

Editorial

# Catalytic Hydrogen Production, Storage and Application

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Hydrogen is a clean fuel for transportation and energy storage. It has several attractive features, including a higher energy content by weight, use in fuel cells that produces only water as a by-product, storage in small and large quantities by various methods, and established transportation and infrastructures [1]. A hydrogen economy consists of three steps, i.e., hydrogen production, storage, and applications. All three steps involved in a hydrogen economy can be divided into catalytic and non-catalytic approaches. For catalytic processes, the efficiency highly depends on the type and physico-chemical characteristics of the catalysts. Therefore, for the improvement of these catalytic processes, the development of highly efficient and stable catalysts is highly required [2].

There are various methods to produce hydrogen. These methods are characterized by the source or feedstock used for hydrogen production. These include hydrogen production using fossil fuel (gray hydrogen); hydrogen production from fossil fuel combined with carbon capture, utilization, and storage (blue hydrogen); renewable energy-derived hydrogen (green hydrogen); bioproduction of hydrogen; nuclear hydrogen production; and hydrogen production as a by-product in various industries. Among the various methods, steam reforming of natural gas (methane; fossil fuel) is the most industrially developed process. A total of 95% of hydrogen in the United States is produced from the steam reforming process, providing 10 million metric tons of hydrogen annually [3]. The disadvantages of this method include high energy consumption, high production cost, and the use of harsh reaction conditions. Moreover, as a heavy amount of greenhouse gases such as carbon dioxide is released, this method is environmentally unfriendly. Electrocatalytic hydrogen production from water splitting is the most promising and environmentally friendly process among all methods. Nowadays, researchers are devoting efforts to developing efficient electrodes from non-precious, earth-abundant, low-cost metals [4,5]. A review paper published in this Special Issue highlights the application of earth-abundant electrocatalysts for water splitting to produce hydrogen [6]. This review paper describes the current approaches to using non-precious metals and their oxides in hydrogen production and suggests future directions to obtain highly efficient and cost-effective processes. The photocatalytic hydrogen production technique is also gaining researchers' attention as it is environmentally friendly. A research paper in this Special Issue [7] presents the fabrication of Ni complexes and their application to photocatalytic hydrogen evolution. The research in this paper proved that the mechanisms for photocatalysis and electrocatalysis follow different pathways using the same catalysts.

Hydrogen storage is of pivotal importance in hydrogen-based technologies, especially in large-scale applications. The most used hydrogen storage technologies include compressed gas, cold/cryo-compression, liquid hydrogen storage, metal-organic frameworks, and metal hydrides. In recent years, researchers have considered liquid organic hydrogen carriers and ammonia as potential hydrogen carriers [8,9]. These materials have advantages including easy handling, transportation, and carbon-free processing. However, this process is highly dependent on the catalysts. In Japan, researchers keenly prefer the development of technologies for ammonia as hydrogen carriers [10]. Ammonia contains 17.6 wt% of hydrogen compared with 12.5 wt% in methanol. At an industrial scale, the Haber-Bosch



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process is used to catalytically convert fossil fuel-derived hydrogen to ammonia, requiring high-temperature (450–600 °C) and pressure (10–25 MPa) conditions [11,12]. The critical drawbacks of this process are the use of severe reaction conditions and the release of a heavy amount of carbon dioxide produced during hydrogen production from steam reforming of methane. Carbon dioxide-free green ammonia cannot be produced by the Haber–Bosch process using renewable-derived hydrogen as, firstly, it utilizes an iron-based catalyst, which is not suitable for fluctuated hydrogen supply; secondly, renewable-derived hydrogen is produced at room temperature, which will highly require energy to operate at the severe conditions of the Haber–Bosch process [13,14].

The hydrogen economy concept is incomplete without considering the application of hydrogen safely and economically as a zero-greenhouse gas emission fuel for automobiles, industries, and power plants. Among various hydrogen applications, fuel cells are considered the main field of utilization of hydrogen as an energy source. New developments in this field aim at lowering costs and improving the performance and durability of the catalytic procedures. Besides being a fuel for vehicles, hydrogen is widely used in refineries, fertilizer production, food processing, and ammonia and methanol production.

Summarizing, the present Special Issue aims to briefly demonstrate the critical challenges in developing all aspects of the hydrogen economy. The guest editor would like to express her gratitude to the editorial team and all the authors for their valuable scientific contributions.

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