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Editorial: Lithium-ion batteries: manufacturing, modelling and advanced experimental techniques

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Editorial on the Research Topic
Lithium-ion batteries: manufacturing, modelling and advanced experimental techniques

Introduction

Lithium-ion batteries (LIBs) are critical to energy storage solutions, especially for electric vehicles and renewable energy systems (Choi and Wang, 2018; Masias et al., 2021). Their high energy density, long life, and efficiency have made them indispensable. However, as demand grows, so does the need for innovations that enhance safety, longevity, and sustainability (Wu et al., 2019; Zh et al., 2023; Patel et al., 2024). This Research Topic presents key advancements across state estimation, health monitoring, predictive modeling, and sustainable manufacturing techniques, offering a comprehensive overview of recent breakthroughs in the field.

One crucial area addressed is the manufacturing of LIBs, which forms the foundation for how batteries are produced (Matthews et al.). Integrating advanced experimental techniques significantly improves our observational capabilities, enabling more precise measurements and better understanding of battery behavior under various conditions. Additionally, modeling serves as the “glue” that connects manufacturing processes and experimental observations. It allows researchers to integrate cross-sectional data to make more informed decisions regarding battery design, production, and management (Matthews et al.; Guo et al.; Qian et al.). The next logical step in this evolution is the creation of a nexus that synthesizes all the information gathered from these three areas—manufacturing, experimentation, and modeling. Such an interconnected network would provide a deeper understanding of battery systems, increasing both the efficiency and wisdom behind decisions on battery use and development.

Several standout contributions in this Research Topic illustrate the progress being made. For example, the use of the Unscented Kalman Filter (UKF) for state-of-charge (SOC) estimation represents a significant leap in battery management systems (BMS) (Guo et al.). SOC estimation is vital for tracking the charge level in a battery, ensuring efficient operation, and avoiding scenarios that could cause degradation, such as overcharging or deep discharging. While Extended Kalman Filters (EKF) have been popular, they fall short in non-linear situations. The UKF, however, delivers more accurate and stable SOC predictions even in complex environments, improving reliability in electric vehicle BMS.

Another important contribution comes from the application of genetic algorithm-backpropagation neural network (GA-BPNN) for predicting battery capacity and end-of-discharge (EOD) (Xu et al.). Accurately predicting capacity is crucial for extending battery life and ensuring safety. Traditional methods can be slow and less reliable. In contrast, the GA-BPNN method offers a data-driven approach that enhances efficiency and accuracy, making it more applicable in real-world scenarios where precise capacity monitoring is essential for safety and customer satisfaction.

Moreover, the integration of decision trees with support vector machine regression (SVR) represents a breakthrough in state-of-health (SOH) estimation (Qian et al.). SOH estimation is essential for assessing the overall health of a battery and predicting potential failures. This hybrid approach selects critical battery features that affect performance, reducing the training time required while maintaining high accuracy. As a result, faster, more reliable SOH estimations are possible, which will improve safety and extend the operational life of batteries in both electric vehicles and energy storage systems.

On the materials side, the introduction of solvent-free NMC622 electrodes is a major innovation in sustainable manufacturing processes for LIBs (Matthews et al.). Traditional production methods involve toxic solvents, leading to environmental damage and higher costs. By adopting PTFE nano-fibrils, the solvent-free method reduces the environmental footprint while enhancing electrode stability and performance. This shift not only addresses sustainability concerns but also helps improve the overall lifespan and efficiency of the batteries. As industries prioritize sustainability, the adoption of such methods will be key in reducing the carbon footprint of LIB production.

This Research Topic reflects the growing understanding of LIB technology through the intersection of materials science, data-driven algorithms, and sustainable manufacturing practices. The advancements shared in this Research Topic underscore the importance of interdisciplinary approaches to pushing the boundaries of LIB performance. From improving predictive models to creating more environmentally friendly materials, these studies lay the groundwork for future innovations in energy storage technologies.

Perspectives

In conclusion, the Research Topic highlights several key advancements that are shaping the future of lithium-ion batteries, with a focus on state estimation, health monitoring, and sustainable manufacturing. As the demand for LIBs continues to rise, these innovations point to the critical need for both technological advancement and environmental responsibility. The following areas are identified as essential for ongoing research and development:

1. Bridging Predictive Models with Real-World Applications: As data-driven algorithms advance, their integration into real-time BMS will be critical to ensuring accurate and reliable SOC, SOH, and capacity predictions in practical applications.
2. Sustainable and Eco-Friendly Materials: With increased focus on reducing environmental impact, the development of solvent-free electrodes and other sustainable production processes will be vital for minimizing the carbon footprint of LIB production while maintaining high performance.
3. Enhancing Data-Driven Prognostics: Leveraging machine learning techniques, such as GA-BPNN and hybrid decision tree-SVR models, will be central to improving battery health monitoring and predictive maintenance systems.
4. Collaborative, Multidisciplinary Approaches: Continued collaboration between materials scientists, engineers, and data scientists will be necessary to address the technical and environmental challenges that face the next-generation of LIB technology.

The advances discussed in this Research Topic will not only contribute to more efficient and reliable LIB systems but also support the transition toward more sustainable and environmentally responsible energy storage solutions. These innovations will continue to drive the progress needed to meet the growing global demand for greener energy technologies.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declare that no Generative AI was used in the creation of this manuscript.

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