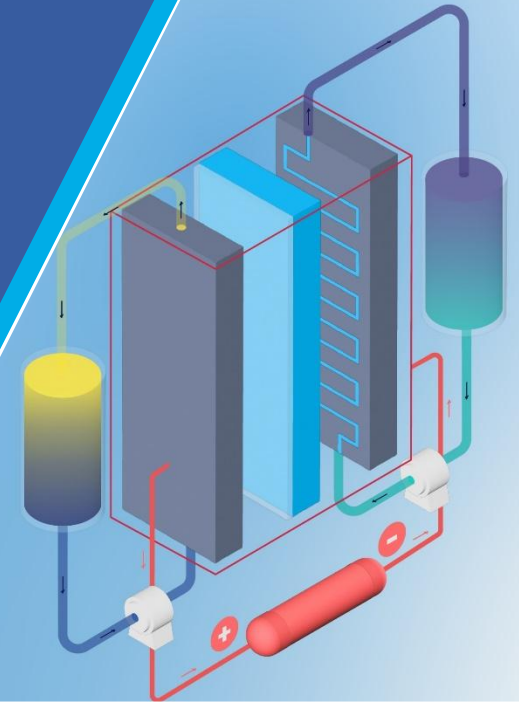


The Global View of the Flow Battery Market

Conrad Nichols – Senior Technology Analyst, IDTechEx



IDTechEx

IDTechEx Provides Clarity on Technology Innovation...



**Market
forecasts**



**Technology
assessment**



**Market
sizing**



**Technology
scouting**



**Strategic
advice**



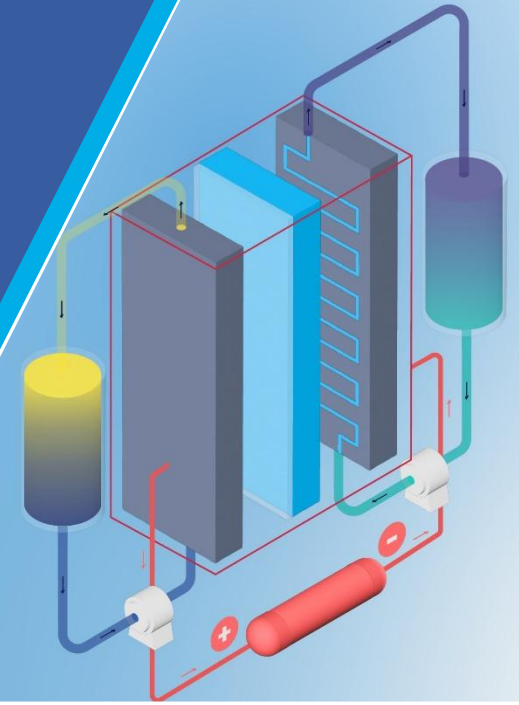
**Company
profiling**

...And Covers a Wide Range of Topics

IDTechEx



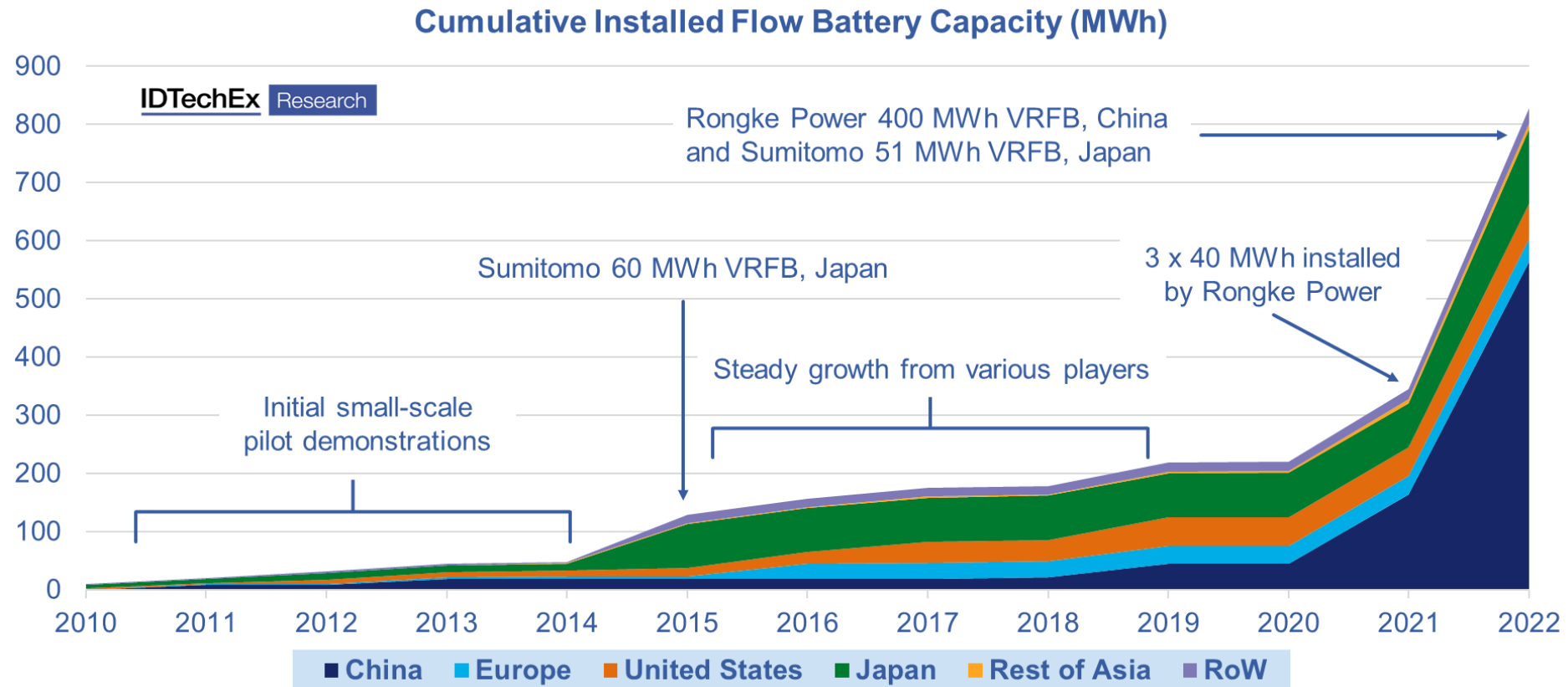
Existing Flow Battery Market



IDTechEx

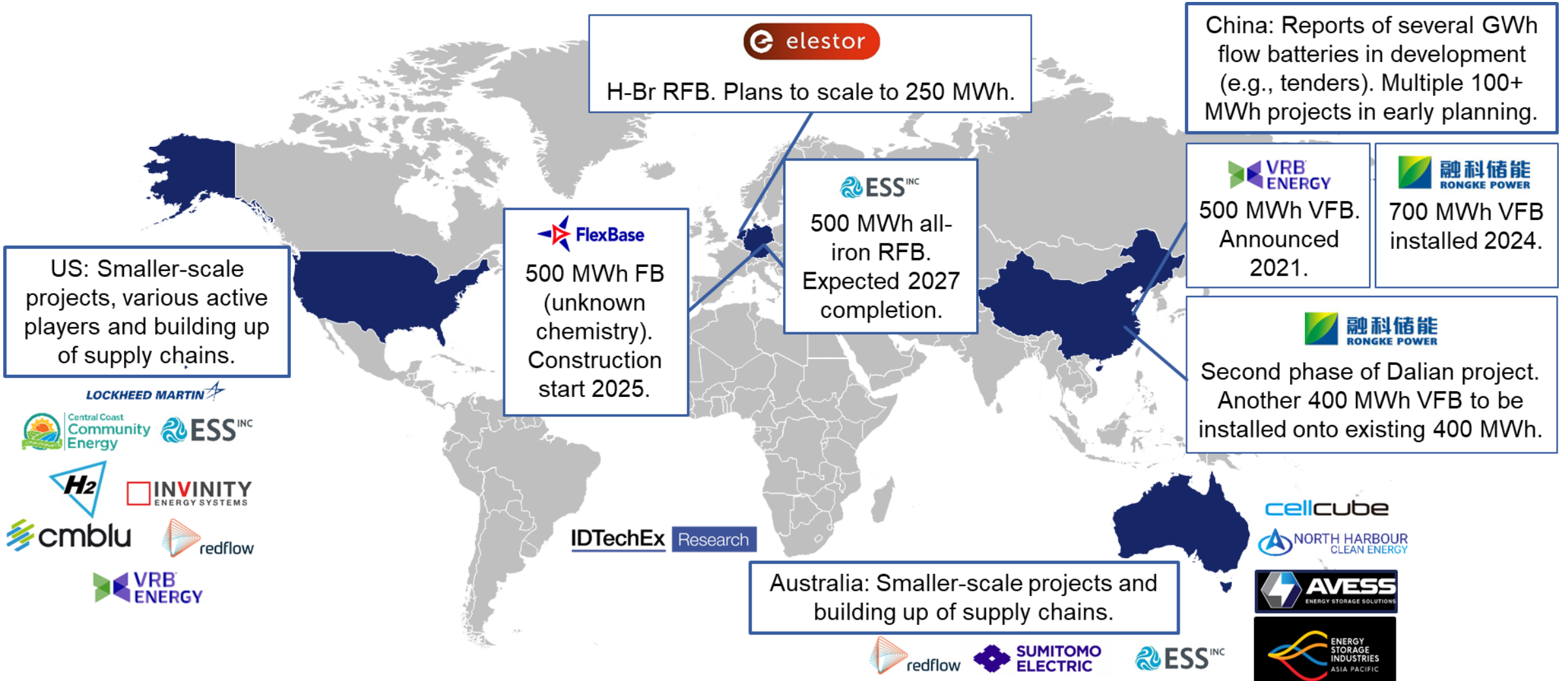
Cumulative Installed Flow Battery Capacity By Region (MWh)

- Steady flow battery (FB) growth over the last decade, made up of many smaller-scale projects.
- A few large-scale projects have created and will continue to create spikes in total installed global capacity (MWh).



(This includes identified FB project data, there are likely unidentified projects, especially in China).

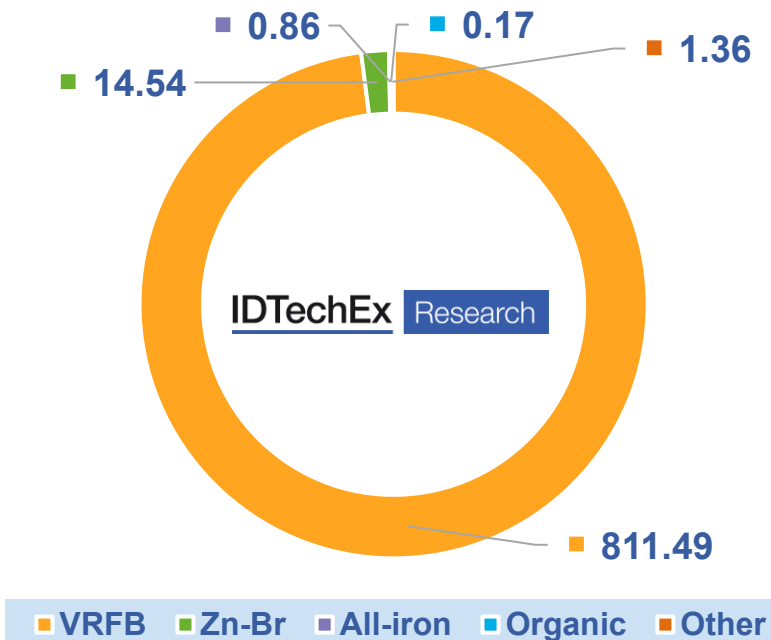
Key Large-scale Flow Battery Projects and Announcements



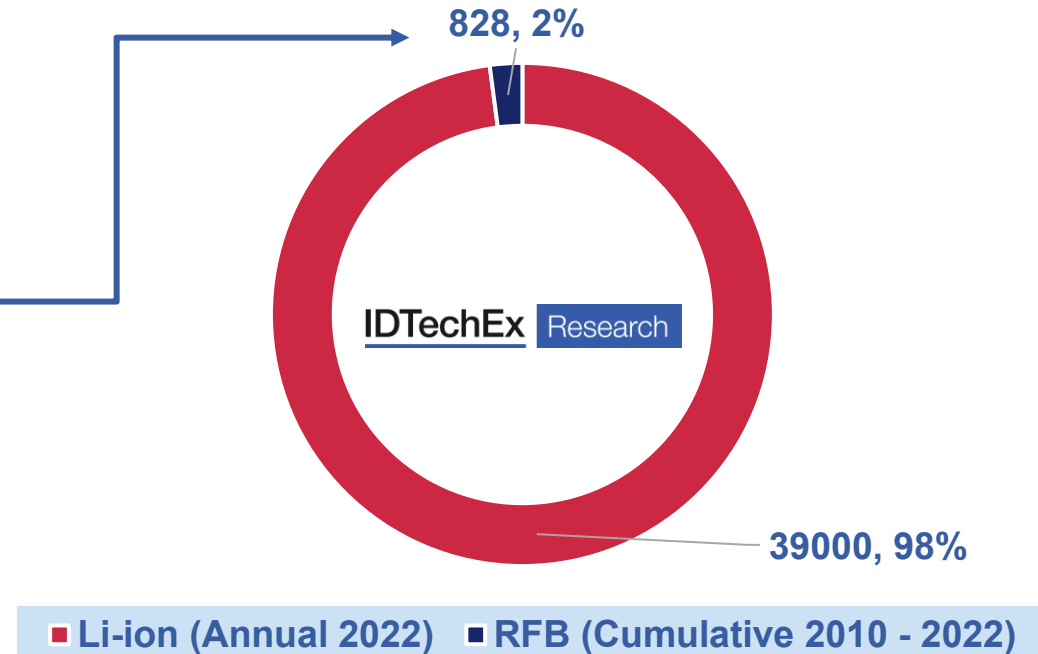
Flow Battery Market Chemistry Share and Comparison to Li-ion BESS

- Totalled flow battery (FB) installed capacity is dominated by the vanadium FB (VFB); well-understood technology and most player activity.
- However, compared to even the volume (MWh) at which *annual* Li-ion battery energy storage systems (BESS) is being deployed, cumulative FB deployment is much lower.
- **Li-ion BESS is a cheaper technology compared to the VFB. (US\$200+/kWh vs US\$500+/kWh). Due to high cost of vanadium electrolyte, and vanadium supply limited mostly in China and Russia.**

Cumulative Installed RFB Capacity by Chemistry (MWh) (End of 2022)

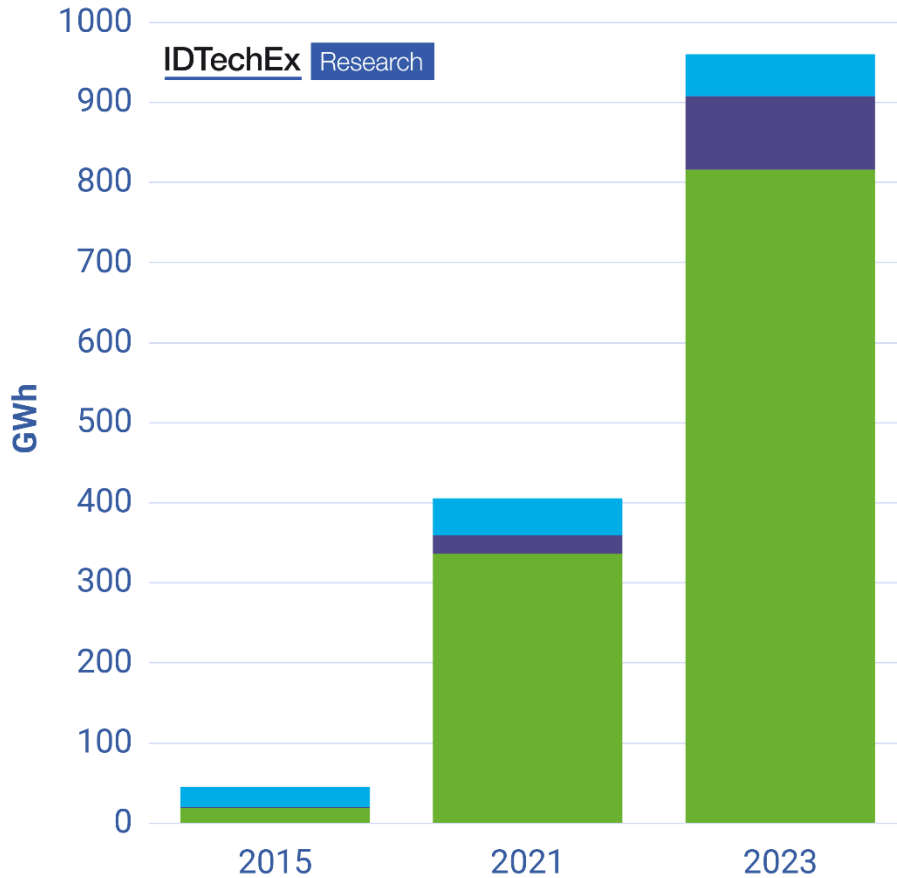


Cumulative RFB (2010 - 2022) vs Annual Li-ion (2022) Installed (MWh)

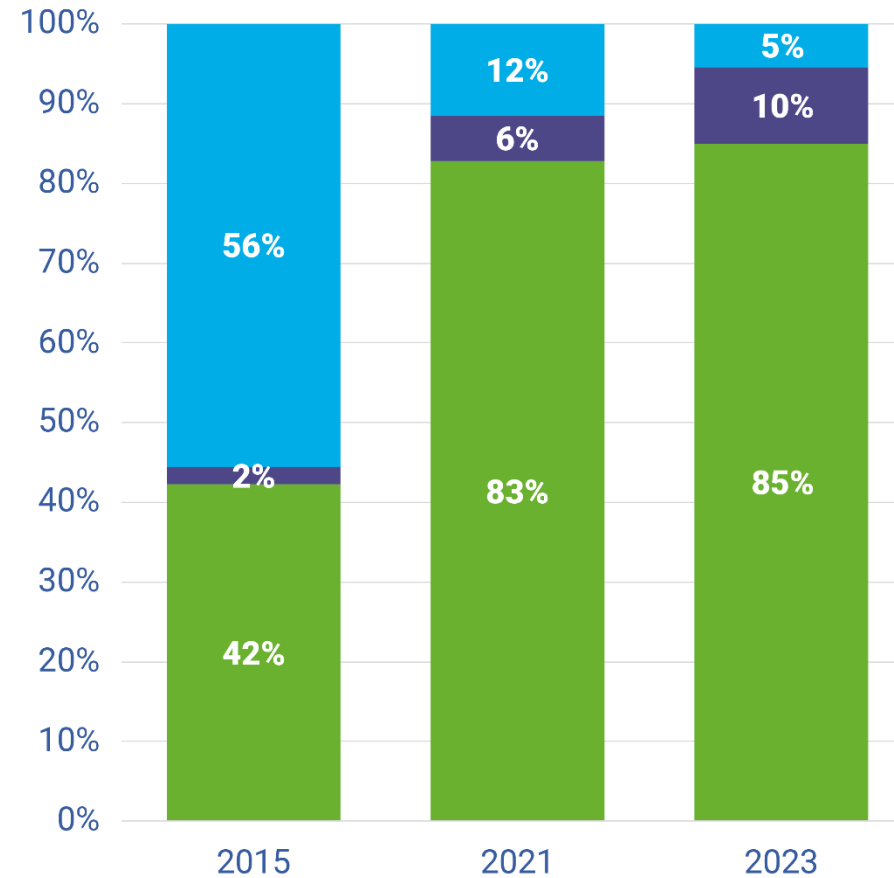


Li-ion BESS Growth Will Continue At Pace in the Medium-Term for Shorter Duration and Large Grid-Scale Applications

Li-ion Battery Demand by Sector (GWh)



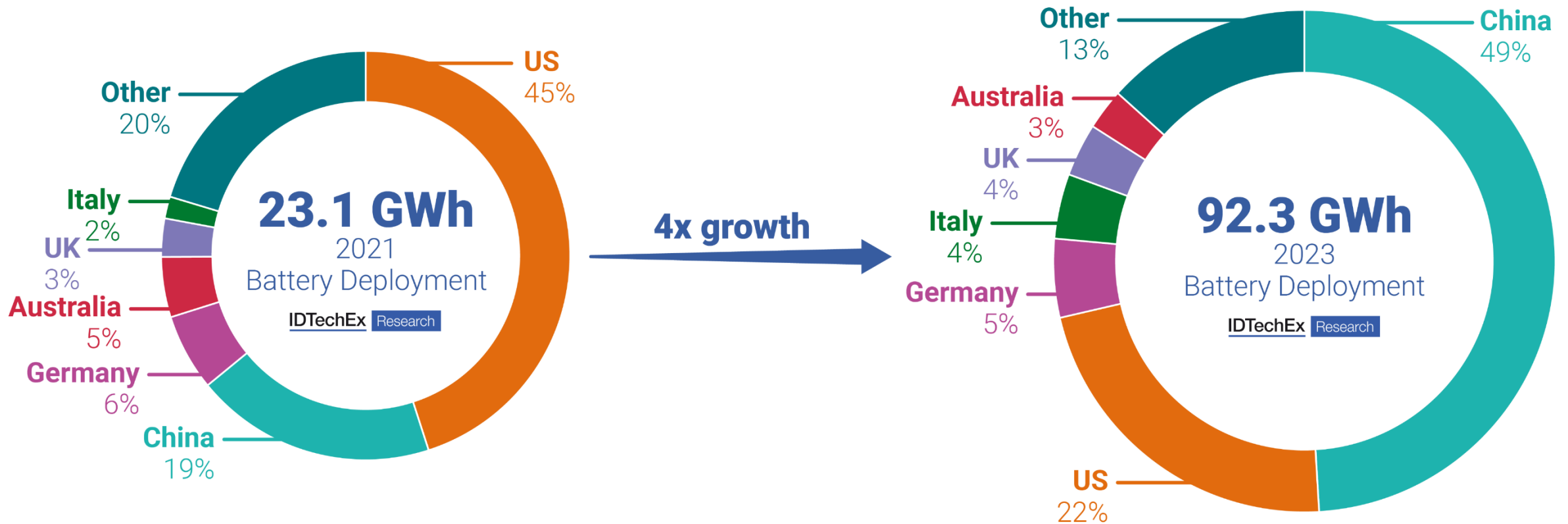
Li-ion Battery Demand by Sector (%)



EV ESS Consumer

Li-ion BESS Deployments by Country 2021 vs 2023

China and the US are responsible for most BESS installations in the past few years. However, other countries are showing the early signs of large and emerging grid-scale BESS markets which could shake up global outlook.



Strategies for VFB Players

- VFBs likely to remain dominant FB over next few years, given greater existing player activity and understanding of technology.
- FB players will be leveraging key technology advantages over Li-ion with customers in medium-term where possible:

General Flow Battery Advantages

Long cycle life (20,000+) →

Lower theoretical LCOS than Li-ion

Safety: non-flammable electrolyte →

Key advantage over Li-ion

Recyclable and recoverable electrolyte →

Leasing models for vanadium electrolyte could be key workaround for avoiding high CAPEX

Energy & power decoupling →

Important for long-term market growth

Strategies for VFB Players and Other Emerging Flow Battery Chemistries

- VFBs likely to remain dominant FB over next few years, given greater existing player activity and understanding of technology.
- FB players will be leveraging key technology advantages over Li-ion with customers in medium-term where possible:

General Flow Battery Advantages

Long cycle life (20,000+) →
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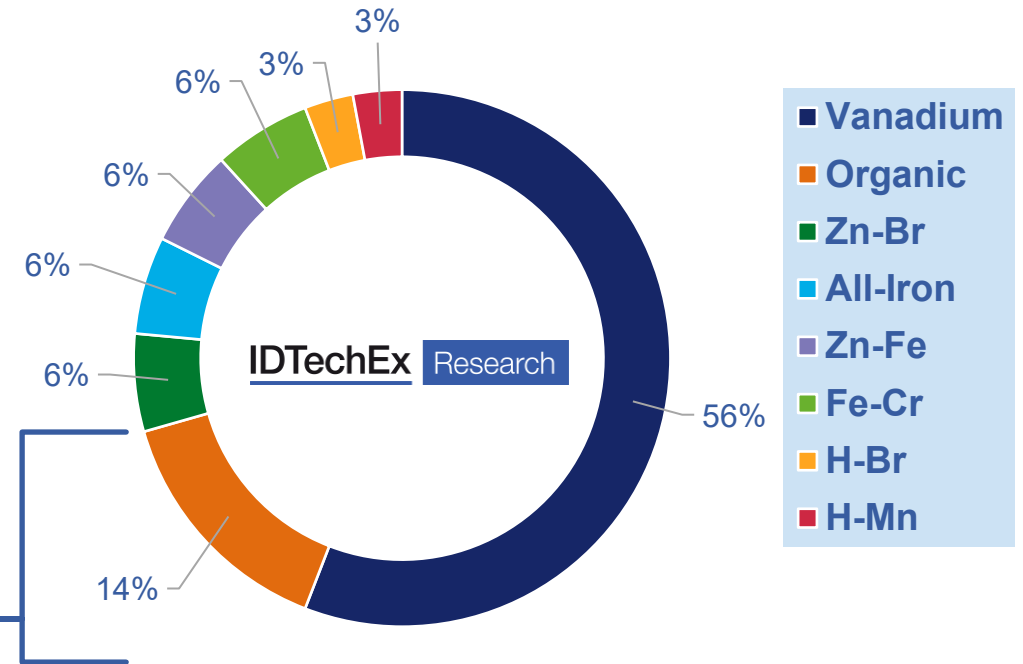
Safety: non-flammable electrolyte →
Key advantage over Li-ion

Recyclable and recoverable electrolyte →
Leasing models for vanadium electrolyte could be key
workaround for avoiding high CAPEX

Energy & power decoupling →
Important for long-term market growth

- Cheaper flow battery chemistries are being developed, promising the use of cheaper, more widely abundant materials.
- This includes organic, zinc-bromine, all-iron, zinc-iron, hydrogen-bromine, hydrogen-manganese, and iron-chromium flow batteries.

Number of Flow Battery Players, By Chemistry



Organic Flow Battery Players



Germany



Italy



France



US



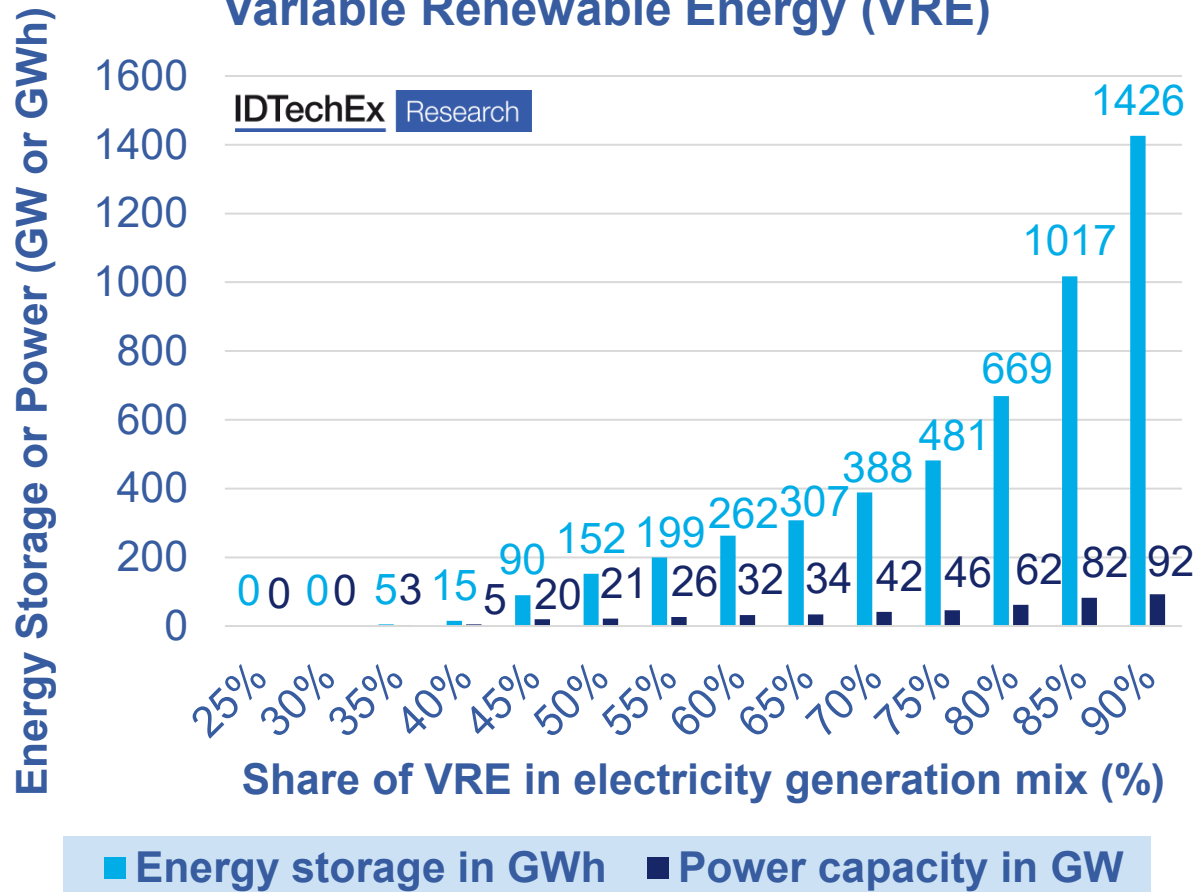
US

Introduction to Long Duration Energy Storage and How Flow Batteries Will Play a Future Role

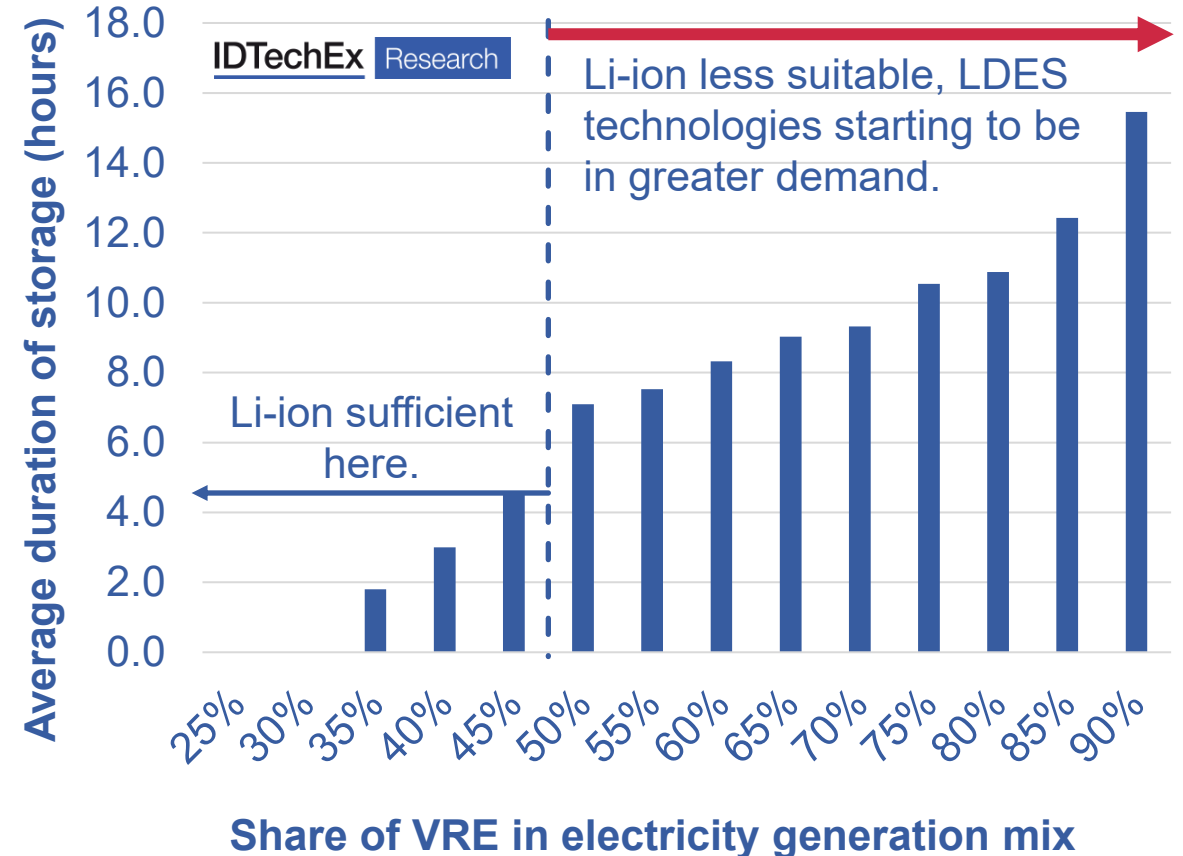


What is LDES and Why Will We Need It?

Increasing Storage Capacity Requirements with Increasing Share of Variable Renewable Energy (VRE)

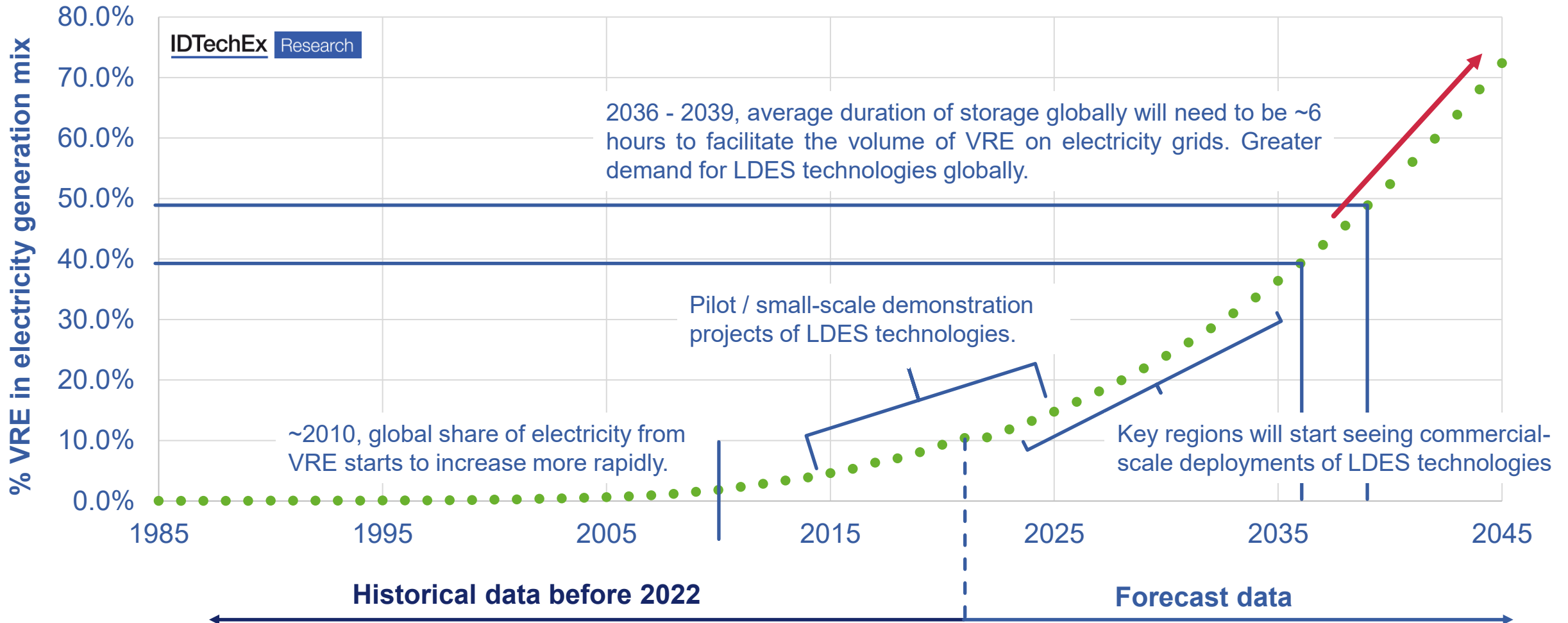


Increasing Duration of Storage Requirements with Increasing Share of VRE



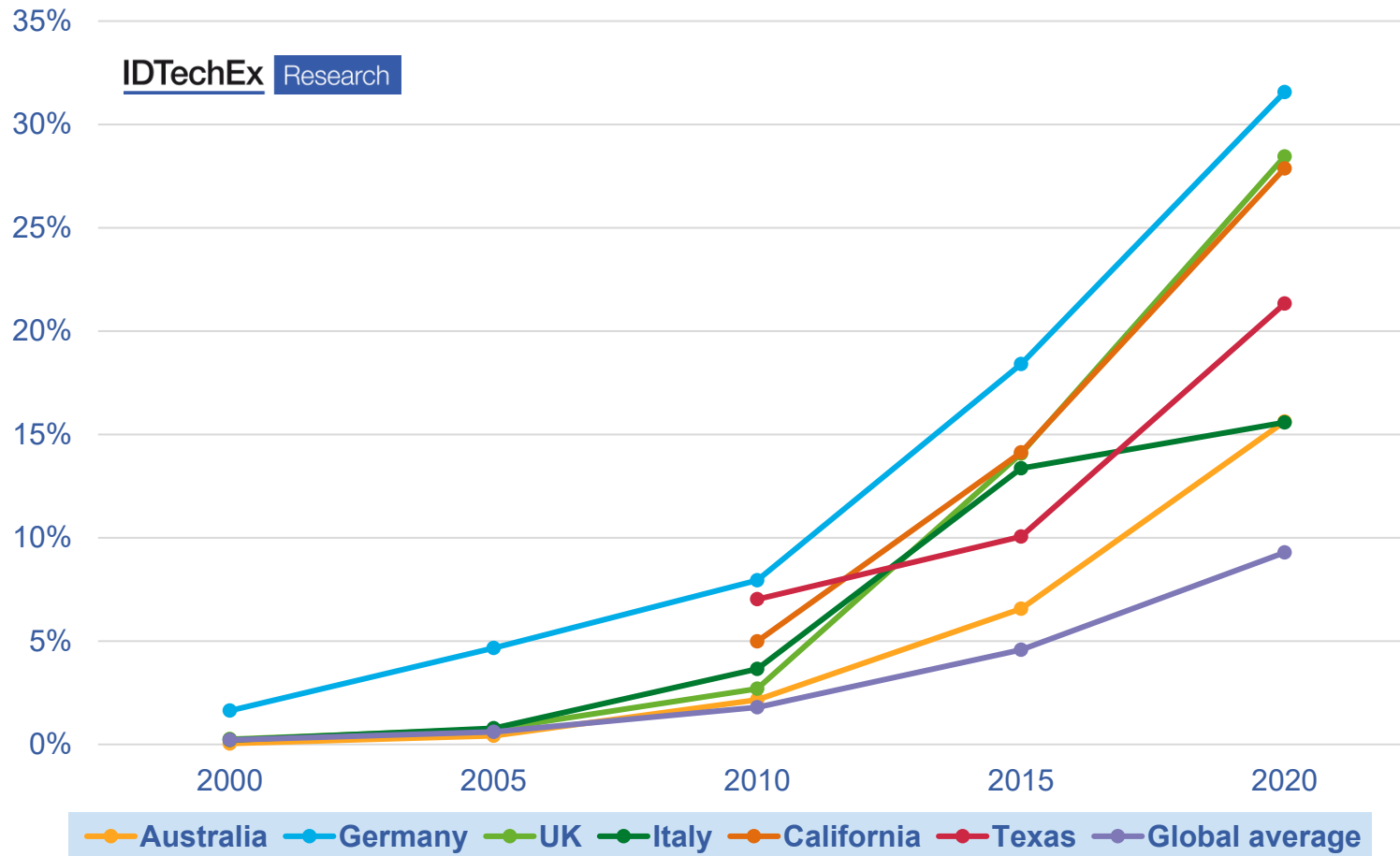
When Will LDES Be In Demand?

% VRE in Global (Average) Electricity Generation Mix



The Earlier Adopting Regions of LDES

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



IDTechEx Research

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%

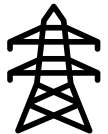
Key Customers of LDES Technologies



Customers

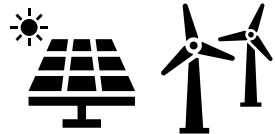


Why?



Utility companies

To shift energy over longer timeframes as VRE penetration increases



Renewable energy developers

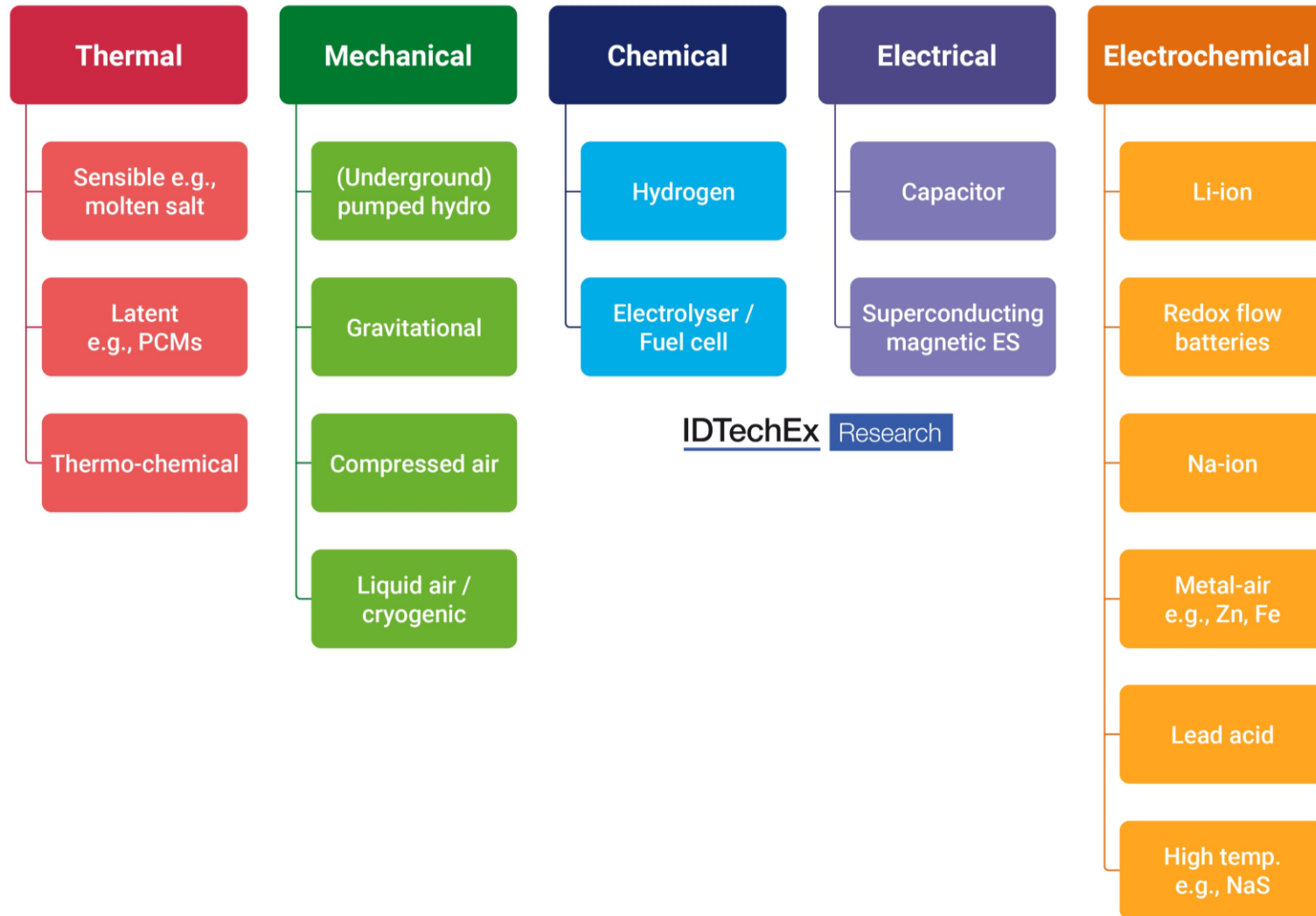
To bid into emerging LDES tenders



Off-grid mining?

To use large LDES systems that do not require underground infrastructure. Reduce demand for Li-ion BESS / diesel generators?

Energy Storage Technology Classification

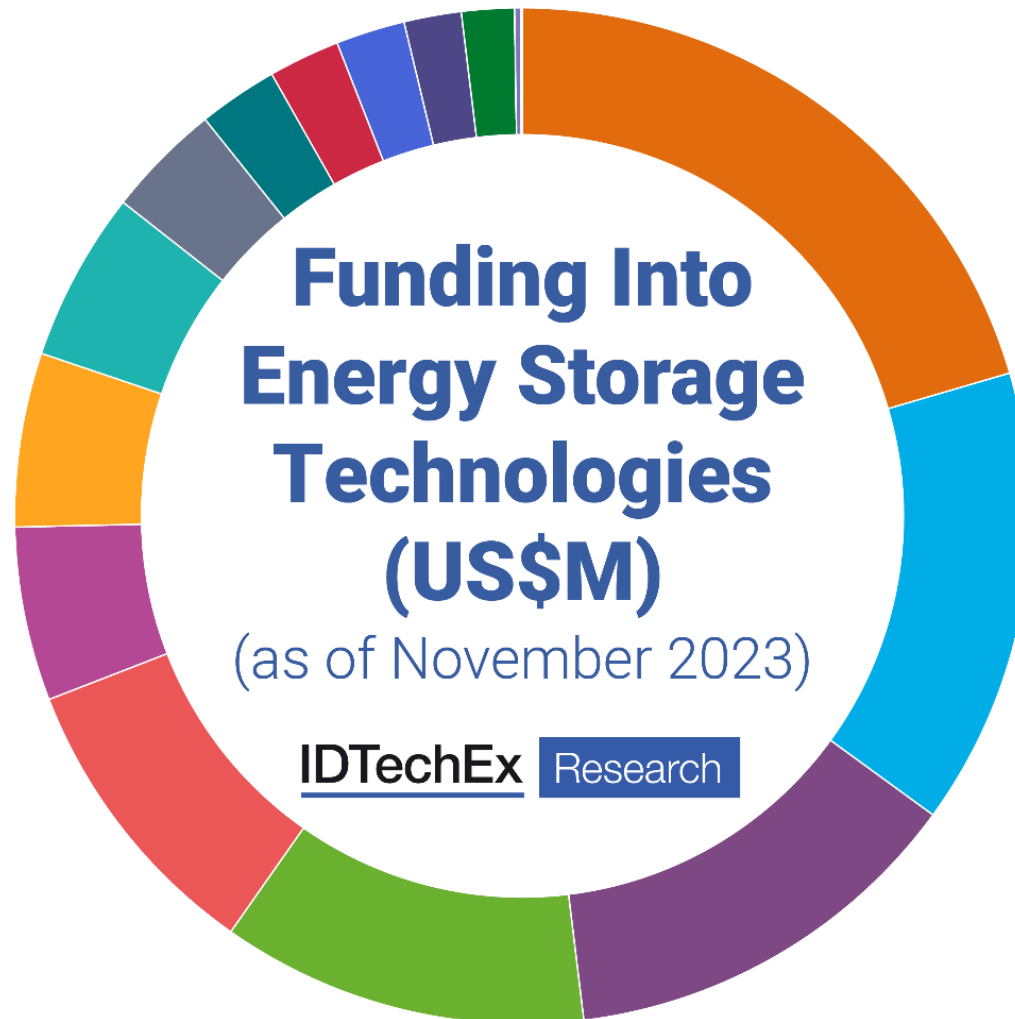


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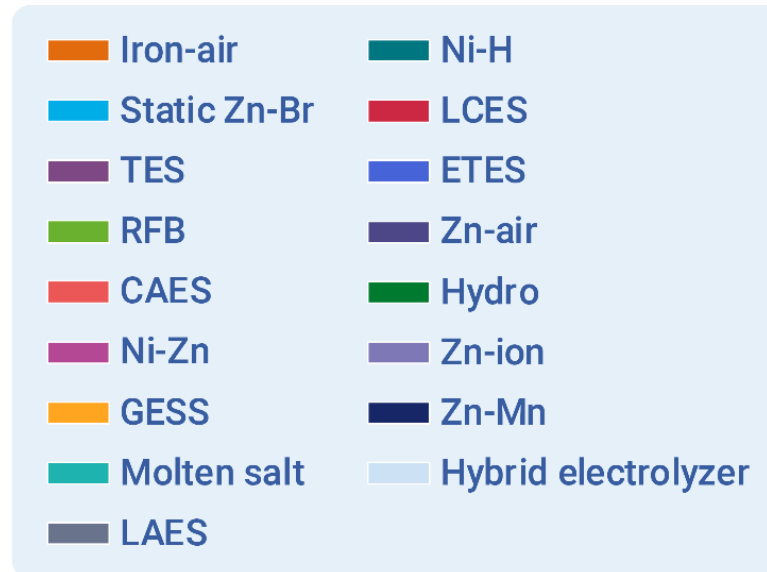
Key Considerations



Funding into LDES Technologies

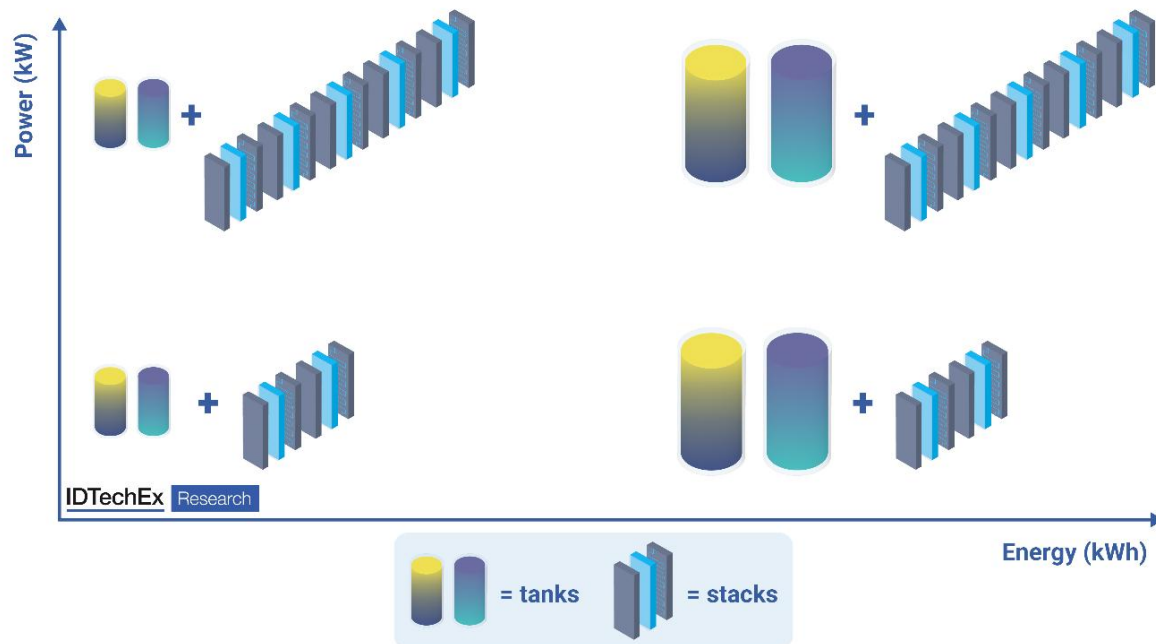


As of the end of 2023, ~US\$4.0B had been invested into LDES technologies.

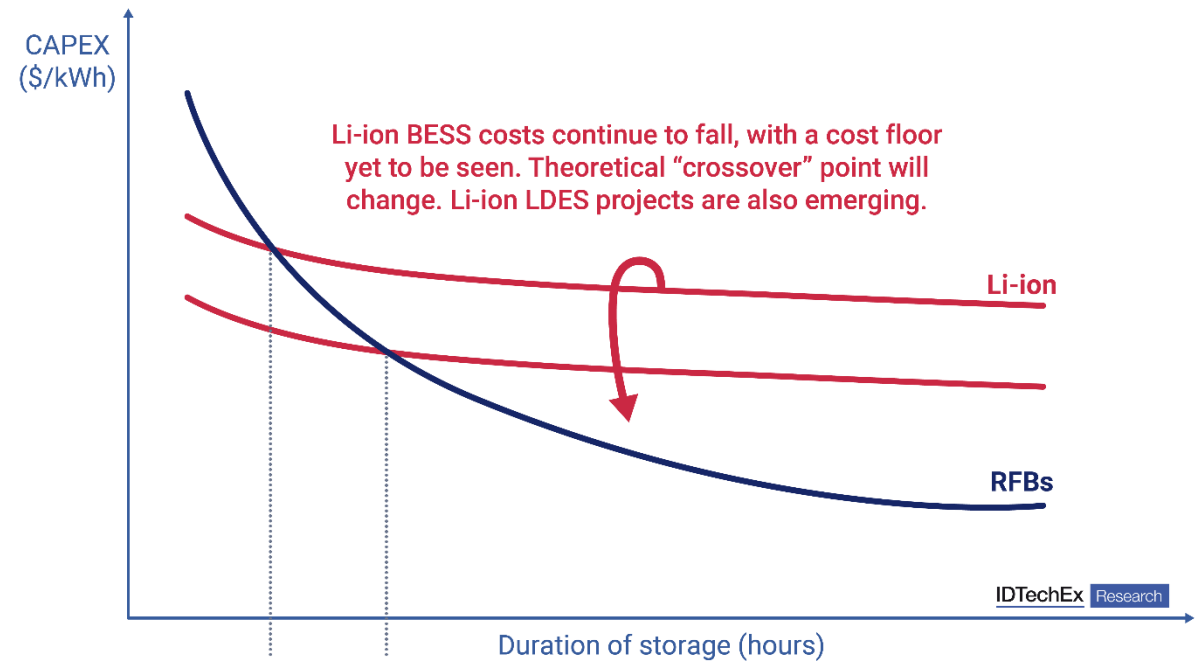


Theoretical Advantage of Flow Batteries: Energy and Power Decoupling

Energy and Power Decoupling in a Flow Battery System



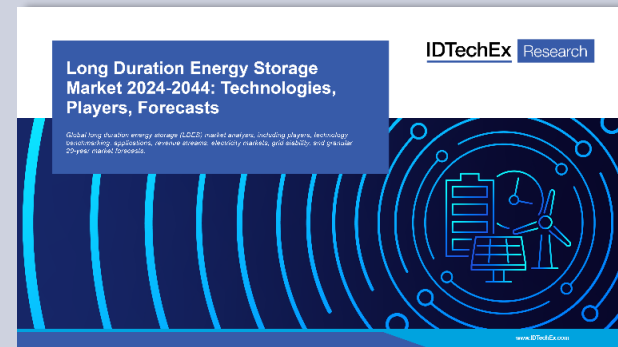
CAPEX of Flow Battery vs Li-ion BESS over Increasing Duration of Storage



Examples of LDES Technology Comparisons

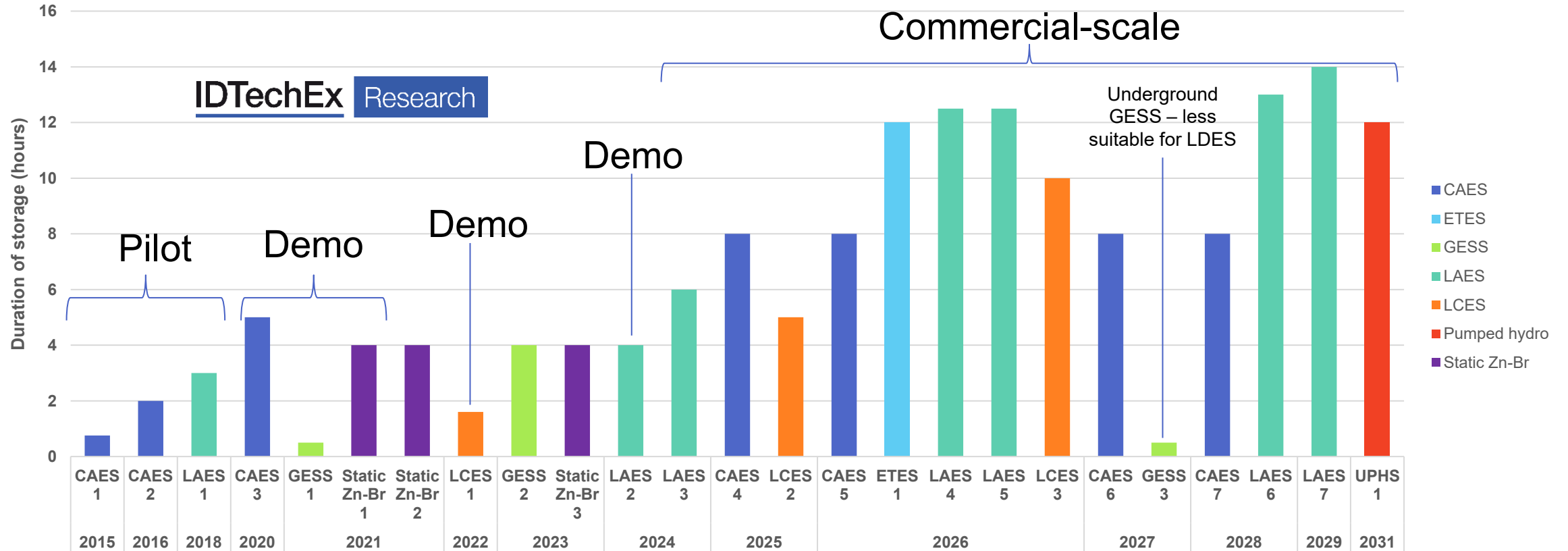
Technology	CAPEX (US\$/kWh)	Round-trip efficiency	Cycle Life / Lifetime	Energy density – System level
Li-ion	200-350	~95%	2,000-10,000	100-150 Wh/kg, 200-300 Wh/L
VFB	500-800	70-80%	20,000+	10-30 Wh/kg, 10-40 Wh/L
CAES	300+	~50% (Up to 70% if adiabatic).	50+ years	2 – 10 Wh/L – large underground cavities 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.



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)

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

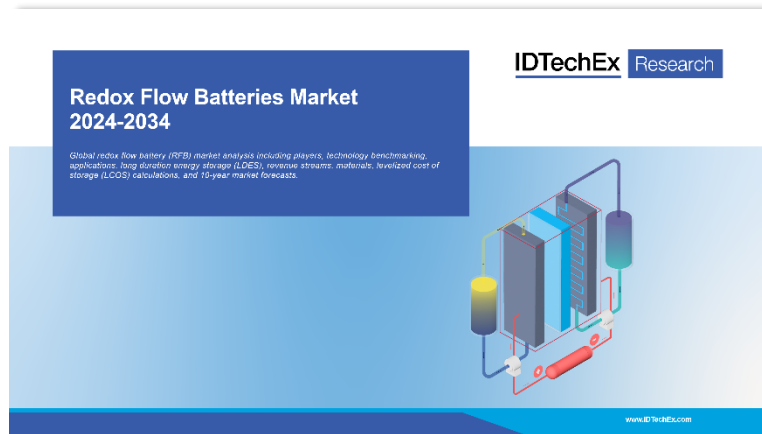
Factors should increase with increasing VRE penetration

Redesigns to CM contracts, to recognize other benefits of storage

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

The Global View of the Flow Battery Market and Thank You For Your Attention

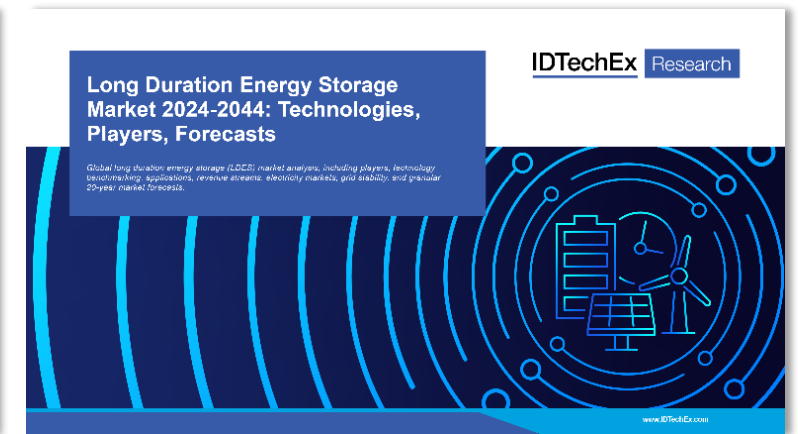
- VFBs will remain the dominant FB technology in the medium term.
- Its high upfront cost remains a key barrier to wider implementation, with Li-ion BESS offering cheaper costs.
- Alternative FB chemistries are being developed, using more widely abundant and cheaper materials for electrolyte.
- FB penetration could be higher in the future with increasing demand for LDES in key regions, irrespective of chemistry.
- Other energy storage technologies will compete as viable LDES options balancing various performance metrics with cost (including Li-ion).



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