Advancing Sustainable Battery Technologies:

From Electrode Design to Green Recycling

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Abstract

Batteries represent a crucial technology for transitioning society from fossil fuel dependency toward sustainable energy generation and transportation. However, the exponential growth in battery demand presents significant sustainability challenges, including dependence on critical metals, high energy consumption and greenhouse gas emissions during manufacturing, and environmental concerns from battery disposal. In response, we endeavor to establish fundamental tools for sustainable batteries that address the entire lifecycle from design to end-of-life management. Our research introduces innovative molecular engineering strategies to develop organic composite electrodes from Earth-abundant elements as viable alternatives to conventional transition metal-based electrodes. We have demonstrated that specific pore chemistry combined with extended π-conjugation networks in organic composites enhances electrical conductivity and energy storage capacity, achieving performance competitive with commercial electrodes. Beyond material design, we are advancing green approaches for end-of-life battery to foster a circular economy in battery technology. Our direct recycling method for lithium-ion batteries transcends current prevalent recycling approaches (pyrometallurgy and hydrometallurgy), eliminating their inherent drawbacks of high energy consumption, lengthy processing times, and toxic chemical usage. This holistic approach to battery development, encompassing both material design and sustainable recycling methods, not only helps mitigate supply chain vulnerabilities for critical metals but also reduces environmental impact, ultimately advancing the development of truly sustainable energy storage technologies.

Keywords: Sustainable batteries, Organic electrodes, Molecular engineering, Circular economy, Direct recycling

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