Chapter 1

Materials for Hydrogen Production:
Synthesis and Storage

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ABSTRACT

Achieving global decarbonization goals by 2050 hinges on green hydrogen production via water electrolysis. With increasing demand for hydrogen in renewable energy, industrial sectors, and transportation, the importance of this technology continues to grow. This chapter delves into hydrogen production fundamentals and recent advancements in water electrolysis, emphasizing its pivotal role in generating green hydrogen. Key mechanisms of water splitting, such as electrocatalysis, photocatalysis, and photoelectrolysis, are explored. Special focus is given to advanced electrocatalysts, including both noble metals and cost-effective alternatives, that enhance the hydrogen evolution and oxygen evolution reactions. Innovative photocatalytic materials, including transition metal chalcogenides and phosphides, are highlighted for their efficiency gains through heteroatom doping and cocatalyst integration. Storage solutions and hydrogen's industrial applications in sectors like

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energy, chemicals, and transportation are also examined, presenting a roadmap for future development.

1. INTRODUCTION

The pressing challenge of climate change and the ambitious goal of achieving carbon neutrality by 2050 have significantly intensified the global pursuit of sustainable energy solutions. Among these, green hydrogen production has garnered considerable attention due to its potential to play a pivotal role in the transition to a low-carbon economy. Green hydrogen, produced using renewable energy sources such as wind, solar, and hydropower, offers a clean alternative to traditional fossil fuels, which are major contributors to greenhouse gas emissions. The concept of a "hydrogen economy" envisions hydrogen as a central energy carrier, powering various sectors including industry, transportation, and residential heating, while enabling the storage of renewable energy and balancing supply and demand. However, to realize this vision, several critical challenges must be addressed. First, accurately forecasting future hydrogen demand is essential to align production capacities with market needs. The global energy landscape is evolving rapidly, and policy uncertainties add complexity to these projections. Policymakers must develop clear and stable regulatory frameworks to support the growth of the hydrogen economy, incentivize investments, and reduce risks for stakeholders. Second, ensuring the availability of adequate renewable energy resources is crucial for the large-scale production of green hydrogen. The production process, particularly electrolysis, requires significant amounts of electricity, which must come from renewable sources to maintain the "green" label of the hydrogen produced. This necessitates a massive expansion of renewable energy capacity, which in turn requires substantial investments, infrastructure development, and technological innovation. According to the International Renewable Energy Agency (IRENA), the demand for green hydrogen could reach approximately 3 exajoules (EJ), equivalent to around 15 million tonnes (Mt) of hydrogen, by 2030. This projection underscores the need for rapid scaling of hydrogen production capabilities. Furthermore, analysis by the Hydrogen Council and McKinsey & Company suggests that to meet a demand of 20 to 30 Mt of green hydrogen, an installed electrolysis capacity of 200 to 250 gigawatts (GW) would be required, assuming 6000 operational hours per year (IRENA, 2021; International Energy Agency (IEA), 2020). This scale of production represents a significant challenge, as the current global capacity is far below these targets. Looking further ahead, IRENA's World Energy Transitions Outlook outlines an even more ambitious scenario, projecting the consumption of 400 Mt of green hydrogen by 2050. To achieve this, a total installed electrolyzer capacity of 5 terawatts (TW) would

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