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Post-Lithium Storage—Shaping the Future

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Electrochemical Energy Storage is one of the most active fields of current materials research, driven by an ever-growing demand for cost- and resource-effective batteries. The lithium-ion battery (LIB) was commercialized more than 30 years ago and has since become the basis of a worldwide industry, supplying storage capacities of hundreds of GWh. With an increasing fraction of vehicles being "battery electric", and with a growing demand for buffer storage in local and connected power grids, the demand for battery materials grows very fast, and price fluctuations seriously influence the developing battery market.[1] With estimated annual production capacities of 3 TWh by 2030[2,3] supply chains become increasingly critical, and new economic dependencies show up.

1. The Future of Electrochemical Energy Storage

Certainly, it is still a major role of electrochemical materials research to further improve the function of LIBs. However, research focusing on alternative battery chemistries and cell concepts as well as on the necessary materials will offer alternatives to the existing and further advancing technology—promising diversified, more sustainable, high-performance storage technologies based on readily available raw materials and green production processes. Clearly, sodium-ion batteries (SIBs) are now advancing to real-life applications, and their development is fast due to the many lessons learned from the build-up of LIB technology.[4] While the LIB market is further maturing, providing premium-type cells comprising nickel manganese cobalt (NMC) cathodes for high-energy and high-power applications and more budget-type cells based on lithium iron phosphate (LFP) cathodes for low-cost batteries, the SIB is entering into the market from the "low-performance" end, competing primarily with LFP-based LIB. The outcome of this competition has not yet been decided, and materials research for SIB is intensifying.

Along with these developments, the societal need for sustainable batteries in various fields of application is also growing, together with sector-specific demand, for example, for ultra-safe batteries. This stimulates research into other cell concepts with other mobile ions and other cell reactions. Such "post-lithium" (and "post-sodium") research is transforming more into research for complementary ("side-by-side") technologies that expand the range of possible applications of batteries in general.[5]

However, independent from any techno-economic consideration, exploring alternative cell concepts and cell reactions has also a strong and deep-rooted scientific motivation: In chemistry and materials science, understanding chemical trends, deriving overarching theoretical concepts, and gaining deeper knowledge of the role of the different chemical elements in different binding situations has always been at the core of research. In this regard, electrochemical materials research has always been at the forefront in connecting chemical reactivity with the underlying physical world of energetics, that is, thermodynamics, and kinetics. Thermodynamic driving forces can be measured in terms of cell voltages, while reaction rates correspond to electric currents and transferred electric charges. Thus, the framework of electrochemistry provides a uniquely suited field for the study of chemical reactivity and stability in quantitative terms.

From this perspective, the exploration of alternative battery cell concepts, relying on elements other than those used in LIBs, such as monovalent ions like potassium (K), fluorine (F), and chlorine (Cl), or on multivalent ions such as magnesium (Mg), calcium (Ca), or aluminum (Al), may not only pave the way to new applications and may ease techno-economic dependencies—it primarily helps to deepen our understanding of electrochemical concepts and their connection with the materials world. In an increasingly electrified world, electrical energy be gained from renewable or nuclear sources, and with further advancing technologies in any respect, electrochemistry and electrochemical materials research will play a key role in the "energy and materials" nexus.

2. Special Collection on Post-Lithium Concepts and Materials

Against this background, the collection of invited papers in a joint issue of the Wiley–VCH journals Advanced Energy

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Materials, ChemSusChem, and Batteries & Supercaps highlights the status of research into post-lithium cell concepts and materials. More than fifty papers on various subjects have been collected and provide an up-to-date source of information on post-lithium research—many of them from the Cluster of Excellence "POLiS" (Post Lithium Storage), funded by the German Research Foundation—DFG.

The important role of SIBs and their components is highlighted by quite a large number of papers in the current collection. A deeper understanding of the hard carbon anode and its solid-electrolyte interphase (SEI) in SIBs is provided, for example, by Palanisamy et al. in the article batt.202300482, novel cathode coatings for layered active materials are presented by Brugnetti et al. (batt.202300332), while full SIB cells are analyzed in detail by Stüble et al. (batt.202300375). Whether Na metal anodes with fast plating and stripping kinetics (cf. aenm.202302729 and aenm.202302322) can be safely operated in solid-state cells with -type solid electrolytes, is an open question. The fast progress in the development of SIBs and the related issues of potential mass production is discussed by Sada et al. and Klemens et al in the articles aenm.202302321 and batt.202300291. Not surprisingly, potassium-ion batteries (PIBs) show at the horizon, and a number of papers discuss the corresponding materials challenges, e.g., in hard carbons (aenm.202302647) or cathode materials (aenm.202302961). Obviously, cell concepts with multivalent ions still pose serious barriers on the way to competitive cells, yet a number of papers show attractive paths forward, e.g. by utilizing organic or novel inorganic electrode materials in the case of Mg, Ca, and Al (cf. batt.202300285, batt.202300308, cssc.202300932 and cssc.202301224). Particularly, the transport of multivalent ions in the solid state is still a critical issue and is highlighted by Glaser et al. and Jeschull et al. in the articles aenm.202301980 and aenm.202302745 in the case of Mg ion transport. A novel chloride solid electrolyte with high conductivity is presented by Karkera et al. (aenm.202300982), and a novel concept for organic redox-flow batteries with aqueous electrolytes is reported by Kim et al. (aenm.202302128), and all-organic anionic full cells by Bhosale et al. (cssc.202301143). Not least, in-depth studies with less-conventional techniques used in battery research are presented by Karcher et al. (aenm.202302241), demonstrating the use of microcalorimetry and of tip-enhanced Raman spectroscopy by Dinda et al. (aenm.202302176) in the study of SIBs.

This special collection illustrates the scientific progress in multiple aspects, including chloride ion, multivalent, organic, potassium, and sodium batteries, as well as battery production, sustainability, and theoretical studies. These latest ideas and innovations show the way toward a more sustainable energy infrastructure and will trigger the development of new technologies and applications that will power our future.

Conflict of Interest

The authors declare no conflict of interest.

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