BATTERY CHEMISTRY TRENDS IN THE GLOBAL UTILITY-SCALE BESS

The Great Divergence expected between 2025 and 2035.

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THE GREAT DIVERGENCE: GLOBAL UTILITY-SCALE BATTERY CHEMISTRY TRENDS FOR 2025–2035

EXECUTIVE SUMMARY

The year 2025 marks an inflection point in the history of the global energy infrastructure. Utility-scale Battery Energy Storage Systems (BESS), having expanded four-to-five-fold since 2020 to reach an installed base approaching 3 TWh, has moved beyond its experimental phase into a period of industrial maturity and chemical diversification. The era where a single lithium-ion chemistry (NMC) served everything from consumer electronics to electric vehicles (EVs) and grid services has ended. In its place, competitive forces compelled the rigorous matching of specific electrochemical properties to distinct uses.

The primary narrative of 2025 is the absolute hegemony of Lithium Iron Phosphate (LFP) batteries in the short-duration (2–4 hour) utility sector. Driven by a structural decoupling from the EV performance race, LFP has displaced Nickel Manganese Cobalt (NMC) due to superior cycle life, stronger safety profiles, higher thermal runaway temperatures, and immunity to cobalt supply chain volatility. By late 2025, LFP commands over 75% of the stationary storage market, with pack prices breaching the $100/kWh threshold in competitive markets, effectively commoditizing short-duration storage.

However, the most disruptive development of the mid-2020s is the commercial breakout of Sodium-Ion (Na-ion) technology. Once a theoretical contender, Na-ion has entered gigawatt-scale mass production in 2025, spearheaded by massive facility investments in China, such as the 20 GWh Guangde plant and BYD’s 30 GWh Xuzhou facility. While currently trailing LFP in energy density, Sodium-Ion’s superior low-temperature performance and reliance on ubiquitous soda ash rather than volatile lithium carbonate, position this chemistry as the primary challenger for the utility throne in temperate and cold-climate zones by 2030.

Simultaneously, the Long-Duration Energy Storage (LDES) sector has transitioned from benches in labs to commercial reality. The commissioning of Form Energy’s 1.5 MW/150 MWh Iron-Air pilot in Cambridge, Minnesota, in late 2025 serves as a technological bellwether for multi-day storage. Concurrently, the operational success of the world's largest Vanadium Redox Flow Battery (175 MW/700 MWh) in China demonstrates the

scalability of flow chemistries for intra-day cycling. Domestic US innovators like Eos Energy Enterprises are also scaling zinc-halide chemistries, supported by significant capital infusions and state-level manufacturing incentives in Pennsylvania.

This chemical diversification is occurring against a backdrop of intense geopolitical friction. The United States, navigating the complex implementation of the Inflation Reduction Act (IRA) and the subsequent "One Big Beautiful Bill Act" (OBBBA) of July 2025, has seen a bifurcation of its domestic market. While downstream deployment is booming, the midstream manufacturing sector has faced significant attrition, evidenced by the cancellation of gigafactory projects by players like Freyr and Kore Power, who struggled to compete with the capital efficiency of Asian manufacturers.

This report provides a technical and market overview of these trends. It examines the physics of thermal runaway risks, the economics of material supply chains, and the policy frameworks shaping the battery chemistry mix of the next decade.

1. MACRO-STRUCTURAL DYNAMICS OF THE 2025 BESS MARKET

The utility-scale storage market of 2025 could be defined as a "speciation" event. Just as biological organisms adapt to specific niches, battery chemistries are specializing. The market has realized that the high-energy-density requirements of an electric vehicle (which needs to be light, dense and small) are fundamentally different from the requirements of a grid battery (which needs to be cheap, durable, and sturdy).

1.1. THE DECOUPLING OF EV AND BESS SUPPLY CHAINS

In the decade preceding 2025, the stationary storage market was a secondary outlet for EV battery manufacturing. Grid batteries could be "reject" cells from EV lines or simply identical NMC cells packaged in larger containers. This coupling meant that BESS pricing and availability were linked to EV demand shocks, that is, when EV demand surged, the additional supply came at the expense of BESS.

In 2025, this dynamic has fractured. The widespread adoption of LFP for BESS has created a distinct supply chain, while high-performance EVs continue to utilize high-nickel NMC or explore solid-state derivatives. The operational profile of utility-scale assets dictates this split. An EV battery may cycle once or twice a week, whereas a grid-balancing battery often cycles daily or twice daily or even more if the BESS is arbitraging prices. The market has, therefore, prioritized the 4,000–10,000 cycle life of LFP over the energy density of NMC.

Furthermore, the global installed capacity of 3 TWh by the end of 2024 and an expected Compound Annual Growth Rate (CAGR) of about 15% from 2025 through 2035, has forced the consideration of new chemistries.

The sheer volume of lithium carbonate required to meet both EV and BESS demand using only lithium-ion would place unsustainable pressure on mining output. This resource constraint is the primary driver behind the aggressive acceleration of Sodium-Ion manufacturing capacity in 2025.

1.2. THE "ONE BIG BEAUTIFUL BILL ACT" (OBBBA) AND US MANUFACTURING

A critical element of the 2025 landscape is the legislative environment in the United States. Following the foundational Inflation Reduction Act (IRA), the passage of the **One Big Beautiful Bill Act (OBBBA)** in July 2025 introduced new complexities to the domestic manufacturing sector.

While the bill aimed to streamline certain tax uncertainties, it also altered the demand landscape, leading to a period of readjustment.

The first half of 2025 was characterized by a "cancellation wave" where the value of cancelled manufacturing investments in the US exceeded new announcements. This was driven by a combination of high interest rates, the overwhelming cost advantage of imported Chinese cells (even with tariffs), and the technical challenges of scaling new technologies.

- **Freyr Battery:** In February 2025, Freyr cancelled its ambitious "Giga America" battery project in Georgia. Originally slated to produce lithium-ion cells, the company pivoted its strategy entirely to solar manufacturing in Texas, citing the changing financial environment and the commoditization of battery cells.
- **Kore Power:** Similarly, Kore Power's "KOREPlex" facility in Buckeye, Arizona, faced severe headwinds. By early 2025, reports indicated the project was stalled, with the site potentially listed for sale, highlighting the immense difficulty for new entrants to compete with vertically integrated incumbents.

This consolidation suggests that while the US market for *deploying* storage is robust, the market for *manufacturing* cells is consolidating around a few major players with deep pockets and established technology, leaving less room for startups.

1.3. 2025 AS A DEPLOYMENT "BUMPER YEAR"

Despite manufacturing turbulence, 2025 is recorded as a "bumper year" for energy storage deployment globally. The fundamental economic drivers—penetration of intermittent renewables and explosive load growth from data centers and electrification—have sustained a compound annual growth rate (CAGR) projected at over 20% through 2030.

Utilities are no longer piloting storage; they are integrating it as a core asset class. The "large load" dynamic, driven by AI data centers and cryptocurrency mining, has created localized pockets of extreme power demand (e.g., in Texas and Northern Virginia), necessitating GW-scale storage for reliability and capacity firming.

2. LITHIUM IRON PHOSPHATE (LFP): THE UTILITY-SCALE HEGEMON

By 2025, LFP has established itself as the "gold standard" for utility-scale BESS. This dominance is a structural transformation rooted in the physics of safety and the economics of longevity.

2.1. TECHNICAL SUPERIORITY IN STATIONARY APPLICATIONS

The advantages of LFP in a grid context are multifaceted and decisive. The olivine crystal structure of the $LiFePO_4$ cathode offers inherent robustness compared to the layered oxide structure of NMC.

Cycle Life and Augmentation Strategy: The most critical metric for utility project finance is cycle life. A typical NMC cell, while energy-dense, may degrade significantly after 2,000–3,000 cycles. In contrast, modern LFP cells in 2025 are routinely rated for **6,000 to 10,000 cycles** before reaching 80% State of Health (SOH). For a utility asset amortized over 20 years, this difference is financially existential. An NMC system would require at least one, and likely two, full battery augmentations (complete module replacements) over the project's life. An LFP system, if managed with appropriate thermal and depth-of-discharge protocols, can operate for 15+ years with minimal augmentation. This drastically lowers the Levelized Cost of Storage (LCOS), making LFP the undisputed choice for 2-hour and 4-hour duration projects.

The Flat Voltage Challenge: One technical nuance of LFP is its extremely flat discharge curve. The voltage of an LFP cell remains nearly constant across a wide range of State of Charge (SOC), typically fluctuating less than 1 mV per 1% change in SOC between 35% and 95% capacity. While this provides consistent power delivery, it makes SOC estimation incredibly difficult compared to NMC, which has a predictable voltage slope. In 2025, this challenge has been met with advanced Battery Management Systems (BMS) utilizing Kalman filtering algorithms and coulomb counting to accurately track energy status. However, the risk remains that a slight sensor error can lead to large discrepancies in perceived vs. actual charge, necessitating frequent calibration cycles.

2.2. THE COST DISADVANTAGE OF COBALT AND NICKEL

The 2025 market continues to be defined by raw material economics. NMC chemistries rely on nickel and cobalt. Cobalt, primarily sourced from the Democratic Republic of Congo, has historically been a source of extreme price volatility and ethical supply chain risk. LFP eliminates both cobalt and nickel, utilizing iron and phosphorus—materials that are globally abundant and cheap. By late 2025, global lithium-ion pack prices have fallen to approximately **$108/kWh** , with LFP cells trading at a 20-30% discount relative to NMC. This price wedge is insurmountable for NMC in applications where weight is not a constraint.

2.3. MANUFACTURING LANDSCAPE: THE US-CHINA DIVIDE

In 2025, China continues to dominate LFP production, controlling over 90% of the global LFP cathode active material (CAM) supply chain. Major Chinese OEMs like CATL and BYD have continued to refine cell-to-pack technologies (e.g., BYD's Blade Battery, CATL's Tener), further reducing costs and improving volumetric energy density. The US market, however, is attempting to stand up a domestic LFP ecosystem to capture IRA tax credits.

- **American Battery Factory (ABF):** ABF is constructing a network of LFP gigafactories, with its Tucson, Arizona facility serving as a flagship. The company aims to localize the supply chain, partnering with firms like First Phosphate to secure domestic CAM.
- **Ford & Others:** Automakers like Ford have also localized LFP plants (e.g., Marshall, Michigan) to serve both EV and stationary needs, recognizing that LFP is the future of standard-range electrification.

Despite these efforts, the "Domestic Content" bonus of the IRA remains a high bar. While module assembly is increasingly happening in the US, the sourcing of precursor chemicals often still leads back to China or Free Trade Agreement (FTA) countries, creating a complex compliance landscape for developers.

3. THE CHALLENGER: SODIUM-ION BATTERIES

If LFP is the king of 2025, Sodium-Ion (Na-ion) is the insurgent revolution. 2025 marks the year Sodium-Ion graduated from laboratory curiosity to industrial heavyweight, driven by the strategic imperative to decouple from the lithium supply chain.

3.1. THE 2025 COMMERCIAL BREAKOUT

The latter half of 2025 witnessed a sequence of aggressive manufacturing announcements that signaled the maturity of the Na-ion supply chain.

- **Guangde 20 GWh Plant:** In November 2025, a massive 20 GWh sodium-ion battery manufacturing plant was announced in the Guangde Economic and Technological Development Zone, China. This facility alone represents a capacity greater than the entire global lithium-ion capacity of a decade prior.
- **BYD's 30 GWh Facility:** BYD broke ground on a 30 GWh sodium-ion plant in Xuzhou, rapidly scaling production to feed both its low-cost EV lines (e.g., the Seagull) and its stationary storage division.
- **HiNa Battery:** A pioneer in the field, HiNa Battery has operationalized gigawatt-scale lines and supplied the world's first 100 MWh sodium-ion energy storage project, validating the technology in a grid-connected environment.

3.2. TECHNICAL ATTRIBUTES: THE COLD WEATHER CHAMPION

Sodium-ion batteries function on a similar "rocking chair" intercalation mechanism to lithium-ion but use sodium ions (Na^+) as the charge carrier. While the larger size of the sodium ion presents challenges for energy density, it offers unique advantages.

Performance Comparison

Feature	LFP (2025 State of Art)	Sodium-Ion (2025 State of Art)	Advantage
Energy Density	160 – 190 Wh/kg	140 – 175 Wh/kg	**LFP** (Marginal lead)
Cycle Life	6,000 – 10,000	3,000 – 6,000+	**LFP** (Currently)
Low Temp (-20°C)	<50% Capacity retention	>90% Capacity retention	**Sodium-Ion**

Transport Safety	Shipped at 30-50% SOC	Shipped at 0V (Fully Discharged)	**Sodium-Ion**
Precursor Cost	Low (Li Carbonate Volatile)	Very Low (Soda Ash Abundant)	**Sodium-Ion**

The **low-temperature performance** of Na-ion is a game-changer for high-latitude BESS deployment. In regions like Minnesota, Canada, and Northern Europe, LFP batteries require significant energy for thermal management (heating) to maintain performance in winter. Na-ion batteries can operate efficiently at -20°C or even -30°C with minimal loss, improving the round-trip efficiency (RTE) of the system by reducing parasitic loads.

The Safety of 0-Volt Transport. A unique logistical advantage of sodium-ion is its ability to be fully discharged to 0 volts without damaging the cell's internal chemistry (unlike lithium-ion, where copper current collectors dissolve at low voltage). This allows Na-ion modules to be transported as inert, non-hazardous cargo, significantly reducing insurance and shipping costs.

3.3. STRATEGIC IMPLICATIONS AND 2030 OUTLOOK

The rise of Na-ion is fundamentally a hedge against lithium scarcity. While lithium prices have stabilized in 2025, the projected 2030 demand exceeds committed mining projects. Sodium, derived from soda ash, is ubiquitously available.

Analysts project the global sodium-ion market to grow from a niche base in 2024 to nearly **300 GWh by 2034**, with China expected to account for over 90% of global production by 2030. By 2027, as the new gigafactories ramp to full utilization, a price war between LFP and Na-ion is anticipated, potentially driving stationary storage costs below **$50/kWh**.

4. LONG-DURATION ENERGY STORAGE (LDES): BREAKING THE 4-HOUR BARRIER

As renewable energy penetration exceeds 50% in leading markets, the value of standard 4-hour Li-ion storage saturates. The grid increasingly requires "capacity firming," or storage that can last 10, 20, or 100 hours to bridge multi-day weather lulls ("dunkelflaute"). 2025 is the year LDES transitioned from pilot projects to commercial infrastructure.

4.1. IRON-AIR: THE RUST BATTERY COMES OF AGE

Form Energy has emerged as the leader in multi-day storage. In late 2025, the company reached a historic milestone with the commissioning of its **1.5 MW / 150 MWh pilot project** in Cambridge, Minnesota, in partnership with Great River Energy.

- **The Technology:** The battery operates on the reversible oxidation of iron. During discharge, the battery "breathes" in oxygen, converting iron pellets into rust (iron oxide) and releasing electrons. During charge, current reverses the rust back to metallic iron and releases oxygen.
- **The 100-Hour Value Proposition:** The Cambridge project demonstrates a 100-hour discharge duration. This allows the utility to store wind energy generated during a windy weekend and dispatch it continuously throughout a calm week.
- **Commercial Scaling:** Form Energy has raised over $405 million in Series F funding and has begun operations at "Form Factory 1" in Weirton, West Virginia. The company has secured massive pipeline agreements, including a 3 GW identified need in PacifiCorp's 2025 Integrated Resource Plan (IRP), validating the utility demand for multi-day assets.

4.2. VANADIUM REDOX FLOW BATTERIES (VRFB): GIGAWATT-SCALE REALITY

Flow batteries have long been promised as the solution for heavy-cycling applications. In 2025, they achieved scale.

- **The World's Largest Battery: Rongke Power** completed the construction of the **175 MW / 700 MWh** Vanadium Redox Flow Battery in Dalian/Xinjiang, China. This system acts as a "power bank" for the city, capable of black-start capabilities and practically unlimited cycling.
- **Decoupling Power and Energy:** The primary advantage of VRFBs is that energy (electrolyte volume) is decoupled from power (stack size). To double the duration, an operator simply adds larger tanks of vanadium electrolyte, making the marginal cost of the 5th, 6th, or 10th hour of storage extremely low compared to lithium-ion, which requires buying linear amounts of cells.
- **Western Market**: While China leads in scale, companies like **Invinity Energy Systems** are deploying projects in the UK and Australia. The challenge remains the capital cost of vanadium pentoxide, though electrolyte leasing models are emerging to mitigate this limitation.

4.3. ZINC-HALIDE: THE DOMESTIC CONTENDER

Eos Energy Enterprises is scaling its "Z3" Zinc-Halide (Zinc-Bromine) technology as a direct, non-flammable competitor to Li-ion in the 3–12 hour segment.

- **Expansion and Investment:** In October 2025, Eos announced a **$353 million** investment to expand its manufacturing operations in Turtle Creek, Pennsylvania, supported by state economic development packages. This expansion aims to ramp annual production capacity to **2 GWh** by the end of 2025.
- **Financials and Backlog:** Eos reported its highest quarterly revenue in history in Q3 2025, doubling its Q2 performance. The company holds a commercial opportunity pipeline exceeding $22 billion, with a firm order backlog of $644 million, indicating strong market traction for non-lithium alternatives.
- **Strategic Partnerships:** Eos has secured significant orders, including a strategic 228 MWh deployment with **Frontier Power** in the UK, validating the technology for international long-duration schemes.

5. TECHNICAL SAFETY ANALYSIS: THERMAL RUNAWAY AND PROPAGATION

Safety remains the non-negotiable metric for utility-scale BESS. The shift away from NMC and the rise of LFP and non-lithium chemistries are largely driven by the need to eliminate catastrophic fire risk.

5.1. COMPARATIVE THERMAL RUNAWAY THRESHOLDS

Data from 2025 safety testing (UL 9540A standards) highlights the stark differences in thermal stability between chemistries.

Chemistry	Thermal Runaway Onset	Vent Gas Composition	Fire Risk Profile
NMC (Li-ion)	~210°C – 280°C	High **CO (36%)**, H2 (19%)	**Critical:** Rapid temperature rise (>1000°C peak). Cathode releases oxygen, fueling the fire from within. High propagation risk.

LFP (Li-ion)	~270°C – 346°C	High **H_2 (41%)**, CO_2 (27%)	**Manageable**: Lower peak temp. (~450°C). No oxygen release from cathode. Harder to ignite, slower propagation.
Sodium-Ion	~260°C – 290°C	CO_2, H_2, Electrolyte Vapor	**Low**: Comparable to LFP. Lower energy density limits peak heat release.
Iron-Air	N/A (Aqueous)	Trace Hydrogen	**Negligible**: Water-based electrolyte. No thermal runaway mechanism exists.
Zinc-Halide	N/A (Aqueous)	None	**Negligible**: Non-flammable chemistry. Safe for indoor/urban siting.

5.2. THE GAS MANAGEMENT CHALLENGE

While LFP is significantly safer than NMC, it is not benign. Upon failure, LFP cells vent significant quantities of hydrogen gas (up to 41% of vent gas volume). If this gas accumulates in a container without proper ventilation, it presents an explosion hazard. Consequently, 2025 BESS designs have standardized around **deflagration venting panels** and **active gas detection** systems that trigger exhaust fans at the first sign of off-gassing.

The "fail-safe" nature of aqueous batteries (Iron-Air, Zinc, Flow) provides a massive siting advantage. Because they cannot enter thermal runaway, these systems can be deployed in dense urban environments, inside buildings, or in sensitive ecological areas where the fire risk of Lithium-ion would be permissive. This safety premium is a hidden value driver for technologies like Form Energy’s and Eos’s.

6. MARKET FORECASTS & FUTURE OUTLOOK FOR 2030

The "trends" of 2025 are not transient; they are foundational pillars for the 2030 grid. The market is moving away from a monoculture toward a diverse ecosystem where chemistry is matched to duration.

6.1. THE THREE-TIERED MARKET STRUCTURE

Based on current trajectories, the 2030 BESS market will stratify into three distinct tiers:

Tier 1: Short-Duration / Intra-Day (0–4 Hours)

- **Dominant Chemistry: LFP** will retain 60–70% market share due to its entrenched supply chain and cost efficiency.
- **Challenger: Sodium-Ion** will capture 20–30% of this segment. It will dominate in cold climates and budget-constrained projects, effectively capping LFP prices.
- **Primary Application**: Frequency regulation, solar smoothing, peak shaving.

Tier 2: Medium-Duration (4–12 Hours)

- **Dominant Chemistry**: A battleground between **oversized LFP** arrays and **Flow/Zinc** batteries.
- **Outlook:** As LFP costs drop, extending it to 8 hours becomes economically viable. However, Zinc-Halide (Eos) and Vanadium Flow batteries offer better economics for heavy cycling (2+ cycles/day) due to zero degradation penalties.

Tier 3: Long-Duration / Multi-Day (12–100+ Hours)

- **Dominant Chemistry: Iron-Air** (Form Energy) and other ultra-low-cost chemistries.
- **Role**: Replacing natural gas peakers. These assets will sit idle for days or weeks, waiting for weather events. High capital cost (Li-ion) is prohibitive here; low CAPEX (Iron) is king.

6.2. STRATEGIC RECOMMENDATIONS

For Utilities: The operational risk profile of BESS has improved with the shift to LFP, but "chemistry fit" is now a required due diligence step. Utilities in northern latitudes must evaluate Sodium-Ion to avoid the efficiency penalties of heating Li-ion systems. For strategic reserve planning, Iron-Air should be integrated into IRPs as a direct alternative to new thermal generation.

For Developers: Supply chain sovereignty is the new premium. While Chinese LFP is the cheapest option, the geopolitical volatility of 2025—evidenced by the OBBBA legislation and trade barriers—makes reliance on a single source risky. Diversifying into domestic suppliers (Eos, emerging US LFP) or alternative chemistries (Sodium-Ion) offers a hedge against future tariff shocks.

For Investors: The arbitrage window for simple lithium-ion projects is closing as the market saturates. The next frontier of value creation lies in **LDES**—technologies that can offer the "capacity firming" services that grids will desperately need as they approach 100% renewable penetration. Skepticism is warranted for new cell manufacturing startups; the failures of Freyr and Kore Power prove that scale is the only defense in the battery industry.

In conclusion, 2025 confirms that the battery revolution is not waiting for a "magic bullet" chemistry. Instead, it is deploying a diverse arsenal of solutions—Iron, Sodium, Zinc, and Phosphate—to build a grid capable of running on intermittent renewables. The chemistry wars are not ending; they are simply moving to new battlegrounds defined by duration, safety, and supply chain sovereignty.