Iberdrola

Capital Markets & ESG Day

21 March 2024

Sustainable Event AENOR EVENTS SUSTAINABILITY

Committed SDG

Energy storage

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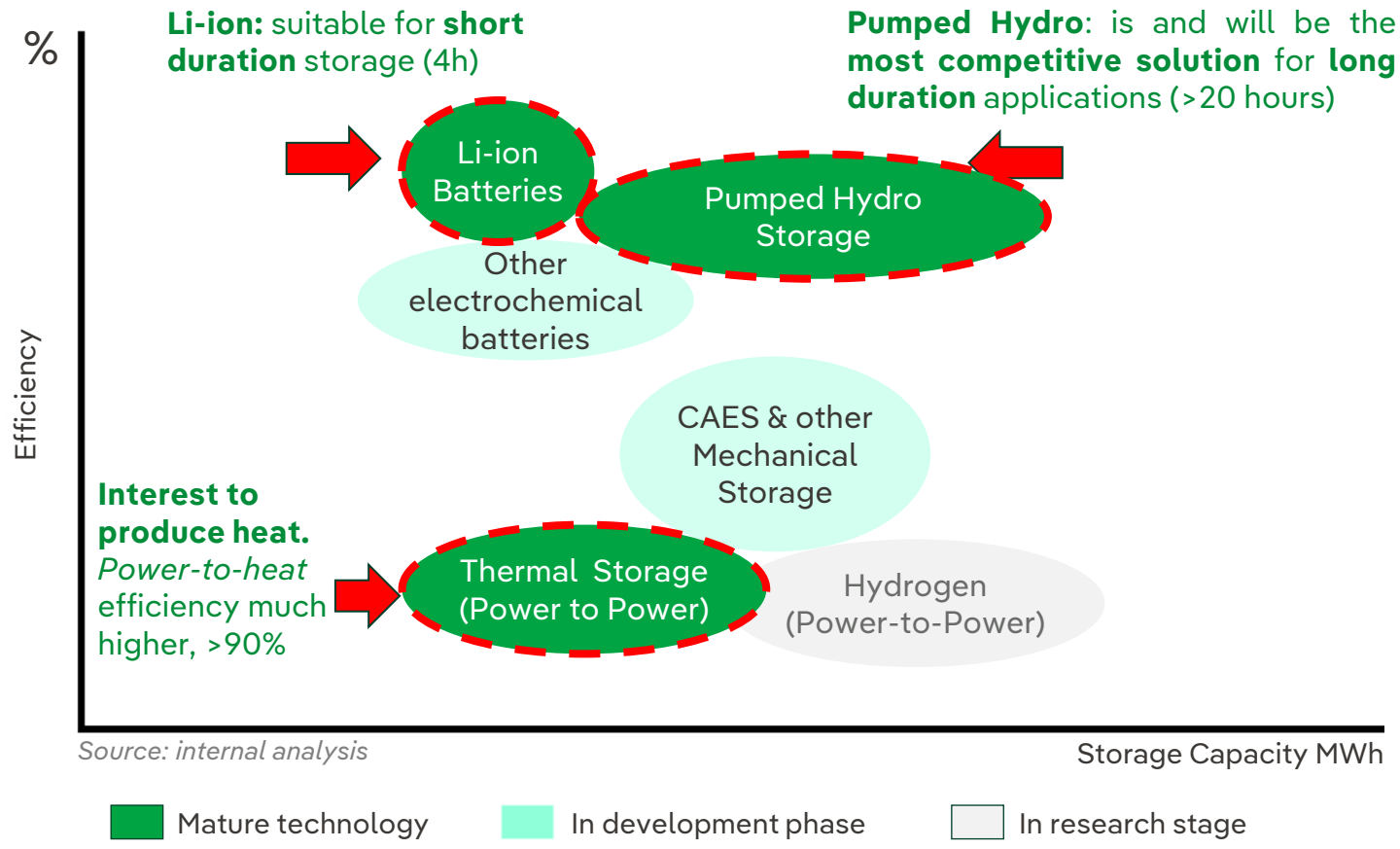
Technologies

Energy storage technologies in the power system *(power-to-power)*

Many energy storage technologies, but only a few are mature and suitable for the power system



Source: internal analysis

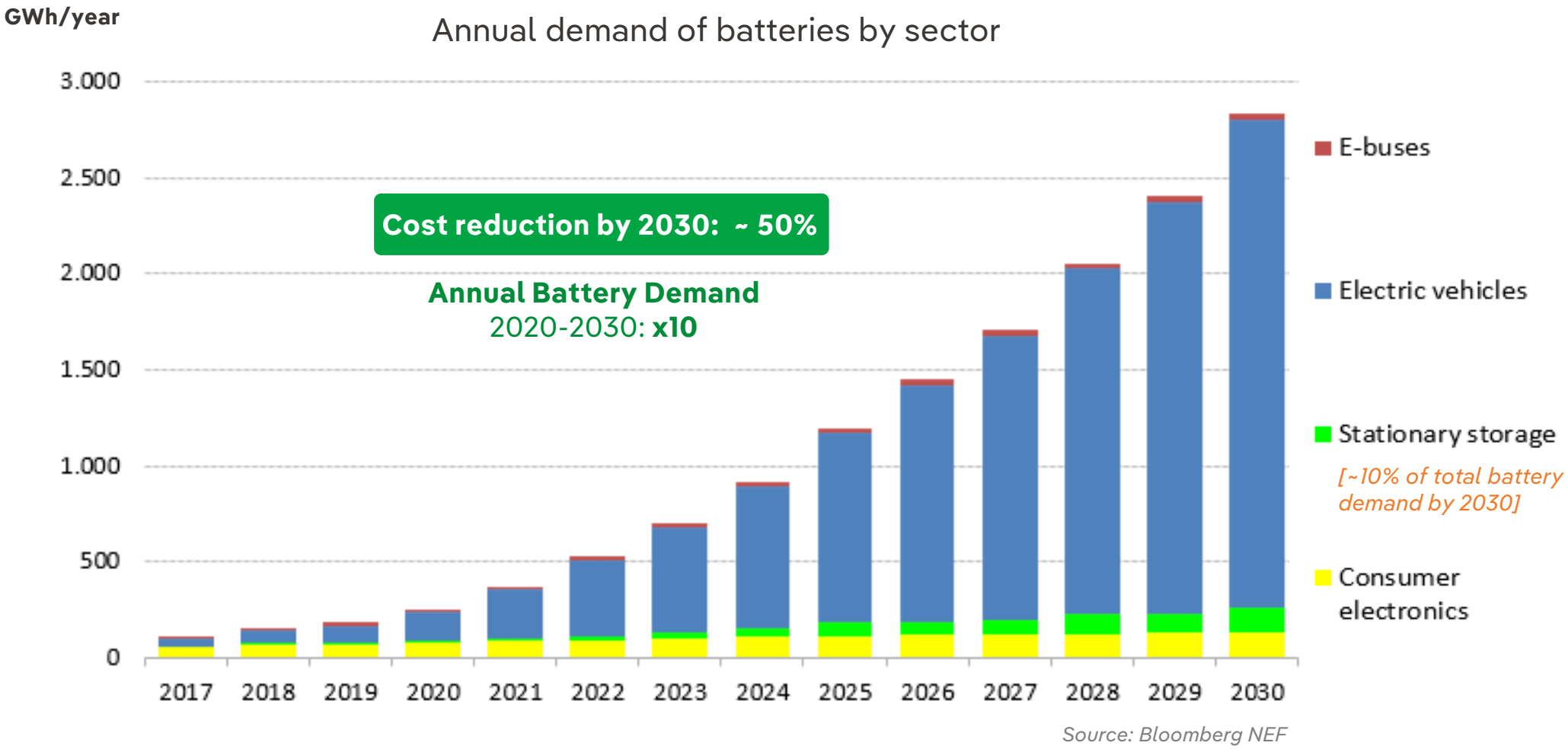
Energy Storage technologies characterisation

- Scale
- Duration
- Density
- Efficiency
- Degradation
- Charge/discharge rate
- Cost
- Safety
- Useful life
- .....

Many other storage technologies, but still in early-to-mid stages of development

Lithium-ion batteries

Electric vehicles are driving li-ion battery demand

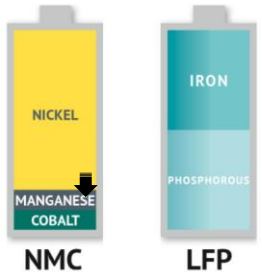


Source: Bloomberg NEF

Battery Technology: Main innovations

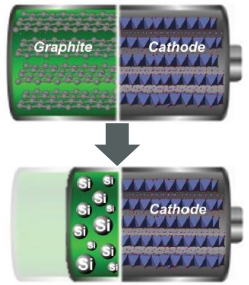
Main innovations are focused on increasing energy density and reducing critical materials

2023-2025



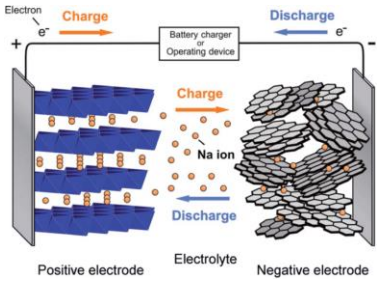
NMC LFP

Cathode
Cobalt reduction
NMC 111 to 9.5.5
LFP dominant in stationary storage

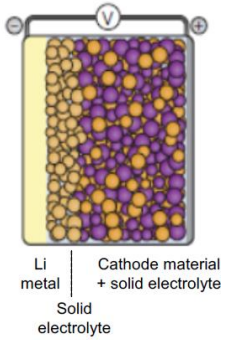


Anodes with silicon
Higher energy density, lower cost

2026-2030



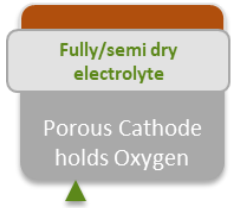
Sodium ion cells
No critical materials albeit lower energy density



Solid Electrolyte
Higher safety, enables use of lithium metal anodes (high energy density)

2030-2035

Ultra-Thin **Lithium metal** (almost anode free)



Oxygen from the air

Li- air
Lithium metal anodes and O_2 in cathodes
(Cell densities >500 Wh/kg)

Innovations beyond the chemistry

- Production
- Cell to pack design
- Mining: extraction and refining of metals
- Battery operation and digitalization
- Standardisation of stationary battery systems

LFP main chemistry for stationary storage in the next years; Na-ion adoption in the medium term

Pumped hydro storage

More than 10 GW of additional pumped hydro potential at competitive cost in existing dams in Spain

Innovations despite its maturity

- Variable speed turbines
- Digitisation
- Battery hybridation

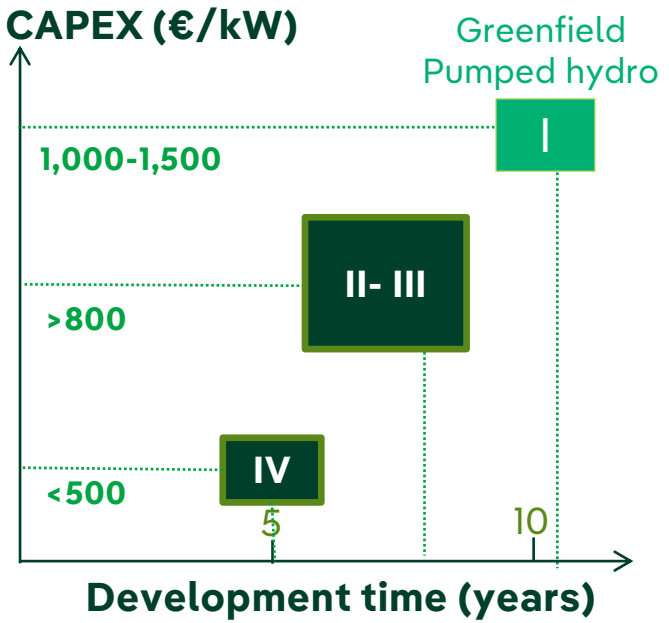
→ Increase flexibility and efficiency
→ Feasible locations expanded

New capacity feasible using existing dams:

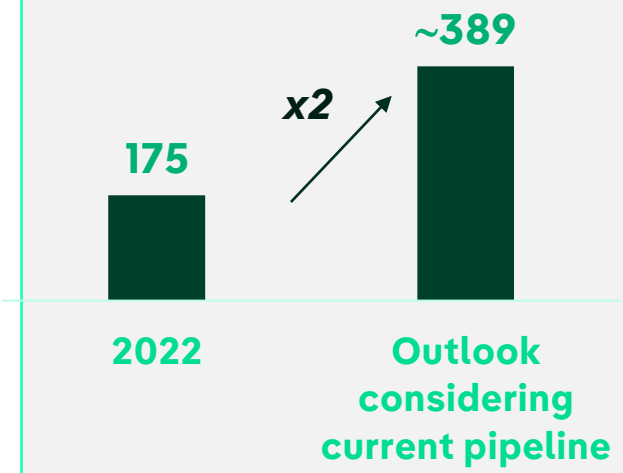
Lower cost, shorter development times & lower environmental impact

Pumped hydro using existing dams:

I	New Pumped hydro facility- greenfield
II	New upper reservoir
III	Connecting 2 existing reservoirs
IV	Retrofit turbine with reversible pump-turbine



Global pumped hydro capacity outlook (GW)



Source: IHA 2023 World Hydropower outlook

Other energy storage technologies *(power-to-power)*

Other energy storage technologies are being developed, but still in early stages

INNOVATIONS

Mechanical

- CAES: Compressed Air
- LAES: Liquid air or CO_2
- Other mechanical

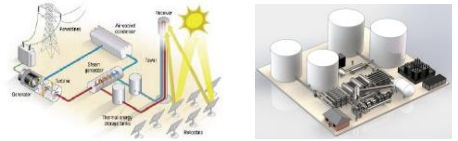
Effic.~50-70%, high capex, +30 years

- No sitting constrains
- Efficiencies > 70%

Thermal

Resistance + **thermal storage** (rocks, concrete, molten salts..) + **steam turbine**

Effic.~30-35%, low capex, +30 years



- Heat pump use: efficiency ~45%.
- Power-to-heat application

Electrochemical

- Vanadium flow batteries
- Other flow batteries
- Other batteries: NaS, Cu..

Effic. ~60-80%, mid capex, 15-20 years

- Cheap chemistries
- Efficiencies> 70%
- More life cycles

Technology closest to market

Deep dive analysis of over 30 technologies: future evolution and costs

Thermal energy storage: Green heat *(power-to-heat)*

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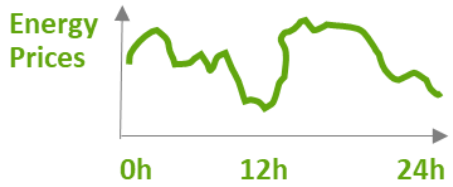
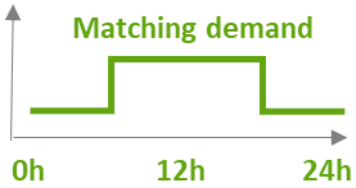
Thermal storage to decarbonize industrial heat; new driver of electricity demand

Green Heat (thermal storage)

Renewables + **Thermal Storage** → **Green Heat**



Electric Resistance + thermal storage + steam generator (90% effic.)



Close to being competitive

Gray Heat *Variable cost*

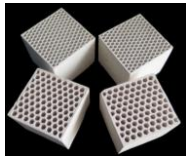
Natural gas → **Heat** (boiler 95% effic.) + **Emissions*** → **Gray Heat**

Thermal storage technologies

Rocks

Molten Salts

Bricks



Water

*Emissions: ~0,15 tCO_2/MWh thermal

Energy storage technology 2030 vision *(power-to-power)*

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By 2030 batteries and other novel technologies will continue reducing their cost…

2030 Competitiveness by hours of storage duration

2030 energy storage in the power system

- **Stationary Batteries** installed by 2030: **x15**
- **Pumped hydro:** the **most competitive** technology in the geographies where it is available
- **Other technologies**: less mature, impact post 2030 (exception: Thermal storage to decarbonize industrial heat)

Iberdrola

- Strong pipeline
- Developing projects
- Technology monitoring

Research centres — Start-ups

Associations, alliances, platforms…

…but pumped hydro to remain the most competitive technology for long duration energy storage

Revenues

Volatility is the new business as usual

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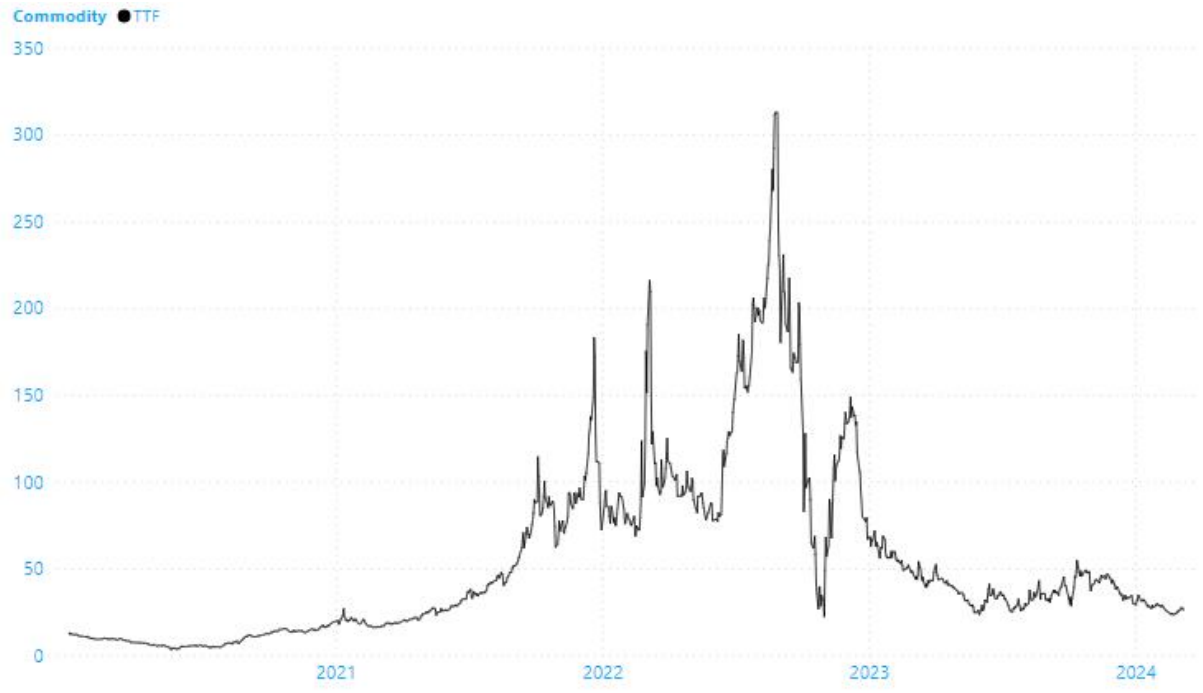
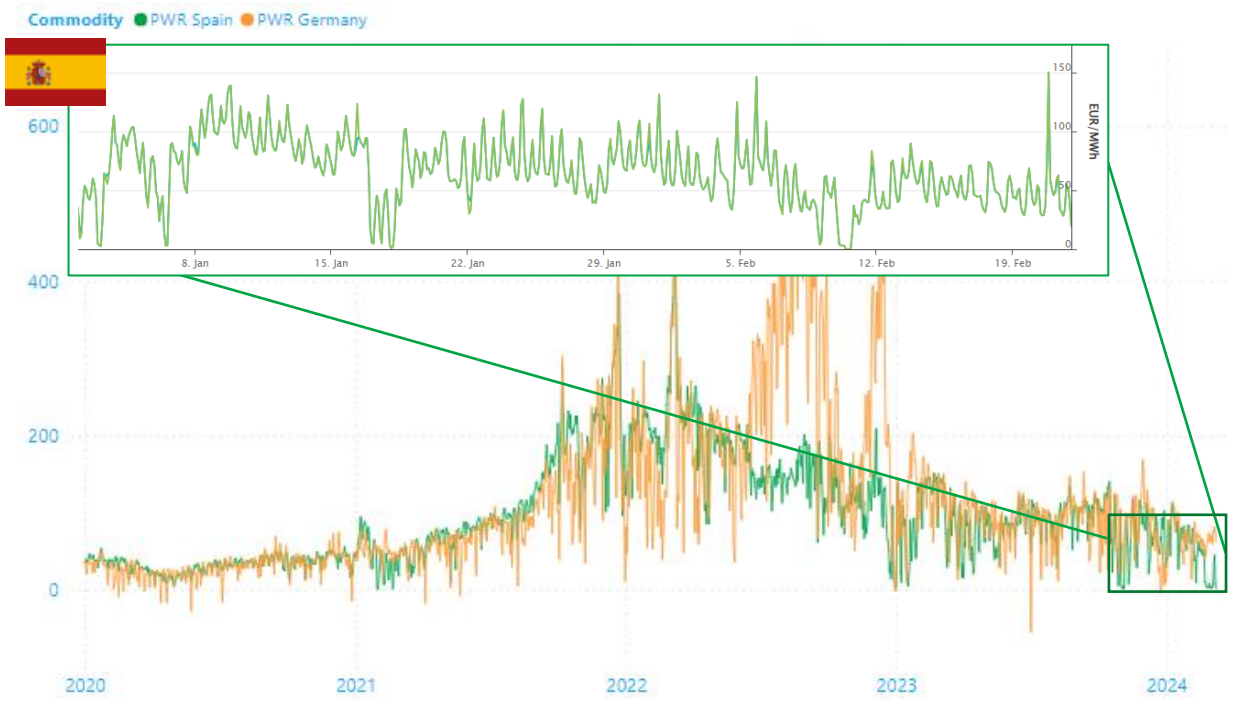
Commodity prices have converged to pre-crisis (Ukraine, pandemic) level but volatility remains high

Volatility in hourly electricity markets is even more extreme as **electricity …can't be stored?**

TTF Spot Prices Evolution (€/MWh)



Power ES & Power GER spot (€/MWh)

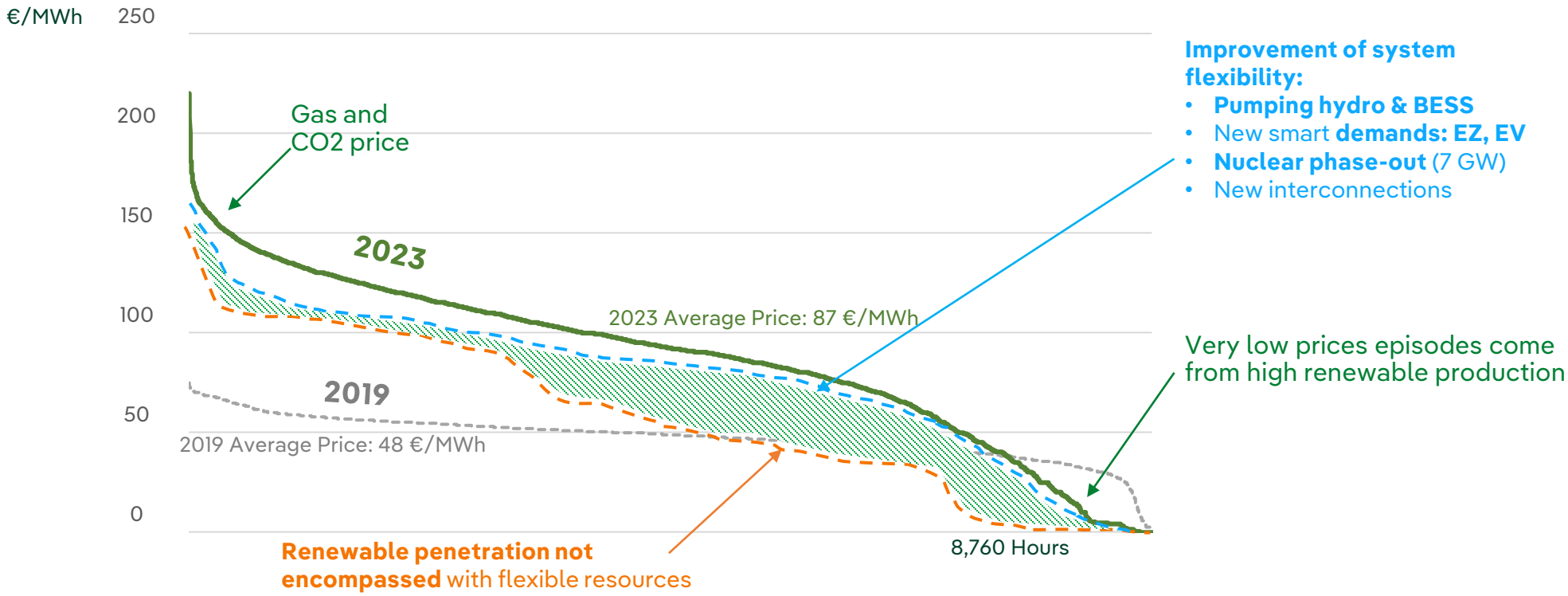


Market Reference: 08/03/24

Price duration curve: an even steeper slide

More frequent low prices episodes and **less firm capacity during off-peaks** will make price duration curve even steeper

Price Duration Curve (Spain)



Storage technologies will have a greater margin to operate

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Winner: flexible hydro and pumping storage

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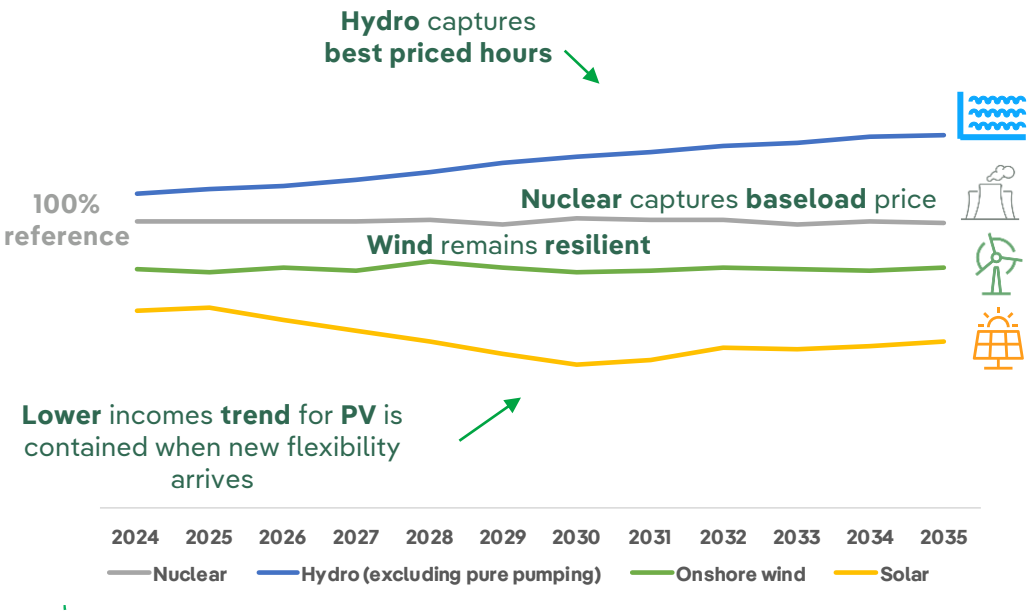
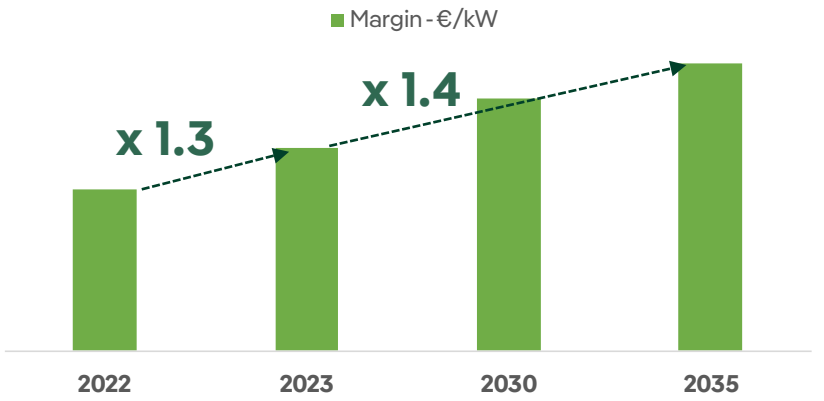
Different impact by technology, with flexible and pumping hydro capturing more value

Risk	Neutral	Opportunity
High risk of cannibalization: lower prices in sunny hours	**Resilient to cannibalization**	**Flexible Hydro** shifts to capture best priced hours **Pumping Storage** will have **higher load factor and margins**

Income / Baseload by Technology in Spain



Pumping hydro in Spain: Energy Margins



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Revenue stacking for energy storage

There are three main sources of revenues for energy storage

...Focus on extracting value by **charging in low-price hours** and **discharging in high-price hours**

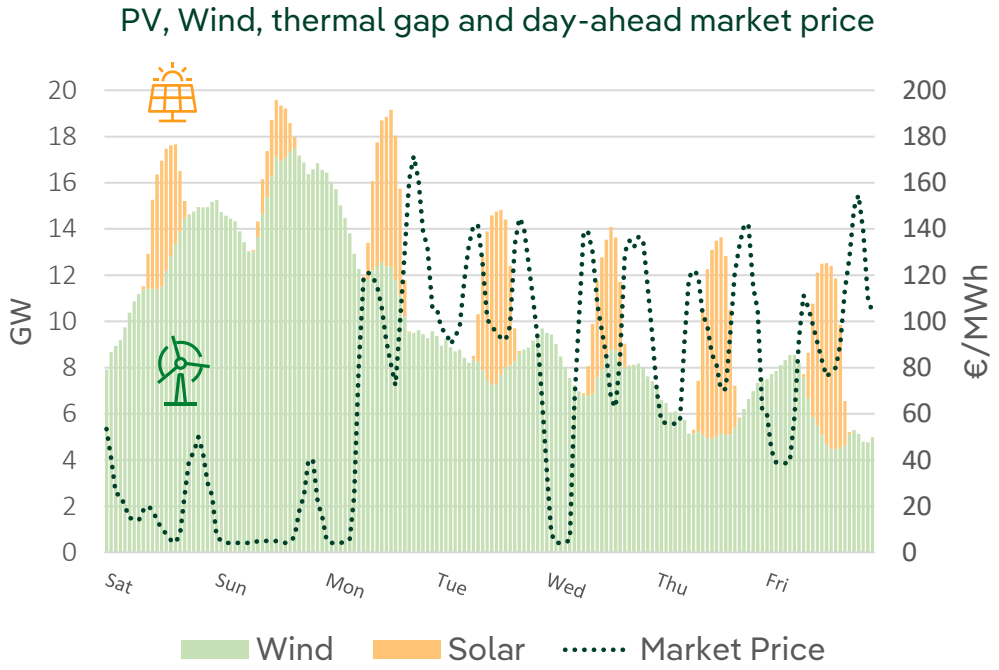
...Focus on **flexibility** required by the TSO

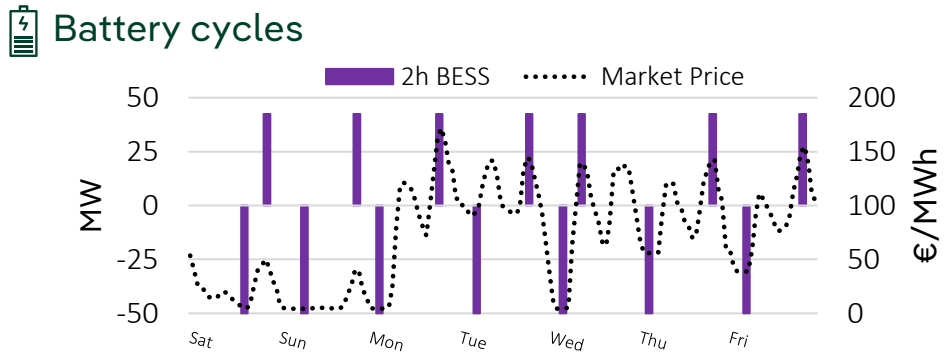
...Focus on **decarbonization, RES integration** and **security of supply** provided to the **System**

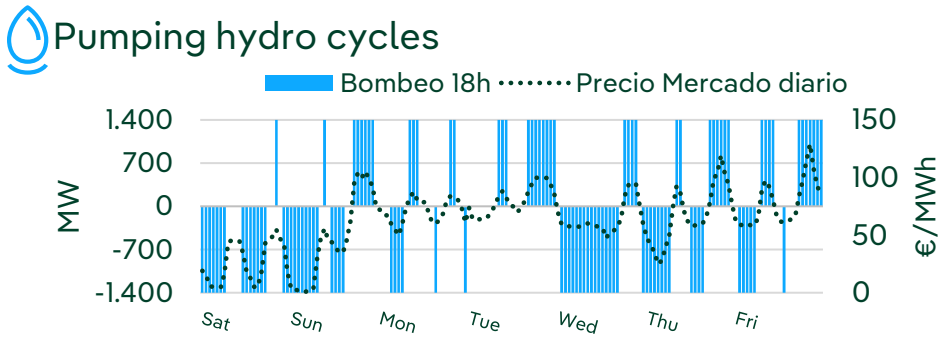
Pumping hydro and batteries can obtain different revenue stacking based on their technical capabilities

Revenue stacking: market arbitrage

Longer duration storage captures daily and weekly arbitrage opportunities







Pumping hydro has 2.5-3x load factor compared with 2h BESS

Revenue stacking: Ancillary Services

Pumping Hydro and batteries can provide Ancillary Services thanks to their flexibility

More relevant

Less relevant

Restoration Reserve (mFRR)- *Tertiary*

- Quick response (in ~15 min) to system contingencies (e.g. change in renewable forecast)
- More RES penetration will mean more request of Restoration Reserve

Fast Frequency Response (aFFR) *Secondary*

- Very quick response (in ~5s) to fine-tune generation and load
- Limited market size with potential cannibalization

Voltage Control

- Voltage Control through reactive power production or absorption, currently provided by synchronous generators

Pumping Hydro will have competitive advantage in Restoration Reserve, as they can produce/pump ~100% of hours

Batteries may have an advantage in Frequency Response as they can easily regulate in charge or discharge mode

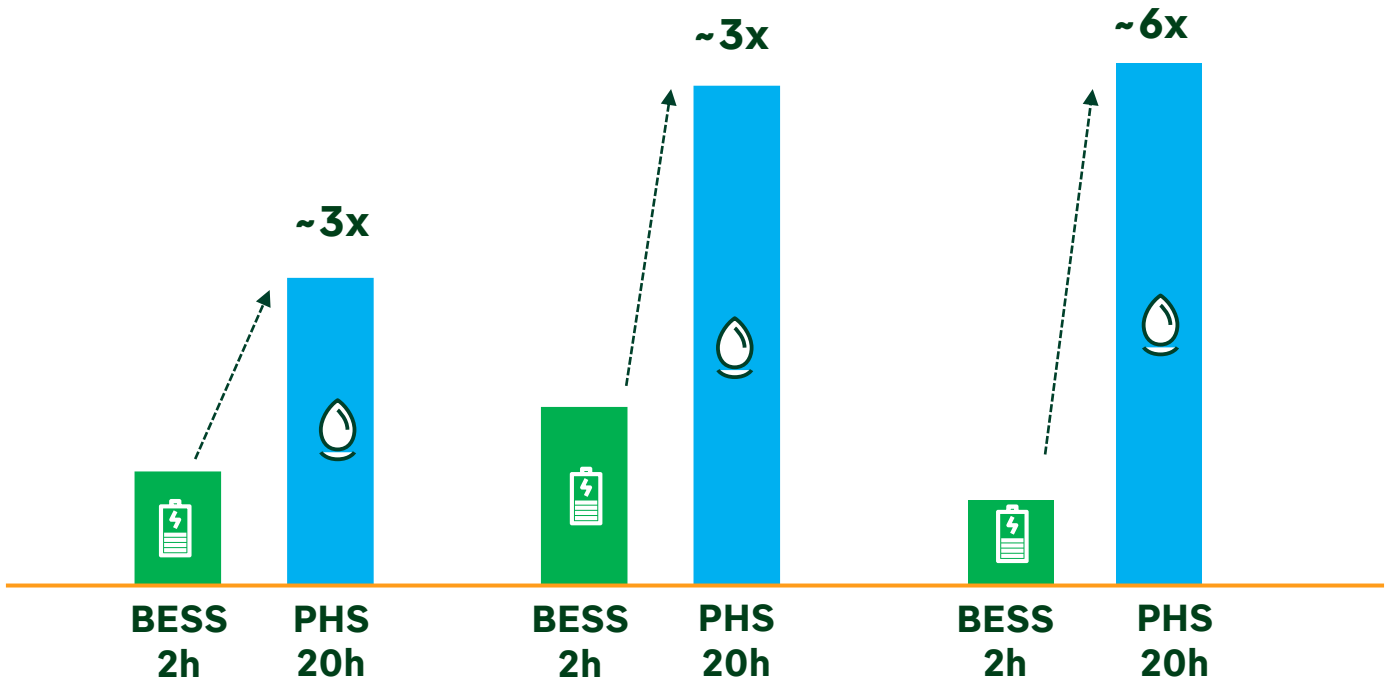
Revenue stacking: Services provided to the System

Pumping hydro is almost **3x more effective than BESS** 2h in terms of **decarbonization and renewable integration**... and **6x** times in terms of **security of supply**

Three key services provided to the system...

... **measured** as:

CO_2 emissions reduction	RES Integration	Security of supply
(Avoided MtCO2 / GW Storage)	(Avoided TWh spillages / GW Storage)	(Derating Factor)[1]



1. UK capacity auctions (2027/28)

Revenue stacking: Summary

Longer duration does matter for collecting higher revenues from Market Arbitrage and Restoration Reserve, and providing more effectively Services to the System

	Market arbitrage	Ancillary services		Services to the System
		mFFR (Restoration Reserve)	**aFFR** (Fast Frequency Response)	**Decarbonization** **RES integration** **Security of supply**
Battery	+	+	++	+
Pumping Hydro	++	++	+	++
Rational	Higher load factor for pumping	Batteries exhaust flexibility quicker	Variable speed required for pumping	Higher derating for pumping More effective in spillage reduction

Potential future revenues through local services provided to the DSO

However, batteries can offer some advantages such as shorter time-to-market and smaller space requirements