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Hydrogen storage: Materials, methods and perspectives

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ABSTRACT

The review focuses on various hydrogen producing and storing methods that can be employed for creating a hydrogen economy. The latest advancements that have been made on different hydrogen storing materials and hydrogen storing technologies which have proven useful both on gravimetric and volumetric basis, have been highlighted. The encouraging and hopeful aspect of their developments is that the most of the materials are approaching the hydrogen storing capacity requirement that have been laid down by DOE. The classification of different systems has been done on basis of their storage mechanism, keeping in mind their advantages and disadvantages while they tend to store hydrogen both in the atomic and molecular form.

Contents

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1. Introduction

In an age of mobile technology energy storage has become an extremely important issue as the energy sources such as fossil fuels and natural gas are not infinitely available and even if they were, their combustion or end products are not environment friendly. One of the alternatives to avoid this problem is to use hydrogen as energy resource. Interest in hydrogen as a vehicle fuel dates back to the year 1800 but got heightened in the 1970s with the oil crises and with technological advances in the 1980s. Through these years, it has been used in everything from balloon flight to rocket propulsion.

Hydrogen gas is a clean, highly abundant and non toxic renewable fuel [1–3]. When it burns, it releases only water vapour into the environment. There are no spilling or pooling concerns because it dissipates quickly into the atmosphere [4–6]. It contains much larger chemical energy per mass (142 MJ) than any other hydro-carbon fuel. Hydrogen has a very high energy content by weight (3 times more than gasoline), very low energy content by volume (4 times less than gasoline) and burns faster than conventional gasoline [5]. It is 3.2 times less energy dense than natural gas and 2700 times less energy dense than gasoline. Hence, hydrogen proves to be an energy carrier [6], rather than an energy source, which means that it stores and delivers energy in a usable form. Major attracting property of hydrogen is its natural compatibility with fuel cells. The higher efficiency of hydrogen (60%) compared to gasoline (22%) or diesel (45%) improves the efficiency for future energy use [6,7].

This paper describes the present status of different materials and methods of hydrogen storage, along with different perspectives required for creating a hydrogen economy. Although there have been numerous reviews on hydrogen storage [8–10] but this one, along with focusing on hydrogen storing materials, also includes various sources of hydrogen production. We have also included the pros and cons that these materials possess over one another. Earlier papers either exclusively focus on metal hydrides [11,12] or on carbon materials [13–15]; but we, in addition to these, have also included other materials that store hydrogen through chemical storage and physisorption. Further, we have included various mechanisms of hydrogen storage, along with their merits and demerits, together with recent development on hydrogen technology. The review also focuses on what hydrogen economy is, how it is going to benefit the society, and the progress that has been made in hydrogen storage along with the challenges that still remain.

1.1. Hydrogen economy

The term “Hydrogen Economy” refers to the infrastructure which is used to support the energy requirements of society, based on the use of hydrogen in place of fossil fuels. Hydrogen production and transportation costs get absorbed in the price of the synthesized chemicals. Further, the cost of hydrogen is irrelevant as long as the final products find markets. The hydrogen economy infrastructure comprises of five key elements—production, delivery, storage, conversion, and applications, which are in different stages of technological advancement [16]. The hydrogen economy is highly beneficial for society as it will lead to opening of new industries to produce materials along with changes in vehicle power sources, which would finally result in reduced pollution levels. The advantages of the hydrogen economy include the release of water as a bi-product, no oil spills, elimination of green house gases and finally less economic dependence on the middle east oil reserves [6]. The problems with the fossil fuel economy are so severe and demanding, whereas, the environmental advantages of the hydrogen economy are so significant that the nations and the governments across the globe are making huge efforts to enhance the prospects of the hydrogen economy. Hydrogen is a secondary energy resource and therefore, it must be made available for energy needs from a variety of sources and resources.

2. Sources of hydrogen

2.1. Biological sources

Algae deprived of sulphur will produce hydrogen in a bioreactor. Cyanobacteria and Microalgae are among the algae that possess the ability to produce hydrogen with the help of the enzyme called hydrogenase. The hydrogen producing efficiency due to this process is reported to be 10–20% [17].

$$2H^+ + 2X_{reduced} \xrightarrow[(hydrogenase)]{} 6H_2 + 2X_{oxidised} \quad (1)$$

2.2. Wind

Wind energy is a renewable energy resource and this energy can be used to generate electricity [10] that can be used to produce hydrogen through water electrolysis. Nowadays proton exchange membrane (PEM) electrolyzers are used which have replaced alkaline (KOH) electrolyzers in terms of rate of hydrogen production [18]. But this technology faces certain limitations such as fluctuations in wind velocity, thermal management and cost of the electrolyzers.

2.3. Thermolysis of water

Water is covalently bonded so energy is necessary to break this molecule apart into hydrogen and oxygen by using heat as the source. This process is known as thermolysis [19]. The method is less preferred on industrial and commercial scale due to material constraints.

$$H_2O\,(l) + \text{heat} \rightarrow H_2\,(g) + O_2\,(g) \quad (2)$$