


Chapter 4

Exploring the Chemistry of Energy Storage Systems Batteries, Supercapacitors, and Energy Storage

Krishna Kumar

 <https://orcid.org/0009-0001-9707-3155>

Guru Gobind Singh Indraprastha University, India

Gulshan Kumar

Guru Gobind Singh Indraprastha University, India

ABSTRACT

The rising global energy demand combined with the rising trend on renewable energy systems underlines the necessity of having efficient, sustainable, and scalable storage technology for energy. This chapter looks into the foundational chemistry of advanced energy storage systems, which lies in next-generation batteries, supercapacitors, and hydrogen storage technologies. The chapter highlighted challenges associated with energy storage devices along with the role of innovative materials and electrochemical mechanisms. It then discusses some recent breakthroughs in material science, with an emphasis on the development of high-performance electrodes, electrolytes, and solid-state materials. The chapter concludes by outlining future trends which push the design and optimization to accelerate energy storage systems, so that the next generation of technologies can set the stage for a more sustainable and energy-efficient future.

DOI: 10.4018/979-8-3373-1409-9.ch004

1. INTRODUCTION

The global energy landscape is undergoing profound change, pushed by the growing urgency to diminish reliance on fossil fuels and mitigate adverse impacts of climate change. Among these alternatives are solar and wind as renewable sources, which have made tremendous gains but still offer several challenges because they are inherently intermittent and variable. It will require the design and deployment of energy storage systems that are critical enablers for the global energy transition by ensuring efficient utilization and management of energy. Such energy storage systems play a very fundamental role as they help to integrate energy supply and demand at various scales and provide much-needed flexibility, reliability, and resilience in power grids, thus enabling the widespread integration of renewable sources of energy (Raut et al., 2024). Beyond grid-scale applications, energy storage technologies are indispensable in modern advancements such as portable electronics, electric vehicles, and smart grids, where efficient, durable, and sustainable energy management is paramount. At its heart, chemistry underlies any energy storage technology that governs the capture, storage, and release of energy. Consequently, chemical principles dictate the efficiency, capacity, charge-discharge dynamics, safety, and lifespan of the systems. From this myriad of energy storage technologies, the two most significant ones to date are batteries and supercapacitors, largely because of their complementary advantages. Batteries work through electrochemical reactions, where the energy is stored in the form of chemical potential and released through redox reactions (Oyedotun & Mamba, 2024). The development of battery technology has been quite phenomenal, from the traditional lead-acid and nickel-cadmium batteries to the advanced lithium-ion batteries that dominate the market today. The high energy density and impressive cycle life associated with the ability to serve applications varying from consumer electronics to large-scale energy storage are among the reasons for the high penetration of lithium-ion batteries. These, however, come with problems such as resource availability, thermal instability, and environmental issues, and researchers have been directed into new generations of battery technologies: solid-state batteries, lithium-sulfur-based batteries, and others including sodium-ion or magnesium-ion systems (Lim et al., 2023). Instead, supercapacitors store their energy by charging electrostatic charge build-up and, by contrast to battery storage, there is no consumption of chemicals by chemical reactions involved; this provides fundamentally different supercapacitor designs. Supercapacitors therefore demonstrate exceptionally high-power densities, ultrafast charge/discharge rates, long cycle lives. Supercapacitors have strong potential for real-time energy distribution applications; besides, it represents a lot in the utilization, such as systems of regenerative braking, supplementary power supply backup, hybrid solution for energy sources (Venkateswarlu et al., 2023). However, they have a major limitation

30 more pages are available in the full version of this document, which may be purchased using the "Add to Cart" button on the publisher's webpage: www.igi-global.com/chapter/exploring-the-chemistry-of-energy-storage-systems-batteries-supercapacitors-and-energy-storage/384697

Related Content

Biological Nutrient Removal by Suspended Growth Systems

Ezerie Henry Ezechi, Augustine Chioma Affamand Khalida Muda (2020). *Handbook of Research on Resource Management for Pollution and Waste Treatment* (pp. 264-293).

www.irma-international.org/chapter/biological-nutrient-removal-by-suspended-growth-systems/242019

Dynamic Characterization and Site Response Studies for an Offshore Site Based on Detailed Geotechnical Tests

T. G. Sitharam, Naveen Jamesand Monalisha Nayak (2015). *International Journal of Geotechnical Earthquake Engineering* (pp. 50-80).

www.irma-international.org/article/dynamic-characterization-and-site-response-studies-for-an-offshore-site-based-on-detailed-geotechnical-tests/134043

Dynamic Analysis of Homogenize Earthen Dam Using Blanket Layer Technique

Behrouz Gordanand Azlan Bin Adnan (2013). *International Journal of Geotechnical Earthquake Engineering* (pp. 68-82).

www.irma-international.org/article/dynamic-analysis-of-homogenize-earthen-dam-using-blanket-layer-technique/80188

Synergistic Role of Artificial Intelligence and Machine Learning in Enhancing Hydrophyte-Based Heavy Metal Stress Management

Pushkar Singh Rawatand Shalini Singh (2026). *Hydrophyte Strategies for Heavy Metal Stress Mitigation* (pp. 285-324).

www.irma-international.org/chapter/synergistic-role-of-artificial-intelligence-and-machine-learning-in-enhancing-hydrophyte-based-heavy-metal-stress-management/396384

Biosorption of Dye Molecules

Aisha Zaman, Papita Das and Priya Banerjee (2016). *Toxicity and Waste Management Using Bioremediation* (pp. 51-74).

www.irma-international.org/chapter/biosorption-of-dye-molecules/141793