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SODIUM-ION BATTERIES

A TECHNOLOGY BRIEF

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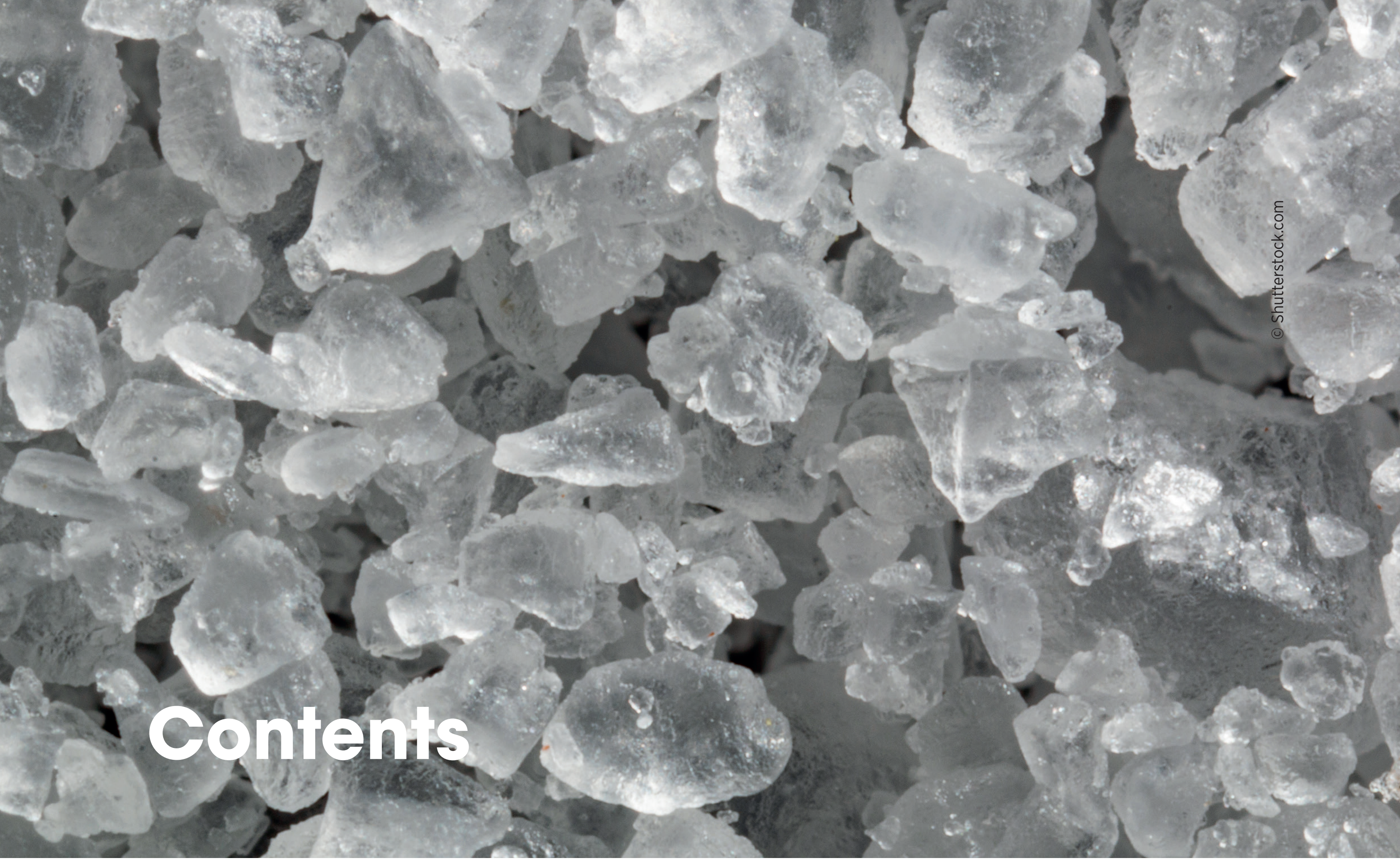

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Abbreviations

Ah	ampere hour
CATL	Contemporary Amperex Technology Co., Limited
CEPRI	China Electric Power Research Institute
C-rate	charge and discharge rate
EV	electric vehicle
Fe-PBA	iron-based Prussian blue analogue
GW	gigawatt
GWh	gigawatt hour
ICE	internal combustion engine
IRENA	International Renewable Energy Agency
km	kilometre
kWh	kilowatt hour
kWh/m	kilowatt hour per cubic metre
LFP	lithium iron phosphate
LIB	lithium-ion battery
mAh/g	milliampere hours per gram
NaS	sodium sulphur
NMC	nickel manganese cobalt oxide
Ni-Cd	nickel-cadmium
NiMH	nickel-metal hydride
Pb-acid	lead-acid
PES	Planned Energy Scenario
SIB	sodium-ion battery
TMO	transition metal oxide
USD	United States Dollar
V	voltage
VRF	vanadium redox flow
W	watt
WETO	World Energy Transitions Outlook
Wh	watt hour
Wh/kg	watt hour per kilogram

1. Executive summary

The energy transition relies not only on the widespread deployment of renewables, but also on the increased capacity for battery storage. Energy storage technologies, including batteries, are crucial for improving the flexibility of power systems while maintaining grid stability. Their importance will continue to grow as the share of renewables in energy mixes increases.

Batteries are also key to transforming the transport sector. Battery-powered electric vehicles (EVs) are expected to dominate road transport by 2050. As the transition accelerates, the need for battery storage in both stationary applications and EVs intensifies concerns about the availability of critical materials for batteries.

Several EV battery types exist, with lithium-ion batteries (LIBs) playing a dominant role due to their long lifespan, high energy density and ability to deliver energy quickly. However, supply chain disruptions in 2021–2022 and recent geopolitical tensions have heightened concerns about the resilience and affordability of LIB supply chains, driving growing interest in alternative chemistries such as sodium-ion batteries (SIBs).

SIB construction is similar to that of LIBs, which allows manufacturers to leverage existing knowledge and experience. Unlike LIBs, SIBs rely on sodium compounds derived from abundant raw materials (*e.g.* soda ash), which are far more plentiful than lithium. This abundance suggests SIBs could help ease supply chain pressures and diversify the battery landscape.

SIBs are an emerging technology with promising cost-reduction potential and performance parameters increasingly comparable to those of LIBs. As a less mature technology, SIBs still have significant room for improvement and greater potential for cost reductions, whereas LIBs are a more mature and optimised technology with potentially limited efficiency gains remaining. The future market penetration of SIBs will depend on their ability to scale efficiently while matching LIBs in cost and energy density. Over the long term, the broader geographical distribution of sodium may also mitigate risks of supply disruption and price volatility.

The SIB market is currently in its nascent stage but may see significant growth in the coming years. Global SIB production capacity could reach up to 70 GWh per year by 2025 and expand to nearly 400 GWh per year by 2030 (BMI, 2025). According to IRENA's 1.5°C Scenario, global EV battery demand would reach about 4 300 GWh per year by 2030 (IRENA, 2024a). In a scenario aligned with the 1.5°C goal, SIBs would account for less than 10% of total EV battery demand by 2030 based on current assumptions.

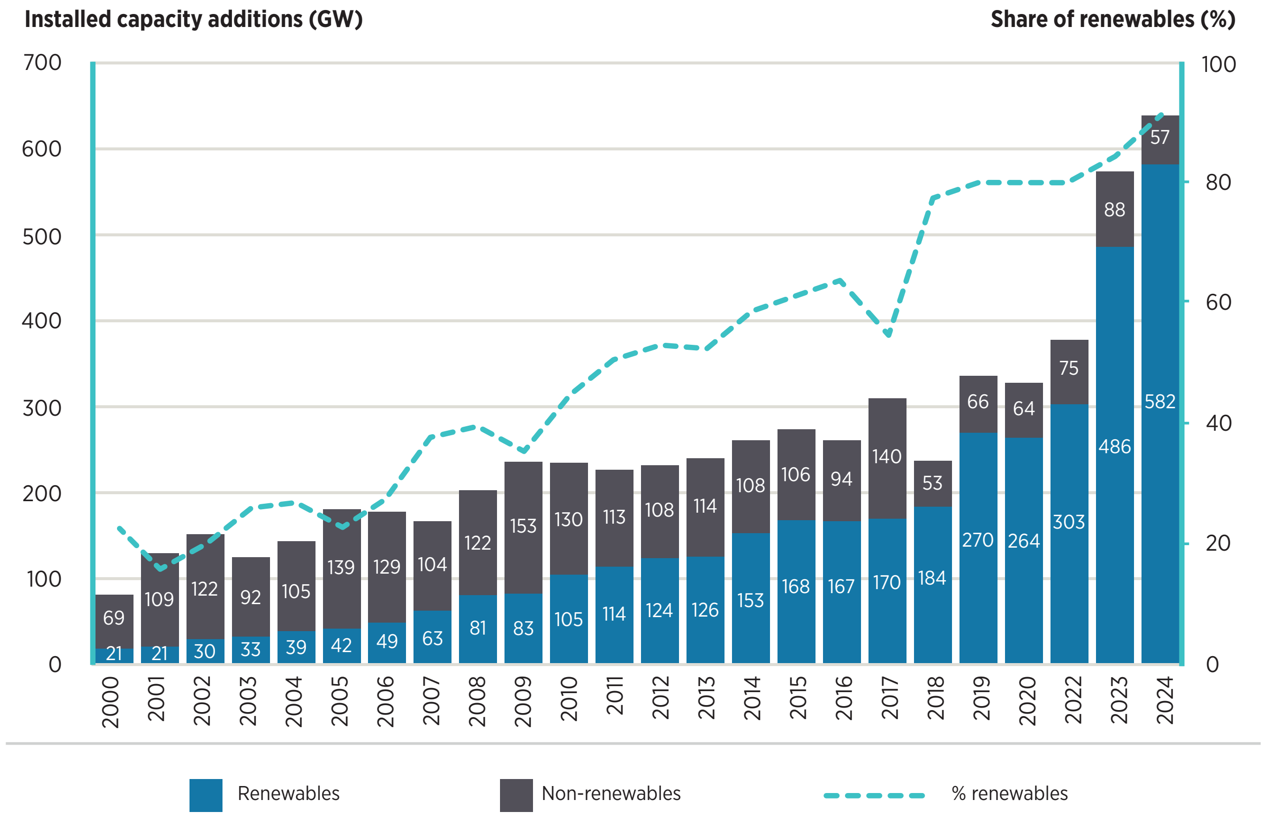
It remains to be seen whether SIBs will play a complementary role to LIBs or emerge as a disruptive alternative. Their biggest advantage is the high natural abundance of sodium. Wide material availability can reduce supply chain risk, support lower costs, and make SIBs a promising alternative to LIBs. To fully harness this potential, it will be crucial to improve key performance indicators - especially energy density - in the coming years. Recent announcements indicate rapid progress: in April 2025, CATL unveiled its production-ready Naxtra range of low- and high-voltage SIBs for EVs with an energy density of 175 Wh/kg and enabling up to 500 km range per charge. If innovation continues to drive the rapid development of this technology, SIBs could play a major role in the decarbonisation of the road transport sector.

2. Overview of battery storage technologies

2.1 IMPORTANCE OF BATTERY STORAGE FOR THE ENERGY TRANSITION

Recent years have seen remarkable progress in renewable power generation technologies, with significant cost reductions opening the door to a more sustainable energy future. The year-on-year growth in renewable capacity additions, as seen in Figure 1, demonstrates their considerable momentum.

Figure 1 Annual power capacity installations, 2002-2022



Note: GW = gigawatt.
Source: (IRENA, 2024b).

The energy transition is changing how we produce and consume energy. Direct and indirect electrification of major demand sectors – buildings, transport and industry – could triple global electricity demand by 2050 according to IRENA's analysis (IRENA, 2023a). To address the resulting infrastructure and system challenges, battery storage technologies will be crucial. Electricity storage will be essential to enhance the flexibility and efficiency of power systems while maintaining grid stability, especially as the share of variable renewable energy sources continues to increase. Among multiple storage technologies, battery storage technologies stand out for their ability to be deployed in a wide variety of locations and climates, to scale in a modular fashion and to rapidly react to changes in energy demand, absorbing, holding and then reinjecting electricity as required by the grid.

IRENA's 1.5°C Scenario requires global battery storage capacity to increase from 17 GW in 2020 to 360 GW in 2030 and 4 100 GW in 2050 to provide the flexibility needed for a power system based on renewable electricity, as shown in Table 1. Beyond the power sector, battery storage will also be essential for decarbonising end-use sectors. In transport, for instance, batteries are the core technology enabling electric vehicles (EVs), which are expected to make up around 90% of road transport by 2050 (IRENA, 2023a).

Table 1 EV deployment and battery storage capacity forecasts, 2020-2050

		Historical	1.5°C Scenario	
		2020	**2030**	**2050**
Electric and plug-in hybrid light passenger vehicle stock (million units)	**Global**	10	359	2 782
	G20	10	328	1 811
Battery storage (GW)	**Global**	17	359	4 098
	G20	16	278	2 925

Source: (IRENA, 2023a).

2.2 BASICS OF BATTERY STORAGE

Batteries are devices that convert chemical energy into electrical energy. They typically consist of an anode (negative electrode), a cathode (positive electrode), an electrolyte and a separator. Charging a battery moves ions from the cathode to the anode through the electrolyte, storing electrical energy. During discharge, the ions flow back to the cathode, converting the stored energy into electricity. Different battery types utilise different materials to tailor the performance of the battery to suit the requirements of the target application.

The performance of batteries can be defined by the following parameters:

- **Capacity** (ampere hour [Ah]" is te amount of current thar a battery can deliver over a specific time period. The total amount of energy a battery can store can be obtained by multiplying the capacity by the nominal voltage (watt hour [Wh] = Ah × voltage [V]).

- **Charge and discharge rate** defines how fast energy can be charged/discharged[1] and is measured using the C-rate. The C-rate is a unitless ratio that relates the charge or discharge current to the battery's nominal capacity, where a higher C-rate means a faster charge or discharge.

- **Cycle life** of a storage system is the number of charge and discharge cycles that a battery can complete before losing performance and reaching a certain state of health; it is generally closely related to the C-rate and working temperature. Higher discharge rates and operating temperatures result in lower cycle life.

- **Efficiency** (or roundtrip efficiency, %) is the ratio of energy output to energy input of a storage system during one cycle, indicating the energy losses that occur during storage and discharge (IRENA, 2017).

- **Gravimetric energy density** (watt hour per kilogram [Wh/kg]) measures the amount of energy stored per unit of mass of the battery, which is important for applications like EVs and portable electronics where weight is an issue.

- **Volumetric energy density** (kilowatt hour per cubic metre [kWh/m^3]) measures the amount of energy stored per unit of volume, which is important for applications where space is at a premium and where there is a volume limitation for the battery, *e.g.* in EVs and mobile phones.

Batteries can be used in a variety of applications and services, including:

- **Transport,** for example powering auxiliary systems of conventional internal combustion engine (ICE) road vehicles or the electric motors in EVs. Additional uses are foreseen in the road freight segment, as well as in some segments of maritime transport and aviation.

1 *For example: A 1C rate indicates a charge or discharge rate equal to the battery's capacity, meaning it would theoretically take one hour to fully charge. A 2C rate indicates a charge or discharge rate that is twice the battery's capacity, meaning it would take 30 minutes to fully charge. A 0.5C rate indicates a charge or discharge rate that is half the battery's capacity, meaning it would take 2 hours to fully charge.*

- **Power systems:**

  › **Peak shaving**, that reduces demand for power generation during periods of peak demand. This is achieved by charging batteries during periods of low demand when there is excess energy produced and discharging them during peak demand periods. This also contributes to increased integration of renewable energy sources.

  › **Grid support**, providing critical ancillary services such as voltage and frequency regulation.

  › **Off-grid/mini-grid systems**, ensuring reliable power supply in remote areas or islands that are not connected to centralised electricity grids.

  › **Optimising the operation of renewable generation**, for example when paired with hydropower plants it can improve their capability to provide primary frequency response while reducing turbine wear and tear (Drommi *et al.*, 2024).

  › **Back-up power**, offering immediate and uninterrupted power supply.

2.3 BATTERY STORAGE TECHNOLOGY LANDSCAPE

Substantial progress has been made in the development of battery technologies in recent decades, with research focused on extending their lifetime and performance metrics while reducing their cost (PNNL, n.d.). This has resulted in the development of multiple battery types, each with different characteristics that make them suitable for different applications; for example, lead-acid (Pb-acid) batteries are commonly used for electrical systems in conventional ICE road vehicles and back-up power systems; nickel-cadmium (NiCd) and nickel-metal hydride (NiMH) batteries are used in consumer electronics; sodium sulphur (NaS) and vanadium redox flow (VRF) batteries are suitable for stationary storage applications; lithium-ion batteries (LIBs) are widely used in EVs, stationary storage and consumer electronics; and sodium-ion batteries (SIBs) with similar applications to LIBs, with a few caveats that will be discussed in the following chapters. Table 2 below shows the performance characteristics of different battery technologies.

Table 2 Present-day performance parameters of different battery technologies

	Pb-acid	NiCd	NiMH	NaS	VRF	Li-ion	SIB
Gravimetric energy density (Wh/kg)	25-50	30-80	40-110	150-240	10-130	150-300*	90-160
Volumetric energy density (kWh/m^3)	70-135	15-150	40-300	150-350	10-33	200-700	250-375
Lifetime (years)	2-15	10-20	2-15	10-15	10-15	5-15	10-15
Cycle life (no. of cycles)	250-2 000	1 000-5 000	300-1 800	2 500-40 000	10 000-16 000	1 000-12 000	500-8 000
Efficiency (%)	63-90	60-90	50-80	75-90	75-85	85-95	≈92
Working temperature (°C)	18-45	-40-50	-30-70	300-350	5-45	-20-60	-40-80

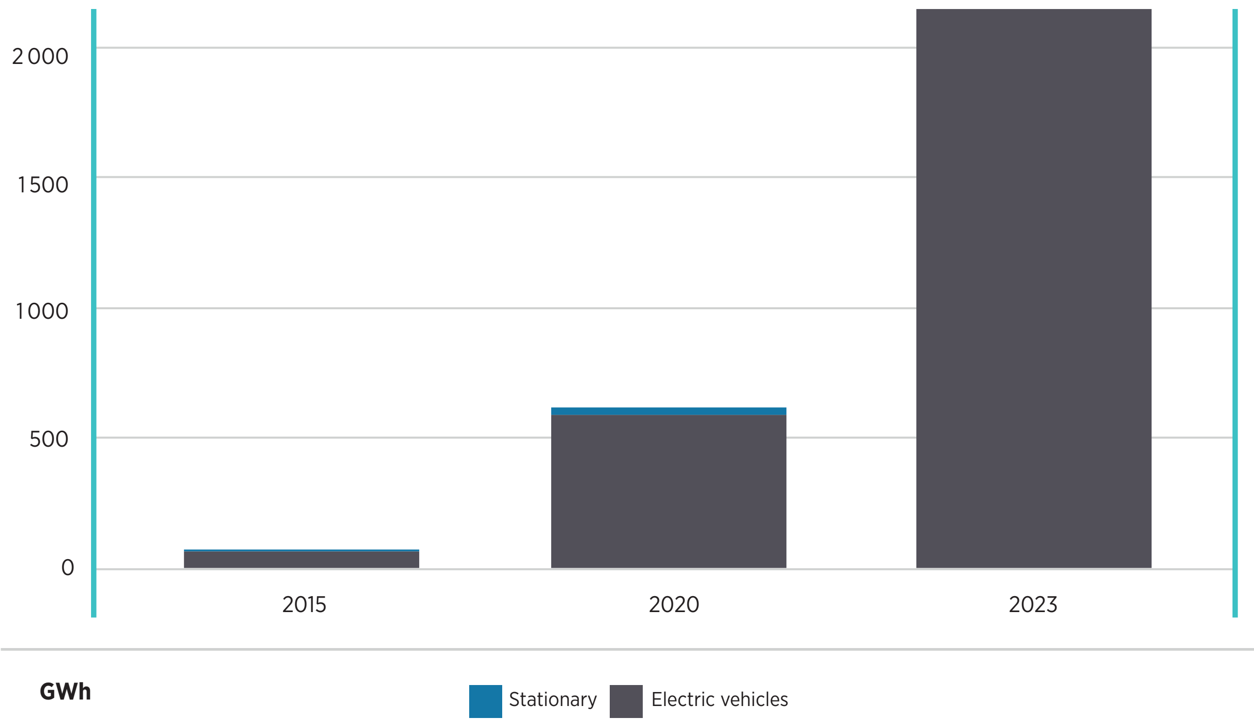
** In April 2023, Chinese battery company CATL announced a condensed battery with an energy density of up to 500 Wh/kg (CATL, 2023a).*

Notes: Pb = lead-acid; NiCd = nickel-cadmium; NiMH = nickel-metal hydride; NaS = sodium-sulphur; VRF = vanadium redox flow, Li-ion = lithium-ion; SIB = sodium-ion. This table includes batteries that are being mass produced as at the time of writing. Latest announcements indicate mass production of SIBs with a higher gravimetric density of 175 Wh/kg by the end of 2025.

Source: (Abraham, 2020; Faradion, n.d.; Hua, 2023; Peters *et al.*, 2021; Šimić *et al.*, 2021; Yang *et al.*, 2022)

The past decade has witnessed unprecedented growth in battery usage in both mobility (i.e. EVs) and stationary storage, as seen in Figure 2 below. Driven mainly by rapid advancements in LIB technology and plummeting costs, LIB deployment has grown by almost 35 times since 2015, reaching over 2 400 GWh (IEA, 2024).

Figure 2 Li-ion battery volumes in use by application, 2015-2023



Based on: (BNEF, 2023; IEA, 2024).

LIBs have been at the forefront of modern energy storage solutions due to their high energy density and versatility; however the growing demand for these batteries has led to concerns regarding sustainability, resource availability, geopolitical considerations and potential supply chain bottlenecks (Gielen and Lyons, 2021; IRENA, 2023b). While there are sufficient materials to support the energy transition, including lithium, there is concern about the battery supply chain's ability to keep pace with ever-growing EV demand and the volatility of lithium carbonate prices, which skyrocketed in 2022 (IRENA, 2023b; Trading Economics, n.d.a). Such concerns have resulted in the markets exploring alternative technologies, such as SIBs.

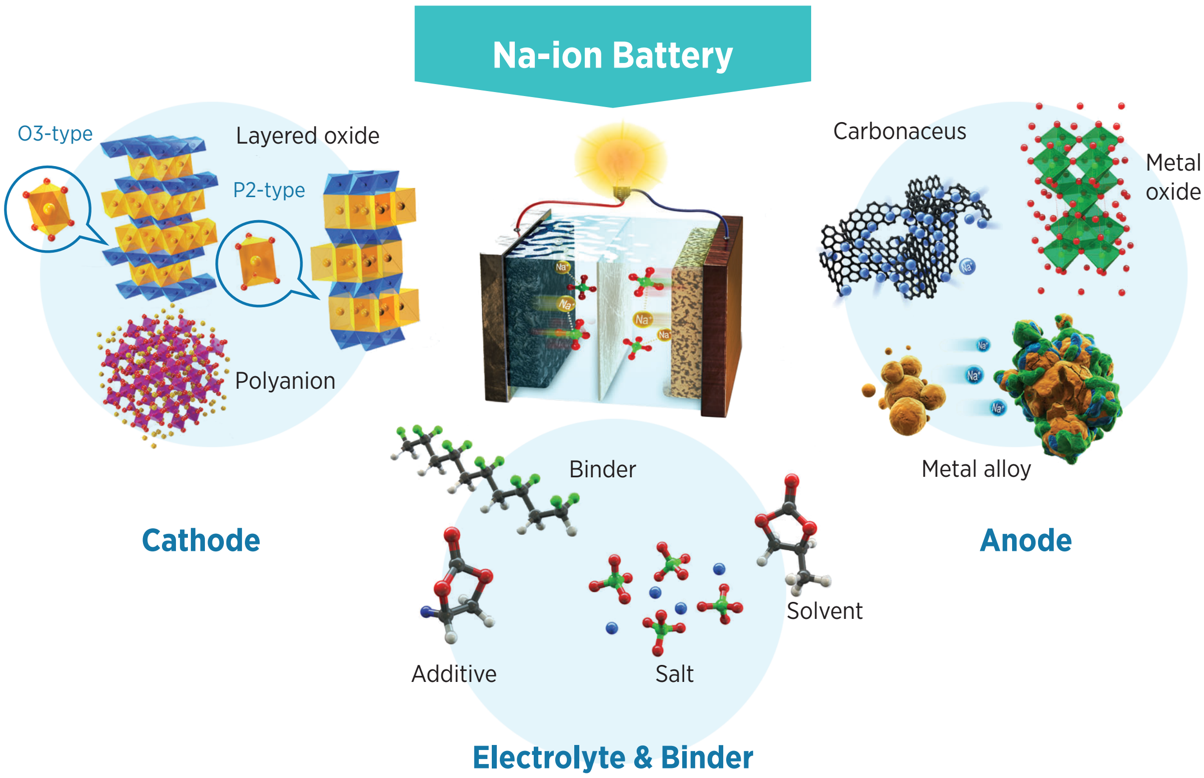
3. Sodium-ion batteries

Although initially explored alongside LIBs in the 1970s and 1980s, SIBs were largely sidelined due to the rapid advancement and commercial success of LIBs, their poorer performance relative to LIBs and the technological limitations of the time (Hwang *et al.*, 2017). However, the discovery in the 2000s that, unlike graphite anodes, hard carbon anodes offer excellent reversible sodium storage capacity, reignited scientific interest in SIBs. Growing concerns regarding lithium availability further accelerated the development of SIB technology, positioning it as a potential alternative to LIBs (Wahid *et al.*, 2018).

3.1 CONSTRUCTION AND MATERIALS

The construction of SIBs is similar to that of LIBs (see Figure 3). However, they rely on sodium compounds for the electrolyte rather than lithium. Cathode materials for SIB technologies are usually categorised into layered oxides, polyanions and framework materials. Anode materials are usually categorised into carbonaceous materials, transition metal oxides, and intermetallic and organic compounds. For the current collector, SIBs can use aluminium for both the anode and the cathode, whereas copper is required for the anode current collector of LIBs since lithium alloys with aluminium at low voltage (Hwang *et al.*, 2017).

Figure 3 Schematic of a sodium-ion battery



Source: (Hwang *et al.*, 2017).

Cathode

Several cathode compositions are being explored for use in SIBs. The three main families of cathode materials used in SIBs today are layered oxides, polyanionic compounds and framework materials such as Prussian blue analogues. Table 3 shows some of their basic characteristics.

Table 3 Cathode and anode materials for SIBs

Material	Family	Specific capacity (mAh/g)	Avg. voltage (V vs Na^+/Na)	Voltage window (V vs Na^+/Na)
Cathode				
$Na_{2/3}Mn_{0.67}Ni_{0.22}Co_{0.07}O_2$	Layered oxide	105	3.3 V	2.0-4.2 V
$Na_{0.67}Ni_{0.2}Co_{0.2}Mn_{0.6}O_2$	Layered oxide	132.2	3.4 V	1.5-4.2 V
$Na_{2-x}Fe_3(PO_4)_3$	Polyanionic	130	3.4 V	2.0-4.2 V
$Na_3MnPO_4CO_3$	Polyanionic	125	3.5 V	2.5-4.5 V
$Na_{1.89}Mn[Fe(CN)_6]_{0.97}$	Prussian blue	150	3.5 V	2.0-4.0 V
Anode				
Hard carbon	-	300	0.3	0.01-2.0

Notes: mAh/g = milliampere hours per gram; V = voltage. Specific capacity indicates the amount of charge a material can store per unit of mass. Average voltage represents the average voltage at which the material operates during charge and discharge cycles. Voltage window represents the range of voltages in which the material can operate safely.

Sources: (Chen et al., 2013; Essehli *et al.*, 2020; Fan *et al.*, 2024; Fu and Fu, 2020; Müller *et al.*, 2023; Ren *et al.*, 2017; Song *et al.*, 2015; Wang *et al.*, 2022).

Layered transition metal oxides (TMOs) have the general formula Na_xMO_2, where M represents one or more (transition) metals, typically iron (Fe), manganese (Mn), nickel (Ni), zinc (Zn) or copper (Cu). TMOs have a relatively high energy density and are considered to be a promising cathode material for SIBs (Wei *et al.*, 2024).

Polyanionic compounds combine a transition metal, usually vanadium (V), with polyanions (*e.g.* phosphate [PO_4^{3-}], pyrophosphate [$P_2O_7^{4-}$], sulphate [SO_4^{2-}], silicate [SiO_4^{4-}] and fluoride [F^-]) to obtain an average voltage during cycling. Polyanionic compounds have a high sodium diffusion coefficient and small volume change during sodium insertion/removal, which makes them a promising high-speed charging cathode (Salehi *et al.*, 2021).

Iron-based Prussian blue analogues (Fe-PBAs) are a family of framework materials with a similar structure to Prussian blue. They are constructed from metal ions linked together by cyanide (CN^-) groups. Fe-PBAs have the advantages of large power capability and low cost (Li *et al.*, 2019; Reid, 2023).

Anode

Carbonaceous materials are the preferred anode materials for SIBs because of their excellent conductivity, diverse preparation processes, low cost and the availability of renewable precursors. Among the various carbonaceous materials, hard carbon and soft carbon materials are considered to show the most potential for SIBs (Hou *et al.*, 2017). Hard carbon is the most common anode material in commercial SIBs. They are produced via solid-phase pyrolysis of biomass or phenolic resins, which are abundant and typically low cost, and can also be produced from other fossil-based petrochemical sources, although the inefficient carbonisation and intricate post-processing can increase their cost (BMI, 2024a).

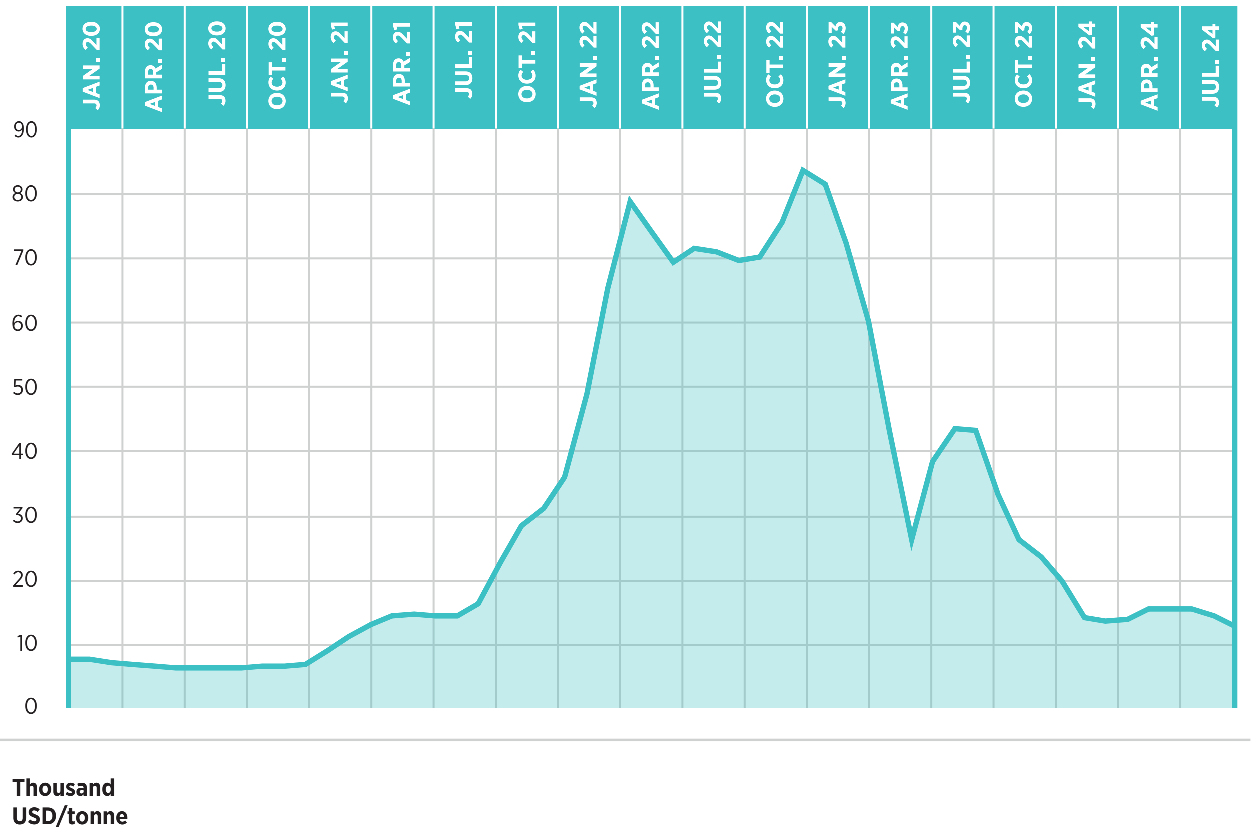
Electrolyte

SIBs rely on sodium compounds for the electrolyte, similarly to how LIBs rely on lithium. The electrolyte needs to be electrochemically and thermally stable, ionically conductive and electronically insulating, as well as have low toxicity. The most common electrolytes for SIBs are sodium hexafluorophosphate ($NaPF_6$) and sodium perchlorate ($NaClO_4$) salts in carbonate ester solvents, particularly propylene carbonate (PC) (Hwang *et al.*, 2017).

3.2 SUPPLY CHAIN

LIBs lead today's battery markets because of their high energy density and broad applicability. Yet, rising demand has intensified concerns over sustainability, critical material supply, and geopolitical and supply chain risks (Gielen *et al.*, 2021). Although the availability of critical materials such as lithium may not be the primary constraint, battery supply chains may face challenges in keeping pace with the rapidly growing demand for EVs (Gielen, 2021). A further risk lies in the volatility of lithium prices, which skyrocketed in 2022 and 2023, as illustrated by the lithium carbonate prices shown in Figure 4 (Trading Economics, n.d.a). These concerns highlight the need to develop alternative technologies and ensure sustainably optimised storage solutions.

Figure 4 Lithium carbonate prices, 2020-2024



Source: (Trading Economics, n.d.a).

SIBs could ease supply constraints and price volatility linked to lithium-based batteries by expanding the range of viable chemistries and reducing dependence on lithium mining and processing. Sodium is far more abundant than lithium – around 1 000 times more abundant in the Earth's crust and roughly 60 000 times more abundant in the oceans (NCBI, n.d.a, n.d.b).

SIB manufacturing primarily relies on soda ash (sodium carbonate) as the main sodium precursor. Soda ash is widely used across several industries, and is far more abundant than lithium, making it less susceptible to resource availability concerns and price volatility. Natural soda ash resources globally are estimated at 47 billion tonnes, while reserves are estimated at 25 billion tonnes (USGS, 2023).[2] Soda ash can also be, and already is, produced synthetically from salt and limestone, both virtually unlimited resources. This opens the possibility for its production around the globe, although at a higher economic and environmental cost than natural soda ash, whereas the more accessible lithium sources are more geographically concentrated. Despite the global potential for SIB technology, as of today, over 95% of the announced SIB production capacity is in China (McNulty and Williams, 2023).

2 *A mineral resource is a mineral deposit that has been identified and measured. A mineral reserve is a subset of a resource that is economically and legally extractable.*

3.3 PROS AND CONS

SIBs are emerging as a promising alternative to established battery technologies. Their technical attributes, safety profile, sustainability and cost considerations hold potentially significant implications for the energy landscape.

Performance and safety

As shown in Table 2, despite being an emerging battery technology, SIBs have performance parameters that are comparable or even exceed those of other battery technologies. SIBs have excellent capacity retention, even in freezing temperatures, fast charging times (80% charge in 15 minutes) and competitive cycle lives (80% capacity retention after 4 000-5 000 cycles) (CATL, 2023a; Faradion, n.d.).

While the energy density of SIBs is currently lower than some high-end LIBs, with today's commercial cells reaching energy densities as high as 175 Wh/kg (see Table 1), it is important to note that this is comparable to some lower-end LIBs and already significantly surpasses other technologies like lead-acid and nickel-based batteries. Moreover, the development trajectory of SIBs is promising, with manufacturers expecting the next generation of SIB cells to exceed 190-200 Wh/kg (CATL, 2023; Faradion, n.d.). In its latest announcement, CATL has announced an energy density of 175 Wh/kg for the Naxtra passenger EV battery that is planned to go into mass production in 2025. These advancements, if achieved, could make SIBs a viable alternative in various applications, particularly where cost, safety and sustainability are paramount considerations.

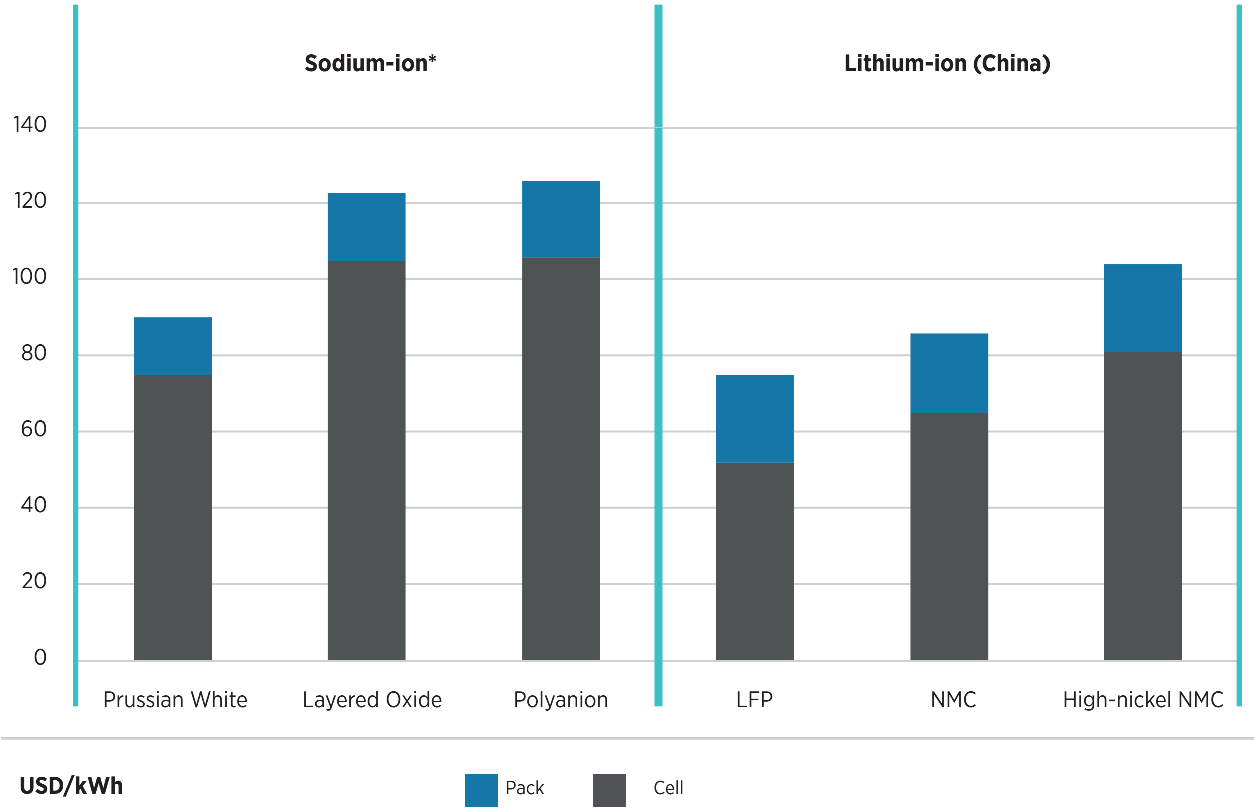
SIBs have also shown promising results in terms of safety, having wider operating temperature ranges and a more stable anode-electrolyte mixture than LIBs, which helps with thermal stability, better abuse tolerance and the possibility of being safely transported fully discharged (Chayambuka *et al.*, 2020; Desai *et al.*, 2022; Zhao *et al.*, 2013). This is especially the case for SIBs using polyanionic compounds and Prussian blue analogues in their cathodes.

Costs

The case for SIBs gained prominence in 2021, when lithium carbonate prices began skyrocketing, SIBs started to be considered a potentially cheaper alternative to LIBs and a number of battery manufacturers announced their plan to commercialise this technology. As seen in Figure 4, lithium carbonate prices have come down since then (Trading Economics, n.d.a), so whether SIBs are a cheaper alternative to LIBs, in particular lithium iron phosphate (LFP) batteries, in the longer term is yet to be seen. Some sources set the price threshold for battery-grade lithium carbonate at USD 20 000/tonne in order for SIBs to keep their competitive advantage in terms of cost (BMI, 2024b).

The average cost of SIB cells in 2022 was in the range of USD 80-105/kWh, depending on their chemistry, with these costs going up to USD 90-125/kWh for battery packs (Reid, 2023). In comparison, the average cost of LIB cells in April 2024 was in the range of USD 52-81/kWh and battery packs were USD 75-104/kWh depending on the battery chemistry (BNEF, 2024). Although the cost advantage of SIBs over LIBs seen in 2021 has disappeared due to the rapidly falling cost of LIB raw materials, some manufacturers expect the cost of SIB cells to drop to as little as USD 40/kWh once production scales up (Degen *et al.*, 2023).

Figure 5 Comparison of average battery pack costs



Notes: LFP = lithium iron phosphate; NMC = lithium nickel manganese cobalt oxide. Sodium-ion battery costs are from 2022, so current costs could be lower than depicted.

Based on: (BNEF, 2024; Reid, 2023).

Cost could still be one of the competitive advantages of SIBs over LIBs due to a number of factors. The first of these is the abundance and accessibility of sodium, a material that is considerably cheaper than lithium. The price of sodium carbonate between 2020 and 2024 ranged between USD 100/tonne and USD 500/tonne while the price of lithium carbonate over the same period of time ranged between USD 6 000/tonne and USD 83 000/tonne (Trading Economics, n.d.a, n.d.b). Beyond this, the global distribution of sodium reduces the risk of supply chain disruptions and price volatility. Another important factor is that SIBs utilise more affordable materials in their construction, for example generally cheaper cathode materials such as manganese and iron, and the use of aluminium collectors instead of copper ones (Abraham, 2020; Casey, 2024). Finally, SIBs have a higher cost reduction potential than LIBs due to the technology being in its early stages.

Sustainability

SIBs also offer advantages in terms of sustainability, utilising more abundant and cheaper materials than LIBs, such as sodium instead of lithium, or aluminium instead of copper. Beyond that, some SIB cathode chemistries, for example Prussian white and polyanion, do not contain minerals such as nickel or cobalt (Reid, 2023). All of these could contribute to reducing the need for critical materials for batteries.

Overall, the lifecycle environmental impact of SIBs per kWh could be comparable to that of the best performing LIBs and generally better than most lithium nickel manganese cobalt oxide (NMC) technologies, despite SIBs' lower gravimetric density (needing more materials than LIBs to reach the same storage capacity) and commercial maturity (Peters *et al.*, 2016). Beyond that, the sustainability of SIBs could be further improved, for example if the industry moved away from layered oxide cathodes, which contain nickel, if the hard carbon used in the anodes were produced from organic waste (Peters *et al.*, 2016).

3.4 APPLICATIONS

SIBs are emerging as a viable alternative to traditional battery technologies, and their unique properties position them well for a variety of applications. Their cost-effectiveness, safety and sustainability make them particularly attractive for large-scale energy storage, EVs and various industrial uses. As research and development continue to push the boundaries of SIB technology, we can expect their range of potential adoption to expand, contributing to a more sustainable and diversified energy future.

Stationary storage

One of the most promising applications for SIBs is stationary storage. The increasing need to integrate variable renewable electricity sources like solar and wind power necessitates efficient and cost-effective energy storage solutions. This can already be seen today, as evidenced by astounding growth in the use of stationary battery storage, both utility scale and behind the meter, which has grown by a factor of more than 60 since 2015 (see Figure 2) (BNEF, 2023; IEA, 2024).

SIBs could be well-suited to this purpose, as they offer promising safety features, good performance across a range of temperatures and seemingly competitive lifespans. Moreover, since size and weight are not critical constraints in stationary applications, the lower energy density of SIBs compared with LIBs is less of a concern. Furthermore, SIBs could also play a crucial role in low-temperature and high-temperature environments due to safety, where they can outperform LIBs. This combination of factors positions SIBs as a strong competitor to LIBs in the rapidly growing stationary storage market.

If the announced specifications from manufacturers are accurate, SIBs could serve as the solution of choice in countries and regions that require wider operating temperature ranges. However, SIBs can also be integrated with LIBs to adapt to location-specific requirements and offer the best of both worlds. According to (CATL, 2021), these two battery technologies can be combined and arranged in various configurations, achieving more than 80% system integration efficiency (weight or volume of cells versus weight or volume of battery pack).

Electric vehicles

Due to their fast-charging capabilities, safety profile and wide operating temperature ranges, another potential application for SIBs is in EVs. This is especially the case for short-range models, given SIB's current gravimetric energy density of up to 160 Wh/kg. In fact, several Chinese battery and car manufacturers have already announced plans to launch compact EVs powered by SIBs,[3] and the first models already on the road. Beyond that, SIBs have a huge potential to rapidly penetrate the electric two- and three-wheeler market (BNEF, 2024).

3 *Including from: CATL (CATL, 2021), Chery (CATL, 2023b), BYD (Jiang, 2023), JAC/HiNa (JAC Motors, 2023), Faradion (Gupta, 2020), Natron (Businesswire, 2022) and PNNL (Hede, 2022), among others.*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SIB-powered EVs have ranges around 250 km (Rho Motion, 2024), which is suitable for urban settings. For reference, the average distance covered by a person in urban settings in select European countries, ranged between 5-19 km per day (Eurostat, 2021), which means a SIB powered EV could last several weeks in a single charge.

Two- and three-wheelers are another promising market segment suitable for SIBs. They play a particularly important role in developing and emerging markets, especially across Asia. In 2024 China, India and Southeast Asia together accounted for around 80% of global two- and three-wheeler sales and recent industry announcements highlight the growing interest in SIB adoption for these vehicles. The Chinese manufacturer Yadea has already introduced SIB-powered electric scooters. In India, companies such as Jitendra EV plan to commercialise two-wheelers with SIB packs by 2026 (Energetica India, 2024; IEA, 2025; Yadea, 2025).

Similar to stationary applications, hybrid batteries could also play a role in electrifying mobility, by integrating lithium and sodium batteries and compensating for the lower gravimetric and volumetric energy density of SIBs relative to LIBs, while leveraging their high power capabilities and low-temperature performance (CATL, 2021). In 2025, CATL announced the Freevoy Dual-Power Battery system, which includes a sodium-LFP dual-power option. While still at the announcement stage, this concept demonstrates how sodium-ion technology could be integrated with lithium-based chemistries to combine the advantages of each system (CATL, 2025).

Others

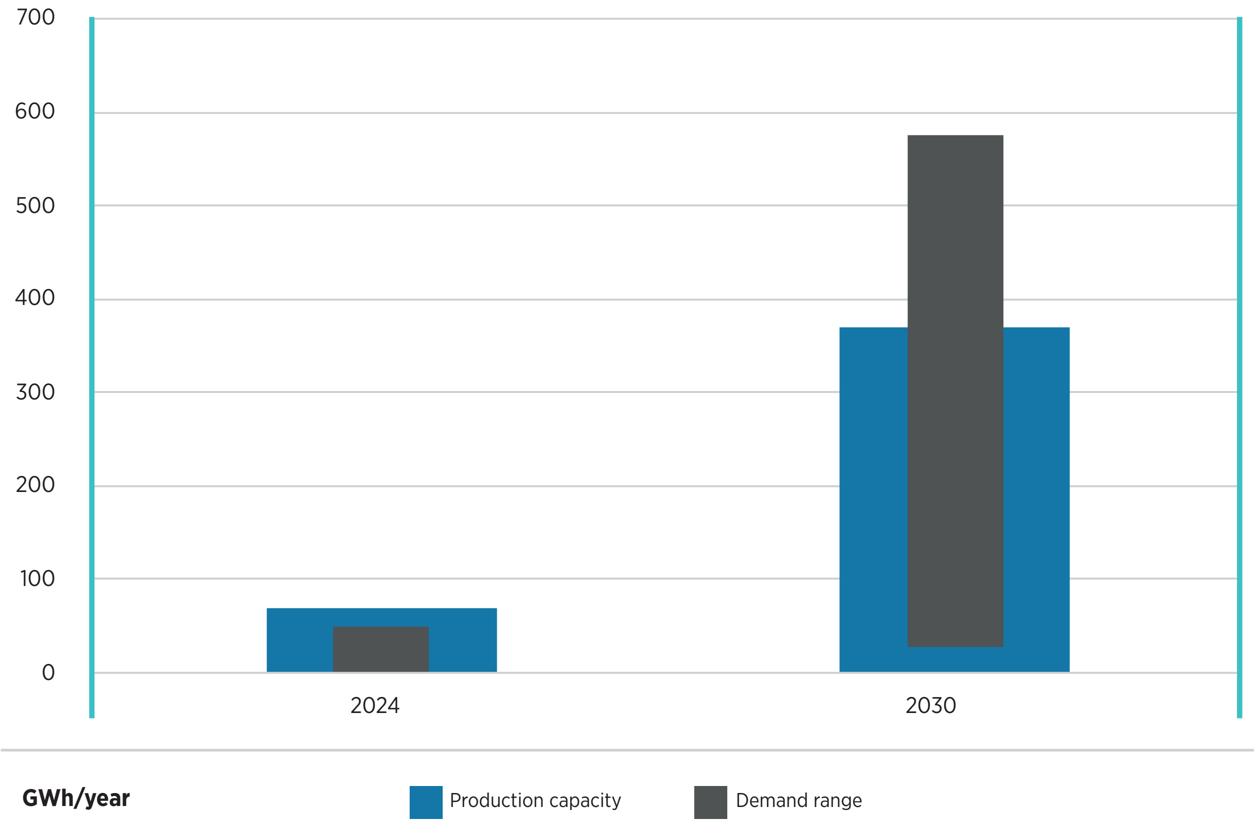
Beyond powering EVs, SIBs could play a role in retrofitting, by replacing lead-acid batteries in conventional road vehicles, or in electric two- and three-wheelers for example, tripling battery energy density, and outperforming them in terms of cycle life, low-temperature performance, safety, sustainability and fast charging capabilities (see Table 2).

SIBs are also finding use in various other applications, including high-power cells for small devices and power tools. Additionally, their safety and stability make them a potentially suitable option for electrifying ground-based industrial applications, such as powering industrial trucks and airport ground equipment (Degen *et al.*, 2023).

4. Status and outlook

The SIB market is currently in its nascent stage but may see significant growth in the coming years. By the end of 2025, the global production capacity for SIBs is expected to reach 70 GWh per year, predominantly concentrated in China and dominated by layered metal oxide cathode chemistries (BMI, 2023a). While the market share of SIBs remains relatively small compared with LIBs, production capacity forecasts suggest an optimistic outlook for producers, with estimates of production capacity exceeding 400 GWh per year by 2030 (BMI, 2025). At the same there appears to be uncertainty about the future market penetration of SIBs, with demand forecasts from different sources ranging widely across 50-600 GWh per year by 2030 (Degen *et al.*, 2023), as seen in Figure 6. As a point of comparison, the entire market for lead-acid batteries is around 400-450 GWh (Degen *et al.*, 2023).

Figure 6 Demand and production capacity forecasts for sodium-ion batteries



Source: (BMI, 2024c; Degen *et al.*, 2023).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The future capacity deployment of SIBs is as yet unclear. There are still challenges to overcome. For example, in relation to ensuring sufficient demand and a robust supply chain. announcements of new hard carbon production capacity are not keeping up with those of SIBs. If this continues to be the case, it could be a limiting factor for the growth of SIBs (BMI, 2023b).

While the potential for SIBs is substantial, as evidenced by the production capacity and demand forecasts, they should not be seen as a full substitute for LIBs, but rather as a complementary technology that can help ease some of the sustainability and availability concerns surrounding the battery supply chain. The long-term success of SIBs is likely to depend on a number of factors, including cost and material availability. Bottlenecks in the lithium supply chain, lithium shortages or higher lithium costs would all be likely to result in higher penetration rates for SIBs, while further cost reductions in LIBs would be likely to have a negative effect on SIB demand.

The future success of SIBs is also tied to ongoing research and development efforts to improve their performance and address their limitations. Innovations are expected to lead to significant improvements in energy density, such as the expected improvements that will take them from 160 Wh/kg to 200 Wh/kg (CATL, 2021). Additionally, hybrid battery configurations (*e.g.* sodium-lithium and sodium-ion-supercapacitor hybrids) are being explored to leverage the strengths of different technologies and further enhance the performance of SIBs (KAIST, 2024).

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