Chapter 7
Chalcogenide Nanocomposites Enabling Materials for Future Energy Solutions

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ABSTRACT

The many functions of chalcogenide nanocomposites in cutting-edge energy systems are critically examined in this talk, with a focus on synthetic processes, environmental effects, and performance improvement techniques. Sustainable synthesis methods—such as hydrothermal, solvothermal, and UV-assisted techniques—are given special consideration because they have many benefits, including reduced ecological impact, scalability, and cost effectiveness. Important drawbacks are methodically assessed, such as inadequate cycle stability and subpar energy conversion or storage efficiency. The suggested remediation techniques include compositional engineering to increase electrical conductivity, electrode architectural modification to promote ion/electron transport, and thorough explanation of physicochemical degradation routes under operating settings.In order to solve these issues, the discussion emphasizes the critical role that multidisciplinary research—which integrates materials science, electrochemistry, nanotechnology, and environmental engineering—plays.

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INTRODUCTION

The global energy landscape has changed significantly in recent years due to a greater emphasis on environmental sustainability and the urgent need for high-efficiency, low-emission energy options. This paradigm shift has raised the need for advanced functional materials capable of addressing the complex and multidimensional issues inherent in modern energy production, storage, and conversion technologies, (Huang et al., 2016; Liu et al., 2010; Yuan et al., 2021). The development of next-generation material systems designed to maximize energy harvesting, usage, and lifetime sustainability has become necessary due to the intrinsic constraints of traditional fossil-based energy sources as well as growing environmental and geopolitical issues. Research in materials science, especially in the design and engineering of nanostructured materials with adjustable physicochemical characteristics and multifunctional capabilities, has been greatly pushed by the continuous push for sustainable energy solutions, (Yadav et al., 2021; Yuan et al., 2017). These nanomaterials have better electrical, optical, and catalytic capabilities, higher surface area-to-volume ratios, and improved interfacial dynamics—all of which led to higher energy conversion efficiency and less environmental impact. With a wide range of applications, such as electrochemical energy storage systems (such as lithium-ion batteries, sodium-ion batteries, and supercapacitors), energy conversion platforms (such as photovoltaic cells and thermoelectric modules), and electrocatalytic systems for green hydrogen (Kannan et al., 2023) and other sustainable fuels, the field of energy materials is currently a pillar of modern research and technological advancement. Nanomaterials offer enhanced electrical, optical, and catalytic properties, alongside higher surface area-to-volume ratios and improved interfacial dynamics. These characteristics contribute to greater energy conversion efficiencies and reduced environmental impact. With broad applicability across technologies-including electrochemical energy storage systems (e.g., lithium-ion and sodium-ion batteries, supercapacitors), energy conversion platforms (e.g., photovoltaic cells and thermoelectric modules), and electrocatalytic systems for green hydrogen and sustainable fuel production—energy materials have become a cornerstone of modern scientific research and technological innovation.

Within this evolving landscape, chalcogenide-based nanocomposites have emerged as highly promising candidates for overcoming key challenges in next-generation energy materials. Chalcogenides, composed of Group 16 elements (sulfur, selenium, and tellurium), are especially attractive due to their exceptional semiconducting, optoelectronic, and thermoelectric properties. Their optimal bandgap energies, high charge carrier mobilities, and intrinsic structural flexibility make them well-suited for integration into a wide array of energy-related devices and applications. The many functions of chalcogenide nanocomposites in cutting-edge energy systems are