Chapter 8
Hydrogen Storage Challenges and Solutions

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ABSTRACT

Abstract: Hydrogen is widely regarded as a promising clean energy carrier, yet its effective storage presents significant challenges that hinder widespread adoption. This chapter provides an in-depth exploration of various hydrogen storage technologies, examining their advantages, limitations, and potential solutions. We focus on physical, chemical, and material-based storage methods, evaluating key factors such as energy efficiency, safety, and economic feasibility. Additionally, we highlight emerging advancements in novel materials, hybrid storage systems, and policy frameworks that could play a pivotal role in addressing current storage challenges. The chapter concludes by discussing future directions and the need for continued research to overcome technical and economic barriers, ultimately enabling large-

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scale hydrogen adoption as a cornerstone of a sustainable energy future.

INTRODUCTION:

Hydrogen is increasingly seen as a key component of future energy systems due to its high energy density and zero-emission potential. However, storing hydrogen efficiently and safely poses significant challenges. This chapter examines different hydrogen storage technologies, their limitations, and potential breakthroughs. Hydrogen has emerged as a pivotal element in the transition toward a sustainable energy future (A. Bag et al. (2023). As the world struggle with the dual challenges of reducing carbon emissions and meeting rising energy demands, hydrogen offers a compelling solution due to its high energy content and environmental benefits. Unlike conventional fossil fuels, hydrogen combustion produces only water as a by-product, making it an ideal candidate for clean energy applications. However, despite its promising attributes, hydrogen storage remains a significant technological and logistical challenge that must be addressed to enable its widespread adoption (G. Roymahapatra et al, (2022). One of the key advantages of hydrogen as an energy carrier is its superior gravimetric energy density-approximately three times that of gasoline. This characteristic makes it an attractive option for applications in transportation, power generation, and industrial processes. However, its low volumetric energy density poses a considerable obstacle to practical storage solutions. Hydrogen is the lightest element in the periodic table, and under standard conditions, it exists as a gas with extremely low density. As a result, storing hydrogen efficiently requires advanced methods that enhance its density while maintaining safety, economic feasibility, and ease of use. Hydrogen storage technologies can be broadly classified into three categories: physical storage, chemical storage, and materials-based storage (H. S. Das et al, (2025). Physical storage involves compressing hydrogen gas at high pressures or liquefying it at cryogenic temperatures to achieve higher densities. Compressed hydrogen storage is the most mature and widely used method, especially in fuel cell vehicles and industrial applications. Liquid hydrogen storage, on the other hand, offers greater energy density but requires extreme cooling (-253°C) and sophisticated insulation techniques to prevent boil-off losses. Chemical storage methods involve bonding hydrogen with other elements to form stable compounds, such as metal hydrides, ammonia, and liquid organic hydrogen carriers (LOHCs). These methods offer promising alternatives for safe and efficient hydrogen storage, as they allow for reversible hydrogen uptake and release under controlled conditions. However, challenges such as slow hydrogen release kinetics, high operational temperatures, and material degradation need to be overcome before widespread implementation. Materials-based storage focuses on novel approaches such as adsorption in porous

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