Renewable and Sustainable Energy Reviews 43 (2015) 1151–1158

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Hydrogen the future transportation fuel: From production to applications

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ARTICLE INFO

Article history:
Received 12 December 2013
Received in revised form
14 November 2014
Accepted 25 November 2014

Keywords:
Alternate fuel
Electrolysis
Hydrogen storage

ABSTRACT

Transportation of people and commodities being a socio-economic criterion needs clean energy and the demand is kept on increasing with modernization. Consequently, generation of a fuel with safer, efficient, economic and reasonably environmental friendly features is the key issue towards fulfilling such demands. Hydrogen seems to be an ideal synthetic energy carrier due to its lightweight, exclusive abundance and environmentally benign oxidation product (water). However, storage remains a big challenge. In this communication, recent developments in the production of hydrogen fuel, applications and storage together with the environmental impacts of hydrogen as energy carrier are emphasized.

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Contents

1. Introduction

Undoubtedly, the global demand of enhanced energy production and environmental concerns are the mostly cited significant issues in the 21st century [1]. In order to satisfy the world's growing appetite for energy by keeping our planet safe, at least 10 terawatt (TW) of carbon-free power need to be produced by the mid-century [2]. The dramatic increase in the petroleum price, the limited reserve of fossil fuels, the increased environmental worries related to greenhouse gas (GHG) emissions and global warming, the decay in overall human health and safety considerations enforced to search for alternative energy sources to power the motor vehicles worldwide [3].

A significant part of the world total energy being consumed by the transportation machineries [4] lead to the emission of harmful gases in the atmosphere [5]. Presently, a large portion (~65%) of

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http://dx.doi.org/10.1016/j.rser.2014.11.093
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the global energy demand is met by the fluid fossil fuels due their easy availability and convenient use. However, the fossil fuel production will gradually decrease over time [6]. Road vehicles consumes about half the globally produced oil [7]. By 2050, the projected global energy demand will be double or triple and the oil and gas supply is unlikely to be able to meet this requirement. Hydrogen and fuel cells are considered in many countries as an important alternative energy vector for future sustainable energy systems in the stationary power, transportation, industrial and residential sectors [8].

Considering the altitude of local air pollution, climate change, congestion, land use, accidents, and noise level, the current transportation systems will no longer remain 'sustainable'. In the mounting metro cities worldwide, local air pollution from road transport is becoming an alarming issue for urban air quality. GHG emissions from vehicles and fuel production are the other major concern. In the near future, a continual increase in the GHG emissions from the transport sector is predicted. The main reason for it is increasing global demand for fuel [5]. It is established that the burning of fossil fuels is responsible for the increased carbon dioxide levels in the atmosphere ($\sim 3 \times 10^{12}$ kg C/year) [9]. An increase in the average temperature on earth is caused by the dissolution of carbon dioxide in the oceans. Furthermore, the ocean water solubility of carbon dioxide gets decreased ($\sim$3%/K) with the increase of water temperature. Once the average temperature of the oceans is increased up to an optimum limit, then the carbon dioxide solubility equilibrium between atmosphere and ocean will be shifted towards the atmosphere. Consequently, this will lead an additional increase of the greenhouse gas in the atmosphere [10].

The exploitation of hydrogen as the energy carrier in different sectors in avoiding the emission of harmful gases remains highly debatable. However, it is not cost-effective at present. Many solutions for hydrogen supply are likely to emerge depending on level of demand, resource availability, geographic factors and progress on hydrogen technologies. Initially, utilization of hydrogen should develop in large cities having air pollution problems or island nations with high imported fuel costs.

This review examines the possible applications of hydrogen, its various production methods, and usage in different sectors particularly in transport, possible paths forward and the issues associated with a transition toward large-scale exploitation. The economics of hydrogen application in transport sector, actions and policies that might be needed for successful development of hydrogen energy systems are also emphasized.

2. Applications of hydrogen

Majority of the recent literature [7,11–15] focuses on the applications of hydrogen in every part of our social life including industrial, domestic or space. Generally, hydrogen is primarily used in petroleum refining [16,17], ammonia production [18,19] and, to a lesser extent, metal refining such as nickel, tungsten, molybdenum, copper, zinc, uranium and lead [20,21]. It amounts to more than 50 million metric tonnes worldwide in 2006 [22,14]. In the future, hydrogen is likely to be used as fuel in almost all applications where fossil fuels are used today. For transportation in particular, hydrogen would offer immediate benefits in terms of reduced pollution and cleaner environment [11].

Hydrogen is being majorly used for synthesis of ammonia and other nitrogenated fertilizers, refining and desulphurization (hydrogenation reactions, hydrodesulphurization), hydrogenation of hazardous wastes (dioxins, PCBs), chemical plants, food preparation, synthesis of methanol, ethanol, dimethyl ether (DME), alternative fuels synthesis by Fischer–Tropsch (FT) synthesis, gas to liquid (GTL) synthesis technology, rocket fuel, IC engine fuel, high temperature industrial furnaces fuel etc. to cite a few [23]. Primarily, hydrogen is consumed for production of ammonia, other chemicals and in petro-chemistry. Out of the total 500 billion cubic meter (Bm^3) of hydrogen, ammonia production alone consumes 250 Bm^3 followed by the production of other chemical products which consume about 65 Bm^3, and petro-chemistry consume 185 Bm^3 of hydrogen, accounting for 50, 13 and 37%, respectively [7,23]. A recent report exploring various application of hydrogen affirms its significant implications towards electricity generation, cooking food, fuel for automobiles, hydrogen powered industries, jet planes, hydrogen village and on the top for all our domestic energy requirements [12].

3. Hydrogen production

Hydrogen can be produced from varieties of feedstock including fossil and renewable resources. As illustrated in Fig. 1, several process technologies such as chemical, biological, electrolytic, photolytic and thermo-chemical can be used for hydrogen production [24]. A detailed overview of diverse hydrogen production technologies are reported by Holladay et al. [13]. Common hydrogen production methods include.

3.1. Steam methane reforming

Steam methane reforming (SMR) is a process in which the natural gas or other methane stream, such as biogas or landfill gas reacts with steam in the presence of a catalyst to produce hydrogen and carbon dioxide. According to DOE of USA (2010), SMR is approximately 72% efficient in hydrogen generation when starting with natural gas. Conversely, on a lower heating value basis [25] SMR produces a hydrogen rich gas that is typically on the order of 70–75% hydrogen on a dry mass basis, along with smaller amounts of methane (2–6%), carbon monoxide (7–10%), and carbon dioxide (6–14%) [26].

It is worth mentioning that, natural gas reforming produces about half of the global supply of hydrogen and remains the most commonly used method for hydrogen production [11,27–29]. However, it is not an attractive production route for mature hydrogen economy. This is due to the fact that order-of magnitude increase in demand would deplete our finite reserves. Moreover, the concentration of gas reserves in relatively few regions of the world could lead to geopolitical tension and unstable supplies. Environmental impact is also a major concern because reforming natural gas to hydrogen produces as much pollution and CO_2 as burning the natural gas directly. Generation of hydrogen from natural gas is a well established process. If sufficient quantities are produced to power the world's cars and light trucks it would strain the world's supply of conventional methane, making natural gas as geopolitically sensitive as oil [30].

3.2. Gasification of coal and other hydrocarbons

The partial oxidation (POX) process termed as "gasification," generates hydrogen from a wide range of hydrocarbon fuels, including coal, heavy residual oils, and low-value refinery products. In this process, the hydrocarbon fuel is made to react with oxygen in a less than stoichiometric ratio, yielding a mixture of carbon monoxide and hydrogen at 1200 to 1350 °C [25]. The production of hydrogen is dominated mainly by reforming of natural gas and heavy oil, gasification of coal, heavy oil and petroleum coke [14].

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