TRANSJOVAN CAPITAL
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Next Big Battery Breakthrough to Electrification

Sodium-ion Batteries – A Compelling Alternative

November 2023

Executive Summary

Na-ion Batteries vs. Li-ion Batteries

- Surging demand for batteries and limited accessible lithium reserves have exposed **vulnerabilities in the Li-ion** value chain. **Na-ion** is a **leading alternative** due to its superior availability, safety, cost and ethical aspects. However, it lags greatly in energy density
- Li-ion dominates all battery markets, i.e., consumer electronics, stationary applications and mobility/transportation. **Potential market** segments/ applications for Na-ion include **EV fast charging** stations, essential **backup power**, energy storage and heavy-duty vehicles

Promising Battery Constructions and Evolving Competitive Landscape

- Out of all Na-ion configurations, **three cathode chemistries** have demonstrated significant potential for success – Layered Transition Metal Oxide, Prussian Blue analogues and Polyanion. The most promising anode at present is hard carbon
- Startups and research labs have made significant progress in Na-ion cell design and performance, tailoring them to **specific applications** by focusing on key factors such as cycle life, energy density and power density

Road to Commercial Production and Key Challenges

- Companies have transitioned from the R&D phase to pilot production, implementing their technologies in energy storage or micro-mobility. Many have formed **partnerships with end customers** to establish factories and tailor cells according to their clients' requirements
- However, there are notable **obstacles** along the path to commercialization with the most critical being the future **pricing of lithium** and the performance of other alternative battery technologies

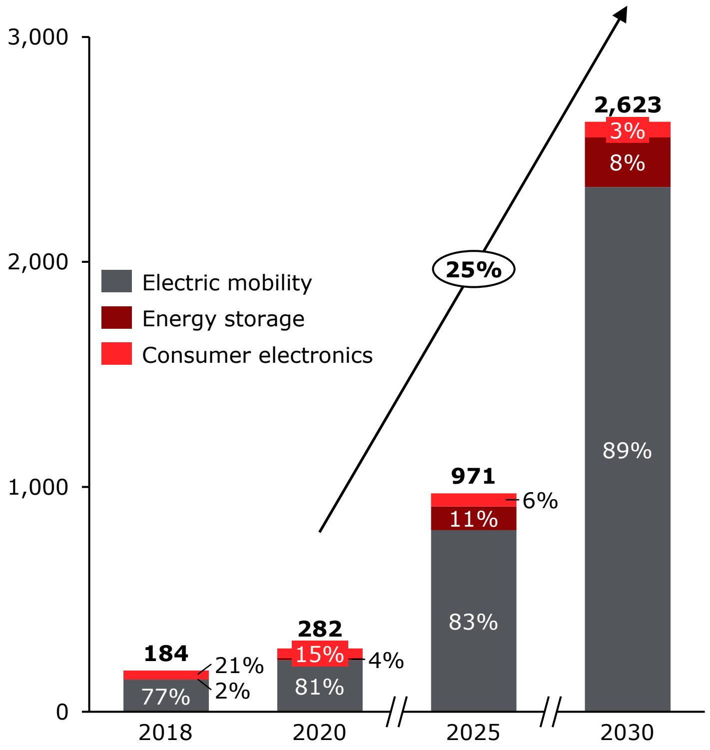
Na-ion vs. Li-ion Batteries

Li-ion Challenges Paving the Way for Na-ion

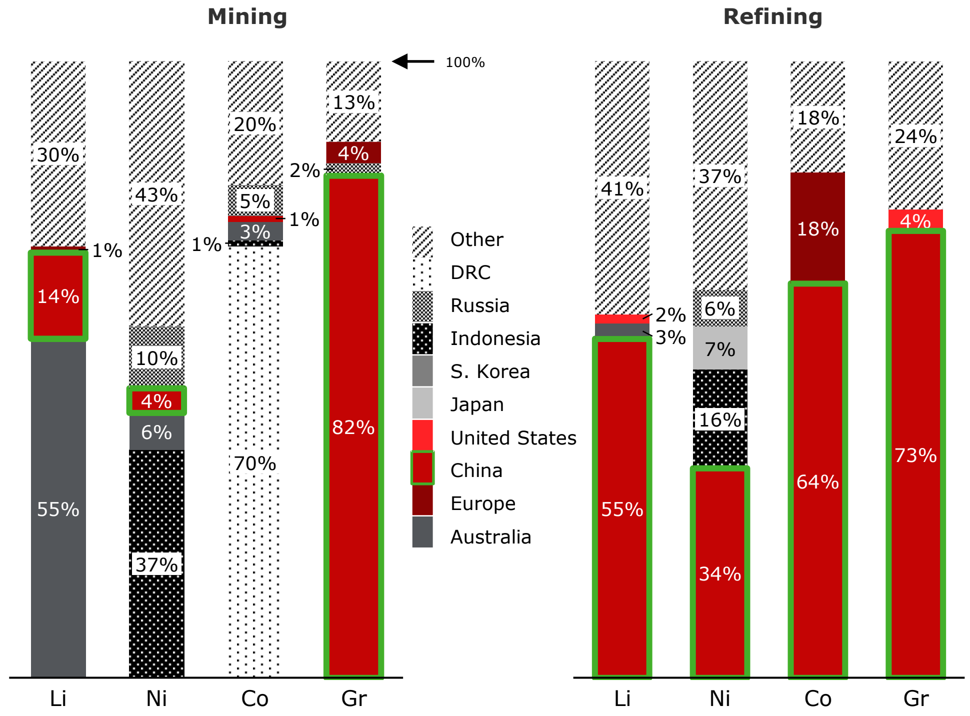
Global rush for Li-ion batteries have exposed their limitations, i.e., scarce high-quality resources, further worsened from the concentrated presence and geopolitical tensions

Batteries are central to realizing the 2°C goal of the Paris Agreement. Li-ion batteries dominate the entire batteries landscape, as global firms race to secure raw material supply and production capacity

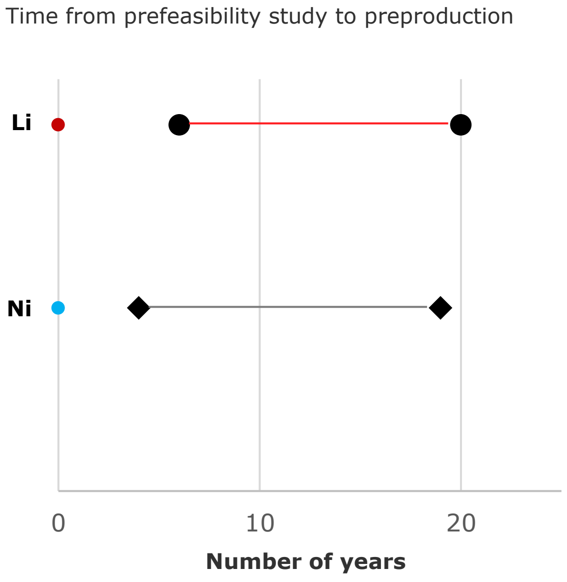
*To observe **significant demand growth** for Li-ion batteries...*



*...But **concentrated supply chains** have heighted the risks during uncertain times...*



*...And new capacity for minerals have **huge lead times***



*Gr– Graphite

Sources: IEA, World Economic Forum

Na-ion Battery Strengths over Li-ion

Na-ion chemistry has recently garnered renewed interest worldwide as institutions seek alternatives to address the shortcomings in the current use of Li-ion batteries

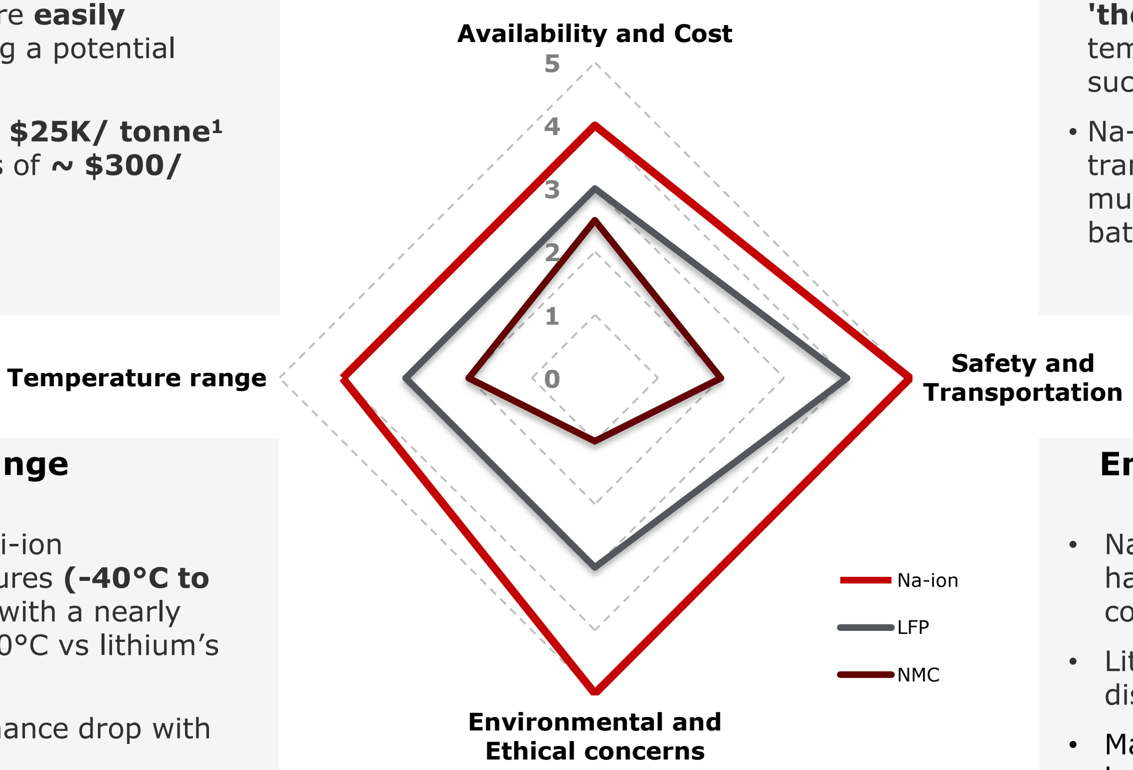
Favorable Aspects of Na-ion

1 Availability and Cost

- Na-ion is > **500x abundant** than lithium and is well dispersed globally. They are **easily extracted**, with seawater being a potential source
- Lithium carbonate prices are **~ $25K/ tonne**[1] vs the sodium carbonate prices of **~ $300/ tonne**[2]

Safety and Transportation 2

- Lithium batteries are more susceptible to **'thermal runaways'** if not stored under ideal temperature conditions, leading to quick succession of heat from **90°C to 400°C**
- Na-ion batteries can be fully discharged for transportation, as against its lithium-ion that must maintain at least **30% power** for its battery health



Temperature range

- Na-ion batteries outperform Li-ion counterparts at low temperatures **(-40°C to 50°C vs. -20°C to ~60°C),** with a nearly **90%** capacity retention at -20°C vs lithium's ~70% retention
- Lithium-ion batteries' performance drop with the temperature

3

Environmental and Ethical concerns

- Na-ion batteries **do not contain cobalt** and have no issues of child labor/ unsafe working conditions in mines
- Lithium's extraction process results in habitat disruption and higher water consumption
- Made with widely available resources, Na-ion batteries are **easily recyclable** after use

4

Sources: 1. Fastmarkets, 2. Intratec, 3. Takomabattery

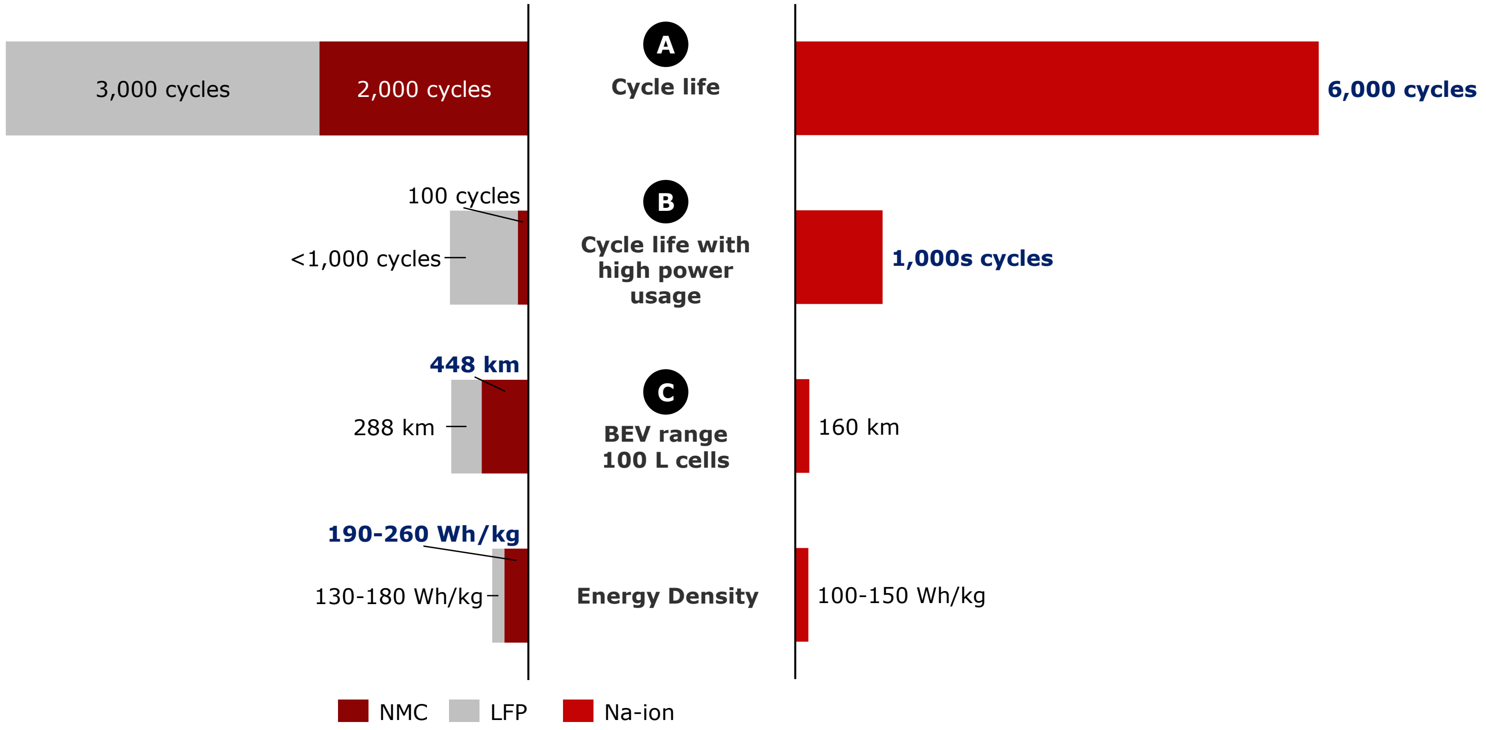
*LFP– Lithium Ferrous Phosphate; NMC– Lithium Nickel Manganese Cobalt

Contrasting Features of Na-ion vs. Li-ion Batteries

A comparison of the fundamental characteristics of the two battery technologies highlight the emerging specific and niche use cases for Na-ion batteries

Key Characteristics

Li-ion batteries | **Na-ion batteries**



Note: The chart is a stacked style bar graph

Applications

A Energy storage solutions

- Due to their **long cycle life** and relatively greater **safety**, Na-ion batteries are ideal for stationary storage uses
- These include **grid storage**, backup power solutions, or energy storage for **renewable energy** systems

B Heavy duty applications

- Na-ion batteries are a suitable choice for heavy-duty applications where **rapid power delivery** is more important than extended range

C Entry-level EVs/ Two and three-wheelers

- These have low range and require frequent charging
- **Widespread charging** infrastructure in urban areas can help with the reduced range. **Low initial cost** from cheaper Na-ion batteries could favor its adoption

Na-ion's high cycle life and power output make them highly suitable for specific uses, e.g., energy storage

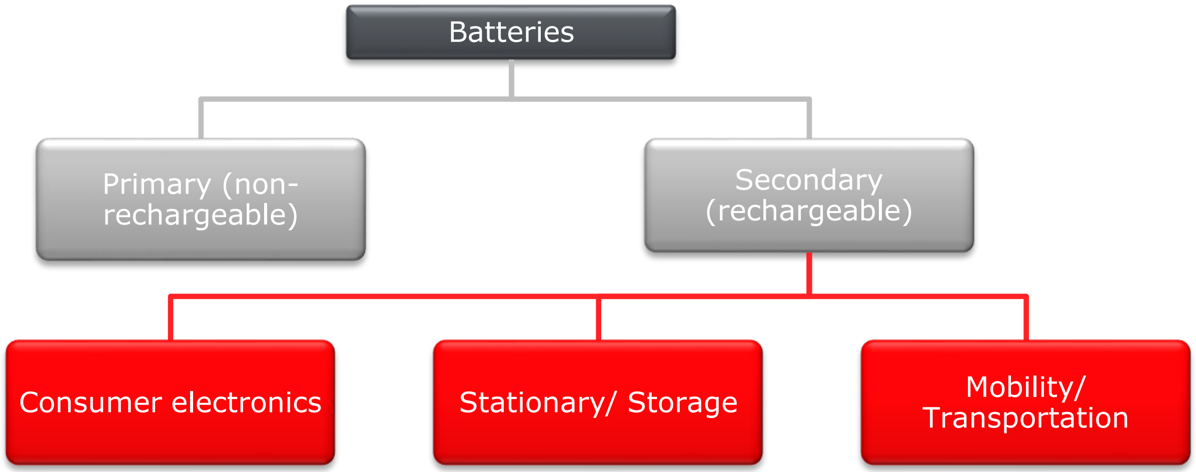
Sources: 1. Wood Mackenzie, PitchBook

Navigating Battery Market Segments and Customer Profiles

Safety and high-power discharge capability make Na-ion ideal for stationary uses | Well-developed charging infrastructure network may propel its adoption in EVs

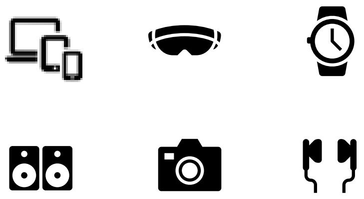
Market Landscape

Battery Market Segments *(Li-ion dominance)*



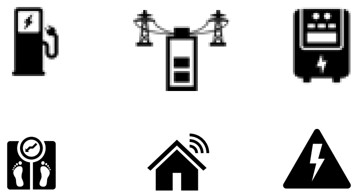
Consumer electronics

- Portable batteries, including micro batteries used in wearables
- Li-ion dominates due to its high **energy density**[1]



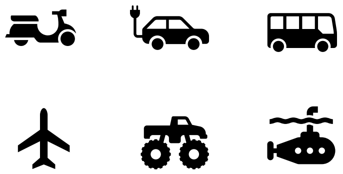
Stationary/ Storage

- Connected to the main source on charge/ discharge
- Li-ion dominates with **53% market share**[2]
- Uses – EV chargers, telecom towers, data centers, grids, medical equipment, industrial



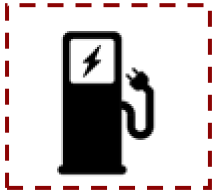
Mobility/ Transportation

- Automotive EVs need better **range,** or energy density
  - Li-ion – 22% market share[3]
- Heavy-duty/ **off-highway EVs** need power density
  - Li-ion – 62% market share[4]
  - In forklifts – 90% share[5]
- Li-ion **dominate aerospace**, military, marine applications[6]

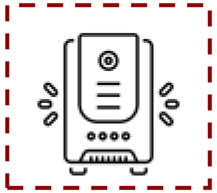


Market Potential for Na-ion batteries

High power use cases



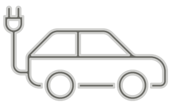
Fast charging EV stations – stationary batteries

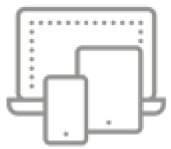


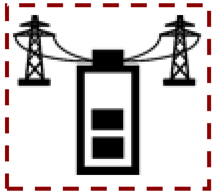
Mission critical backups - Data centers, telecom, Electrical grid

Heavy duty equipment that rely on power delivery

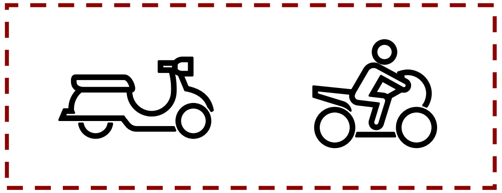
High energy use cases







Grid energy storage – power grids, renewables



Micro mobility – 2/3 wheelers, small range buggy

Applications where Na-ion challenges Li-ion

Sources: 1. Report Linker, 2. Market Research, 3. The BRAINY Insights, 4. Market Research Future, 5. Mordor Intelligence, 6. Military & Aerospace

Promising Battery Constructions | Evolving Competitive Landscape

Na-ion Batteries Internal Structure

Multiple promising chemistries continue to evolve in the space of Na-ion batteries as these gain momentum globally

Popular Battery Constructions

Cathode

Layered Transition Metal Oxide*

$NaMO_2$

- Uses **transition** metals (M): Cu, Ni, Co, Fe, Mn, Cr, V
- High tap density, high operating potentials, high capacity – makes it **highly attractive** among all
- Variants: P2-type, P3-type, O3-type, mixed (P2/P3/O3)
- Capacity range of ~ **140-190 mAh/g**

Prussian Blue/ Prussian White/ Other Analogues

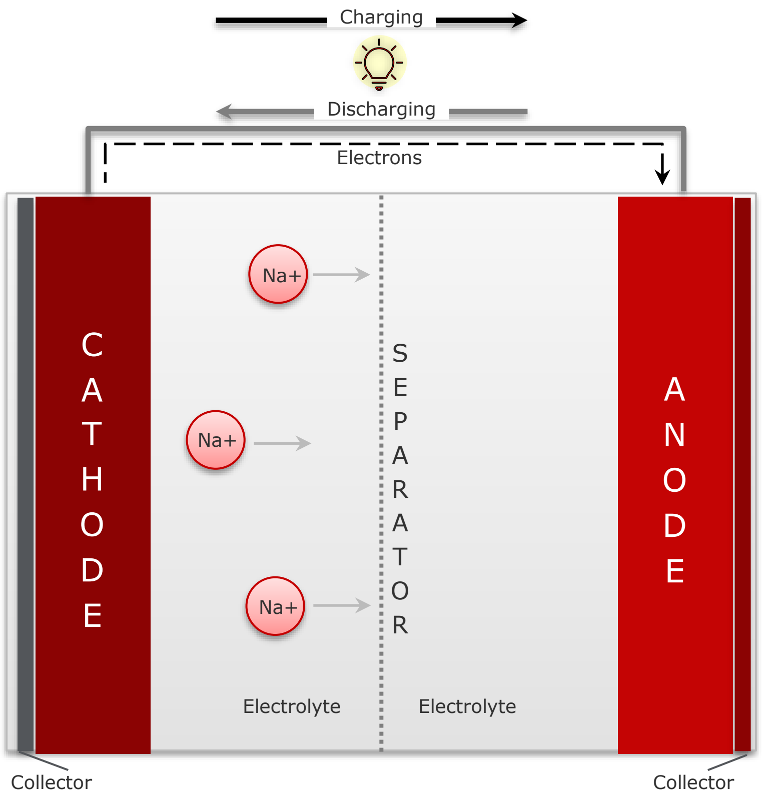
$Na_xFe[Fe(CN)_6]$, $Na_{1.88(5)}Fe[Fe(CN)_6]\cdot 0.18(9)H_2O$

- Cage like structure leads to **high structural stability** ⇨ higher cycle life, **power capability**
- Can deliver capacity of **150-160 mAh/g** at an average discharge voltage of ~ 3.4V

Polyanion

$Na_3M_2(PO_4)_3$, $Na_3V_2(PO_4)_2F_3$

- A polymer with repeating structure
- Strong covalent bonding ⇨ higher safety, cycle life
- But lower tap density lowers the energy density
- Some have great cycling stability to deliver capacity of **120 mAh/g** at **high discharge voltages of ~3.6V**



Separator

Polymer

Collector

Aluminum

Anode

Hard Carbon

- Most preferred due to **superior mix** of capacity, low working potential, cycling stability

Graphite

- Alternative to hard carbon, but inferior in the mix of capacity-working potential-cycling stability
- Research into make it a viable option – for e.g., alloying

Others

- Various other materials are being researched currently
- These include tin, molybdenum disulfide, graphene, carbon arsenide

Electrolyte

Aqueous

- These can have lower voltages, energy densities

Non-aqueous

- Some solvents have **high voltage range** (ethylene carbonate, dimethyl carbonate, diethyl carbonate, propylene carbonate)
- Salts most used are $NaClO_4$ and $NaPF_6$

Sources: Wood Mackenzie, American Chemical Society, Journal of Materials Chemistry, Advanced Energy Materials

* M refers to transition metals in the periodic table

Key Players Driving Manufacturing and Adoption

China takes the lead, with production anticipated by late 2023| Startups from the USA, Europe and India also enter the field

Company	Wh/ Kg	Cycle life	Anode	Region	Production	Plan/ Current steps	Applications
Layered Transition Metal Oxide cathode							
faradion / amte power	• Current = 160 • Next-gen = 190	4,000	Hard carbon	UK	**2023 – 2025**	• Faradion and AMTE Power have licensing agreement to share IP, design and manufacturing capabilities respectively • Uses Li-ion **UK** facility to build Na-ion cell prototypes	• Energy storage, e.g., Reliance; Forklifts • EVs
中科海钠 HiNa Battery	• Current = ~160 • Next-gen = 180-200	8,000–10,000	Soft carbon	China	**2022**	• Launched 3 cells (140-155 Wh/kg) • **1 GWh** factory running from Dec-2022; to expand to 5 GWh	• Affordable Evs: JAC EVs, Sehol (VW JV) test vehicle • Energy Storage
SVOLT	• Current = 135 • Next-gen = 160	2,000	-	China	**2023**	• Plans to develop next-gen 160 Wh/kg cell by end of 2023	• Energy Storage – Renewables; Backup power
EVE	• Current = 135 • Next-gen = -	2,500	Hard carbon	China	2025	• R&D and pre-pilot stage • Cylindrical battery based on laminated-oxide cathode	• Currently, exploring use cases with the clients
Prussian Blue/ Prussian White cathode							
CATL	• Current = 160 • Next-gen = 200	3,000–6,000	Hard carbon	China	**2023**	• Plans to establish basic supply chain by end of 2023 • 1st gen cell launched in 2021 – **integrated** along with **Li-ion**	• Chery Auto EVs to use CATL batteries by 2023 end
Natron Energy	• Current = 140 • Next-gen = -	**> 50,000**	Prussian Blue	US	**2023**	• Known for **high cycle life**, high power density • Operational pilot production line in California	• Energy storage; Data centers, e.g., ABB; Telecom • **EV fast** chargers E.g., UA, Chevron
Altris	• Current = 150 • Next-gen = 160	**-**	Hard carbon	Sweden	**2023**	• Running pilot production line; 1GWh cathode factory by 2023 • Prussian White cathode capacity of **160 mAh/g** – the highest	• Energy storage – grids • Commercial transport
Polyanion cathode							
TIAMAT	• Current = 122 • Next-gen = -	> 5,000	Hard carbon	France	2025	• **High power density** of 2-5kW/ kg	• EV mobility • Energy storage
GODI	• Current = 120 • Next-gen = -	10,000	-	India	2025	• R&D stage for Na-ion batteries	• Energy storage
ZOOLNASM 众钠能源	• Current = 120 • Next-gen = -	5,000-8,000	Hard carbon	China	**2023**	• **Launched 4 cells**; to start commercial production in 2023	• Energy storage – renewables, grids, telecom • 2/3-wheelers, e.g., Tailing Technology; Forklifts
Combination strategy cathode							
鹏辉 GREAT POWER	• Current = - • Next-gen = -	3,000-6,000	Hard carbon	China	**2023**	• Uses **both layered oxide** system and **polyanion** system • Successful demonstration of its Na-ion cell prototypes in 2022	• Datacenter – 5MW/10MWh for QNCDC in 2023 • Utility-scale energy storage applications

Sources: Company websites, Energy-storage News, Electrive, CleanTechnica, Batterynews, CNEVPOST

Up till 2023

Road to Commercial Production | Key Challenges

Road to Commercial Production and Adoption

Success in currently identified uses of Na-ion, e.g., energy storage and micro mobility, will drive exploration of other applications, including heavy-duty EVs

Progression from R&D to practical use in micro-mobility, energy storage and premium EVs, will require improving sodium-ion battery **energy density** and establishing **strong supply chains**

R&D

- Many startups are in the **advanced stages** of developing a technology
- Most of the R&D is based in **China**, with push from the local agencies
- China also has the highest patents in the field
- Advances in **cell design and construct** underway to achieve better density

Product Development

- Several have already developed a successful product post completion of the R&D stage
- Some startups are **seeking partnerships** to take it to production

Production

- Few have begun pilot production/ are building factories and have agreements with clients
- 28 factories (**100 GWh in pipeline by 2030**) are planned/ operating/ being built, with most in China

Applications

Micro mobility

- **Low-cost** and high safety of Na-ion has led to faster adoption in 2-3 wheelers/ affordable cars

Energy storage

- **Issues with Li-ion** supply, low cost of Na-ion and better power output has favored its adoption for energy storage uses

Heavy duty EVs

- Na-ion's **better power output**, temperature ranges and improving energy density of next-gen cells to enable its use

Premium/ Luxury EVs

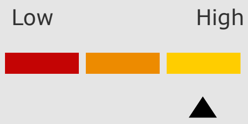
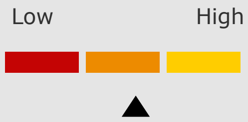
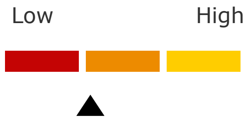
- **Na-ion will continue to lag Li-ion** as Na atoms are heavier than Li ones, leading to lower energy density and poor range

Companies at various stages

Sources: Benchmark Minerals

Likely Barriers to Na-ion Battery Commercialization

The transition from pilot stage to full-scale commercialization is contingent on the long-term lithium pricing and rival technology performance

Threats	Description	Level of Impact
Prices of Lithium	• **Short-term** lithium prices have declined or stabilized since the records highs in 2022 of over $80,000 per tonne[1] • Also, **cost advantage** of Na-ion batteries may **reduce** in the **long-term** if innovation in the lithium extraction process makes lithium easily accessible or if its new reserves are discovered	
Competing alternative next-gen technologies	• Several alternate promising battery technologies are being pursued in the labs, with large corporations being the sponsors, e.g., solid-state batteries by Toyota, **lowering** available **resources** for Na-ion and being a **potential threat**, if commercially proven • Few **novel** energy storages include flow batteries, Form Energy's iron-air battery, EnerVenue's nickel-hydrogen battery, Ambri's liquid metal battery, Eos Energy's zinc hybrid battery[2]	
Technical superiority of China	• China not only hosts majority current and upcoming Na-ion factories but also is a central hub for scientific innovation in this field, boasting the highest number of filed patents • In the future, as Na-ion matures, China may benefit immensely from a head start in the supply chains and from governmental incentives, leading to **concentration risk** for global customers	
Lower overall cost-effectiveness	• While raw material costs are lower, **total cost** of producing a Na-ion cell **for an end application** ($320/ KWh) is currently higher than that of LFP cell ($280/ KWh)[3]. This may hinder its adoption among certain price-sensitive customers • Governmental incentives to labs and end-users along with private sponsorships will help improve Na-ion performance and bolster its standing as a strong challenger to Li-ion batteries	

Notes: 1. Clean Technica, 2. Energy Storage News, 3. Goldman Sachs
Sources: Internal analysis

Closing Thoughts

Na-ion batteries might displace Li-ion in specific market segments | As batteries are pivotal to many applications, agile customers may forge alliances to drive transformative changes

- Na-ion batteries will dominate among all the prominent Li-ion alternative battery technologies
  - They have superior safety, raw material availability and power output vs. Li-ion. However, currently lower energy density makes them out of reach of premium EVs
  - Research labs have made strides in Na-ion cell chemistry to improve its performance. Players seek **collaborations with end-users** to build custom energy solutions
  - Bolstered by government impetus, **China** will likely see many companies start **commercial** production and launch **Na-ion EVs** by the end of **2023**

- Future possibilities may include new and promising Na-ion battery formulations exhibiting **energy densities** closely aligned with those of **Li-ion** batteries
  - As Na-ion goes mainstream with energy storage and affordable EV uses, **more research dollars** will flow from governments and corporates to expand its potential
  - End-user companies that made early **collaboration** moves with **Na-ion players** to jointly explore applications will be at the **pole positions** in their industries

- ***'Battleground of the future'***- Where to play and How to win
  - Batteries are poised to become the cornerstone of future end applications; challenges surrounding Li-ion battery supply may pave the way for Na-ion to capitalize
  - Na-ion technology will require partnerships and **large consortiums** to emulate success of Li-ion. Savvy corporates may act quickly to partner with labs/ startups for technologies that align with their **target end markets** to jointly build battery solutions, e.g., construction equipment, generators
  - Early moves would enable end-use corporates to be at the forefront in of their industry transformation and **securing battery** supply chains

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Important Sources

- Company websites
- Wood Mackenzie
- PitchBook
- Energy Storage News
- Fast Markets
- Benchmark Minerals

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