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Review

A review on production, storage of hydrogen and its utilization as an energy resource

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ABSTRACT

Energy price is rising due to rapid depletion of fossil fuels. Development of renewable and non-polluting energy resources is necessary for reducing pollution level caused by those conventional fuels. Researchers have recognized hydrogen (H_2) as such an energy source. Hydrogen is a potential non-carbon based energy resource, which can replace fossil fuels. Hydrogen is considered as the alternative fuel as it could be generated from clean and green sources. Despite many advantages, storage of hydrogen is a serious problem. Due to high inflammability, adequate safety measures should be taken during the production, storage, and use of H_2 fuel. This review article elucidates production methods and storage of hydrogen. Besides this safety related to H_2 handling in refilling station, and automobiles has also been discussed. Study shows that safety program and awareness could be fruitful for increasing the acceptance of hydrogen as fuel.

Contents

1. Introduction

Energy is an essential requirement for the development of the modern nation. Therefore, energy is a key consideration in discussions of sustainable development. Renewable resources, such as solar radiation, winds, waves, and tides are environmental friendly. Conversion of waste materials to useful energy forms like

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hydrogen (biohydrogen), biogas, bioalcohol, etc., is possible through waste-to-energy technologies [1]. In recent times, the importance of hydrogen fuel has been recognized and its use is gaining more and more importance because, the extensive utilization of fossil fuels has accelerated their depletion and these fuels contribute harmful oxides of carbon, nitrogen, sulphur, etc. which are responsible for global warming [2]. Hydrogen is a potential non-carbon based energy system, which can replace fossil fuels. Hydrogen is considered as the alternative fuel as it can be generated from clean and green sources. However, presently very less percent of hydrogen is produced from renewable sources through water electrolysis while rest of it is still derived from fossil fuels [3,4]. Hydrogen is future fuel and energy carrier; it is carbon free and hence environmentally friendly. Hydrogen is considered a clean and efficient energy carrier, since its combustion only produces water as byproduct.

Hydrogen is a worldwide-accepted clean energy carrier as it is source-independent [5] and has a high energy content per mass compared to petroleum (Table 1). Due to these advantages, H_2 can be used as energy sources for different appliances, such as hydrogen fuel cell vehicles and portable electronics. The reaction product is water, and there is no CO_2 emission. Although there are some nitrogen oxides produced during high temperature combustion, environmental pollutant can be fully removed during low temperature utilization such as by fuel cells [7].

Gahleitner [8] has done a critical study on power-to-gas strategy. Outcome of this study shows that the number of power-to-gas pilot plants that produce hydrogen from fluctuating renewable power sources and either apply it to electricity generation or feed it into the gas distribution system is increasing all over the world. Some European countries are using this technology for storing power as hydrogen gas. A strong focus on this technology is becoming apparent in Germany, where several projects have been realized and numerous further systems are being planned. Wind or solar energy is used to generate electricity in most power-to-gas pilot plants. These energy sources can fluctuate strongly, and therefore there is a great need for energy storage. Power-to-gas systems can be operated in various combinations with the public grid and/or the gas distribution system. Each combination has different requirements for system design and type of components and is suited for different applications.

For the utilization of H_2 as an energy carrier, some factors to be consider; production from cheap and renewable source, proper storage, safe handling of H_2 fuel cell, and refilling station.

2. World scenario

Due to its exceptional properties and versatility, hydrogen is an increasingly strong option for replacing fossil fuels in the long-term [9]. A large number of feasibility studies have been carried out based on simulation models for the introduction of hydrogen into the energy systems of Europe and Asia [10–12]. Leaver and Gillingham [13] developed a multi-regional integrated energy systems model to assess the economic impact of hydrogen fuel cell, hydrogen internal combustion, and battery electric technologies on the economy of New Zealand. Base case results suggest that a hydrogen fuel dominant vehicle fleet offers economic savings over a conventional fleet but requires the largest sequestration capacity as 75% of hydrogen fuel production is derived from fossil fuel. This UniSyD model is constructed with four primary modules that incorporate key sectors of the energy economy. The four primary modules are fossil resources, electricity production, hydrogen production, and transport. In the model hydrogen is produced on the forecourt by small scale electrolysis or steam methane reforming or on a larger scale by centralized production using coal or biomass gasification and steam methane reforming plants. Centralized co-generation of hydrogen and electricity using coal gasification and a solid oxide fuel cell topping cycle is one of the lower cost methods of hydrogen production due to the ability to partially offset production costs by selling electricity back to the market at peak times. Forecourt production options are always the first constructed, as initial demand is small.

Governments of different countries and researchers have begun to assess the possibility of hydrogen as alternative fuel and to actualize a hydrogen economy into their own energy systems. The models used in various countries are given in Table 2 [14–24].

For a long time Canada maintains a strong position in the hydrogen and new energies communities. In June of 2001, the Canadian Transportation Fuel Cell Alliance (CTFCA) of the Government of Canada created one of the initiatives under Action Plan 2000 for greenhouse gas emission reductions. Canada has played a leading role in bringing hydrogen technologies to their current viable role in changing the energy infrastructure. From an industrial innovation initiative in essential technologies such as production by electrolysis and end-use in fuel cells to government leadership initiatives in supporting codes and standards writing [25].

Hydroelectricity-Hydrogen Energy System (HHES) can be used for energy to remote or isolated areas such as rural villages, hotels, frontier regions and islands [26]. The HHES has great scope for development in countries with a large hydroelectricity potential, such as Norway [27], Brazil [28], Canada [29] and Venezuela [30]. In Latin America, R&D programs on hydrogen energy are scarce, with Brazil the leader in research on H_2 energy production from renewable sources, in particular hydroelectricity [31,32]. Contreras et al. [33] have done a feasibility study based on the modeling and simulation of the production of hydrogen from hydroelectricity in Venezuela. In order to do so, mathematical structures were devised (for 20 years time horizon, as from the year 2000) that model the behavior of hydrogen production, the efficiency of energy conversion, the cost of electricity and the cost of electrolyser, on the basis of historical data, bibliographical references and information provided by manufacturers.

Table 1
Energy contents of different fuels.

Fuel	Energy content (MJ/kg)
Hydrogen	120
Liquefied natural gas	54.4
Propane	49.6
Aviation gasoline	46.8
Automotive gasoline	46.4
Automotive diesel	45.6
Ethanol	29.6
Methanol	19.7
Coke	27
Wood (dry)	16.2
Bagasse	9.6

Adapted from Ni et al. [6].

Table 2
Different models used in various countries.

Country	Model	References
UK	THESIS model	[14]
Denmark	Balmorel model and the Danish energy system	[15,16]
EU	European HySociety Project	[17–19]
Italy	Italy-Markal model	[20]
Taiwan	Taiwan general equilibrium model-energy for hydrogen (TAIGEM-EH)	[21]
Switzerland	Swiss MARKAL model	[22]
Austria	Dynamic framework	[23]
Germany	Scenario-based model	[24]