Emerging Technologies: Sodium-ion Briefing

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In recent months **sodium-ion batteries** have reached the headlines in the EV space due to a number of both rumours and announcements of its use in vehicles. The reality is that this chemistry will likely see good usage in a number of applications. In this briefing we will cover the technical details of the cathode and anode chemistries, how cost competitive sodium-ion cells can be against lithium counterparts, its use cases (in EVs and beyond), current routes to commercialisation and, an overview of where the technology stands today in its three main applications: ESS, 2&3-Wheelers and Electric Vehicles.

Executive Summary

Sodium-ion (Na-ion) has been explored as a potential cheaper alternative to lithium-ion (Li-ion) in the past decade. The technology is considered a good lower energy, low cost "drop-in" alternative. Adopting Na-ion mean the industry can focus on technologies that require limited CapEx to adapt Li-ion manufacturing equipment to produce Na-ion.

Any rise in Li-ion raw materials demand and pricing due to increased EV production will make Na-ion an increasingly attractive option **for lower energy demand applications.**

As well as replacing Li with cheaper and more abundant Na, this cell chemistry **doesn't require expensive copper current collectors.** Aluminium can be used for both positive and negative electrodes. This also means that sodium-ion batteries can be created in a symmetrical format – where the same material is used for both positive and negative electrodes.

Na-ion cells also benefit from significantly **better cycle and calendar life**. Suppliers suggest that it can be stored at a fully discharged state, owing to its greater stability, increasing safety.

Developers expect scaled production to give a **20-30% cost saving compared to LFP**. Despite its lower energy potential with CATL quoting values of 160Wh/kg, this level makes it a real competitor for popular LFP which will only increase if second generation exceed 200Wh/kg as some developers claim.

Manufacturing at scale will require the creation of **new value chains** for material manufacturing, which can differ substantially from Li-ion. This will require new anode and cathode active materials (CAM), as well as battery grade sodium salts and inactive cell components. CAMs for sodium-ion have to be carefully selected to accommodate the larger size of the sodium ions.

Cell Chemistry

Cathode

Cathode materials, like NCM, are layered metal oxides, meaning they form structures that allow positive ions (like lithium and sodium) to be stored between the layers. The **larger ionic radius of sodium** means it does not insert as easily into those layers. This means fewer ions can be stored per unit area and can cause expansion of the cathode, meaning increased material degradation during cycling. This same phenomenon happens at the anode, meaning **graphite can not be used** in sodium ion cells under standard conditions.

There are three main types of cathodes that are currently being developed for sodium-ion, detailed in Table 1.

	Prussian Blue Analogues (PBA)	Layered Transition Metal Oxides	Polyanionic
Example formula	$Na_{2-x}Fe[Fe(CN)_6]$	$Na_aNi_{(1-x-y-z)}Mn_xMg_yTi_zO_2$ $Na_aCu_{(1-x-y-z)}Mn_xMg_yTi_zO_2$	$NaFePO_4$ $Na_3V_2(PO_4)_2F_3$
Specific capacity (mAh/g)	120-160	100-190	80-140
Cycle life			
Upper Voltage Limit (V vs. Na^+/Na)	3.8	4.1	4.0
C-rate			
Manufacturing	Complex, very moisture-sensitive	Can leverage existing LIB infrastructure	Can leverage existing LIB infrastructure

Table 1. Comparison of sodium-ion cathode materials

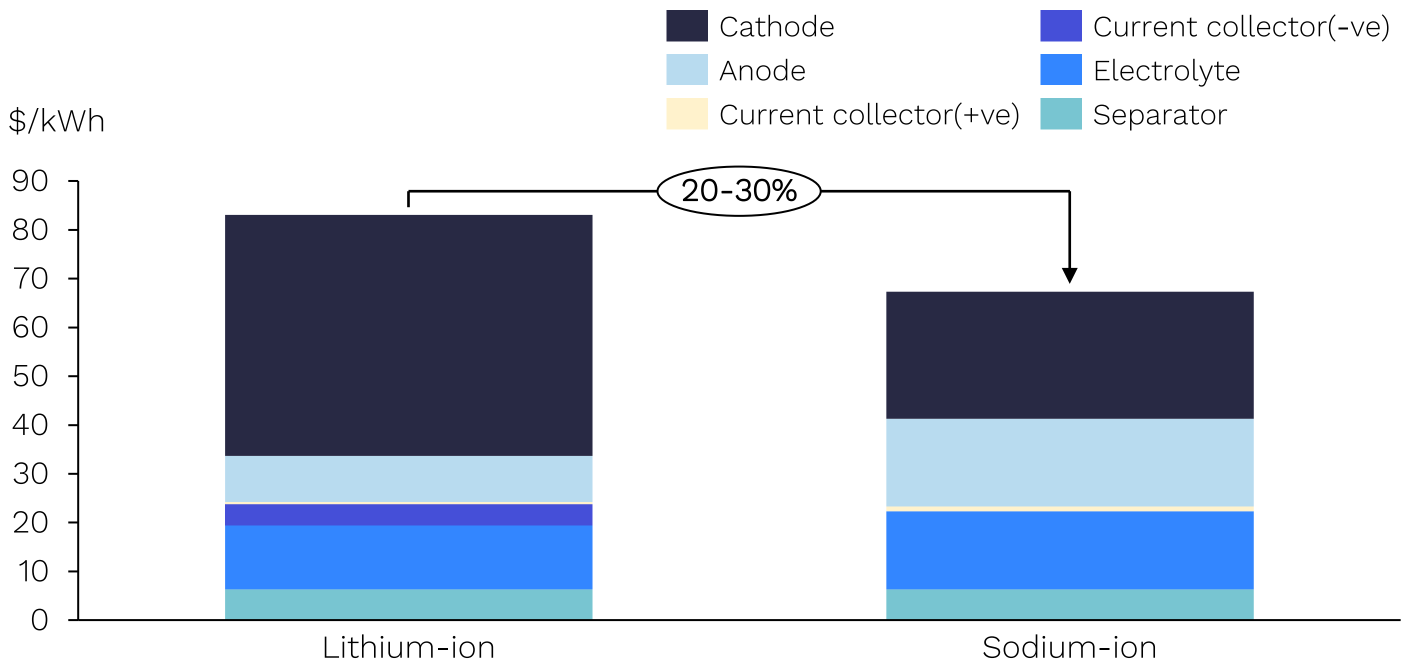
Anode

Due to the incompatibility of Na ions with traditional Li-ion anode material, graphite, in standard electrolyte systems, **hard carbon** is the most commonly used anode material. Hard carbons can be made from almost any carbon-based feedstock, including sugar and coconut shells, as well as coal and petroleum derivatives. Currently, to create hard carbon from renewable resources is more expensive than from fossil fuel derivatives due to the intensive purification steps required to create sufficiently high purity hard carbon for battery applications. This makes hard carbon more expensive than graphite and due to the need to have thicker electrodes more material is required per kWh. There are reportedly some **supply chain issues** surrounding hard carbon affecting the Chinese manufacturers moving to scaled sodium-ion production. Current hard carbon materials were not developed with sodium in mind, meaning significant collaboration between hard carbon manufacturers and sodium-ion developers will be required to fully optimise. Additionally, **hard carbon production is not currently at the scale required** to meet the potential demand of scaled sodium-ion cell manufacturing.

Cost Competitiveness with Lithium-ion

- While sodium-ion is sold as a low-cost alternative to lithium-ion, due to the relative infancy of scaled production it is likely the **cost benefits will, at least initially, be quite limited**. Secure supply chains will need to be developed to feed the commercialisation, which as discussed will be significantly different from current lithium-ion due to the intrinsic material differences.
- Cathode material costs for sodium-ion have the **potential to be significantly cheaper** than for lithium-ion batteries (LIBs) as they can be made from inexpensive metal elements like iron, without the need for nickel and cobalt.
- In terms of electrolyte, the synthesis of high purity battery-grade sodium salt ($NaPF_6$) still requires further development to bring cost down. While the raw sodium material costs are cheaper than lithium, the final saving is not significant for the electrolyte (2-5%). Additionally, due to the increased thickness of electrodes in sodium-ion cells the volume of electrolyte required to achieve good soaking will be greater than in lithium-ion.
- Removing the cost of copper current collectors does have a significant effect on cell costing, with **aluminium foil being 9 times cheaper per kg than copper**.
- For the rest of the cell components (tabs, packaging, tape etc.) it will be very similar to LIBs and, can utilise much of the same manufacturing infrastructure. **This means that cells of both chemistries could be assembled on the same lines**. This will significantly lower the CapEx cost for companies already producing LIBs. Additionally products will already be on the market for pure NIB producers to purchase without having to commission specialised equipment.

Estimated cell cost comparison



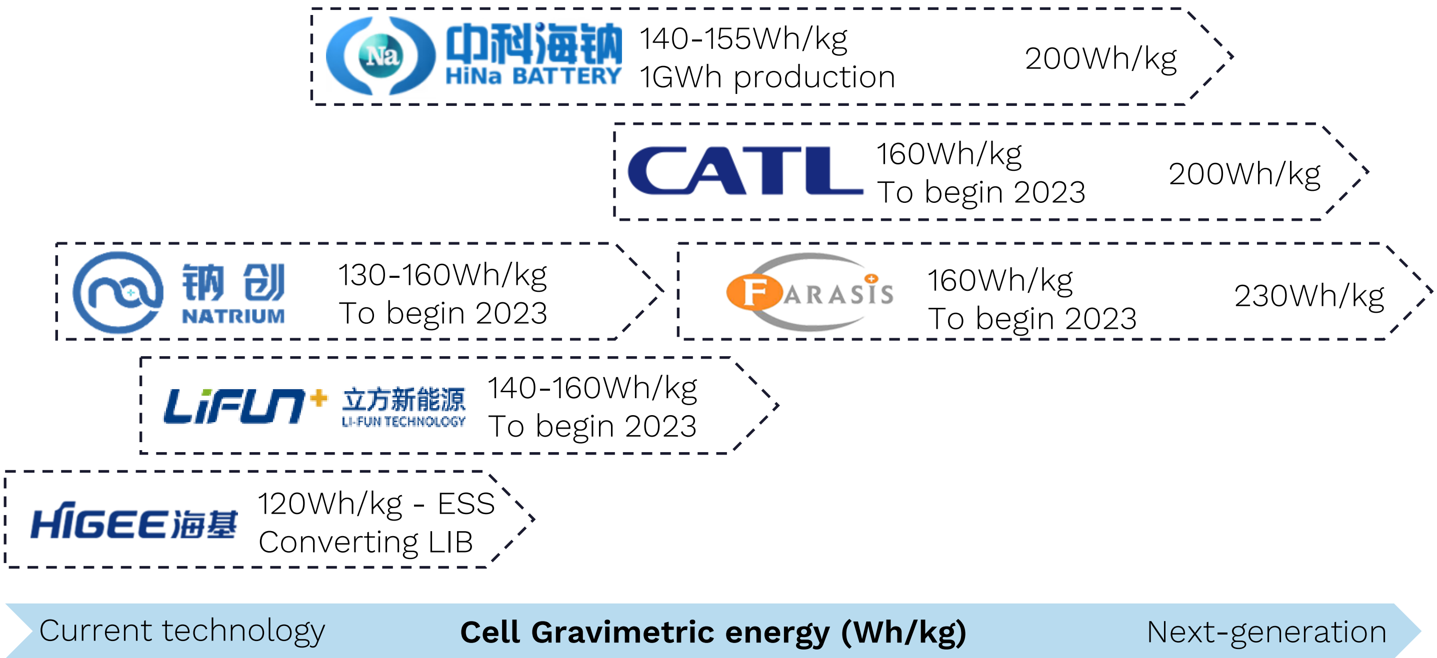
Commercialisation of Sodium-ion

Begins in China

Scale production for sodium-ion is currently localised exclusively to China, with **HiNa** leading the way. Other Chinese manufacturers plan to begin scale sodium-ion cell production in 2023 including **CATL, Farasis, Natrium** and **Li-FUN.** All quote first generation energy densities of between 130 and 160Wh/kg.

- **HiNa Battery Technology Co**, was the first Na-ion developer to begin GWh-scale production at the end of 2022 and is primarily targeting BESS and 2&3-Wheeler applications. It also recently began testing of its products in EVs. HiNa recently unveiled two other sodium-ion products, both prismatic cells, with energy densities of 145 and 155Wh/kg (80 and 240Ah respectively), capable of cycle lives between 2000 and 6000 cycles. Additionally, HiNa says that its Na-ion products all have nominal cell voltages of 3.1V, which is only slightly lower than that of LFP cells (3.2V). A higher nominal cell voltage allows for greater energy but the potential for Na cells is intrinsically lower than Li, so to be able to achieve comparable cell voltages shows great progress.
- **CATL** is quoting some of the highest energy densities for first generation sodium-ion products (160Wh/kg at the cell level), which given CATLs propensity for creating efficient cell-to-pack designs with its Qilin battery packs, **overall pack densities could be in the region of 140Wh/kg**. CATL is also planning to use its sodium-ion cells in a hybrid pack. Its AB battery pack solution will allow sodium-ion cells to be placed alongside lithium-ion, to allow benefits of both technologies.
- **Farasis Energy** have reportedly converted some of its lithium-ion capacity at its Ganzhou plant to produce sodium-ion cells. It reports a second generation sodium-ion cell with the highest energy density of 230Wh/kg

Chinese developers in mass production/to start 2023



Commercialisation of Sodium-ion

Material Supply Chain

Further up the chain from the cell manufacturers there is plenty of action from Na-ion material suppliers too. Again, this is being led in China. Previously CATL has said the path to commercialisation will be focusing on setting up its supply chain for production in 2023. With fewer updates recently it remains to be seen the progress CATL has made at this point in time.

Most material suppliers still hesitate to expand from early-stage trials unless they can lock into contracts with the leading Na-ion player such as HiNa Battery and Li-Fun Technology. As the leading players ramp up capacity and prove the viability of Na-ion batteries in commercial projects, more and more material suppliers will enter the market.

Many existing CAM developers, like Umicore, are exploring Na-ion cathode materials. Owing to the relative similarities between lithium and sodium-ion cathode materials, specifically the layered oxides and polyanionic materials begin akin to NCM and LFP.

Na-ion Battery Material Supplier

Planned/Under Construction

Operational*

Sanyou Group and HiNa Battery signed a strategic agreement to invest in a 100,000 tonnes battery grade sodium carbonate project in Tangshan.

Han Xing Technology is investing RMB5.1 billion to build 100,000 tonnes of Prussian Blue production capacity and ten Na-ion battery cell production lines. The company also plans to invest RMB1.5 billion in an anode production project in Xingjiang.

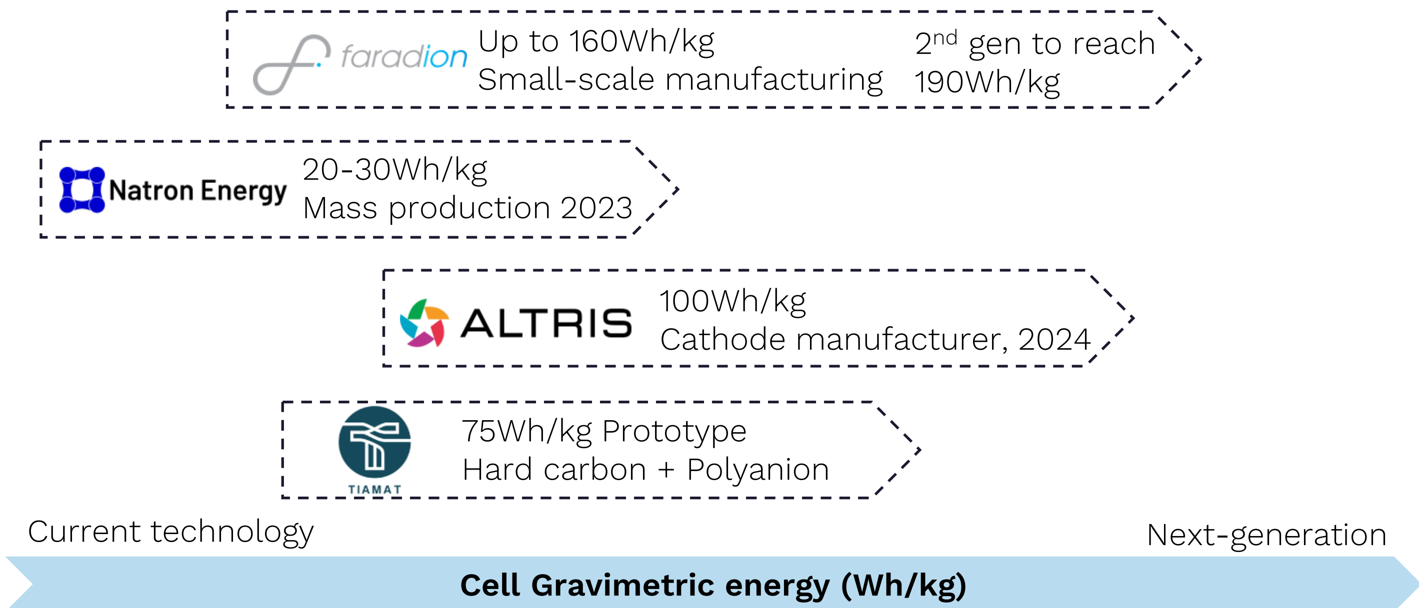
BTR Material confirmed that its anode material for Na-ion battery has been certified by several Chinese clients. The company has received tonnes-level orders. BTR will plan more production capacity according to the market demand.

*Including trial and testing production lines

Looking outside of China

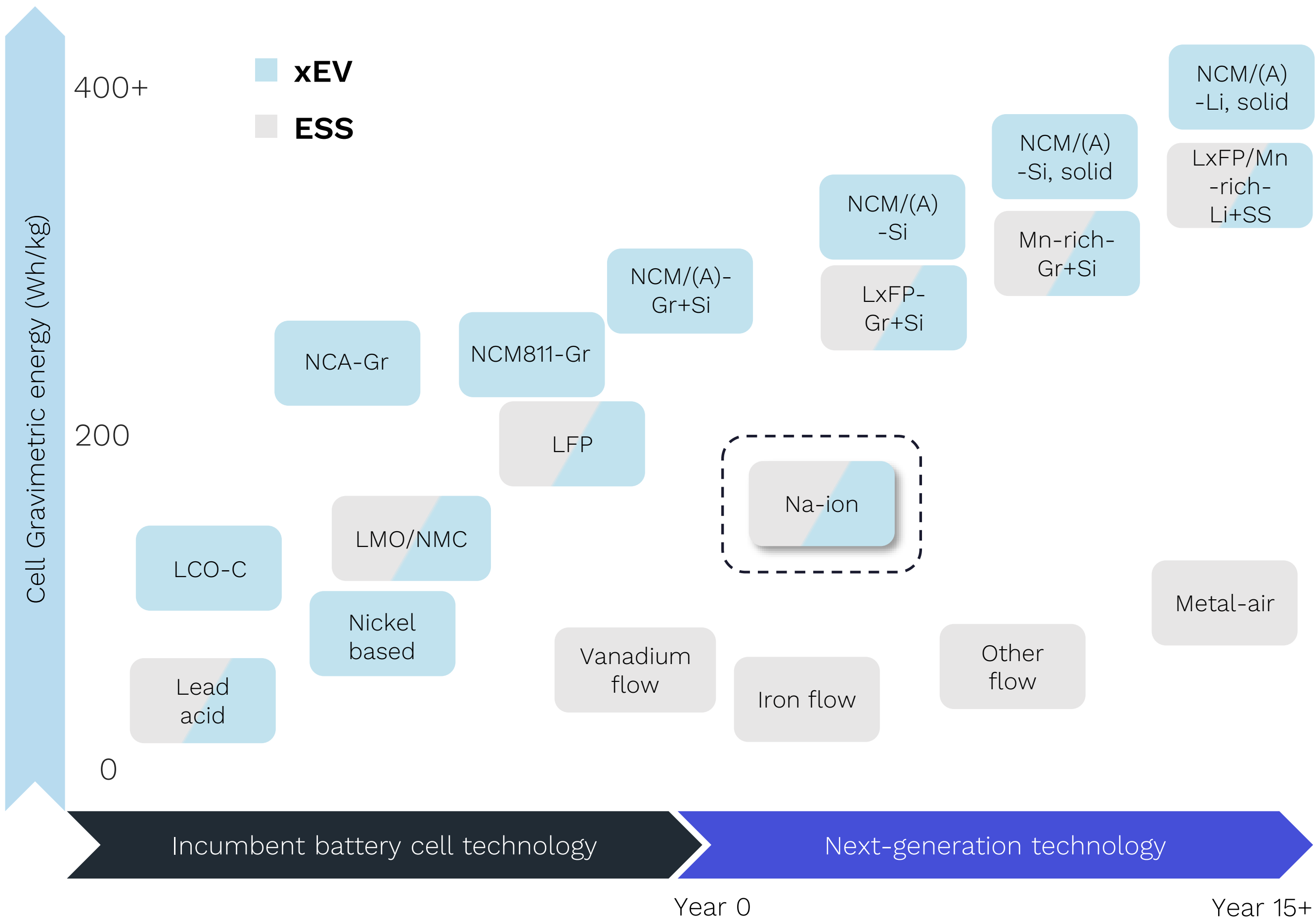
- Only one developer outside of China is slated to begin mass production this year, US-based **Natron Energy**. Natron's cells have energy densities of 20-30Wh/kg, making its use unlikely in higher energy density applications such as EVs, therefore targeting BESS market such as data centres and telecoms. Its cells are of a symmetrical format, using PBA as both the positive and negative electrode.
- Other developers outside of China include UK-based **Faradion**, now owned by an Indian company, Reliance Industries. In 2022, Faradion installed its first BESS unit for BTM applications in Australia. Faradion has openly been working on sodium-ion cells for EV applications since 2016 when it received GBP38.2 million to produce a prototype sodium-ion EV battery with the aims of commercialisation by 2025. Faradion is now capable or producing its Na-ion cells at small scale but with the GBP25 million investment from Reliance comes the intention of accelerating commercial rollout. Reliance plans to produce sodium-ion cells using Faradion's technology at its proposed Gigafactory in western India. Where it believes the demand for cheaper sodium-ion cells will not be hampered by the slight sacrifice in energy density when applied in India's massive 2&3-Wheeler market as well as smaller EVs.
- **Altris**, based in Sweden, are focused in developing its sodium-ion PBA cathode material, Fennac. But are also developing a patented non-flammable electrolyte optimised for its sodium-ion chemistry. Altris are constructing a pilot production facility but delays mean it will likely not come online until next year. Once operational, it will have a 1GWh capacity, capable of producing 10 tonnes of Fennac cathode per day. The company plans to target the European ESS market and create an all-European value chain.

Non Chinese developers



Use Case of Sodium-ion

- The **main use-case for sodium-ion is predicted to be in the ESS and 2&3-Wheeler markets**, due to its lower energy density than lithium-ion alternatives. However, with optimisation of cell and pack level energy densities, as we have seen for that of LFP, there could be a market for sodium in **lower range EVs**.
- Sodium-ion will initially enter the **ESS market** due to the shorter validation timeline and lower barrier to entry in regards to energy density. Sodium-ion is a good fit for ESS applications due to its inherent safety and wider operational temperature (-20 to 60 C).
- The first generation of sodium-ion cells will lean heavily on **existing lithium-ion infrastructure**, where materials are not necessarily optimised for sodium-ion. This will mean that performance will not reach full potential while the main focus is the scale-up of production.
- Sodium-ion does have potential to enter into the EV market, likely not in great volume with the first generation of products but, going forward the cost benefits of scaled production could make it an attractive option. Similarly as we have seen with the development of lithium-ion, energy density of sodium-ion will only improve as the technology matures. **We are already seeing sodium-ion cells being tested in small EVs.**



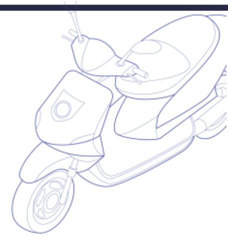
Use Case of Sodium-ion

ESS

Sodium-ion batteries offer a good lower energy, low cost “drop-in” alternative to LFP for stationary applications, where in general energy density is less important.

- In 2022, we saw the first MWh-scale sodium-ion battery ESS stations enter operation. In 2023, a 60MWh/30MW sodium-ion battery (**HiNa**) ESS project is planned to come online in Anhui, China
- **PylonTech**, a leading BTM ESS provider, plans to invest RMB220 million in a 1GWh sodium-ion battery production project. Its sodium-ion battery received TUV certification in March 2023.
- **High Star**, a leading Chinese energy storage solution provider, signed strategic agreement with **HiNa Battery** to develop sodium-ion BESS products.

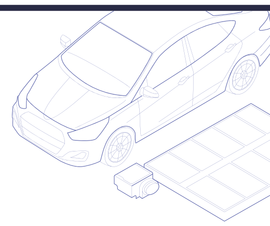
2 & 3-Wheeler



Sodium-ion batteries have been tested in 2&3-wheelers for a number of years now, offering a safe, low cost alternative.

- **NIU** plans to launch its sodium-ion battery 2-wheelers in 2023.
- **Aima** launched its sodium-ion battery 2-wheeler prototype in 2021. However, so far, there is no confirmation on when its first Na-ion 2 wheeler will be available to the market.
- **Xingheng** (a.k.a. **Phylion**) launched Chaona F1, its first sodium-ion battery product. The company expects that Chaona F1 powered 2-wheelers will soon be available to the market. Xingheng supplies Li-ion batteries to leading 2-wheeler producers such as Yadea and Aima.

EV



Sodium-ion batteries currently have potential in low range, low cost small segment EVs, primarily in Chinese market.

- **HiNa Battery** unveiled a test vehicle, the **Sehol E10X from JAC Motors** fitted with a 25kWh (120Wh/kg) Sodium-ion battery pack, giving a range of 252km. The cylindrical cells within the pack have energy densities of 140Wh/kg (12Ah), making it comparable to that of CATL’s Qilin battery packs..
- **Farasis** plans to begin supplying **Jiangling Motors (JMEV)** with sodium-ion battery packs for its EV3 small electric car, which is due to enter mass production by the end of Q2.
- Several rumours are currently circulating around the use of sodium-ion from other OEMs such as **BYD.**

Rho Motion's View

- Sodium-ion presents an interesting opportunity as a complementary chemistry to lithium-ion. In use-cases where the primary driver is cost sodium-ion has the potential to displace some lithium-ion demand, primarily LFP.
- Initially, we will see the greatest progress of commercialisation from large cell manufacturers who already have significant capacity for lithium-ion production where the risk of converting some of this for sodium-ion will be low.
- It is worth considering the LCE price in China has dropped around 50% from its peak in 2022. If the cost of LFP battery continues to decrease, the cost advantage of sodium-ion battery will be weakened. Currently, sodium-ion battery kWh cost is not much cheaper than LFP battery due to the lack of economies of scale. If the supply chain cannot be commercialised soon, sodium-ion batteries entry to market may be delayed.
- There will be a latency in adoption caused by the hesitancy of OEMs to switch from a known chemistry in lithium-ion to a new one still in its infancy. Its adoption may be seen as a gamble by many given that there is still so much optimisation to be done and will likely require collaboration and investment from OEMs with the sodium-ion developers in order to adapt the technology for practical use.