Assessing the Promise and Potential of Sodium-ion Batteries in 2026

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1. Executive Summary

Sodium-ion (Na-ion) batteries represent the next generation of grid energy storage technology, offering capabilities and characteristics that surpass those of lithium-ion batteries. Leveraging sodium – a resource approximately one thousand times more abundant in the Earth's crust than lithium[1] – sodium-ion batteries provide a stable and scalable foundation for widespread energy storage.

To keep global temperature rise below 1.5°C, IRENA estimates that battery storage capacity must grow from 256 Gigawatts (GW)[2] today to 4.1 Terawatts (TW)[3] by 2050. Currently, lithium-ion batteries currently comprise 98%[4] of deployed battery storage, but they face critical safety, supply chain, and operational limitations that challenge their ability to scale sixteen times to meet this identified need. While lithium-ion batteries will likely remain the standard for high-density applications such as consumer electronics and long-range electric vehicles, they are increasingly ill-suited for the massive demands of the electrical grid. For the reasons discussed in this white paper, sodium-ion batteries deliver a superior product-market fit and are therefore expected to see significant uptake in stationary storage in the years to come.

Among the sodium-ion chemistries now being commercialized – of which there are three primary types: layered metal oxides, Prussian blue analogs, and polyanionic – one variety of polyanionic known as sodium pyrophosphate (or "NFPP") stands out as an optimal path forward for grid storage. NFPP delivers a combination of characteristics perfectly suited for stationary storage: an unmatched balance of safety, cycle life, power delivery, and temperature resilience. This combination cannot be achieved in lithium-ion without significant tradeoffs in either cycle life, cost, or safety.

As safety concerns grow and BESS operating conditions become more extreme, NFPP maintains performance under demanding duty cycles and high temperatures. Where high energy density lithium batteries require extensive cooling infrastructure, NFPP operates reliably across extreme temperatures. The newest generation of this technology is purpose-built to eliminate thermal runaway pathways entirely, delivering true non-flammability alongside high performance. With this, NFPP is emerging as the pragmatic next step for utilities, OEMs, and policymakers navigating the future of battery storage.

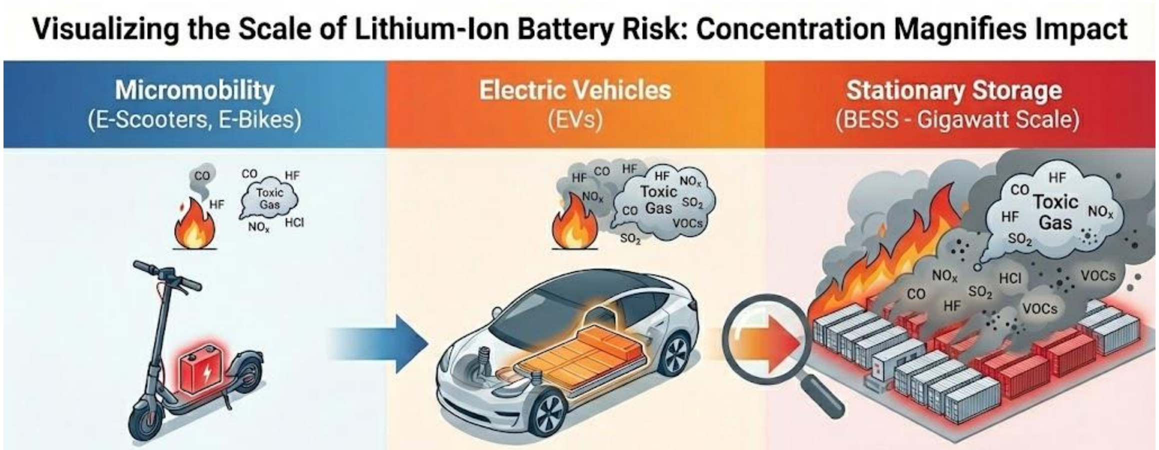
2. The Evolving Landscape of Energy Storage

Global demand for battery energy storage systems (BESS) is accelerating, with lithium-ion – especially LFP – dominating grid-scale deployments. However, as projects scale, three major challenges have emerged: safety and permitting risks, supply chain exposure, and operational requirements.

Safety & Permitting Risk

Lithium-ion's high energy density carries thermal runaway risks. During thermal runaway, the cathode releases oxygen that fuels a self-sustaining reaction with the flammable electrolyte. During this self-sustaining fire, toxic gases within the electrolyte including carbon monoxide (CO), hydrogen cyanide (HCN), hydrogen chloride (HCl), and hydrogen fluoride (HF) are released. If concentration of these gases is high enough, the health impacts can be deadly.

Large concentrations of Li-ion batteries in grid-scale installations increase community risk due to the magnified quantity of toxic gases being emitted all at once during a fire. Toxicity from lithium battery fires in micromobility or electric vehicles are still highly dangerous but are relatively easy to contain using modern firefighter methods and resources.

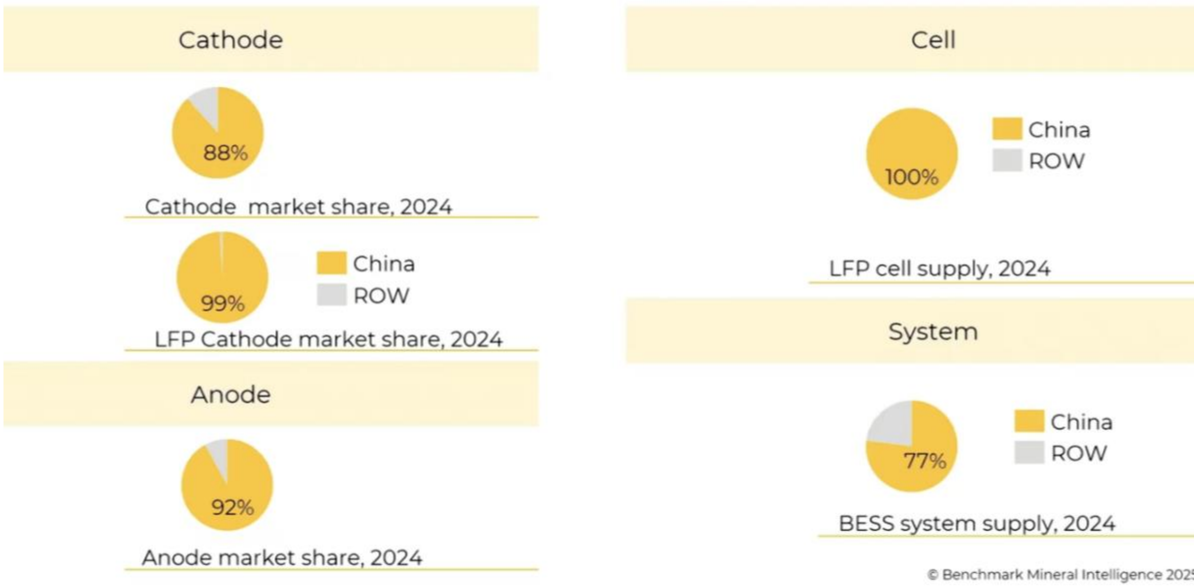


With BESS projects now reaching the gigawatt scale[5], the urgency around this threat is unprecedented. Battery industry members are responding to safety concerns with a string of engineering control add-ons such as intensive cooling systems, 24/7 monitoring, gas sensors, and more, just to keep systems within safe operational parameters.

Communities particularly around the U.S. are enacting moratoria to prevent battery systems from being deployed until risks are sufficiently addressed. Research firm Modo Energy found in New York state, over 100 local authorities have enacted moratoria or bans, covering about 8% of the state, often in response to fire safety concerns and the lack of unified permitting standards[6]. Project withdrawals have exceeded $2 million in some cases due to sunk costs, and permitting remains complicated in New York and other jurisdictions around the United States.

Supply Chain

Supply chain security is another critical concern around long-term reliance on lithium-ion technology. 99% of LFP cathode components, 92% of anode components,
100% of LFP battery cells, and 77% of BESS system supply is controlled by one country – China.[7]



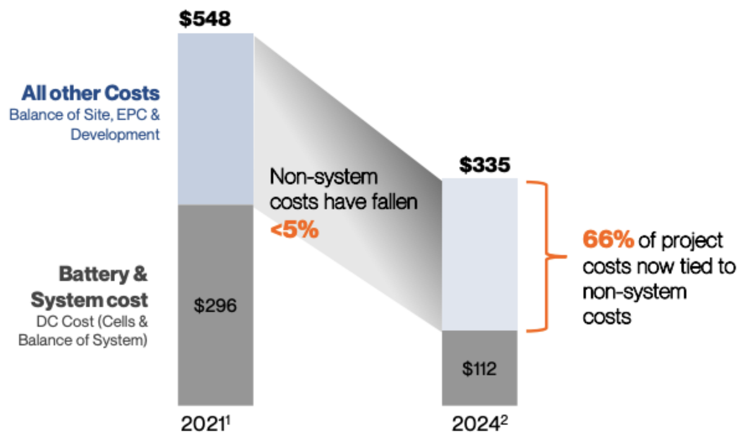
***Source**: Benchmark Mineral Intelligence, The Rise of Energy Storage Systems: Global Deployments, Pricing Trends, and Strategic Market Shifts (2025)*

Since 2018 the United States and China have traded economic regulations around batteries, moving from simple tariffs to complex non-tariff barriers such as foreign entity of concern (FEOC) requirements to qualify for tax incentives. The result is a market where U.S. import duties have increased costs for developers, while Chinese export controls on minerals and machinery have constrained the ability of Western competitors to rapidly scale alternative supply chains.

Operational Limits

Lastly, the operational limits of lithium-based systems have become increasingly clear. Because they rely on volatile chemistries, these systems require extensive maintenance – including HVAC and thermal regulation, voltage monitoring, and other add-ons that contributed to overall cost. They also require frequent servicing including augmentation in which batteries are added to compensate for the loss of capacity in existing ones. These measures are necessary to maintain performance and ensure safe operation. This adds complexity and cost, especially in environments with temperature extremes or high uptime requirements.

Grid-scale LFP batteries draw significant amounts of power to run the active cooling systems needed to prevent thermal runaway, reducing their cost-effectiveness.[8] Even as battery cell costs have fallen, non-battery costs such as operation & maintenance remain elevated as demands of BESS get higher and volatility remains a concern.

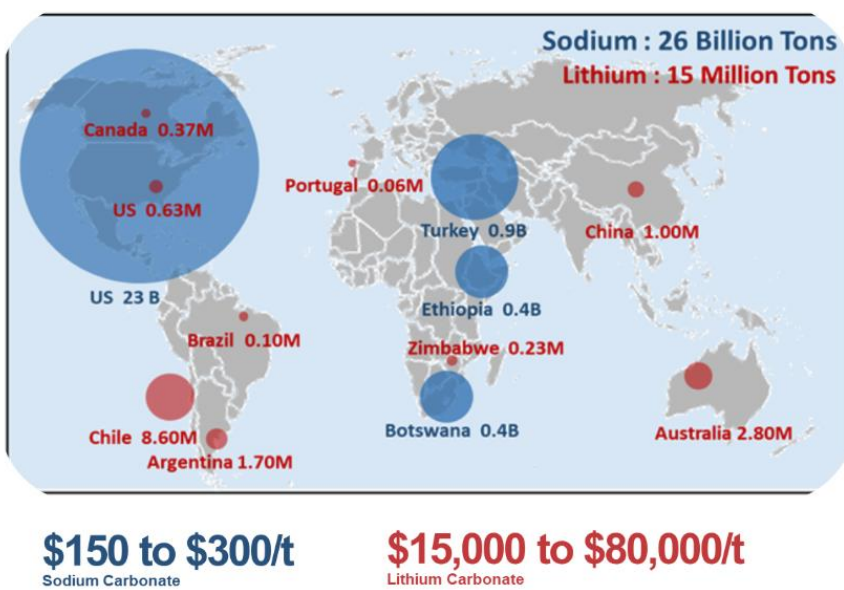


***Source**: Peak Energy, A Strategy for U.S. Production of Grid-Scale Battery Energy Storage Systems (2024)*

With these known limitations, the market demands a new, unified solution for the full spectrum of storage needs. The strategic urgency for alternatives is not just about cost; it is about de-risking the entire battery supply chain from the mine to the meter.

3. Introduction to Sodium-Ion Battery Chemistry

Sodium-ion batteries use sodium carbonate (soda ash), which is over 1,000 times more abundant than lithium, 500 times less expensive to process, and widely available domestically in the United States. In fact, the vast majority (92%) of the world's readily minable natural soda ash reserves are in Wyoming.[9] While lithium carbonate prices fluctuate between $13,000 and $80,000+ per ton, sodium carbonate remains stable at about $300 per ton,[10] reducing exposure to geopolitical supply shocks and providing an overall lower cost on a kilogram basis compared to lithium-based chemistries.[11]



***Source**: Volta Foundation, Battery Report 2024*

Sodium-ion batteries operate on the proven "rocking chair" principle, shuttling ions between a cathode and anode via a liquid electrolyte – the same working mechanism as lithium-ion. However, fundamental chemical differences unlock superior characteristics relative to incumbents like both lithium-ion and lead acid.

Most sodium-ion batteries utilize aluminum current collectors for both the anode and cathode – unlike the copper required for the anode in lithium-ion. This allows for zero-volt discharge (100% depth of discharge, or DoD) meaning the full capacity can be used without degradation to the battery cell). This stands in contrast to lithium-ion batteries, which generally should not be charged beyond 80-90% or discharged below 10-20%. Only about 80% of the total capacity can be accessed with lithium-ion, while 100% of capacity can be accessed with sodium-ion.

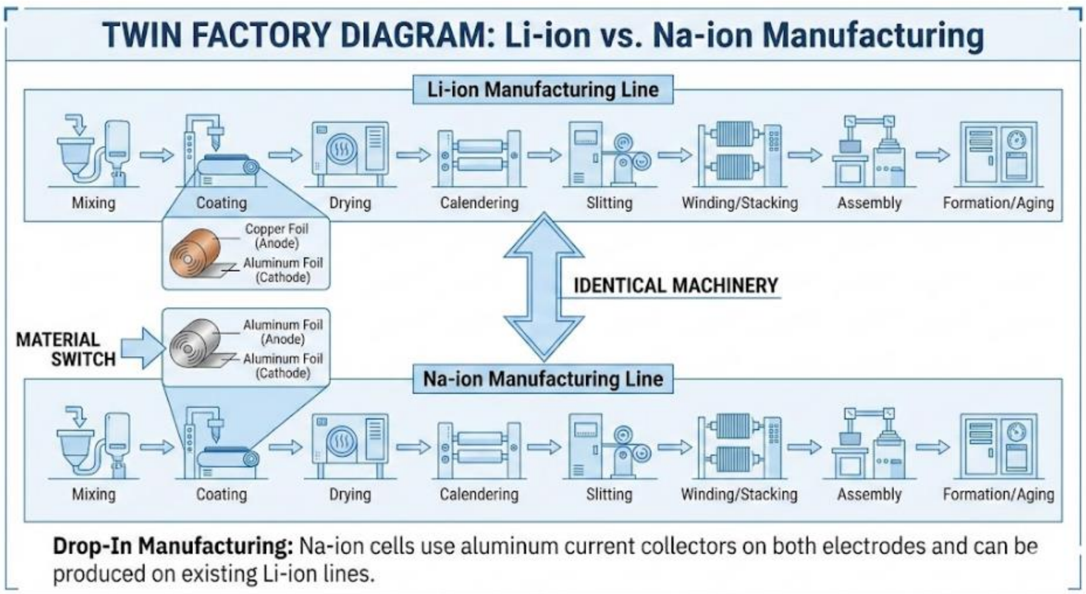
In addition to avoiding damage from 100% DoD, the ability to stay in a state of 0% charge indefinitely significantly enhances safety during storage and transport. Sodium-ion's thermal stability is rooted in the robust chemical bonds of its cathode materials, especially in polyanionic structures which resist oxygen release even under abuse conditions (overcharge, external short circuit, crush, or thermal stress) – a critical safety advantage over lithium-ion oxide chemistries that release oxygen during thermal runaway.

Furthermore, the larger ionic radius of sodium allows for electrolytes with higher ionic conductivity in certain formulations, providing the basis for higher power density and impressive C-rate capabilities – the charge/discharge rate relative to battery capacity - (often 3C–5C, meaning full charge in 12-20 minutes) without the degradation seen in lithium cells.[12]

Na-ion Advantage	Technical Reason(s)
Can be safely discharged down to 0V	Na-ion can cycle 100% DoD without degrading the battery because Na does not alloy with the Al current collector. Safe discharge down to 0V and even overdischarge safety, enables less hazardous transport
High C-rates without accelerated degradation	Na+ has a smaller effective radius and lower desolvation energy compared to Li+, resulting in higher ionic conductivity and faster reaction kinetics.
High Round Trip Efficiency (>95%)	High ionic conductivity and rapid kinetics reduce internal resistance and heat generation, enabling energy recovery rates (>95%) that rival or exceed LFP.
Higher electrolyte reaction point than lithium-ion	Na-ion electrolyte $NaPF_6$ begins releasing energy at 90°C higher than $LiPF_6$ (150°C)

Less impact on IR at low temperatures	Na-ion can retain up to 70% capacity at -20°C, compared to LFP with a lower limit of 0°C

While newer than lithium, sodium-ion has reached a high level of maturity, with multiple chemistries now commercialized (covered in the next section). Crucially, materials like soda ash, iron, and manganese are abundant globally, and the ability to manufacture cells on existing lithium-ion lines with a nearly identical process means capacity can scale rapidly to make up for lost time relative to lithium-ion.[13] This will continue to be an advantage for sodium; as the manufacturing process for lithium-ion batteries becomes more efficient, so does the process for sodium-ion batteries.



4. Performance

The sodium-ion market is segmenting into three primary chemistry families: layered metal oxides (LMO), Prussian Blue Analogues (PBAs), and polyanionic. Each has its own unique set of performance characteristics.

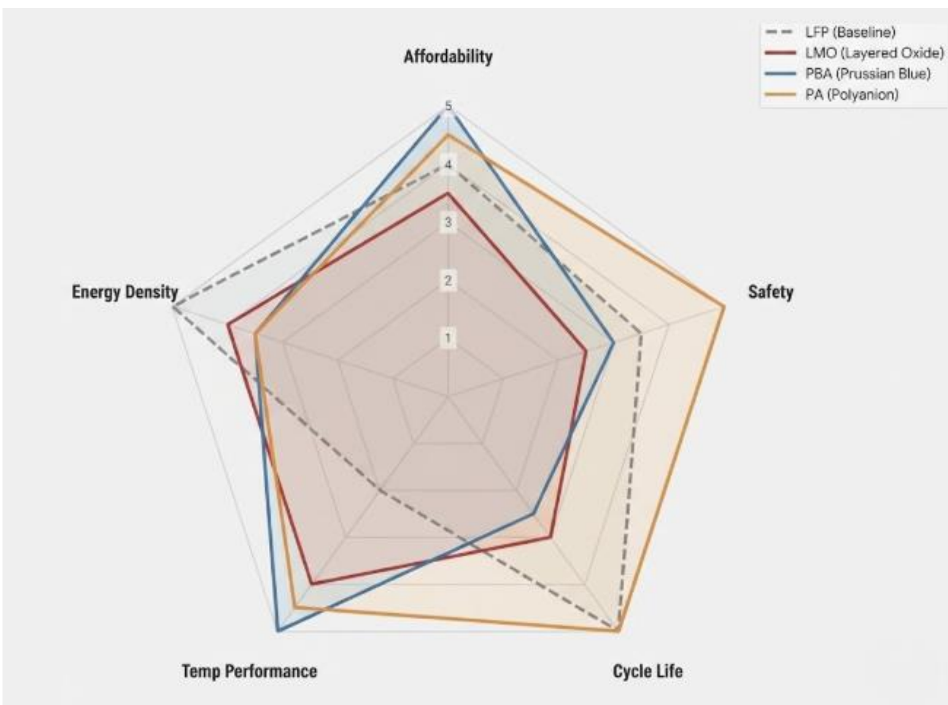
Layered oxides offer high energy density (140-160 Wh/kg) but lower cycle life (~3000), making them ideal for micromobility EVs with shorter system lives. Their main downside is that current products based in layered oxide are still susceptible to thermal runaway and can produce their own oxygen (similar to lithium-ion) as they burn.

Prussian Blue Analogues can provide high C-rates for short bursts of power, but they have historically been plagued by either low density or cycle life challenges, and they also carry the risk of generating toxic hydrogen cyanide in abuse scenarios. While layered oxides are the favored chemistry for micromobility, Prussian blue's best fit is the short-duration, high power segment like uninterrupted power systems (UPS).

For stationary energy storage systems (ESS), polyanionic chemistry is the clear winner. Of the polyanionic chemistries being pursued, a formulation analogous to lithium iron phosphate Li-ion – sodium iron pyrophosphate (NFPP) – stands out with some clear advantages.

Unlike layered oxides that still face thermal runaway risks or Prussian blue analogs with cycle life challenges and toxicity concerns, NFPP delivers the complete ESS value proposition: inherent safety, extended lifespan, and operational flexibility. While layered oxides chase energy density for mobility, NFPP is engineered for the grid. It delivers a cycle life that rivals or exceeds LFP, reaching 10,000+ cycles with exceptional round trip efficiency (RTE) and low self-discharge rates. This durability makes it uniquely suited for the demanding duty cycles of grid stabilization and industrial power backup.

NFPP is the best chemistry for ESS because it excels in the metrics that drive operational value. It offers a wider temperature range, maintaining performance from -40°C to +60°C, which eliminates the need for energy-intensive HVAC systems in many climates. The robust 3D structure of polyanionic cathodes allows for rapid ion movement, supporting high continuous charge and discharge rates (up to 5C or more) and pulse discharges up to 10C. This makes it suitable for both high-uptime applications, like data centers, and intermittent renewables integration. Furthermore, the strong covalent bonds in the polyanion structure prevent oxygen release during thermal events, making NFPP fundamentally safer than oxide-based chemistries and ensuring reliability in high-stakes environments.



5. Stationary Energy Storage: Superior Alternative to LFP

Sodium-ion is uniquely positioned to replace LFP in battery energy storage systems (BESS) markets including commercial & industrial (C&I), data center, residential, defense, and microgrid applications. In these stationary sectors, the top requirement shifts from energy density to reliability, safety, and performance in extreme temperatures.

A key advantage of sodium-ion is its safer chemistry, which simplifies permitting and enables deployment in dense urban environments or zones with heightened safety requirements where fire risk is a primary concern. Lithium-ion batteries can enter thermal runaway at temperatures as low as 110°C and proceed to spike to 900°C, whereas most sodium-ion batteries typically remain stable until 160-180°C and peak in heat generation at much lower temperatures (300°C peak) if they do experience a thermal event. While these temperatures are already much safer than LFP, the newest generation of sodium-ion batteries eliminate pathways leading to thermal runaway altogether. This safety profile is a categorical departure from Li-ion risks and can unlock sites previously considered too risky or expensive for lithium-ion systems, such as building rooftops, basements, and mechanical rooms.

Sodium-ion batteries maintain reliable performance across a wide temperature range – from –40°C to +60°C – compared to LFP's narrower 0°C to 45°C window. This resilience means sodium-ion systems can operate efficiently in freezing or scorching climates without the thermal derating that limits LFP. For stationary storage, this translates to greater site flexibility, fewer restrictions on project location, and improved resource adequacy for critical infrastructure and resiliency projects.

The operational simplicity of sodium-ion further enhances its value for stationary storage. Unlike LFP systems, which require active cooling, frequent maintenance of pumps and fans, and cutoff mechanisms to prevent overheating, sodium-ion batteries can rely on passive or air cooling. This reduces operating expenses by up to 90% for cooling energy consumption, lowers maintenance costs, and minimizes site visits and labor. Fewer moving parts and non-hazardous transport also mean lower insurance premiums and easier logistics.

The table below compares the energy storage-specific characteristics of LFP versus sodium-ion:

Characteristic	Lithium-Ion (LFP)	Sodium-Ion (e.g. NFPP)
BASE ENERGY STORAGE REQUIREMENTS		
Cycle Life	3,000 – 5,000 Cycles	**10,000+ Cycles**
Operating Temperature	Narrow: 0°C to 45°C *(Needs HVAC)*	**Wide: -40°C to +60°C** *(No derating)*
Cooling Architecture	Active Liquid Cooling	**Passive / Air Cooling**
Maintenance & OpEx	High Maintenance *(Frequent service required)*	**Low Maintenance** *(No moving parts)*
SECTORS WITH HEIGHTENED SAFETY REQUIREMENTS (Urban Areas, Data Centers, Residential, Defense, Microgrid, Utility/Municipal)		
Safety Profile	Thermal runaway starts at 110°C, then spikes to 900°C *Suppression systems required*	Onset 160-180°C, peaks at 300°C *Passive cooling sufficient*
Non-flammability	No non-flammable ESS product commercially available	Newest Gen Eliminates Thermal Runaway

By reducing operational complexity and expanding deployment options, sodium-ion technology addresses the evolving demands of stationary energy storage with a compelling combination of reliability, safety, and cost-effectiveness.

6. System-Level Benefits

The true economic advantage of sodium-ion batteries emerges at the system level, where they present a compelling opportunity to compete with lithium-ion technology. To accurately calculate sodium-ion's benefits, it is essential to look at the design of battery energy storage systems (BESS) so that non-cell costs—such as cooling, maintenance, and logistics—are considered as part of the overall economics and not just a cell level $/kWh. [14]

Operational Savings

While cell costs are stabilizing, sodium-ion's durability and operational simplicity significantly enhance its OpEx cost profile and overall Levelized Cost of Storage (LCOS). As shown in the comparison below, sodium-ion (NFPP chemistry) has advantages that positions it as a low-cost alternative to LFP, substantially reducing operating expenses related to cooling, transportation, and maintenance.

The wider operating temperature range simplifies thermal management, removing the need for complex liquid cooling systems, which directly reduces Balance of System (BOS) hardware and parasitic loads that eat into revenue generation.

Metric	Lithium-Ion (LFP)	Sodium-Ion (NFPP)	System Impact
OpEx (Cooling)	High (Active Liquid Cooling required)	Low (Passive / Air Cooling sufficient)	~90% reduction in cooling energy consumption
Maintenance	High (Pumps, fans, filters require service)	Low (No moving parts in cooling)	Less components reduces site visits & labor
Operating Temp Range	0°C to 45°C	-40°C to 60°C	Eliminates or significantly reduces HVAC requirements
Cycle Life	3,000–5,000 cycles	10,000+ cycles	Longer asset life reduces amortization cost
Transport	Hazardous (Class 9), 30% SoC limit	Non-hazardous discharge to 0% SoC	Lower shipping & insurance premiums

Revenue Enhancement

Revenue enhancement is another critical benefit; the high C-rate and cycle life capabilities allow asset owners to perform use cases that stack revenue streams. For example, operators can participate in lucrative frequency regulation markets that require fast response while simultaneously reserving capacity for load shifting. Even with one use case, rapid charge and discharge and multiple daily cycles without accelerated degradation is an economic gamechanger with sodium-ion based energy storage.

The following comparison analyzes a **1 MW / 1 MWh battery energy storage system** operating in a wholesale energy arbitrage market (California ISO). The system charges during off-peak hours when electricity prices are low and discharges during peak demand periods when prices are high, capturing daily price spreads.

Metric	LFP Battery	NFPP Battery	The Operational Impact
Daily Strategy	1 Cycle / Day	2 Cycles / Day	High C-rate allows fast recharge for 2nd peak. Sodium doubles the "active" throughput.
Annual Revenue	$365,000	$657,000	2 Cycles = ~80% more revenue/year.
Upfront Cost (CapEx)	$3,000,000	$2,700,000	10% Lower Cost (Cheaper materials).
Payback Period	8.2 Years	4.1 Years	Break even twice as fast.
10-Year Net Profit	$650,000	$3,870,000	~6x more profit over the decade.
ROI	22%	143%	A significantly higher yielding asset.

Note: The 80% revenue increase for sodium-ion (rather than 100% for double cycles) reflects the second daily cycle which typically captures a smaller price spread than the primary morning/evening peak differential.

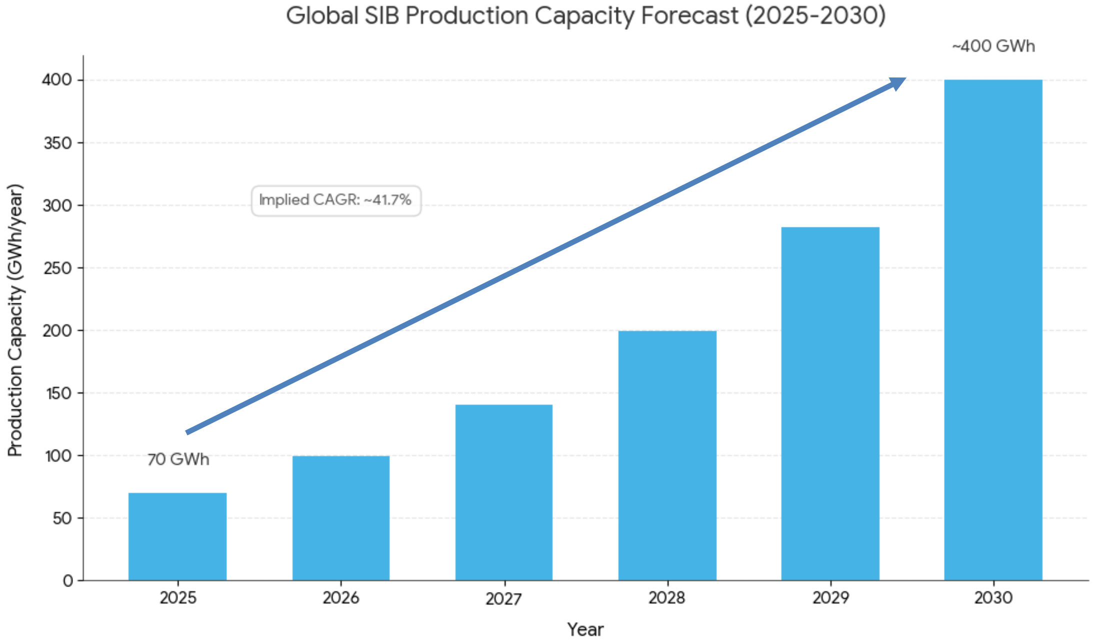
The economic advantage is clear: The combination of lower costs, nearly doubled revenue throughput, and extended asset life translate to a 143% ROI versus 22% for LFP – making sodium-ion not just a technically superior solution, but also capable of passing the business case test. For utilities and energy developers, this means faster capital recovery and higher IRR while unlocking new deployment sites previously off-limits to lithium-ion due to safety concerns. This isn't a marginal improvement; it's a fundamental shift in project economics at large scale.

7. Roadmap to Commercialization

Sodium-ion batteries are now generally considered to be at a mid-to-high Technology Readiness Level (TRL), moving from lab-scale prototypes (TRL 4–6) toward industrialization (TRL 7–9). Some applications, particularly grid storage and light electric vehicles, are already seeing commercial deployment, demonstrating the technology's growing maturity and readiness for large-scale energy storage.

The largest sodium-ion BESS project to come online was the 500 MW / 2 GWh Anhui Conch Cement Tongliao Naimanqi Energy Storage Project in November 24, 2025 and several other installations have surpassed the 1 GWh mark. In the United States, sodium-ion BESS developer Peak Energy has signed a commercial agreement with Jupiter Power for a 720 MWh BESS, with the potential to secure 4 GWh in additional orders.[15] These deployments highlight the rapid progress of sodium-ion batteries from laboratory prototypes to commercial-scale installations.[16]

Recent market analysis projects that the global sodium-ion battery market is poised for explosive growth, with production expected to surge from 70 GWh today to approximately 400 GWh by 2030 (41.7% CAGR), according to Benchmark Mineral Intelligence. This explosive growth is driven by sodium-ion's superior safety and performance characteristics relative to other battery alternatives that could take from LFP's market share.



***Source**: Benchmark Mineral Intelligence, The Rise of Energy Storage Systems: Global Deployments, Pricing Trends, and Strategic Market Shifts (2025)*

Among non-lithium battery technologies, sodium-ion is positioned to capture the vast majority of BESS deployments due to its lower raw material price floor, proven manufacturability and performance advantages. The path to scale is accelerated by the "drop-in" nature of the technology. As US and European markets seek to localize supply chains, existing lithium-ion capacity can be rapidly converted to sodium-ion production. This ability to repurpose infrastructure without building new factories from scratch provides a fast-track to global scale and market penetration. The same cannot be said for other non-lithium battery technologies, which are often based upon a proprietary, bespoke form factor that requires entirely new outfitting and tooling of production lines.

8. Conclusion

Sodium-ion technology, particularly the NFPP chemistry, has emerged as the superior solution for grid-scale energy storage across all operating environments. By establishing a new baseline of reliability, it outperforms lithium-ion in standard conditions while uniquely expanding the horizon of what is possible—enabling safe operation in extreme climates and dense urban zones where volatile batteries cannot go. While the NFPP category provides a substantial safety upgrade over incumbent technologies, the newest advancements in this field now deliver true non-flammability alongside high performance.

The business case for this transition is validated by system-level economics: sodium-ion's operational simplicity and high throughput potential drive a projected 143% ROI for end users, significantly outperforming legacy LFP systems' 22% ROI. With the unique ability to scale rapidly and commercial projects already successfully deployed, sodium-ion is quickly shaping to be a pragmatic, immediate path toward a secure and cost-effective energy future.

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