

SODIUM-ION BATTERIES: THE COST-EFFECTIVE ALTERNATIVE TO LITHIUM-ION BATTERIES?

Lithium iron phosphate (LFP) currently serves as the benchmark for cost-effective lithium-ion battery solutions. Sodium-ion batteries (SIBs) are emerging as a potential alternative, aiming to compete with LFP in price-sensitive applications. Their key advantages include the use of abundant sodium instead of lithium, improved safety under deep-discharge conditions, good low-temperature performance, aluminium rather than copper current collectors on the anode side, and partial compatibility with existing lithium-ion battery production infrastructure. These characteristics make SIBs particularly attractive for stationary storage, starter batteries and short-range mobility applications. In order to achieve a price advantage over LFP, value chains and supply chains must be established to enable large-scale production. This analysis examines the state of the art and how SIBs can be strategically positioned alongside LFP.



State of the art and challenges

SIBs operate according to the same basic intercalation principle as LIBs and therefore share a broadly similar cell architecture. The main differences arise from the choice of active materials and current collectors. On the anode side, **hard carbon** has become established as the active material in place of **graphite**, as the larger sodium ions are not compatible with the graphite structure. In return, aluminum can be used on the anode side as a current collector instead of copper, yielding advantages in terms of cost and weight.

On the cathode side, various material compositions are currently being used and tested. A distinction is made between three main types:

1. **Layered oxides:** High energy density, but limited cycle stability and higher costs due to the use of nickel and cobalt.
2. **Prussian blue analogues (PBA):** Inexpensive to manufacture and with high raw material availability, but lower energy density.

3. **Polyanionic compounds:** Excellent cycle stability (over 10,000 charge cycles possible), but lower energy density and limited availability of raw materials such as vanadium.

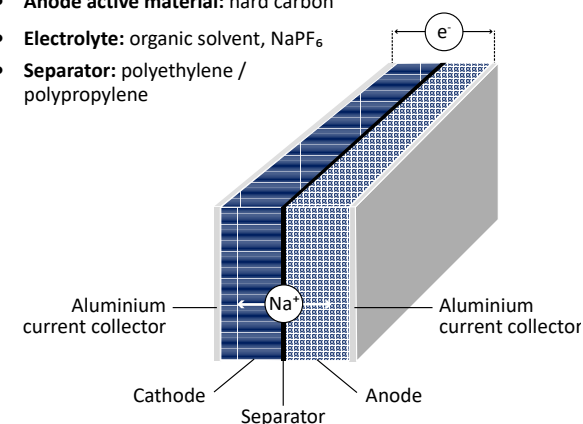
The choice of cathode active material (CAM) has a decisive influence on energy density and specific energy. This is demonstrated by a study in which the energy densities (Wh/L, volumetric) and specific energy (Wh/kg, gravimetric) for commercial CAMs with a hard-carbon anode were modelled. The results are presented in Table 1. Compared with the LFP alternative, which was also modelled, SIBs are inferior, particularly in terms of volumetric energy density.

The lower energy density compared with LFP is one reason why SIBs have not yet been able to fully capitalise on the expected cost advantage. This is demonstrated by a study that examines the cost trend for SIBs over the coming years, taking various factors into account. It forecasts that SIBs could compete with LFP on price from the 2030s onwards, provided that energy density is increased and production costs are reduced through technological advances and economies of scale.

Figure 1: Schematic structure of a sodium-ion battery and selected components used.

Selected components used

- **Cathode active material:** layered oxides, polyanionic materials, Prussian blue analogues
- **Anode active material:** hard carbon
- **Electrolyte:** organic solvent, NaPF₆
- **Separator:** polyethylene / polypropylene



Source: Author's own illustration.

Table 1: Modelled volumetric energy density and specific energy of sodium-ion cells using different cathode active materials and a hard-carbon anode, compared with an LFP reference cell. Source: [Benchmarking state-of-the-art sodium-ion battery cells – modelling energy density and carbon footprint at the gigafactory scale](#)

	Energy density [Wh/L]	Specific energy [Wh/kg]
Layered oxides	333- 419	147- 206
PBA	260- 302	161- 185
Polyanionic compound	310- 366	158- 192
LFP	507	214

Current research priorities

A key area of research for SIBs is therefore the increase in energy density. Other important objectives include improving cycle stability, calendar life and charging and discharging performance. Work is also underway on the development of more environmentally friendly materials.

The key factors for increasing energy density are the cathode and anode active materials, as they determine the cell voltage and are crucial for the storage capacity of Na⁺ ions. Furthermore, the active materials should be cost-effective, cycle-stable and long-lasting.

Hard carbon represents the state of the art for anodes. Optimizations are aimed at further increasing the achievable cell voltage and the storage capacity of

Na⁺ ions in hard carbon. Research is also being conducted into alternative anode active materials. Tin-based anodes, for example, could accommodate significantly more Na⁺ ions, but suffer from poor cycle stability.

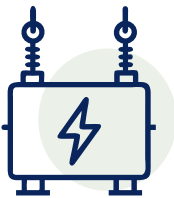
The three main cathode material classes — layered oxides, Prussian blue analogues and polyanionic compounds — offer complementary performance profiles in terms of energy density, cost, cycle stability and raw-material availability:

Layered oxides can achieve the highest energy densities, as they can accommodate a comparatively high amount of Na⁺ ions per unit mass and volume. However, the cost of layered oxides is high when raw materials such as nickel or cobalt are used. Furthermore, cycle stability remains a key limitation, as the repeated insertion and extraction of sodium ions causes mechanical stresses and instabilities. Research is therefore focused in particular on replacing nickel or cobalt with more cost-effective metals such as iron or manganese, and on developing more stable structures to improve cycle stability.

Polyanionic materials are characterized by superior cycle stability, which can exceed 10,000 charge cycles. They lag behind layered oxides in terms of achievable energy density. Vanadium-based polyanionic materials can offer comparatively high cell voltages, but their scalability is constrained by cost and raw-material availability. Therefore, Fe- and Mn-based alternatives are a key research focus. Polyanions exhibit weaknesses in

electronic conductivity, which must be compensated for by conductive coatings (e.g. carbon).

PBAs are attractive due to their low manufacturing costs and the use of inexpensive raw materials. Na⁺ ions can be readily incorporated into their open lattice structure. However, the achievable energy density is lower than that of layered oxides. In terms of cycle stability, PBAs lie between layered oxides and polyanionic materials. Research is focused on increasing the volumetric energy density and improving long-term stability at low temperatures.



Another area of research is the development of [sodium solid-state batteries](#) (Na-SSB). A solid electrolyte is used instead of a liquid electrolyte. This is intended to enable the use of metallic sodium on the anode side and to increase energy density. Research is focused on improving ionic conductivity and reducing interfacial resistance.

Sodium-ion battery research in Germany

The German Federal Government’s [funding catalogue](#) provides an overview of ongoing projects funded by the federal government in the field of sodium-ion batteries. A total of 25 ongoing projects on the topic of sodium-ion batteries were identified using the funding catalogue¹. Among the largest overall projects are ENTISE, with 12 sub-projects, and SIB:DE, with 16 sub-projects.

1 To analyse the German research landscape, the German Federal Government’s funding catalogue was systematically evaluated. A search was conducted for ongoing research projects on the topic of ‘sodium’ (as at June 2026). Projects that could not be categorised under the topics of SIB or sodium solid-state batteries were filtered out. In addition to federal project funding, there are other opportunities to secure funding for projects.

The [ENTISE](#) project (Development of Sodium-Ion Technology for Industrially Scalable Energy Storage) aims to optimize the cathode, anode, electrolyte and processes. The objective is to manufacture the materials on a pre-industrial scale and thereby produce cylindrical cells in small pilot batches.

The [SIB:DE](#) project (Sodium-Ion Battery: Research in Germany) is assessing the suitability of SIBs as a sustainable alternative to lithium-ion technology and preparing for industrial implementation. In addition to developing suitable active materials, the project is investigating the extent to which the existing LIB manufacturing infrastructure can be utilized.

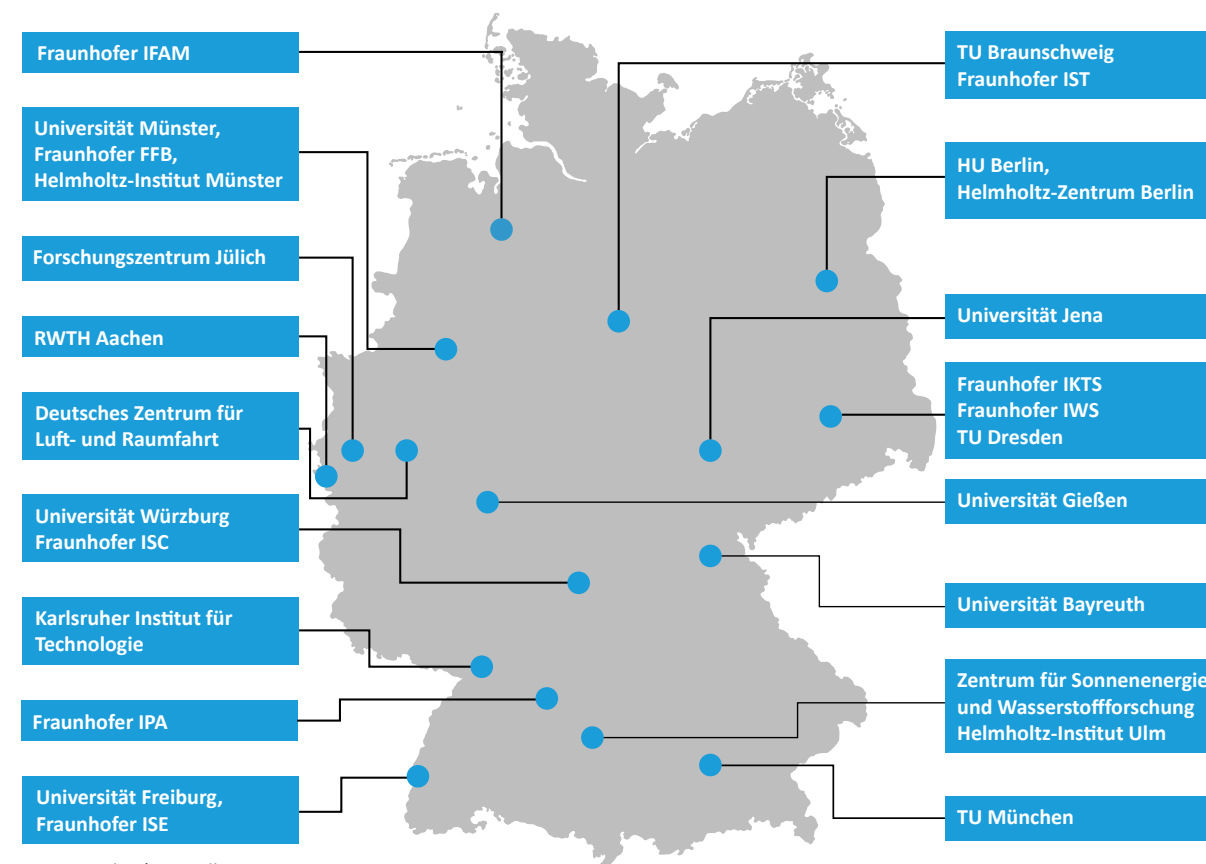
Figures 2 and 3 show the research institutions and companies involved in the projects. The companies cover various stages of the value chain, from component manufacturing to recycling.

Commercialization & Production Capacities

According to the [International Energy Agency \(IEA\)](#), global production capacity for SIBs stood at around 90 GWh/a in 2025 and could be expanded to around 590 GWh/a by 2030. In 2025, the entire SIB production capacity was located in China. According to the IEA, this will change only marginally by 2030: just 17 of the approximately 590 GWh/a of production capacity are planned outside China.

China is thus the clear frontrunner in the commercialization of SIBs. [HiNa Battery](#) began ramping up SIB production on a GWh scale as early as the end of 2022 and has been equipped electric vehicles with since early 2024. [CATL](#) is launching a second-generation SIB under the

Figure 2: Research institutions involved in ongoing projects funded by the federal government on sodium-ion batteries.

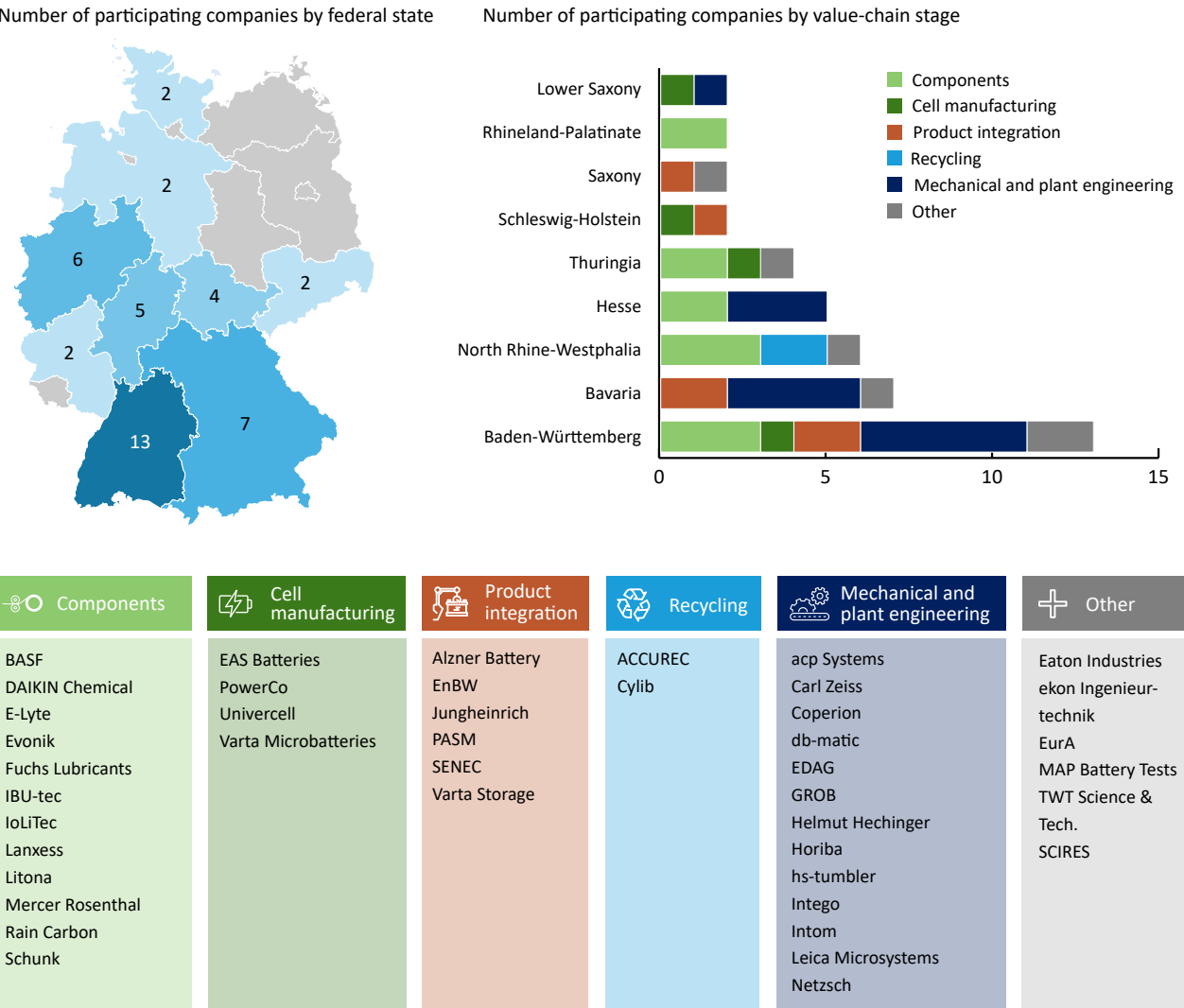


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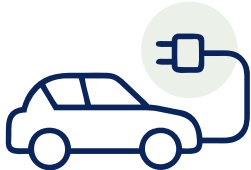
[Naxtra](#) brand, which is due to enter mass production from the end of 2026. This is expected to have a specific energy of 175 Wh/kg.

In Europe, commercialization is less advanced than in China. The focus remains on research and development, as well as on translating laboratory results into scalable

Figure 3: Companies involved in ongoing projects on sodium-ion batteries funded by the federal government.



mass production via pilot production runs. The companies involved in the research projects cover several areas of the value chain. This provides favorable conditions for translating research findings into industrial practice and establishing a value chain in Europe that is partly self-sufficient.



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