsey Power Model

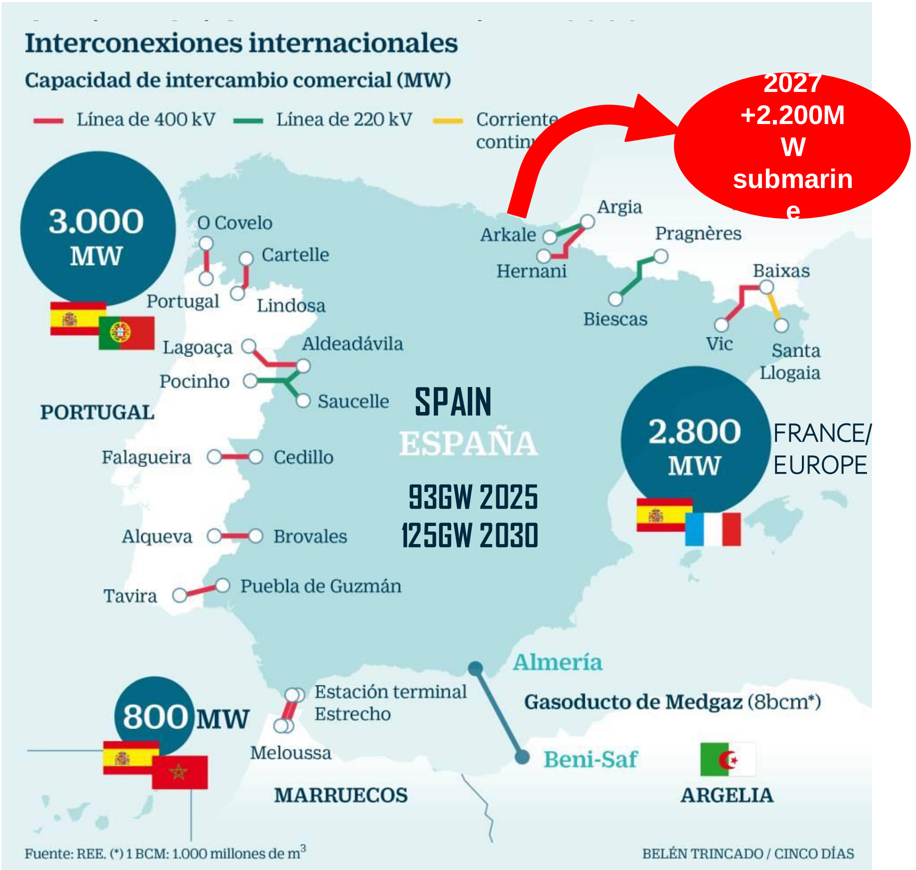
Europe needs long duration synchronous storage

Interconnection target 10% criteria 2020



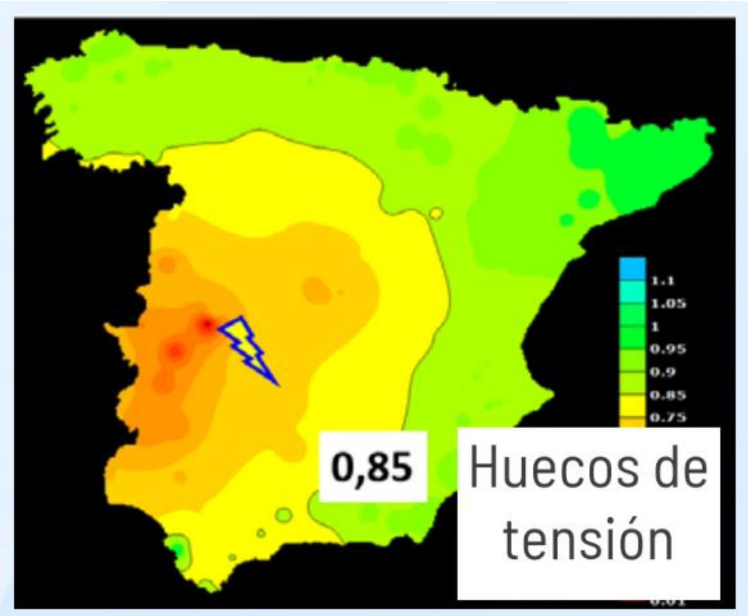
Fullfillment of the 10% interconnection target in 2020

https://eepublicdownloads.entsoe.eu/clean-documents/tyndp-documents/TYNDP2018/rgip_CSW_Full.pdf



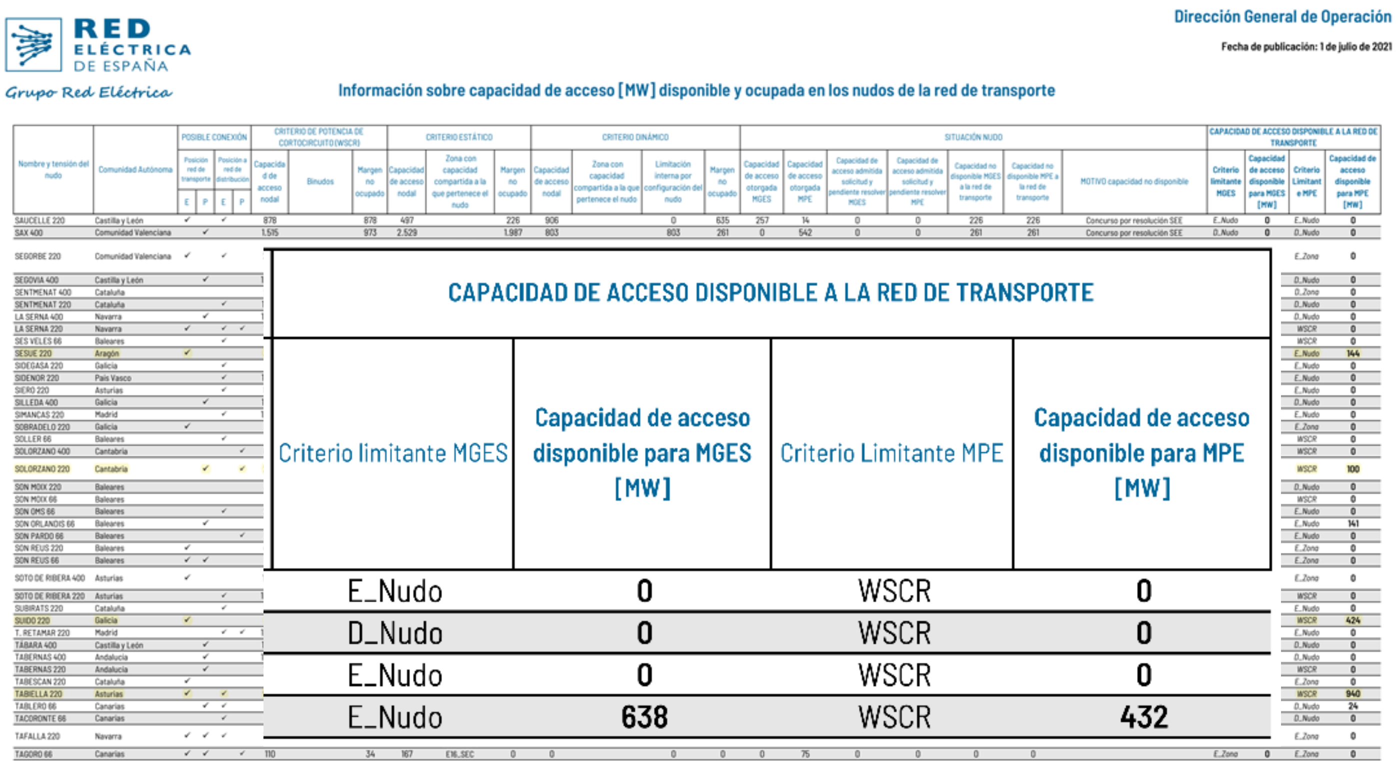
https://cincodias.elpais.com/cincodias/2017/07/10/companias/1499700974_956333.html

Example Spain: 15GW new synchronous generation open in Spanish Grid



Almost 15.000MW excess capacity available for synchronous generators like Malta PHES

https://www.ree.es/sites/default/files/01_ACTIVIDADES/Documentos/AccesoRed/Presentacion_SG_CG_10Sept20.pdf



RED ELÉCTRICA DE ESPAÑA

Grupo Red Eléctrica

Dirección General de Operación

Fecha de publicación: 1 de julio de 2021

Información sobre capacidad de acceso [MW] disponible y ocupada en los nudos de la red de transporte

CAPACIDAD DE ACCESO DISPONIBLE A LA RED DE TRANSPORTE

Criterio limitante MGES	Capacidad de acceso disponible para MGES [MW]	Criterio Limitante MPE	Capacidad de acceso disponible para MPE [MW]
E_Nudo	0	WSCR	0
D_Nudo	0	WSCR	0
E_Nudo	0	WSCR	0
E_Nudo	638	WSCR	432

https://www.ree.es/sites/default/files/12_CLIENTES/Documentos/Capacidad_de_acceso_a_RdT_ED_1sep21.pdf

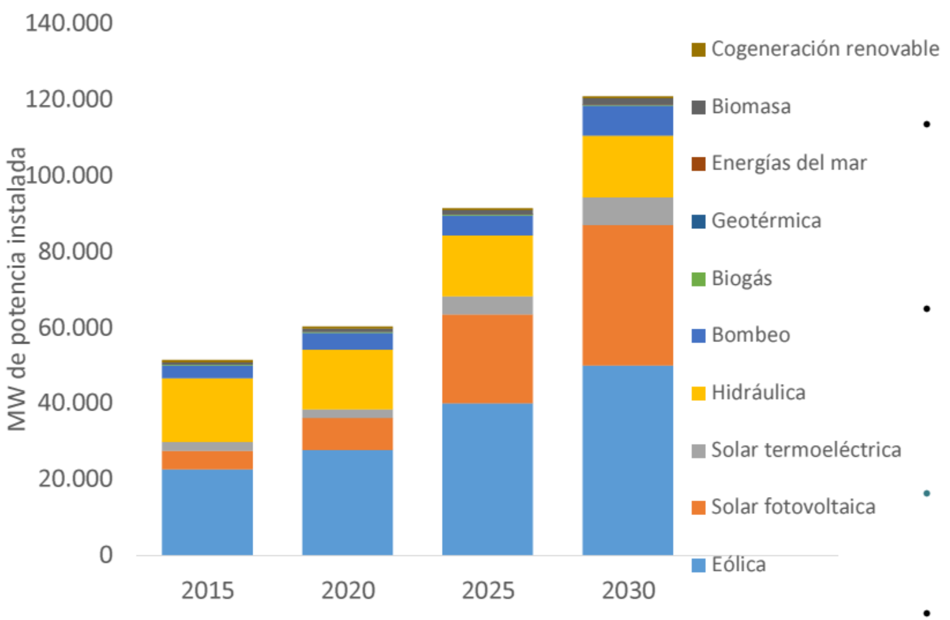
Spain’s National Energy and Climate Plan (PNIEC)

MINISTERIO PARA LA TRANSICIÓN ECOLÓGICA

IDAE

PniEC Energía y Clima

2030 RENEWABLE ELECTRICITY: 74%



Note: the exact breakdown of power generation will depend on the evolution of cost, deployability and performance of each technology (or combination of technologies).

- **57 GW of new RES capacity** (28,5 GW PV, 22,3 GW wind, 5 GW CSP, 0,8 GW biomass, 0,5 GW hydro).
- **6 GW of new storage** (3,5 GW pumped hydro, 2,5 GW batteries) + CSP inherent storage.
- **No new fossil capacity needed**
- Coal phase-out by market mechanisms 2025-2029

Prospects for Long Duration Energy Storage in Germany

05/07/2022

Deploying LDES would reduce power system costs, increase renewable energy utilization and reduce hydrogen consumption

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Key results of modelling the use of LDES in the German power system

1	Lower power system costs	A power system with 15 GW of LDES by 2045 has a cumulated total system **cost advantage of around EUR 24 bn** (2025-2050) compared to a scenario without LDES
2	High sensitivity to H_2 price development	The study assumes rather low hydrogen prices, lifting the price assumption by 10% would **increase the economic benefit of LDES to EUR 40 bn (+ 67%)**
3	Higher utilization of renewable energy	LDES absorb renewable electricity by charging in hours in which renewables production exceeds demand; **curtailment can be reduced by up to 30%**
4	Lower natural gas use	LDES discharge in high price hours and thereby **reduce the amount of electricity generated by conventional gas plants**, and avoid CO_2 emissions
5	Less H_2 required in the power sector	LDES reduce the amount of power generated by H_2-fuelled power plants which translates to a **13% decrease of H_2 required for the power sector until 2050**
6	Increasing profitability of LDES technologies	Some technologies will already become investible under optimal market conditions before 2030, and **profitable under indicative hurdle rates for unsupported projects by 2035**

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Executive Summary

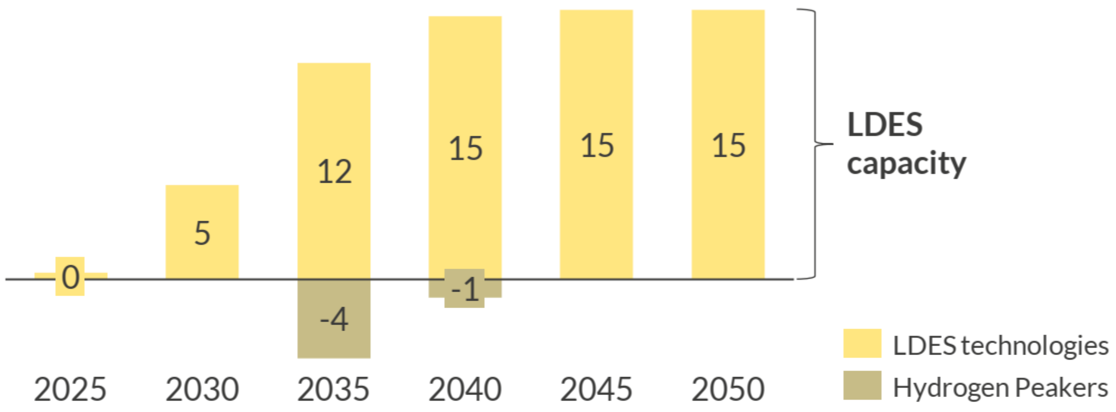
A Net Zero power system by 2035 will see larger and more frequent periods with either excess or insufficient generation from renewable energy sources

This study shows that long-duration energy storage (LDES) technologies are an effective and cost-efficient way to avoid renewables curtailment, lower the amount of hydrogen required for the power sector, and reduce wholesale prices on average

While investments in LDES won't be profitable in the short term, we expect selected technologies to become profitable in the 2030s

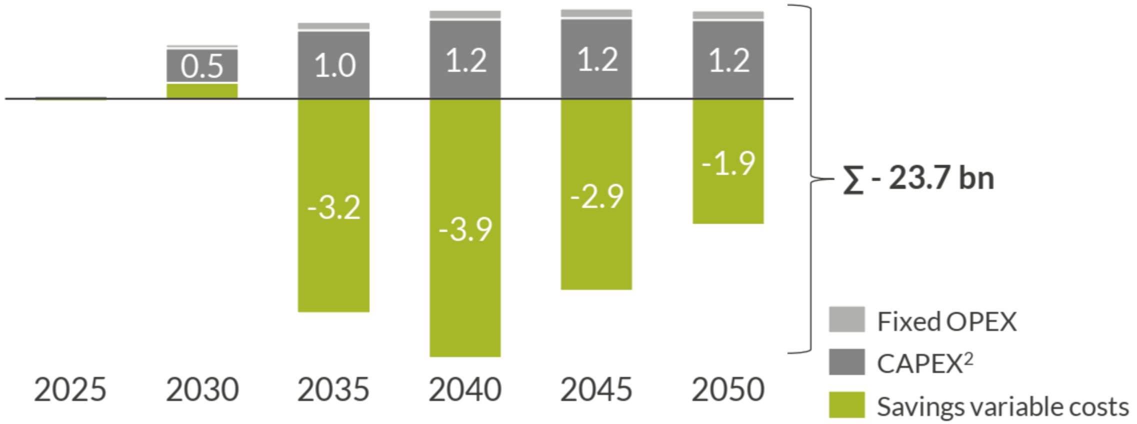
Two power market scenarios are modelled for this study. The Baseline Scenario assumes a Net Zero power system to be achieved by 2035. The LDES Scenario is built on the same assumptions but also includes an additional **LDES capacity of up to 15 GW**. In turn, hydrogen peaker capacity buildout can be backloaded while maintaining the **same level of security of supply**.

Delta of installed capacity LDES vs. Baseline Scenario
GW



The LDES Scenario has a **system cost advantage of around EUR 24 billion** compared to the Baseline Scenario. The cost reduction is mainly driven by savings in the wholesale market (50 bn) where discharging LDES substitute H_2-fuelled power plants with very high marginal costs. Additional costs related to the roll-out of LDES assets (26 bn) are priced in.

Delta of system costs LDES vs. Baseline Scenario[1]
Bn EUR (real 2021)



1) Savings in negative numbers, costs in positive numbers, 2) Annualised CAPEX of LDES investments with 4% interest rate

Source: Aurora Energy Research

The Baseline Scenario is characterised by government targets for renewables buildout and a net zero emission power sector by 2035

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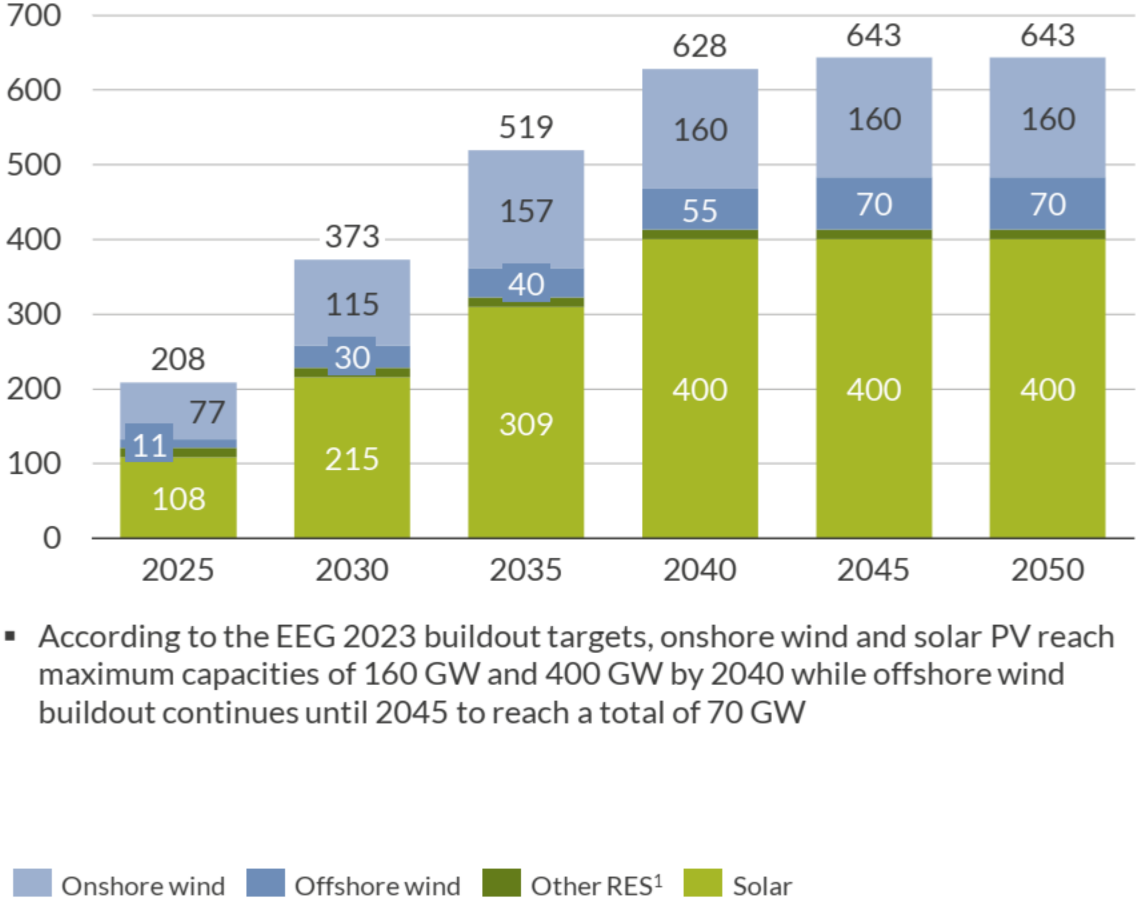
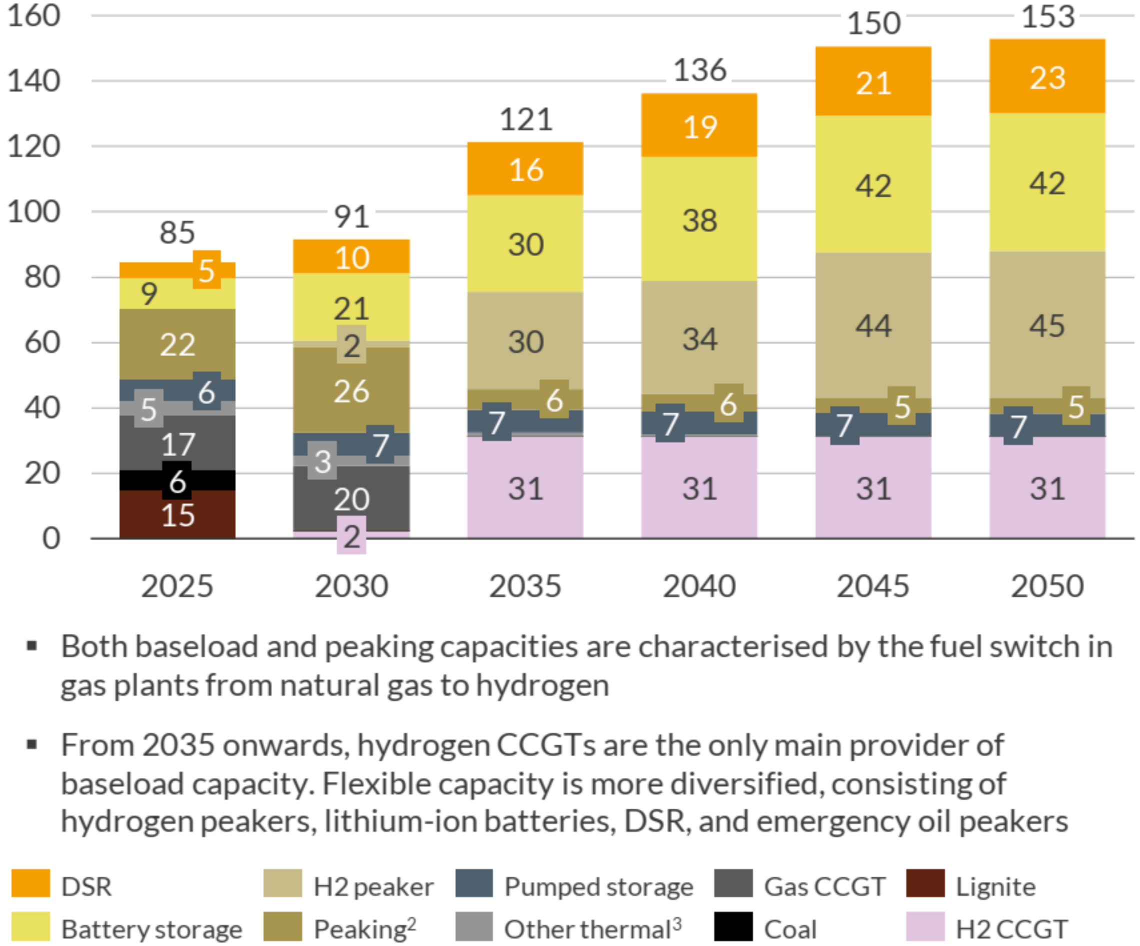
Installed renewable capacity - Baseline Scenario
GW



- According to the EEG 2023 buildout targets, onshore wind and solar PV reach maximum capacities of 160 GW and 400 GW by 2040 while offshore wind buildout continues until 2045 to reach a total of 70 GW

Installed flexible and baseload capacity - Baseline Scenario
GW



- Both baseload and peaking capacities are characterised by the fuel switch in gas plants from natural gas to hydrogen
- From 2035 onwards, hydrogen CCGTs are the only main provider of baseload capacity. Flexible capacity is more diversified, consisting of hydrogen peakers, lithium-ion batteries, DSR, and emergency oil peakers

1) Includes hydropower and biomass, 2) includes gas OCGTs and oil peakers, 3) Including waste plants and on-site industrial thermal power plants.

Source: Aurora Energy Research

Fossil power generation is phased out by 2035 and substituted by renewables and hydrogen plants

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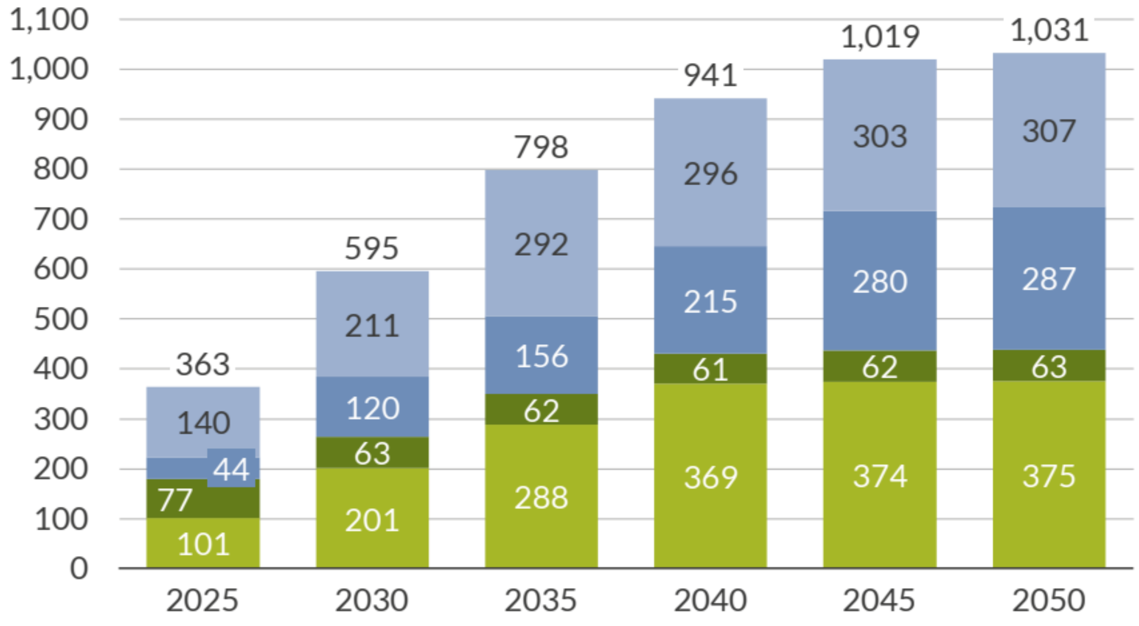
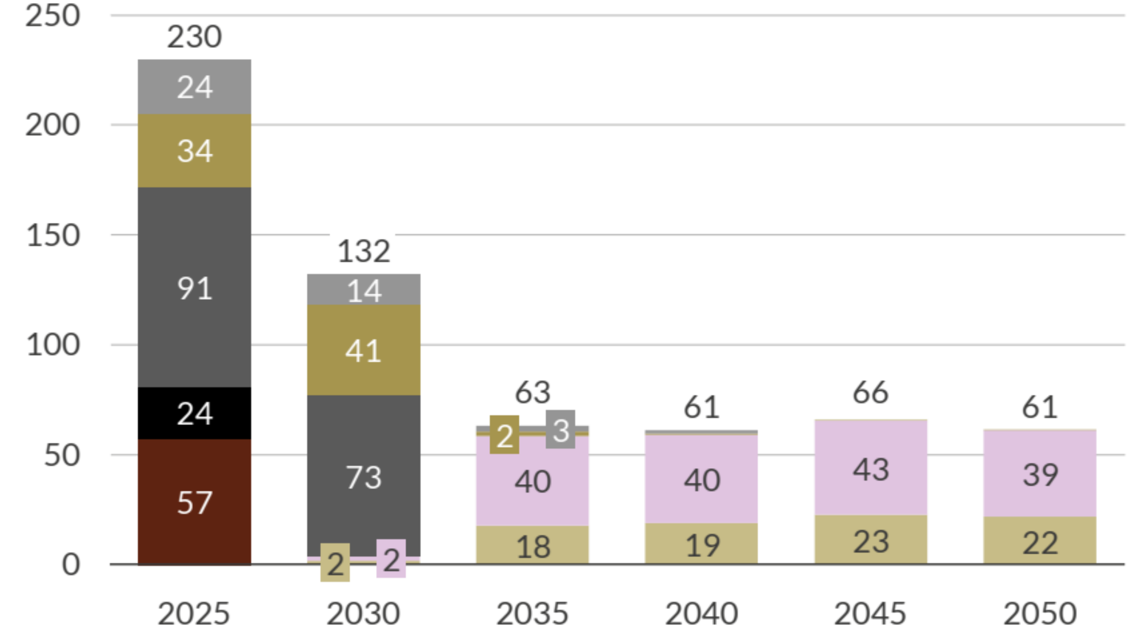
Renewable electricity production - Baseline Scenario
TWh



- Wind offshore generation sees the largest proportional growth of all RES technologies with a more than 6-fold increase between 2025 and 2050
- Driven by the ambitious capacity expansion to 400GW, solar PV replaces wind onshore as the technology with the highest generation between 2035 and 2040

Onshore wind | Offshore wind | Other RES | Solar

Flexible and baseload production - Baseline Scenario
TWh

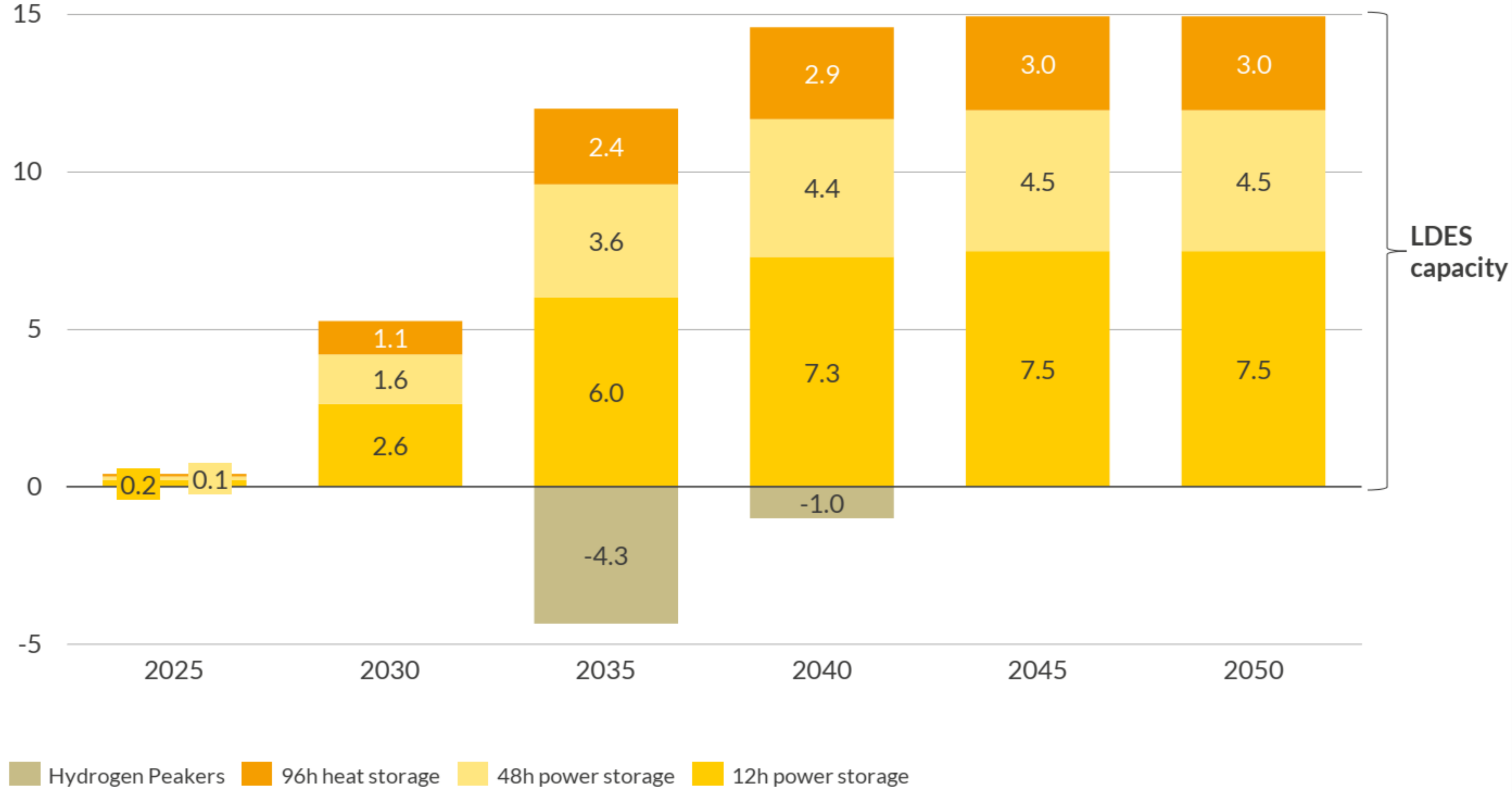


- The sharp decline in baseload generation between 2025 and 2035 is mainly caused by the phase out of coal and lignite capacity
- The transition from gas CCGTs and OCGTs to hydrogen CCGTs and peakers contributes to the reduction as well because the high price of hydrogen compared to natural gas reduces full load hours

Other thermal | Gas CCGT | Lignite | Hydrogen peaker | Peaking | Coal | Hydrogen CCGT

Additional LDES capacity allows to backload hydrogen peaker buildout without lowering security of supply

Installed capacity delta between LDES Scenario and Baseline Scenario
GW



Capacity changes

- To optimise the system cost savings from LDES deployment, 12 GW of capacity are installed by 2035 and 15 GW by 2045
- The deployment of LDES capacity lowers the need for hydrogen fuelled peaker plants by over 4 GW in 2035 while achieving the same level of security of supply as in the Baseline Scenario
- By 2045, the level of hydrogen peaker capacity needed for an equal level of supply security is again identical to that of the Baseline Scenario due to a continued increase of the power demand
- The level of LDES capacity required to replace dispatchable hydrogen peaker capacity over the whole model horizon would not be the most cost efficient

Source: Aurora Energy Research

Integrating LDES into the power system would lower total costs by 23.7 billion Euros until 2050

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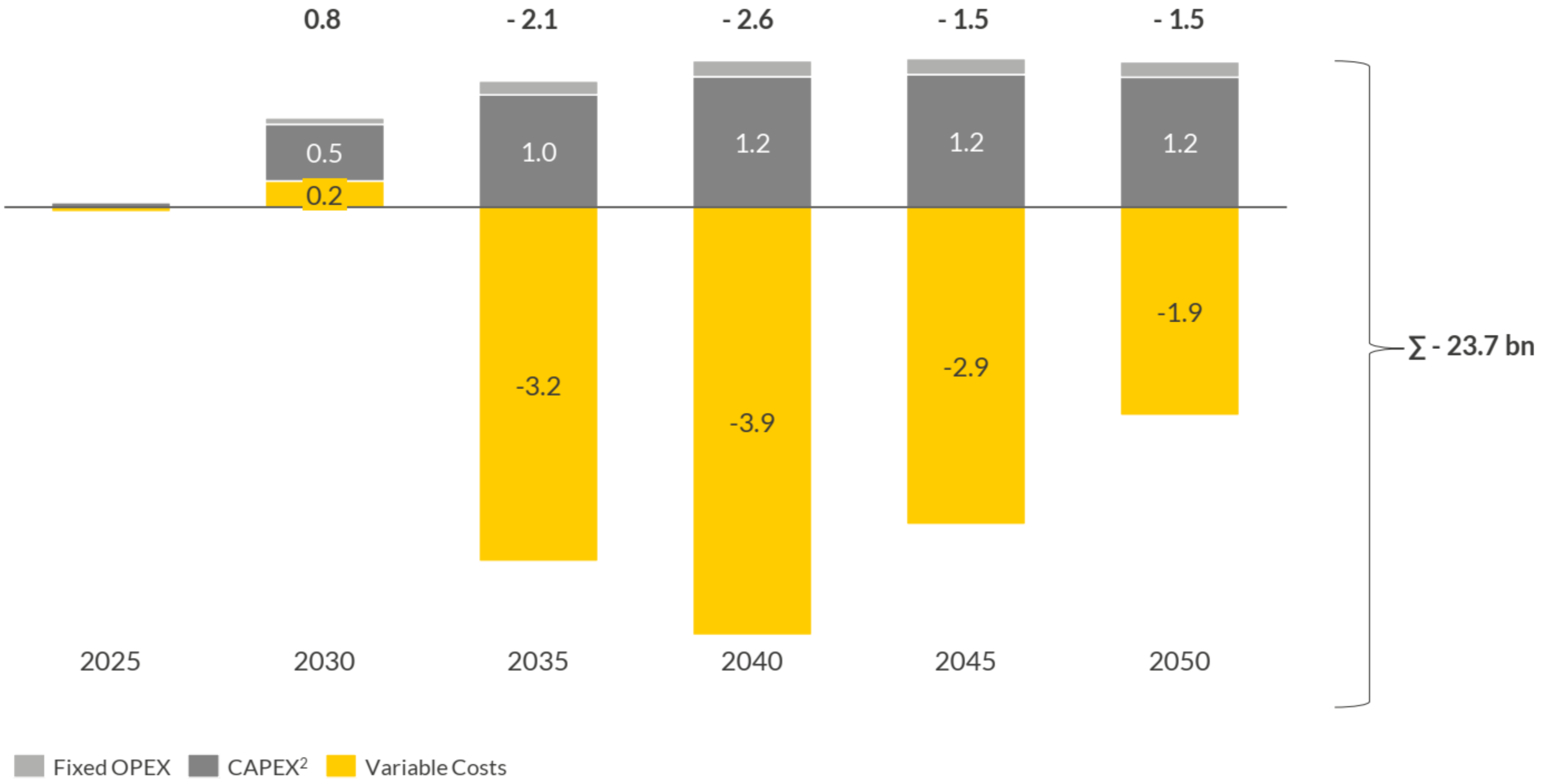
System costs delta between the LDES Scenario and the Baseline Scenario[1]
Bn EUR (real 2021)



Comments

- The reduction in overall system costs is driven by the lower average wholesale power prices in the LDES Scenario compared to the Baseline Scenario
- The savings from lower power prices are partially offset by increases in investment costs related to the roll-out of LDES capacities
- Fixed OPEX for LDES have a minor contribution to the difference in system costs

1) Savings in negative numbers, costs in positive numbers, 2) Annualised CAPEX of LDES investments with 4% interest rate

Source: Aurora Energy Research

Deploying LDES reduces power generation from gas and hydrogen power plants and limits RES curtailment

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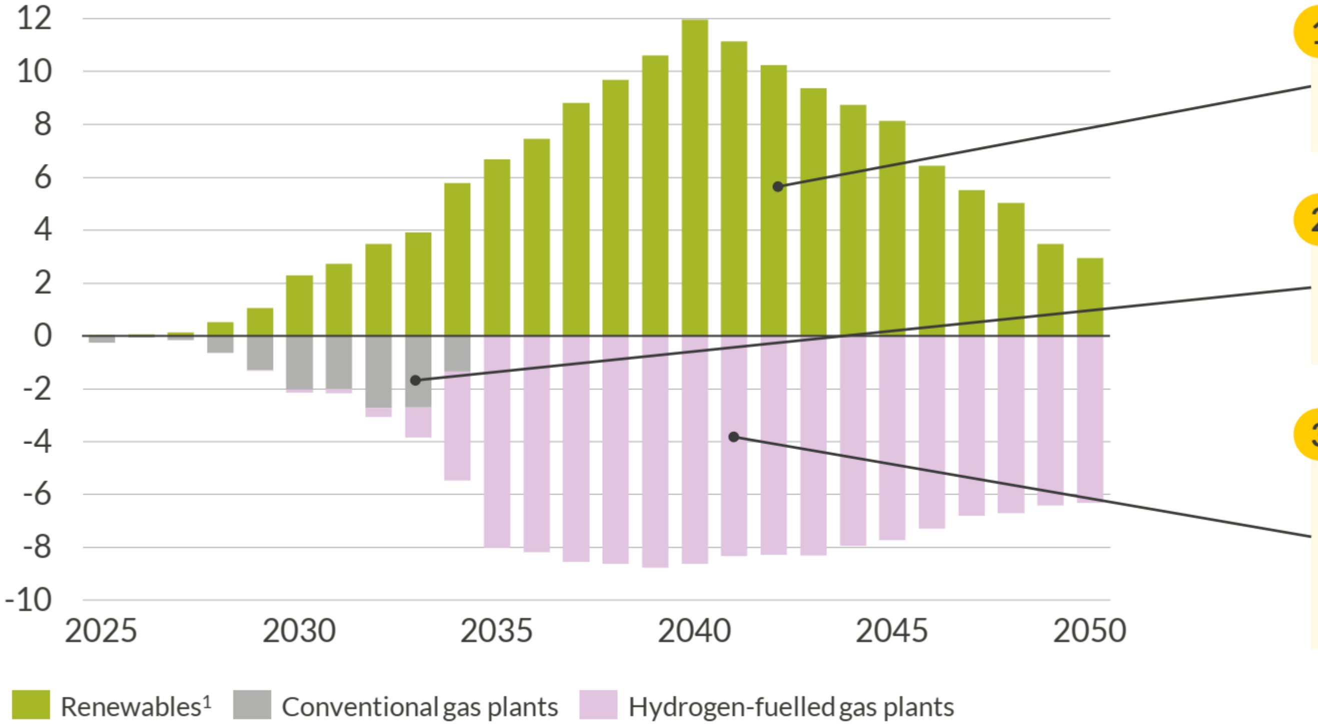
Electricity production – Difference between LDES and Baseline Scenario
TWh



Three main effects from the introduction of LDES to the power system

1. **Higher renewables utilization:** LDES absorb renewable electricity by charging in hours in which renewables production exceeds demand; **curtailment can be reduced by up to 30%**

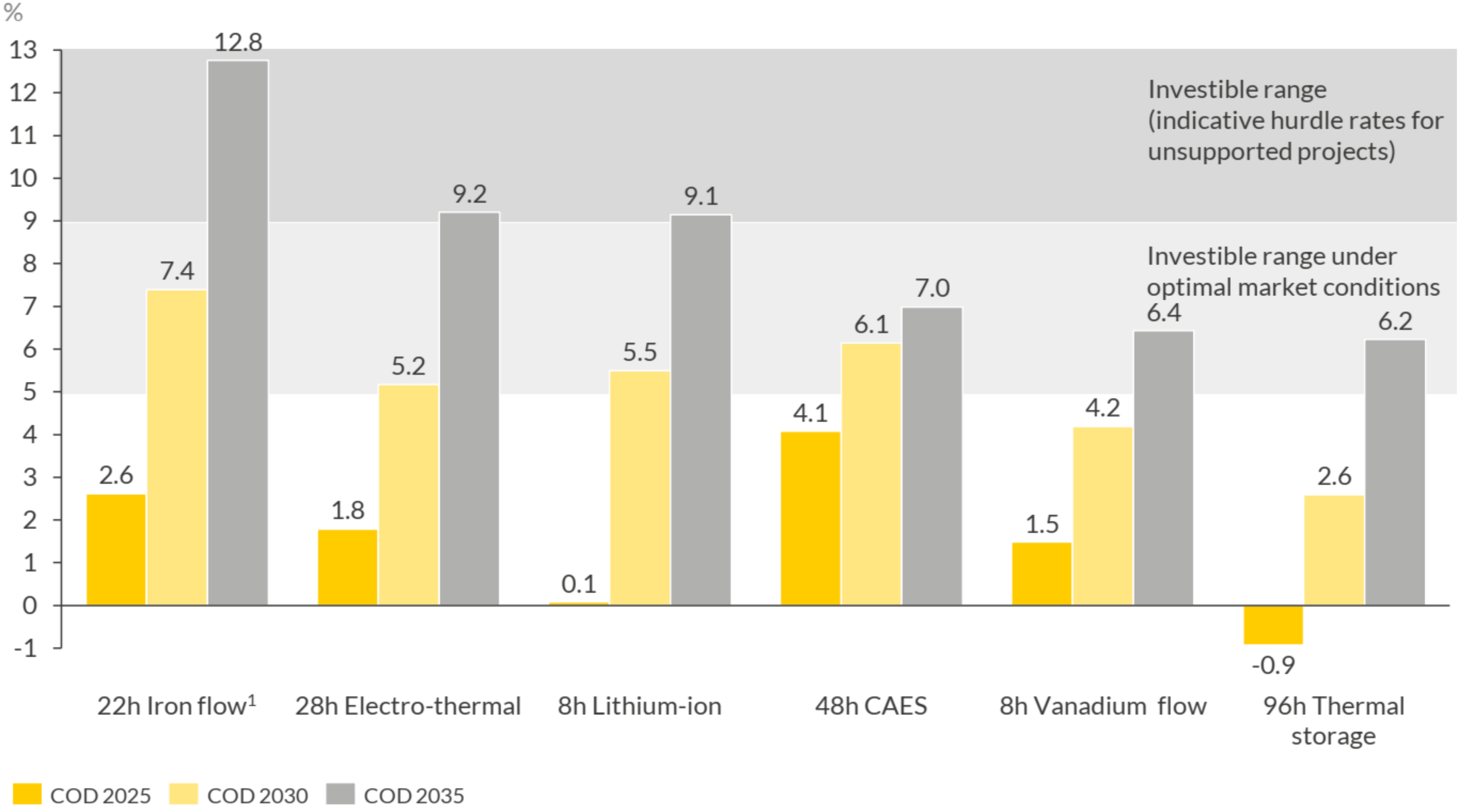
2. **Lower natural gas use:** LDES discharge in high price hours and thereby reduce the amount of electricity generated by conventional gas plants as well as the CO_2 emissions caused in the process

3. **Lower need for hydrogen in the power sector:** After the transition from natural gas to hydrogen, LDES lower the amount of power generated by H_2-fuelled plants which translates to a **13% reduction of hydrogen use** in the power sector. This reduction **decreases Germany's H_2 import dependence and mitigates risks in case of H_2 procurement bottlenecks**

LDES discharge in high price hours and thereby reduce the amount of electricity generated by dispatchable assets, saving natural gas and hydrogen. When charging, LDES absorb renewable power generation which would otherwise be curtailed.

Some LDES technologies will already become investible under optimal market conditions in 2030, and be fully profitable in 2035

Internal rate of returns (IRR) forecast for six selected LDES technologies and three commercial operation dates (COD)



1) "22h" indicates the assumed maximum storage duration in hours

Source: Aurora Energy Research

Comments

- IRR behaviour varies between technologies and is heavily dependent on the assumed date of roll-out
- Improved IRRs in 2035 for emerging technologies such as iron flow and electro-thermal are driven by assumed CAPEX cost declines
- To fully exploit the savings potential on the system cost level, rollout of LDES capacity needs to start before IRRs reach common hurdle rates for unsupported projects
- To bridge this gap and incentivise investments in LDES projects before 2035, a more favourable market environment and policy support which recognises the value and need for LDES is required

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

Installation cost – Capex of LDES solution, construction, balance of system

Lifetime discounted O&M cost – O&M opex costs; Replacement intervals and costs

Lifetime discounted charging cost – 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

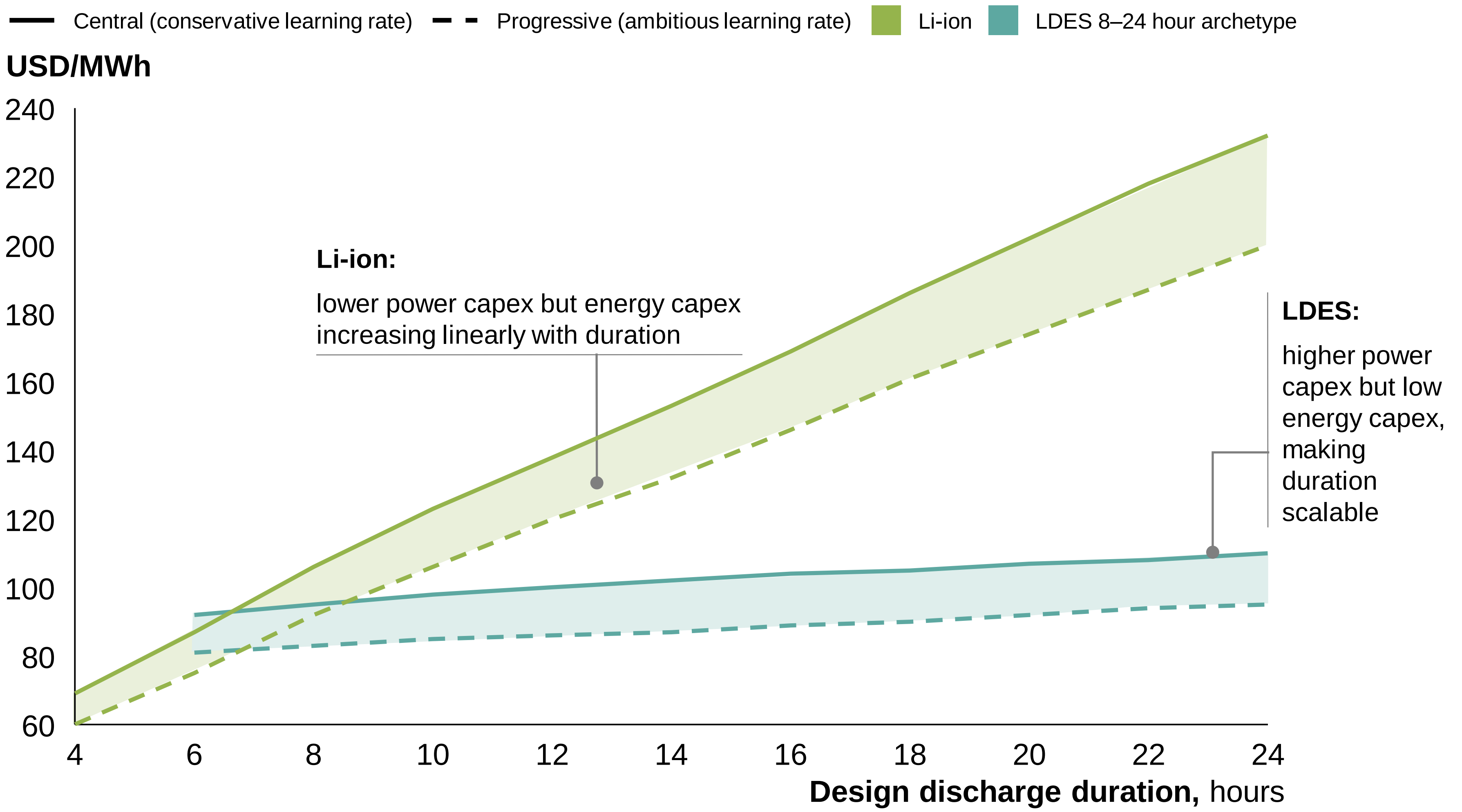
Insights

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)



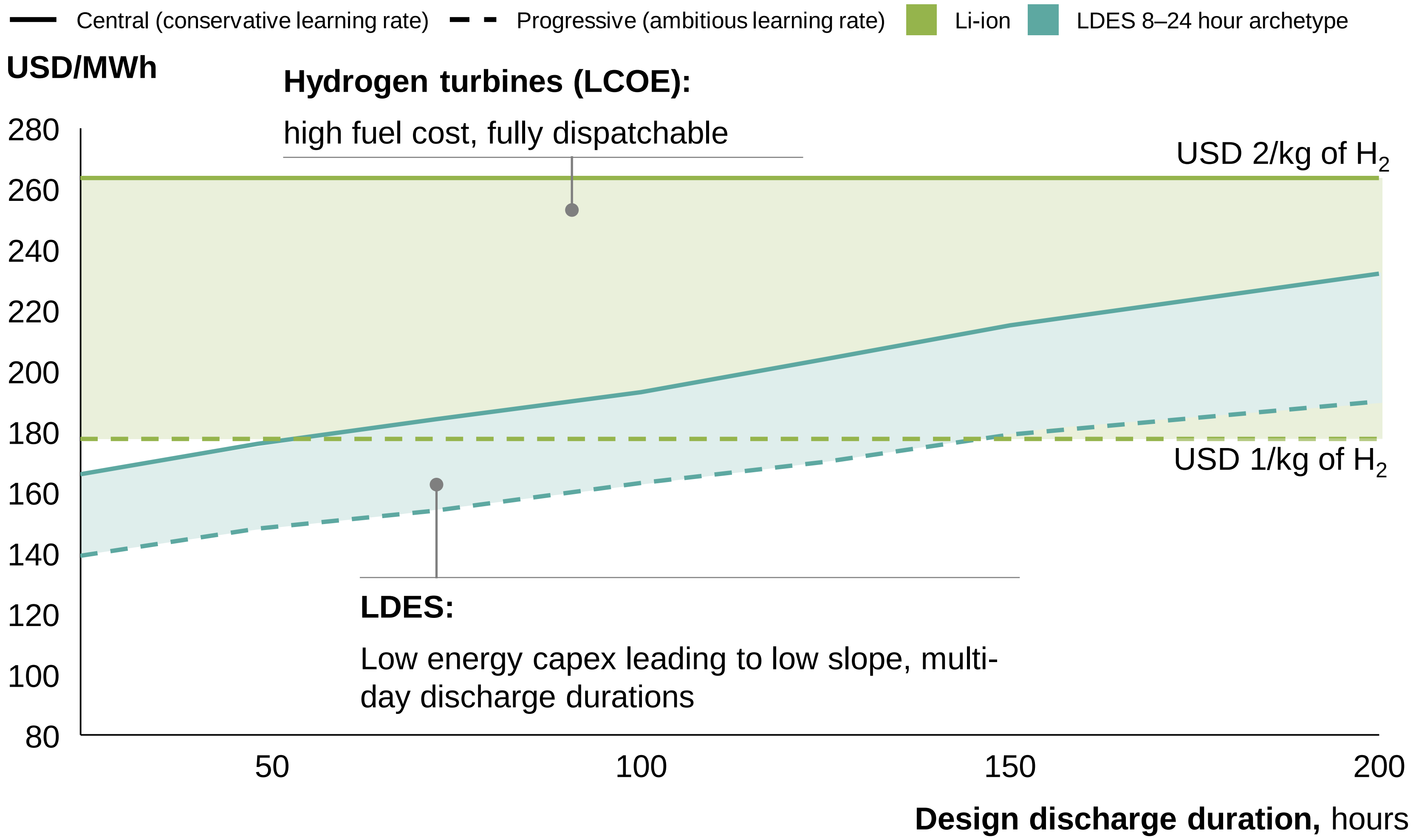
Source: LDES Council member technology benchmarking

Insights

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

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

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

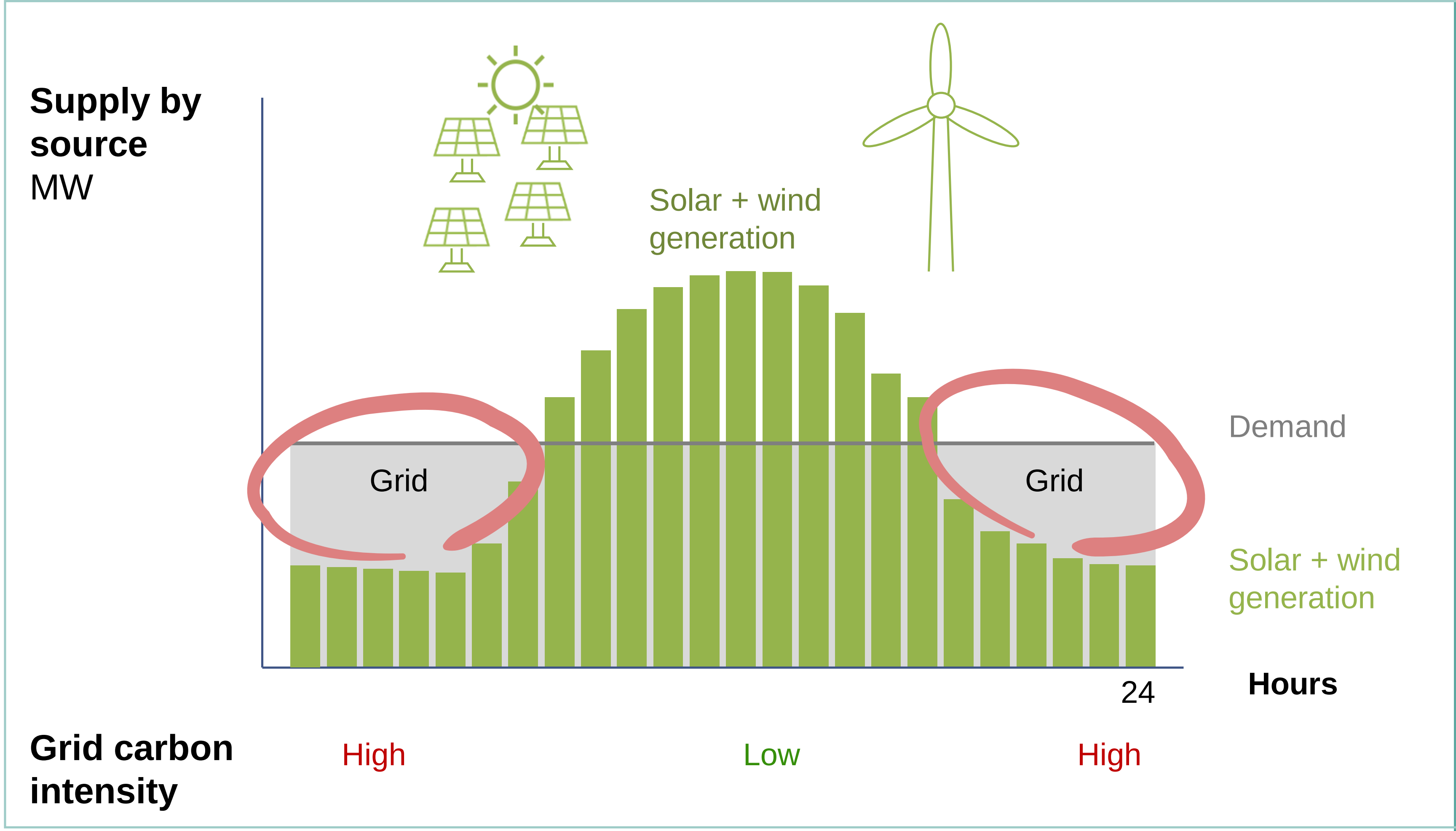


Source: LDES Council member technology benchmarking

Insights

Hydrogen turbines are likely competitive above 150 hours duration

Today's power procurement through renewable PPAs still relies on fossil-based energy in many hours of the day



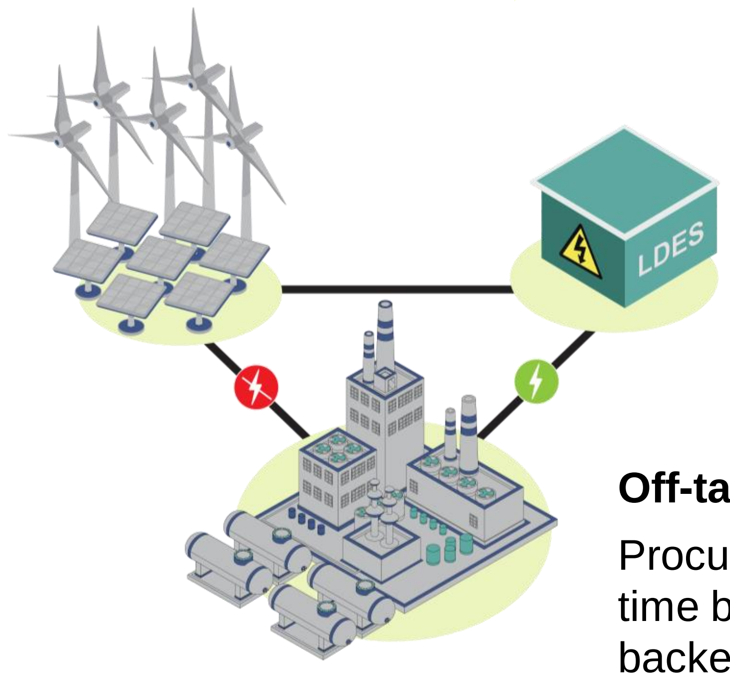
In hours of renewables overproduction, the carbon abatement is lower than carbon emissions resulting from buying power from the grid in hours with insufficient renewables generation

24/7 clean PPAs enable investments in systems for time-matched clean power supply – typically this includes storage

Hybrid system as technical solution for 24/7 clean PPA

Renewables generation

Often Solar and Wind, i.e., non-dispatchable generation



Energy storage

Dispatchable energy storage enables supply when there is no direct renewable generation

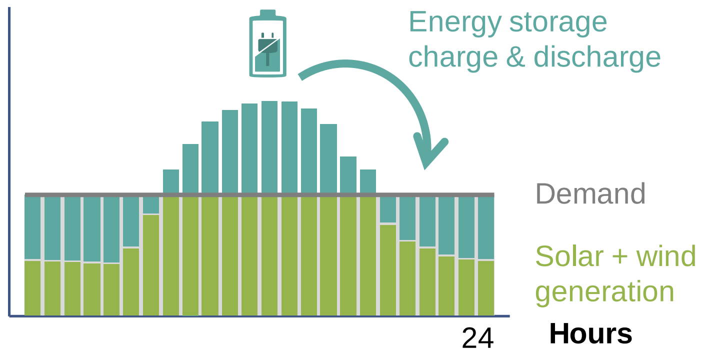
Off-taker

Procuring clean power on a granular time basis through 24/7 clean PPA backed by renewables and storage

Time-matched clean supply

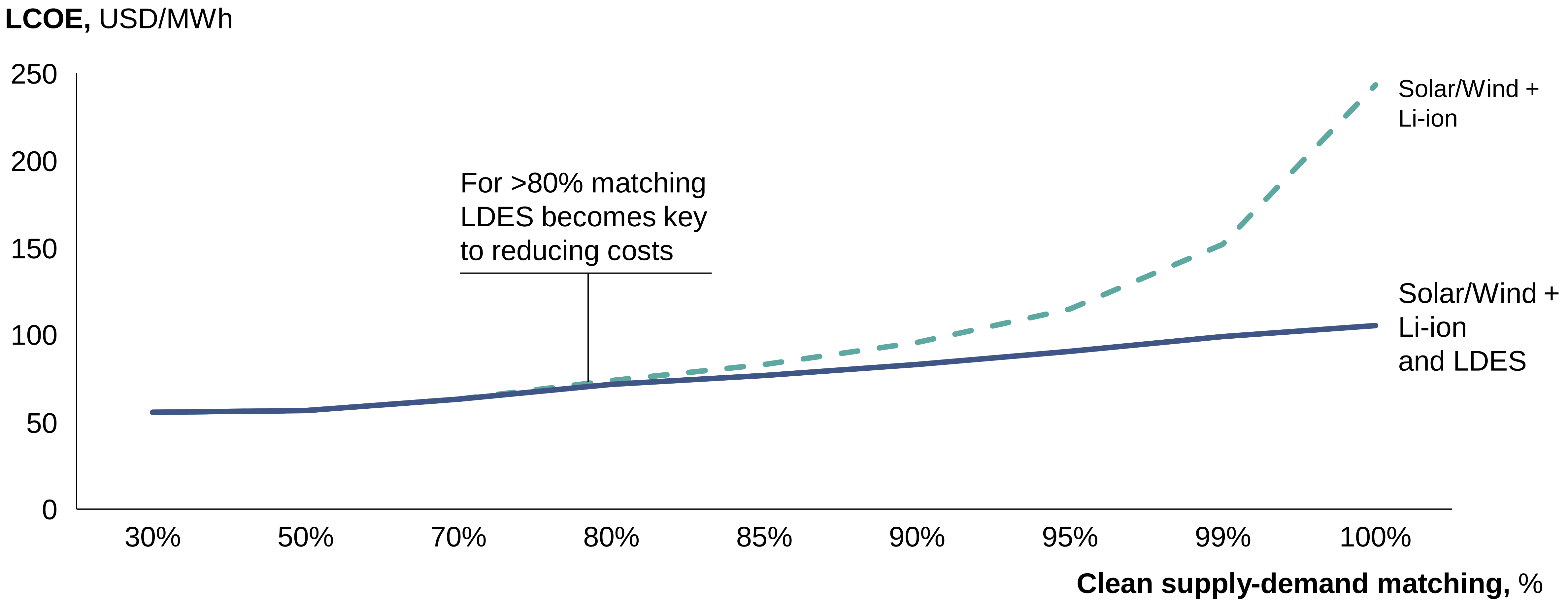
Storage enables matching of clean power supply and demand

Clean power that is supplied for each unit of demand, measured at granular time intervals (e.g., 1 hour or less)



Today, cost for 100% clean supply-demand matching often perceived as prohibitively expensive – LDES can help overcome this barrier

RES + Storage LCOE for different levels of clean supply-demand matching, 2025

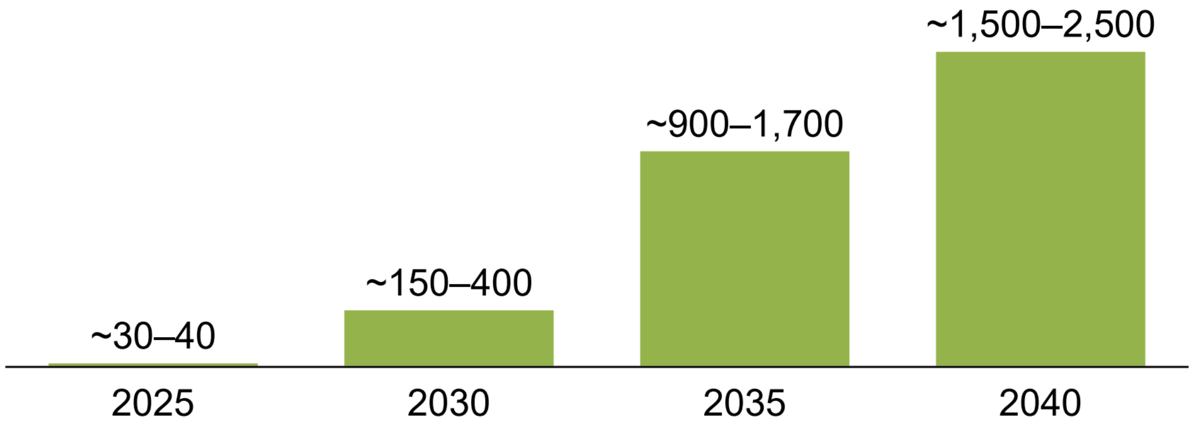


Source: LDES Council 2021 technology benchmark and report, McKinsey Power Model

Total market size for LDES can reach a 1.5 to 2.5 TW by 2040, supporting the required flexibility in net-zero power systems

Global LDES deployment through 2040

GW
Cumulative installed power capacity



	2025	2030	2035	2040
TWh Cumulative installed energy capacity	~1	~5–10	~35–70	~85–140
USD bn Cumulative capex investment	~50	~200–500	~1,100–1,800	~1,500–3,000

Insights

USD ~50bn investments required over the next 5 years

2040 cumulative investment equal to the current global T&D investment made every 2-4 years

Ways to engage with the LDES Council

Download the full report

Net-zero power systems: long duration energy storage for a renewable grid

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