

Long Duration Energy Storage Technologies and Global Market Trends

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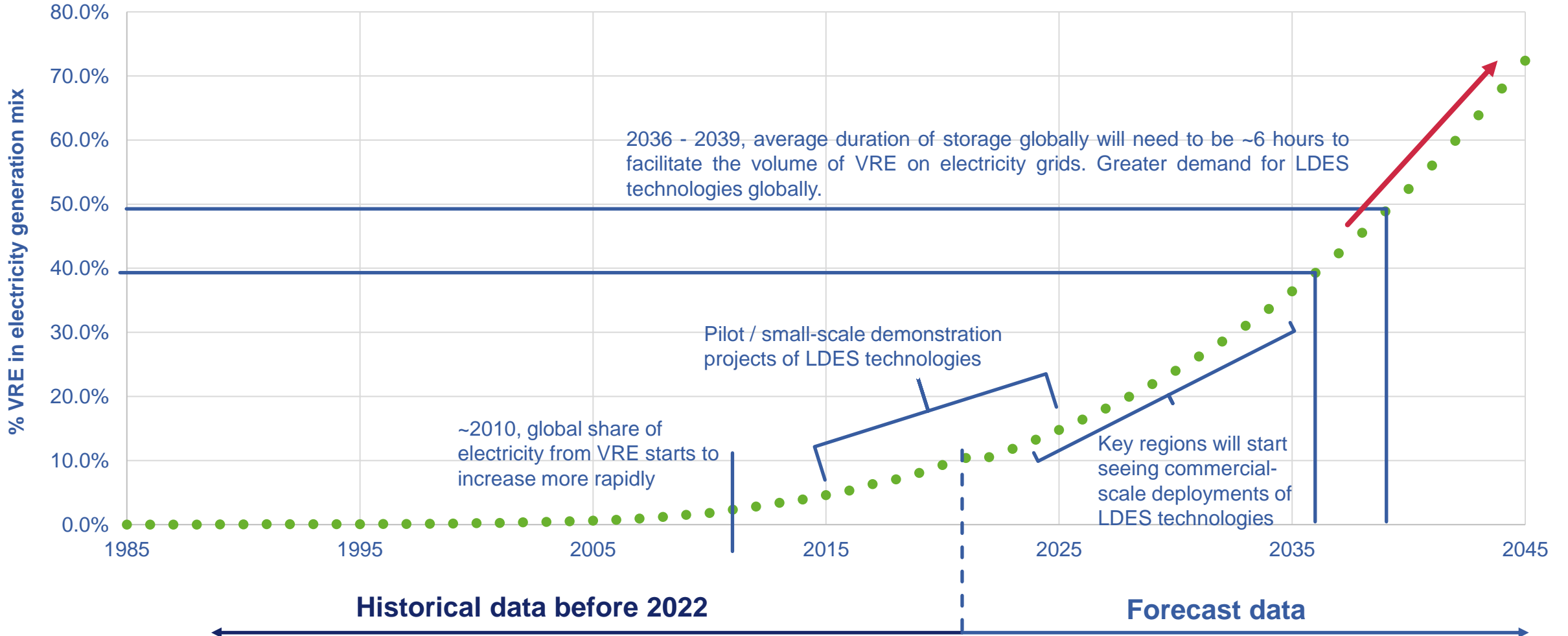


Introduction to LDES



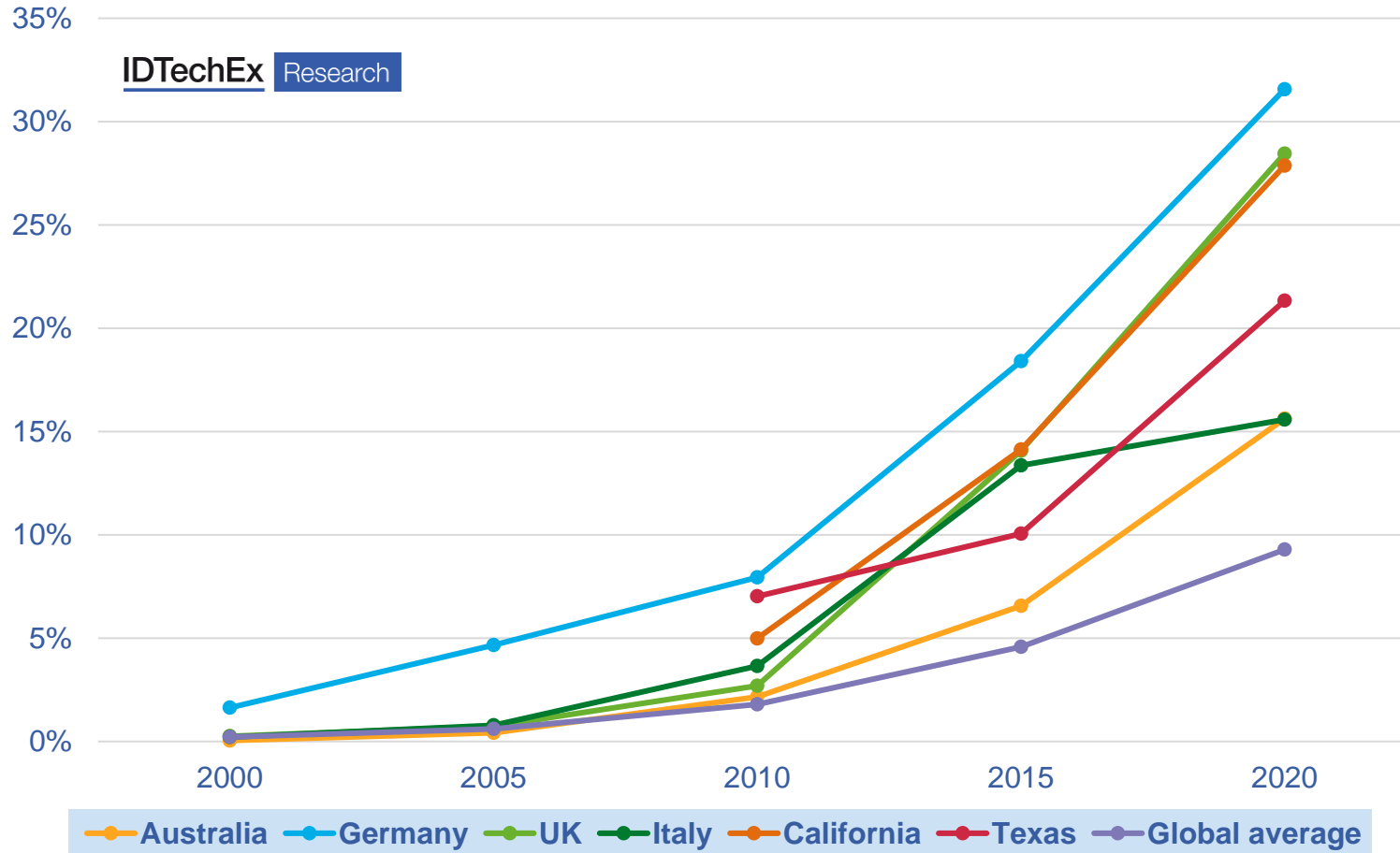
When Will LDES Be In Demand?

% VRE in Global (Average) Electricity Generation Mix



The Earlier Adopting Regions of LDES

Key Countries and US States % Electricity Generated by VRE (by GWh)

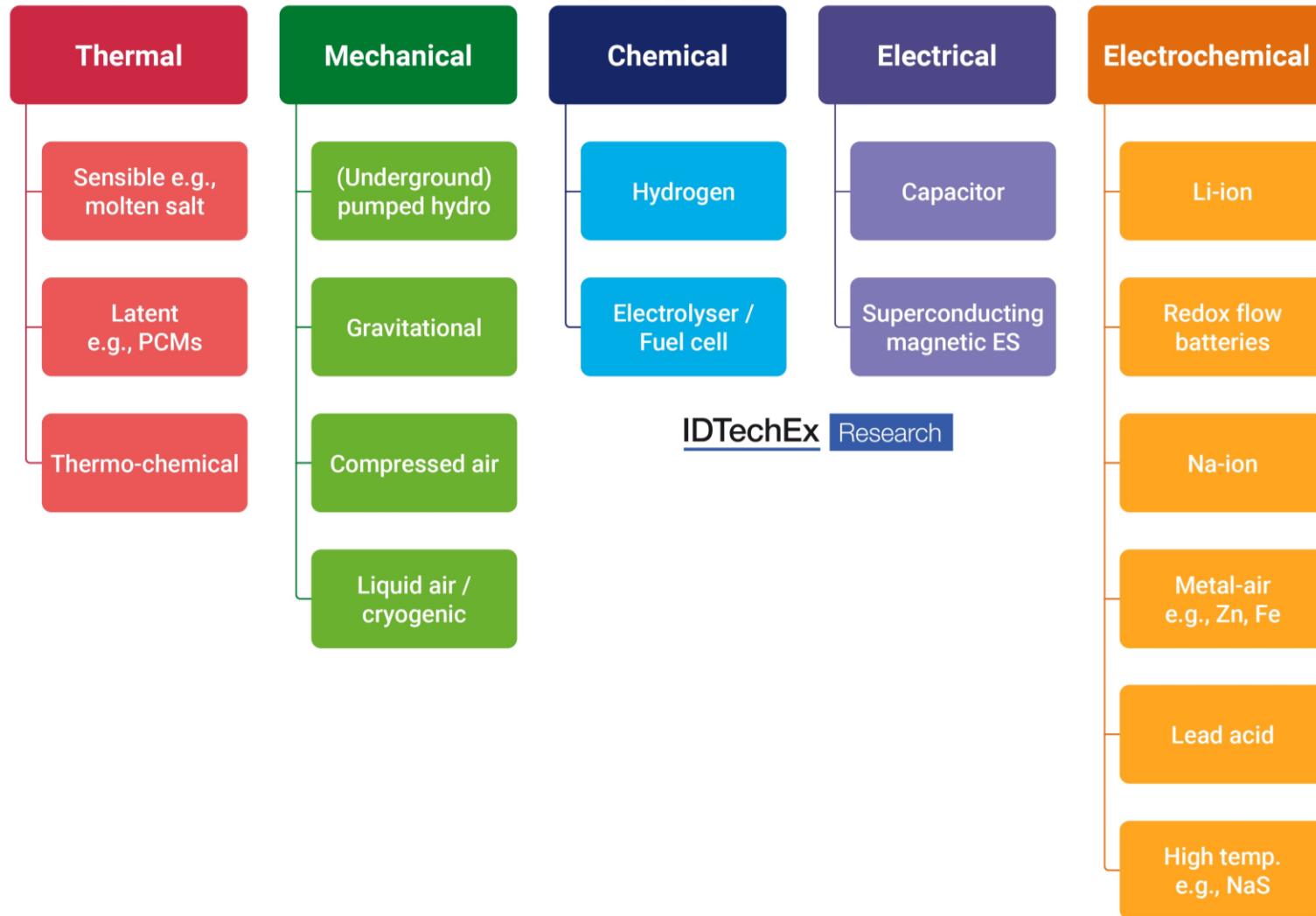


Country / State	% VRE in electricity generation mix 2023 (GWh basis)	% VRE in electricity generation mix 2035 (GWh basis)
Germany	27%	75%
UK	16%	64%
California	25%	63%
Italy	8%	55%
Texas	26%	51%
India	28%	44%
Australia	20%	43%

LDES Technologies



Energy Storage Technology Classification



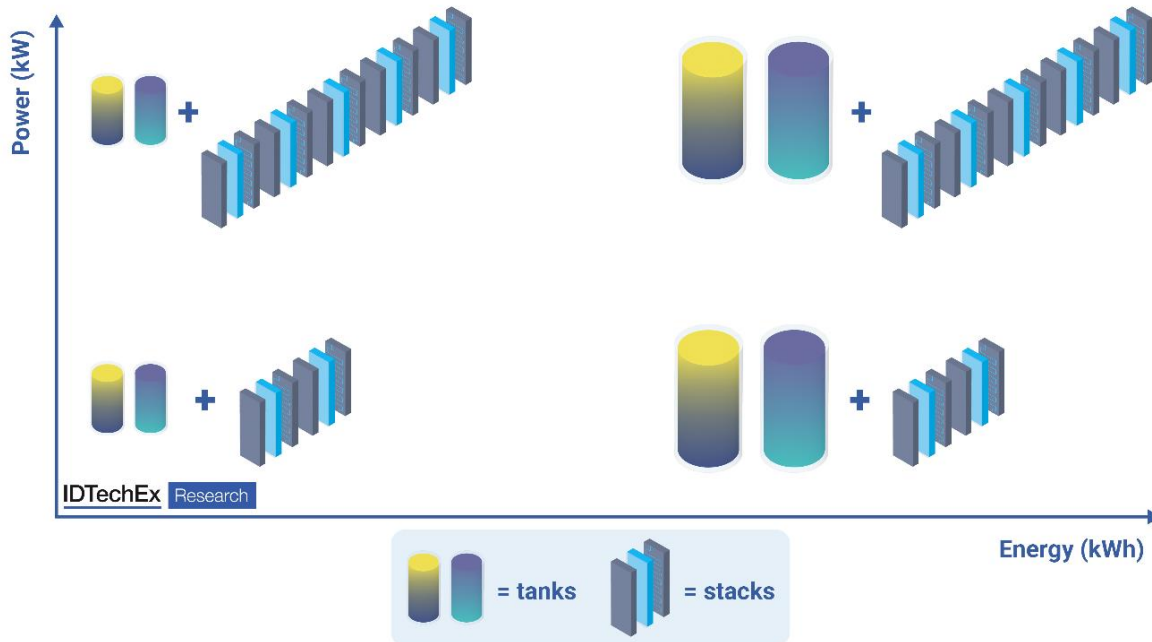
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Key Considerations

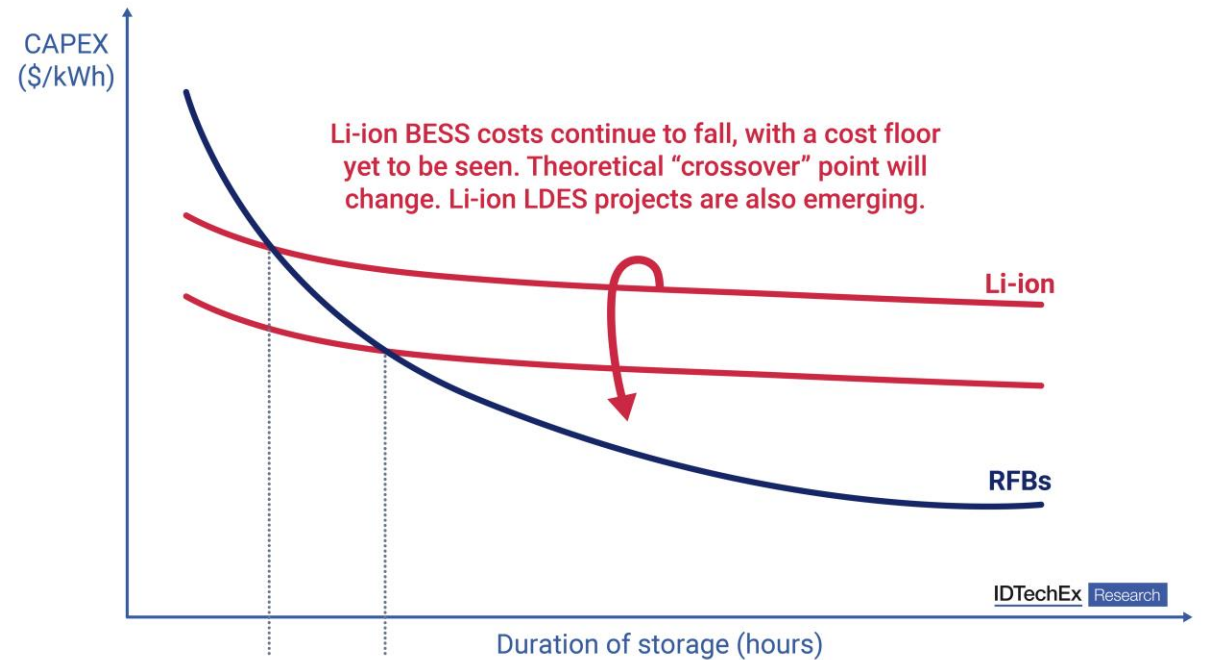


Energy and Power Decoupling

Energy and power decoupling in a redox flow battery system



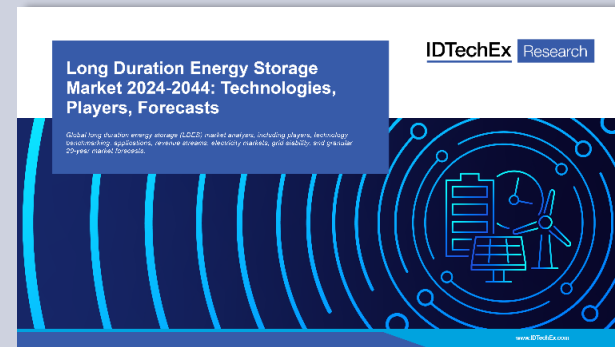
CapEx of RFB vs Li-ion over increasing duration of storage



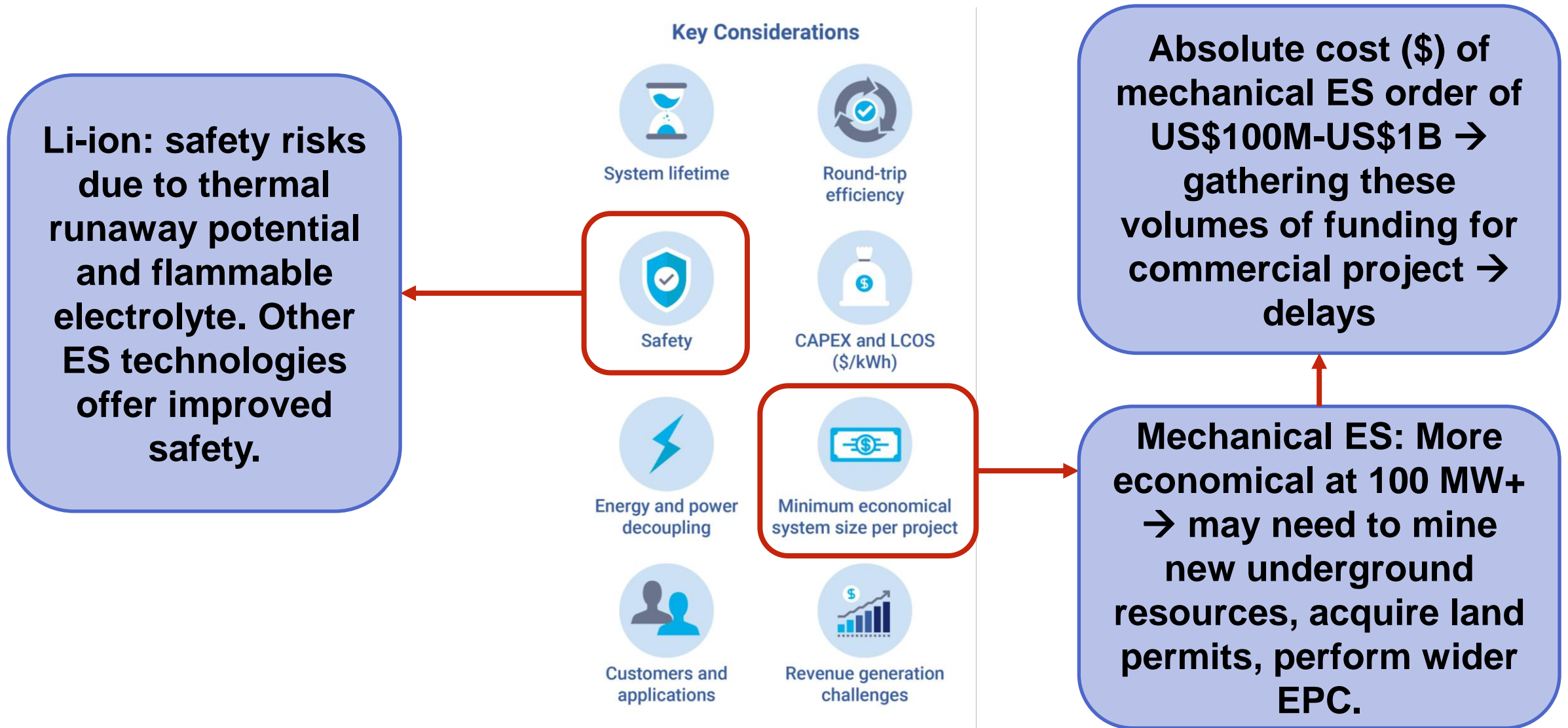
Examples of LDES Technology Comparisons

Technology	CAPEX (US\$/kWh)	Round-trip efficiency	Cycle Life / Lifetime	Energy density – System level
Li-ion	200-350	~95%	2,000-10,000	100-150 Wh/kg, 200-300 Wh/L
VFB	500-800	70-80%	20,000+	10-30 Wh/kg, 10-40 Wh/L
CAES	300+	~50% (Up to 70% if adiabatic).	50+ years	2 – 10 Wh/L – large underground cavities needed.
Thermal	Varies. As low as US\$45/kWh for larger systems, but more likely US\$100+/kWh currently for most systems.	Heat output: ~95% Electricity output: 40-60%	Varies. Latent: 5 – 10 years. Sensible: 20 – 40 years.	Depends on ΔT . Material level: 70 – 180 Wh/kg for molten salt. 50 – 290 Wh/kg for concrete.

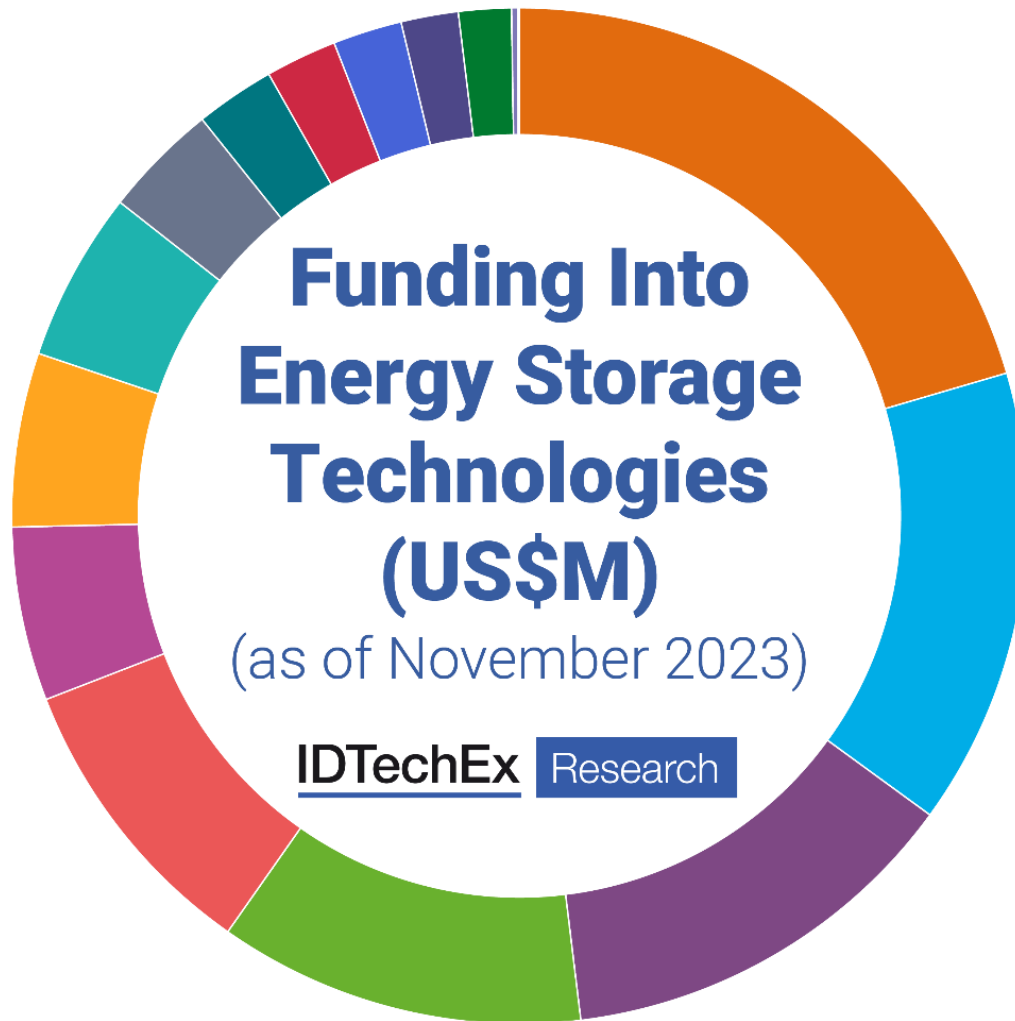
14 technologies benchmarked in the IDTechEx report.



Other Considerations: Safety and Economical Project Size

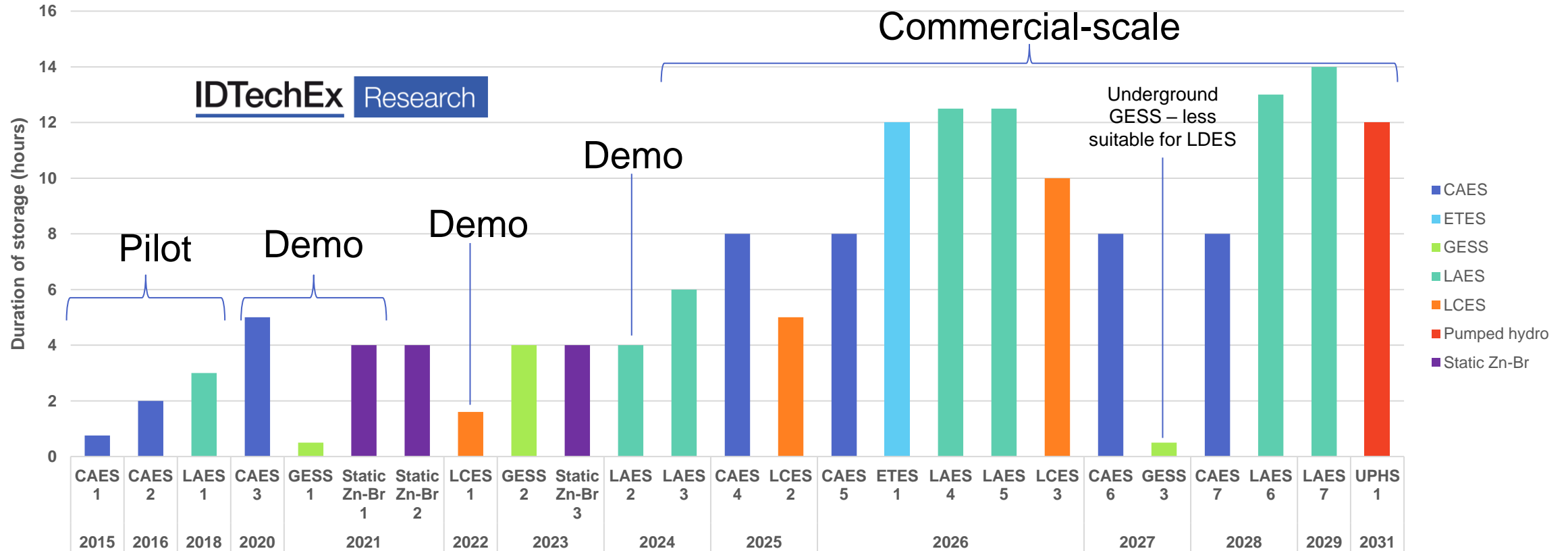


Funding into LDES Technologies



LDES Projects Are Already Coming: Identified Projects Forecast

Duration of storage across key ES projects 2015 - 2031 (omitting ApexCAES and Form Energy projects)

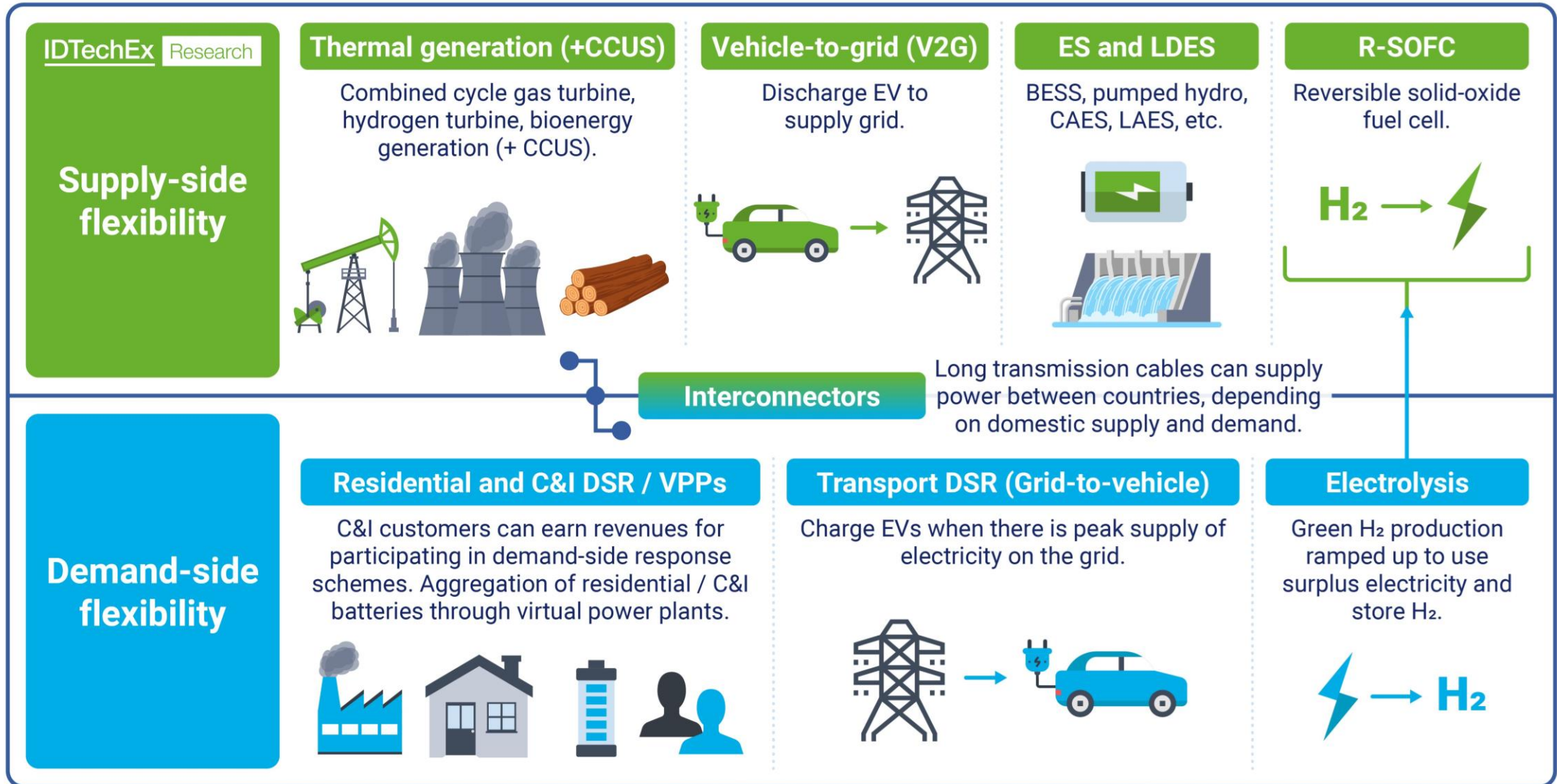


CAES = Compressed air energy storage
 ETES = Electro-thermal energy storage
 GESS = Gravitational energy storage system

LAES = Liquid air energy storage
 LCES = Liquid CO₂ energy storage

Pumped hydro = Underground pumped hydro storage
 Static Zn-Br = Zn-Br battery storage (not RFB)

Other Technologies to Improve Grid Supply-Side and Demand-Side Flexibility



Applications, Customers and Revenue Generation



Grid-Scale Energy Storage Market Applications

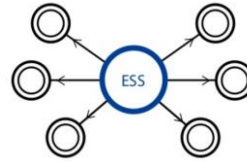
Front-of-the-meter utility services

Energy shifting



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Transmission & distribution deferral



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Peaker plant deferral



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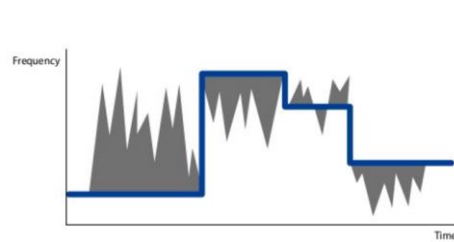
Transmission congestion relief



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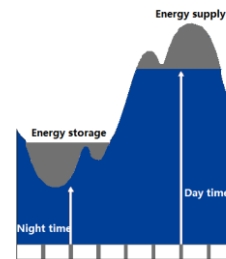
Front-of-the-meter ancillary services

Regulation



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Load following



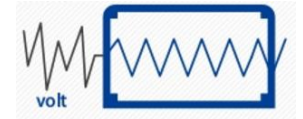
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Frequency response / (non)-spinning / replacement restoration reserves



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Voltage control



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Key Customers of LDES Technologies



Customers

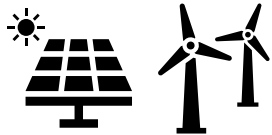


Why?



Utility companies

To shift energy over longer timeframes as VRE penetration increases



Renewable energy developers

To bid into emerging LDES tenders



Off-grid mining?

To use large LDES systems that do not require underground infrastructure. Reduce demand for batteries / diesel generators?

Revenue Generation Outlook for LDES



Revenue Generation Opportunities



Wholesale electricity price arbitrage



Capacity market contracts



Ancillary services



...and Challenges

Not frequent, large, or long enough alone currently for substantial ROI

Do not recognize the other values that storage brings

Separate procurement, remuneration for provision of multiple ancillary services, and effective revenue stacking increases complexity



Potential Solutions

Factors should increase with increasing VRE penetration

Redesigns to CM contracts, to recognize other benefits of storage

Regulatory reform to handle complex revenue stacking scenarios to maximize revenue generation

LDES Summary

LDES technologies will be in greater demand in key regions by the mid 2030s, in order to support growing VRE penetration. Demand will accelerate in the late 2030s, and wider demand globally will only be seen post-2040. Annual market value will be >US\$220B by 2044.

Drivers:

- Increasing penetration of VRE in key regions
- Future material constraints and existing safety risks of Li-ion
- Revenue generation can come from various sources
- Decoupling of energy and power present opportunities for lower costs than Li-ion at longer durations for many LDES technologies
- Opportunities to be procured by different customers; utilities, renewable developers, off-grid mining

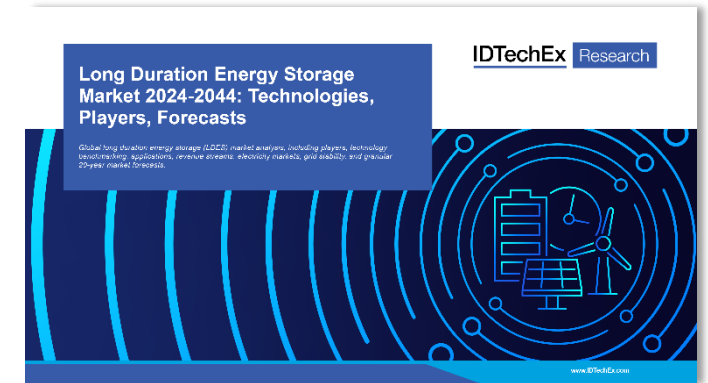
Challenges:

- Revenue generation challenges; including lack of substantial price arbitrage opportunities currently, potential need for reforms to capacity market contracts and ancillary service remuneration to provide longer-term revenue visibility
- Demand heavily influenced by VRE penetration, and governments meeting VRE deployment targets
- Cost reductions (\$/kWh) of key LDES technologies not widely demonstrated commercially, due to lack of demand for LDES technologies currently

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Long Duration Energy Storage Market 2024-2044

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