Chapter 3
Battery Chemistry Li-ion Solid-State and Beyond

Himadri Sekhar Das
https://orcid.org/0000-0002-3509-3388
Haldia Institute of Technology, India

Sudipta Banerjee
https://orcid.org/0000-0003-0150-6794
Symbiosis Institute of Technology, Symbiosis International University, Pune, India

Heranmoy Maity
Ideal Institute of Engineering Kalyani, Nadia, India

Gourisankar Roymahapatra
https://orcid.org/0000-0002-8018-5206
Haldia Institute of Technology, India

ABSTRACT

Battery chemistry has undergone a transformative journey, propelling advancements in energy storage technologies that are pivotal to modern applications. This chapter delves into the evolution and comparative analysis of lithium-ion (Li-ion) batteries, solid-state batteries, and emerging alternatives. Li-ion batteries, known for their high energy density and longevity, have dominated the energy storage market, yet face challenges such as safety concerns and resource dependency. Solid-state batteries, featuring non-flammable solid electrolytes, promise enhanced safety, higher energy densities, and longer lifespans but are hindered by manufacturing complexities and cost. Beyond these, next-generation chemistries, including lithium-sulfur, sodium-ion, and multivalent systems, offer potential breakthroughs in affordability, sustainability, and performance. The chapter examines key materials, electrochemical mechanisms,

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and technological hurdles, alongside discussing future directions such as recycling, sustainability, and integration into renewable energy systems.

INTRODUCTION

Battery technology is essential for contemporary energy storage systems, with uses ranging from portable devices and electric cars to the integration of renewable energy sources (Himadri Sekhar Das, (2025). This chapter examines the chemistry of lithium-ion (Li-ion) batteries, reviews progress in solid-state batteries, and looks into new technologies that hold the potential to go beyond current limitations (Parvizi et al., 2025).

Due to the swift progress in technology and the worldwide shift towards renewable energy, energy storage solutions have become a key focus of contemporary innovation. Batteries, which are crucial elements of energy systems, have undergone considerable development over the years. Lithium-ion (Li-ion) batteries have become a leading technology owing to their high energy density, efficiency, and versatility. Li-ion batteries are now essential to modern life, from powering portable electronics to facilitating electric vehicles and grid storage.

Despite their success, challenges such as safety concerns, limited resource availability, and environmental impacts have spurred research into alternative battery chemistries. Solid-state batteries, for instance, have garnered attention for their use of non-flammable solid electrolytes, offering superior safety and performance metrics. Similarly, emerging technologies like lithium-sulfur, sodium-ion, and multivalent systems hold the promise of overcoming current limitations, such as cost and resource constraints, while meeting the demands of next-generation applications (A. Machín et al, (2024).

This chapter explores the intricate chemistry behind these battery technologies, analyzing their materials, mechanisms, and advancements. Additionally, it explores the obstacles to commercialization and future outlooks, emphasizing how innovative battery systems could transform energy storage and aid in achieving sustainability. We seek to offer a thorough comprehension of how battery chemistry has developed and where it is headed, from Li-ion systems to innovative alternatives, through this investigation.

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