Batteries & Energy Storage

What is Energy Storage?

Energy storage plays a pivotal role in enabling the energy transition. As the world shifts toward renewables, electric vehicles, and decarbonized industry, energy storage, the general process of **storing electricity in some form of energy,** sees increasing demand and becomes a core infrastructure requirement. Traditional coal and natural gas-based electricity production can produce electricity on demand while solar and wind produce energy only when conditions allow, requiring increasing installation of **energy storage in the power generation and energy distribution value chain** to address the mismatch between variable renewable generation and constant demand.

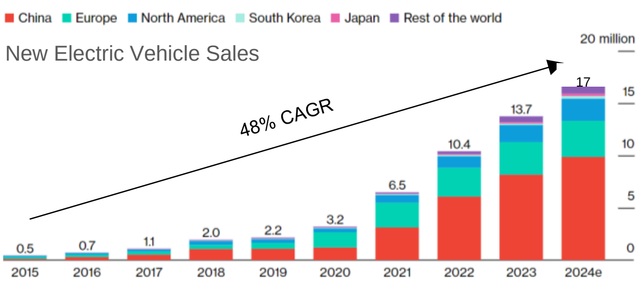
Energy storage is a diverse field of technologies optimized for different timeframes and uses. Mechanical systems like pumped hydro and compressed air serve long-duration needs. Electrochemical batteries such as lithium-ion dominate short-duration and mobile applications. Thermal and chemical storage, including heat batteries and hydrogen, target industrial and seasonal needs. Supercapacitors address fast-response power quality challenges. Although lithium-ion batteries are the mainstream solution**, the rise of long-duration energy storage ("LDES")** is creating opportunities for **alternative technologies to emerge**, each potentially suited to specific needs.

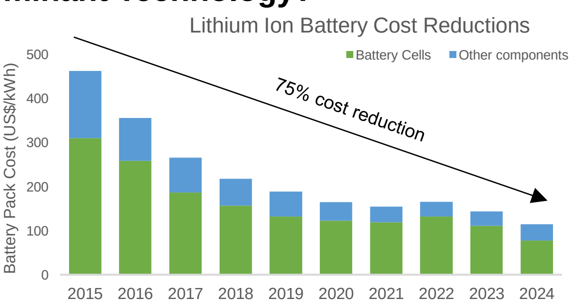
In this paper, we will discuss new directions in lithium-ion technologies, LDES, and the implication in energy storage with the rise of AI.

	Example Tech	Duration	Characteristics	Illustrative Players
Mechanical	• Pumped hydro • Compressed air • Flywheel[1]	4 - 24 hours	• Ideal for bulk grid storage but limited by geographical location • Commercial (TRL 9) • Medium to High efficiency (65-85%)	VOITH, ANDRITZ Hydro, GE, SIEMENS energy
Thermal	• Heat Batteries	6 - 48 hours	• Better suited for industrial and renewable integration • Early stage (TRL 7) • High efficiency (80-90%)	RONDO, ANTORA, SUNAMP
Electrochemical	• Lithium Ion • Sodium Ion	0.5 - 4 hours	• Focused on electric vehicles and grid balancing • Commercial (TRL 9) • High efficiency (90%)	CATL, BYD, TESLA, LG Energy Solution
	• Flow batteries	4 - 12 hours	• Suitable for use cases over 4 hours of storage • Early stage of commercialization (TRL 7-8) • Medium to High efficiency (70-80%)	RKP, FLOW TECH
Chemical	• Hydrogen • Ammonia	Days to months	• Scalable for long duration energy storage • Seasonal fluctuations • Emerging (TRL 7 - 8) • Low efficiency (35-45% without heat recovery)	慕帆动力 arvel-Tech, Mainspring, H2SITE
Electrical	• Supercapacitors	Seconds	• Used for fast response applications such as UPS in data center • Commercial (TRL 8 - 9) • Very high efficiency (95–99%)	SKELETON TECHNOLOGIES, CAP-XX, IOXUS

Note 1: Flywheel is generally used for very short durations up to 15 minutes.

Why have Lithium-ion Batteries Grown into a Dominant Technology?





The initial push for electric vehicles was driven by policy and the need to reduce fossil carbon emissions, but current adoption is increasingly driven by economics. In markets such as China and parts of Europe, the total cost of ownership is now the main driver. There are still limitations due to high costs and underdeveloped infrastructure, especially in many regions like India and Southeast Asia. However, we're starting to see growing investment in EV infrastructure, which could accelerate adoption. Bloomberg estimates that the **cumulative EV sales could reach US$9t by 2030 and US$63t by 2050**. Global EV sales grew from approximately 450k units in 2015 to over 17m units in 2024, representing 18% of new global light-duty vehicle sales in 2024 with 48% CAGR.

Lithium-ion batteries became dominant due to their **strong balance of energy density, weight, and rechargeability**, making them ideal for EVs. Manufacturing advances were led by firms like CATL, Panasonic, and Tesla that scaled output and cut costs. From 2015 to 2024, battery pack prices dropped ~75%, primarily due to scale, production efficiency, and a mature supply chain. Nickel Manganese Cobalt ("NMC") batteries continues to dominate in USA and Europe while adaptation of Lithium Iron Phosphate ("LFP") in China has reached ~64% for new EVs as of Q4'24. We expect **LFP continue growing in Western countries as well** as they are safer and lower cost as compared to NMC.

Due to the **low cost and maturity of the lithium-ion batteries, we expect it to continue** being used for providing intermediate storage**,** particularly for 0.5 to 4 hours of storage.

New Directions for Lithium-Ion

The lithium-ion battery industry continues to undergo rapid evolution thanks to its foundational role to electric mobility, renewable energy penetration and emerging high-power applications. As the market matures, it becomes crucial to understand where innovation, investment and opportunity may still thrive. Given the increasing scale and highly integrated nature of lithium-ion battery manufacturing, many new technologies can take 5-10 years to be commercialized. As a result, in the short-to-medium term, we focus on technologies that offer a **step change in performance** preferably coupled with **drop-in capability** into existing processes to reduce time to market and streamline the manufacturing process.

MATURE SEGMENTS

Cathode Active Material

HIGH CAPEX BARRIER

With cathode material typically being the most valuable part of the lithium-ion battery bill of materials, many cell manufacturers have integrated this technology in-house or work with industry giants who have devoted significant CAPEX and R&D into their market-leading products. The ability for startups to build the necessary scale to compete is limited and exit is likely to be through trade sale.

Battery System Integration

SATURATED MARKET

Leveraging core technology from cell manufacturers, a host of companies have emerged which focus on system integration and delivering catered products into different niche segments such as backup power, renewable energy balancing, maritime propulsion. Without the need to develop a core cell technology, barriers to entry are limited and startups have difficulty building a strategic moat.

OPPORTUNITIES FOR INVESTMENT

INNOVATION ON THE HORIZON

Silicon Anode Material for Higher Energy Density and Charging Speed

By incorporating silicon into traditional graphite **anode material, capacity can be increased by up to 10x** which enables significantly higher energy density. Silicon also enables fast charging with full charge in as little as **12 minutes**, a key customer pain point for BEVs. Most importantly, the technology is **compatible with existing manufacturing processes**. Many battery OEMs such as Panasonic, ATL and CATL have identified silicon-anode material as a key pillar of their next generation of batteries.

INNOVATION ON THE HORIZON

Dry Electrode Process for Cheaper & Sustainable Battery Manufacturing

The dry electrode process eliminates the need for **toxic and highly pollutive** solvents like N-methyl-2-pyrrolidone ("NMP") which are used in traditional slurry-based electrodes. Removing the solvent recovery and drying steps reduces **energy consumption**, **factory area** and manufacturing costs. Dry coating produces thicker, more uniform electrodes which can improve battery performance and longevity. Dry electrodes have already been adopted by Tesla and are being explored by other OEMs.

INNOVATION ON THE HORIZON

Intelligent Battery Management for Safer, Optimized Energy Systems

Intelligent battery management systems ("BMS") use advanced sensors and algorithms to monitor and control battery operation in real-time. These systems enhance safety by **detecting thermal runaway risks** and cell imbalances before they become critical. They also optimize battery performance to **extend lifespan** and **improve efficiency**. Although systems already have a built-in BMS to manage core functions, third-party BMS providers offer **additional cell-level control** to reduce degradation.

KEY GROWTH AREAS TO MONITOR

Battery Recycling to Build Local and Circular Battery Economies

Battery recycling is crucial for **reducing dependency on virgin raw materials** such as lithium, cobalt and nickel which are often sourced from geopolitically sensitive regions. Efficient recycling processes recover valuable metals, mitigating environmental impact by building a circular value chain and potentially reducing cost. However, the market has yet to reach an inflection point and there is **limited feedstock availability** of end-of-life EV batteries to serve the rapidly growing demand for new batteries.

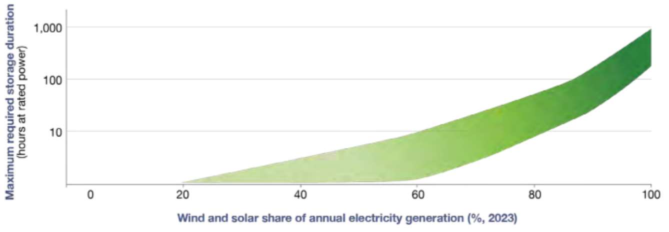
KEY GROWTH AREAS TO MONITOR

Solid-State Electrolytes for Safe and High Energy Density Batteries

Solid-state batteries replace liquid electrolytes with solid polymers or ceramics, **drastically improving safety** by reducing the risk of fires and leaks. These electrolytes also enable **lithium metal anodes**, which offer significantly higher energy density for high-performance applications such as in aerospace. Although solid-state batteries can offer longer lifespans and faster charging, **commercial scale-up may be challenging** due to the technology maturity and changes to manufacturing processes.

Long-Duration Energy Storage

Long-duration energy storage ("LDES") refers to technologies that can be deployed competitively to store energy and support electricity **supply for more than four hours, up to days or even months**. While lithium-ion batteries dominate short-duration storage and EV markets, their linear cost structure may make them less economically attractive for longer storage duration requirement. Currently, options such as flow batteries, liquid air, and compressed air, and hydrogen are being explored for longer durations such as 6 to 36 hours.



Source: Depicted from Albertus, P., Manser, J.S., & Litzelman, S. (2020). Long-duration electricity storage applications, economics, and technologies. Joule, 4(1), 21-32

Up to 8h duration is needed to reach **50-80%** renewable penetration	LDES with **8-100h duration** is needed to reach **70-90%** renewable penetration	LDES with **100+ hour** duration is needed to reach **90%+** renewable penetration

At present, **many of the LDES solutions are at an early stage of development** such as flow batteries, hydrogen, liquid air, etc. Traditional solutions such as pumped hydroelectric face constraints in modularity, location and lead time. **LDES is expected to be cost competitive with lithium-ion for large-scale 8-hour systems in the second half of the decade.** LDES also suffers from limited data on long-term performance, durability and maintenance needs, and potential limitations when fast ramp-up is required.

We believe that as renewable energy penetration increases, LDES technologies will find wider-spread commercial applications. We expect multiple technologies to co-exist in the LDES market as different technology pathways can serve distinct use cases and will be influenced by factors such as location and local supply chains. LDES will also face ongoing competition and potential threats from lithium-based solutions due to continuous cost reduction and performance improvement.

Illustrative Projects

Sichuan, China

Capacity: 10 MW / 20 MWh
Project Completion: 2022
System Supplier: CIMC
Project will use CO_2-based energy storage combined with flywheel. While designed for 2 hours of storage, same technology can be scaled to 8 hours or more.

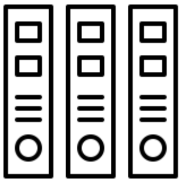
Hubei, China

Capacity: 300 MW / 1.5 GWh
Project Completion: 2024
System Supplier: CEEC
Largest grid-connected compressed air energy storage ("CAES") project in the world and constructed 3-4x faster than a pumped hydro plant would require.

Kalgoorlie, Australia

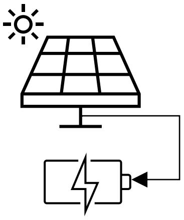
Capacity: 50 MW / 500 MWh
Project Completion: Planned 2029
System Supplier: VSUN Energy
Planned large-scale vanadium flow battery project aiming to strengthen grid reliability and support renewable energy integration for local industry and mining.

What is the Role of Energy Storage in the AI Revolution?



The growth of AI is increasing demand for data centers for processing complex training and inference data. These facilities are energy-intensive and require continuous, reliable power. **Battery-based uninterruptible power supply ("UPS") systems** are used to maintain uptime during grid disturbances for the first 5-10 minutes before backup power systems takeover, and **are taking a more important role given the rise of AI.**

Lead-acid batteries represent **majority of the installed capacity due to low cost and legacy compatibility**. Lithium-ion batteries represent most of the remaining share, offering higher energy density and longer lifespans. However, above a certain temperature, they can enter thermal runaway, leading to potential fire or explosion. For example, fires reported in SK C&C Data Center in South Korea, Digital Realty data center in Singapore, X Data Center in USA, the root cause was linked to the lithium-ion battery based UPS systems. In AI data centers, downtime cost can be significant, making this a material operational risk.



Operators are evaluating alternative energy storage technologies with improved safety. LFP batteries with increased safety measures are thermally stable up to ~270°C, and sodium-ion batteries are non-flammable with potential cheaper raw materials than lithium ion. Nickel-zinc and solid-state batteries are in development with potential for better safety, recyclability, and performance. Due to the reliability related concerns for the new technologies, we expect **lead acid to continue to be dominant in the near term** while Lithium Ion with improved safety and alternative solutions such as Nickel Zinc will increase market share in the longer term.

At the same time, major **cloud and AI data center customers are committing to 100% renewable** energy. This increases dependence on intermittent sources like solar and wind, raising the need for energy storage that can handle both short-term backup and long-duration balancing. This will drive the use of batteries as well as other energy storage solutions to provide clean energy to data centers.

Further Thoughts

1) Diversification from Chinese Manufacturing

Chinese manufacturers in the energy storage sectors are increasingly expanding overseas to mitigate geopolitical risks, circumvent trade barriers, and tap into growing global demand for clean energy solutions. Europe is a popular destination for Chinese companies, offering both market access and the convenience to better serve local customers. Southeast Asia and the MENA region are also attractive options, thanks to their low costs and government incentives. The recent **reciprocal tariffs introduced by the Trump administration might make the MENA region a more popular destination** due to its low tariffs for exports to US.

CATL

Battery Manufacturer
Germany : 14GWh battery
Hungary : 100GWh battery
Indonesia : 15GWh battery

EVE 亿纬锂能

Battery Manufacturer
Malaysia : 680 million cylindrical batteries per year

BTR 贝特瑞

Anode Material Manufacturer
Indonesia : 160,000 tpa anode material
Morocco: 50,000 tpa cathode material & 60,000 tpa anode material

Lopal

Cathode Material Manufacturer
Indonesia: Cathode material plant for 30,000 tpa in phase I and 90,000 tpa in phase II

2) Drop-in Solutions for Lithium-ion with Strong Tailwinds

The lithium-ion battery industry has matured into a large, globally integrated ecosystem with entrenched manufacturing processes and supply chains optimized for scale and cost efficiency. As a result, the adoption of new technologies tends to **favor those solutions that can be integrated into existing infrastructure without significant disruption**. This dynamic makes it challenging for emerging technologies to gain traction unless they align with industry-wide trends and demonstrate clear economic or performance advantages. Promising innovations include drop-in technologies that can be leveraged for different components of the battery such as in the anode, separators, electrolytes or other manufacturing methods.

Company A (U.S.)

Coated nanoporous polymer separators in batteries to extend lifetime and enable lithium metal anodes with liquid electrolytes.

Raising Series B

Company B (U.K.)

Using magnetic fields to extend lifetime, improve charging speed and increase heat dissipation in batteries.

Raising Series A

Company C (China)

Manufacturer of silicon-carbon anode material to major blue-chip customers internationally and expanding overseas.

Raising Series C

Company D (Israel)

High surface area current collectors in batteries to improve conductivity and reduce the amount of material used.

Raising Series C

3) Clean Fuels for Long-Duration Energy Storage

Hydrogen and ammonia are already being integrated into transportation, steelmaking, and industrial heat systems. **This multi-sector alignment enables the infrastructure and investment supporting clean fuels production** to serve a broader base of applications, rather than being tied to storage alone. Ammonia, with 1.7x the volumetric energy density of liquid hydrogen and 200 million tonnes shipped annually, can enable global transport and storage at scale.

These clean fuels can solve long-duration storage challenges where lithium-ion are less economical. Hydrogen can be stored seasonally and reconverted via turbines or fuel cells at projected efficiencies. Ammonia is already being piloted for co-firing in Japan and planned to imported at a large scale in Europe.

While fuel cells would be ideal for up to multi-MW scale applications, **turbines would be the preferred choice for converting the stored hydrogen and ammonia to electricity for applications targeting tens of MW**. One of the Templewater portfolio companies, Marvel Tech, has developed the world's first tri-fuel turbine that can burn natural gas, hydrogen, and ammonia without using diesel as a pilot fuel, making it the only company in the world with such technology. Leveraging the well-established supply chain of gas turbines, Marvel Tech provides a reliable power generation solution that enables **power producers to start with natural gas but allowing them the flexibility to switch to hydrogen or ammonia in the long term** as these molecules become cheaper driven by cost reductions in the electrolyzer technology.

Company A (U.S.)

Linear generator capable of burning hydrogen and ammonia with high energy efficiency.

Raising Series F

Company B (U.K.)

High pressure electrolyzer to removing the need for compressor.

Raising Series A

Company C (U.S.)

High efficiency catalyst for ammonia cracking to enable ammonia combustion.

Raising Series C

Company D (Israel)

New thermodynamic cycle to increase the efficiency of heat engine by 30%.

Raising Series A

Note : Company A, B, C and D are in Templewater's pipeline and not disclosed here as per the NDA with these firms.

Further Thoughts (Continued)

4) Circular Battery Economy

The **battery recycling industry is poised to become a critical component of the global supply chain**, driven by the increasing demand for recycled materials. Currently, feedstock for recycling primarily stems from production scrap. However, the volume of end-of-life ("EoL") batteries, a key input for recycling, is expected to surge significantly post-2030, aligning with the lifespan of EV batteries produced over the last decade.

Regulations are emerging as a key driver for the adoption of recycled materials in battery manufacturing. For instance, EU legislation introduced in 2023 mandates minimum recycled content requirements for industrial machinery batteries and EV batteries by 2030, including 16% for cobalt, 85% for lead, 6% for lithium, and 6% for nickel. Additionally, all waste batteries must be collected free of charge for end-users, regardless of their condition or origin. These initiatives are expected to accelerate recycling adoption and ensure a steady supply of recycled materials. By 2040, recycled materials could supply over 50% of battery material demand, driving sustainability and resource security. As recycling technology advances, this industry will play a pivotal role in the circular economy.

Localized recycling can transform high-demand regions, such as the U.S., into supply hubs, reducing reliance on mining-heavy markets like Democratic Republic of Congo, Chile, and China while lowering carbon footprints. Recycling processes like hydrometallurgy are environmentally efficient, cutting emissions and supporting decarbonization goals.

The majority of battery recycling today **focuses on NMC chemistries** due to the higher availability of black mass from these batteries and the significantly higher value derived from nickel, manganese, and cobalt. In contrast, LFP recycling has seen limited adoption due comparatively lower value from lithium metal, making it less economically attractive. However, some startups are innovating in the LFP sector to reduce recycling costs, improve lithium recovery and the overall recycling economics, positioning this as an area of potential growth and transformation to monitor.

Recycling businesses are increasingly vertically integrated to achieve critical scale, secure higher-value offtake contracts, and access feedstock at competitive pricing. **The market is likely to be led by large, integrated players** with proprietary feedstock sources, and international players with strong tractions are highly valued, limiting room for emerging players in this space.

REDWOOD MATERIALS	ASCEND ELEMENTS	赣锋锂业 GanfengLithium	green li-ion
Recovers lithium, cobalt, nickel, and copper through a combination of mechanical and hydrometallurgical processes.	Proprietary "hydro-to-cathode" process, which directly converts recycled battery materials into new cathode precursors.	Extracts lithium, cobalt, and nickel via hydrometallurgy and integrates recycled materials into new battery production.	Produced pCAM (precursor cathode active material) from black mass and recover >95% of critical metals.
Raised Series D (Aug'23)	**Raised Series D (Feb'24)**	**Publicly Listed**	**Raised Series B (Mar'23)**

5) Alternative Technologies and Chemistries

As energy storage requirements expand across different sectors, the **limitations of lithium-ion batteries are becoming more apparent**. Challenges include thermal risk, constrained access to key minerals, long range for EVs, requirement for longer hours in LDES where lithium ion would be less economical. These issues are particularly relevant in environments such as industrial systems, heavy duty trucking, large-scale mobility platforms, data centers, and LDES, where reliability, thermal stability and economics are critical.

New battery chemistries such as sodium ion, solid state, zinc-based systems and flow batteries are beginning to show potential in addressing these needs. They offer advantages in specific areas such as safety, cost structure, supply chain flexibility, and tolerance to demanding operating conditions. In data centers, for example, the need for consistent high-power availability and lower thermal risk has led operators to explore alternatives to lithium-ion systems.

While these **chemistries are still in early stages of deployment, they reflect a broader shift.** The storage market is moving toward technology diversification, where different applications are likely to be served by different chemistries. We believe lithium ion will continue to dominate, but complementary technologies are expected to play a growing role as technical requirements and regulatory pressures evolve.

Company A (Hong Kong)	**Company B (U.S.)**	**Company C (Singapore)**	**Company D (Japan)**
Nickel zinc batteries with 3x energy density than lead acid batteries targeting the UPS systems in data center.	Energy storage in heat bricks at high temperature with high efficiency storage targeted for industrial applications.	Vanadium redox flow batteries targeting 4 to12 hour energy storage segment for utility scale applications	Nickel-hydrogen storage battery that can be charged and discharged at a rate 20 to 200 times faster than li-ion batteries
Raising Series Seed	**Raising Series C+**	**Raising Series B**	**Raising Series C+**

Note : Company A, B, C and D are in Templewater's pipeline and not disclosed here as per the NDA with these firms.