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# Sodium-Ion Batteries

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Given the significance of reliable and sustainable energy to the modern world, the development of energy storage solutions is critical. Batteries are an inseparable part of this, and as society continues to grow and evolve, so too must battery technologies. By developing a wide range of systems with various properties it is possible to appropriately tailor the subsequent battery properties for given applications—enabling batteries to fulfil the many roles required of them.

Sodium-ion batteries (SIBs) in particular are proving to be an emergent technology with potentially very attractive properties. Key components are predominantly synthesized from low-cost, abundant materials with secure supply chains, and there is considerable interest in research and development for commercial applications. However, despite the relatively rapid progress made in recent years, there still remain significant challenges to be overcome in academic research and product pilot deployment.

This special issue presents a body of work discussing the main topics in SIB research: i) advances in SIB electrode materials, ii) the development of SIB electrolytes, iii) characterization techniques and modeling, and iv) the scale up and commercialization of SIB systems. This issue begins with an overview of sodium battery research carried out during the last 50 years, and includes 14 reviews and 1 industrial progress report to introduce these topics, discuss them in detail, and summarize recent advances.

The choice of SIB constituent materials has a significant impact on electrochemical performance and, consequently, is an area of considerable interest. The selection of electrochemically active material is one key parameter, and three reviews cover the current leading cathode materials: 3d transition metal

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polyanionic materials (with regard to their high voltage performance), Prussian blue analogs (and the relationship between structure and performance), and sodium layered oxides (investigating design strategies towards realizing practical SIBs). Meanwhile, two reviews examine the advantages and disadvantages of using alloying and conversion materials as anodes. A review of carbon anodes (particularly with respect to electrochemical performance and charge storage mechanisms) provides a roadmap for future research, while the use of graphene-based materials in inorganic and organic electrodes has also been examined with a view to exploit enhanced reaction kinetics with a mitigating volume change.

Electrolytes are also of major interest, due to their considerable potential influence on system properties. One review correlates interphase properties and functionalities with electrochemical performance in order to investigate key parameters. Two reviews overview the use of solid state, ionic plastic, and ionic liquid electrolytes, which may have important advantages over conventional liquid organic electrolytes—particularly with respect to safety. The search for electrolytes with improved properties has also highlighted the potential of aqueous SIBs, and one review discusses the current state of this technology in detail.

In order to develop advanced design strategies suitable for future SIB research, it is important to understand their physical and electrochemical processes. To this end, two reviews update computational studies into the SIB degradation mechanisms, as well as the physical and electrochemical processes of the electrode and electrolyte materials, respectively. Meanwhile, another review provides a comprehensive overview of both ex situ and in situ analytical techniques appropriate for characterizing SIB systems.

Finally, the development of SIBs at the commercial level represents a significant step forward for research in this field, and the progress report discusses the work undertaken by two companies (Faradion and Novasis) toward this. Indeed, this work considers not just electrochemical performance, but also the cost and availability of materials which is vital for ensuring the commercial viability of SIB systems. It should be noted that this progress report cannot cover all of the activities of prototyping and commercializing of all the sodium-ion battery technologies. Indeed, several other companies—including the French-network corresponding to the new Tiamat—have gained considerable attention, and there are new start-ups rising above the horizon as well.

This special issue represents the leading work carried out during advanced SIB development—as can be seen by the advances have been made—which is demonstrated by the combination of advanced electrode and electrolyte development, fundamental studies into their physical and electrochemical properties, and computational modelling in facilitating the development of high-performance and cost-effective SIBs. Furthermore, given that "first generation" SIBs have already been produced commercially, it is certain that the future of SIB research is very promising.

It has been both a pleasure and a privilege to edit this special issue, and we would like to particularly thank Advanced Energy Materials editors, Dr. Jipei Yuan and Dr. Guangchen Xu, for coinitiating the special issue and handling all the papers. We would also like to express our sincere thanks to all the authors for their commitment and great work, and to all the reviewers who have made this a high-quality issue for the community.