HYDROGEN A SOURCE OF ALTERNATE FUEL

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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.

***IndexTerms* — Hydrogen, Production, Storage.**

I.INTRODUCTION

Energy is an essential requirement for the development of the modern nation. Therefore, energy is a key consideration in discussions of sustainable development. The burning of conventional resources such as coal and oil increases CO_2 emissions. It damages the environment and affects global warming[23]. Renewable resources, such as solar radiation, winds, waves, and tides are environmental friendly. Conversion of waste materials to useful energy forms like hydrogen (bio-hydrogen), biogas, bio-alcohol, etc., is possible through waste-to-energy technologies. Hydrogen is considered as clean and environmental friendly next generation fuel. The safety and awareness program could be fruitful for increasing the acceptance of hydrogen as fuel.

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. H_2 is a potential non-carbon based energy system, which can replace fossil fuels. H_2 is considered as the alternative fuel as it can be generated from clean and green sources. However, presently very less percent of H_2 is produced from renewable sources through water electrolysis while rest of it is still derived from fossil fuels. H_2 is future fuel and energy carrier; it is carbon free and hence environmentally friendly. since its combustion only produces water as byproduct. Hydrogen is a worldwide-accepted clean energy carrier as it is source-independent 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.

Table 1. Energy contents of different fuels [1].

Types of fuels	Fuel Energy content (MJ/kg)
Hydrogen	120
Liquefied natural gas	54.4
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

II. HYDROGEN SENARIO

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. For a long time Canada maintains a strong position in the hydrogen and new energies communities. Canada has played a leading role in bringing hydrogen technologies to their current viable role in changing the energy infrastructure. Hydroelectricity Hydrogen Energy System (HHES) can be used for energy to remote or isolated areas such as rural villages, hotels, frontier regions and islands. The HHES has great scope for development in countries with a large hydroelectricity potential, such as Norway, Brazil, Canada and Venezuela. Like Europe and America, Asian countries are also developed a lot on hydrogen energy. The Ministry of Science and Technology of Korea launched the Hydrogen Energy R&D Center in 2003. The Ministry of Commerce, Industry and Energy established a national R&D organization for hydrogen and fuel cell development in 2004. Korean government policy is encouraging a fuel-switching from petroleum to hydrogen in road transportation. As hydrogen is introduced into the road transportation sector as fuel, the share of conventional vehicles decreases proportionally, leading to a decrease in CO_2 emission, the improvement of energy efficiency and energy security in Korea.

Table2.Different models used in various countries [2].

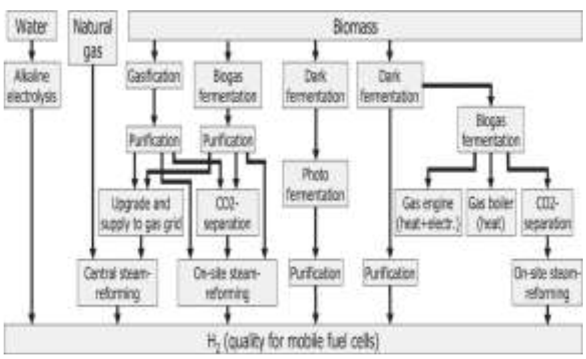
Country	Model
UK	THESIS model
Denmark	Balmorel model and the Danish energy system
EU	European HySociety Project
Italy	Italy-Markal model
Taiwan	Taiwan general equilibrium model-energy for hydrogen (TAIGEM-EH)
Switzerland	Swiss MARKAL model
Austria	Dynamic framework
Germany	Scenario-based model

In India, the Ministry of New and Renewable Energy has constituted National Hydrogen Energy Board that has members from government, industry, academia, and other experts. The main objective of the Board is to frame and implement a National Hydrogen Energy Road Map and National Program. The road map proposed a vision for India 2020 with green initiatives for power generation to a tune of 1000 MW power generation capacity based on hydrogen energy and switchover to 1,000,000 hydrogen powered vehicles. The road map envisages milestones for pilot-scale reactors for hydrogen production through biological, biomass routes extendable to onsite hydrogen production using renewable sources and choice of technologies for commercial production of hydrogen [2].

III. HYDROGEN PRODUCTION METHODS

Production of hydrogen from cheap and renewable sources is the key factor for H_2 energy utilization in real life. There are many sources for H_2 production namely water, glycerol, biomass, etc. The different hydrogen production technologies cover the state of the art technologies steam reforming of natural gas and alkaline water electrolysis as well as biomass based technologies. Literature survey shows that most of the researchers are emphasizing on the utilization of water as a source of H_2 due to its availability.

Fig. 1. Overview of all evaluated process chains



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 [2].

3.1Production of H_2 from water

Hydrogen can be produced from water by different methods i.e., thermochemical splitting, photo voltaic cell and photochemical reaction. Thermochemical water splitting cycles (TCWSCs) utilize multiple chemical reactions, with the net effect of water dissociation to form hydrogen and oxygen. The TCWSCs employ a high temperature thermal energy source such as nuclear or solar energy to drive the cycle.

$$SO_2 + 2NH_3 \rightarrow (NH_4)_2 SO_3$$

$$(NH_4)_2 SO_3 + H_2 O \rightarrow (NH_4)_2 SO_4 + H_2$$

Solar radiation is an abundant source of energy that can be used for electricity production by two different routes namely, photovoltaic (PV) and solar thermal via concentrating collector systems. In PV hydrogen production, storage system is required to get power supply on cloudy and no sunshine conditions. Among the various H_2 production methods, biological H_2 production can be categorized into three major groups: bio-photolysis, photo-fermentation, and dark fermentation. The bio-photolysis of water, carried out by green microalgae and cyanobacteria, is the most desirable route because it only utilizes water and sunlight, the most abundant natural resources. However, there are persistent problems with this route, such as low photochemical efficiency and serious by-product (oxygen, O_2) inhibition on hydrogenase, which catalyses the H_2 production reaction. Bio-photolysis is a water-splitting process that occurs in biological systems. Molecular O_2 and H_2 are produced, with light as the energy source. It is considered the most desirable and eco-friendly route for generating H_2, since only water and light are required. Chlamydomonas reinhardtii is the best studied of the microalgae for direct bio-photolysis[3]

3.2Production of H_2 from glycerol

Considerable amount of glycerol is produced as a byproduct during biodiesel production by transesterification of vegetable oils, which is available at low cost in large supply from renewable raw materials. About 1 kg of a glycerol is formed as a byproduct for every 9 kg of biodiesel. The method of hydrogen production from steam reforming of glycerol over nickel based catalyst promoted by zirconia and supported over ceria. Mixtures of bio-glycerin and bio-ethanol can be used as a raw material to produce H_2 via catalytic steam reforming. The comparison of Pt and Ni catalyst activities showed that the Pt catalysts produced lower H_2 yields. This can be attributed to the lower Pt loading as compared to the metal content of the Ni based catalysts.

3.3Production of H_2 from biomass

An interesting and promising method of biomass utilization is hydrogen production by fermentation. The commercialization of fermentative hydrogen production technology is envisaged after 2015 [3]. Boran et al. [4] have developed a pilot scale tubular photo bioreactor (80 L) for photo fermentative hydrogen production by photosynthetic purple-non-sulfur bacterium, Rhodobacter capsulatus, operating in outdoor conditions, using acetate as the carbon source. The reactor was operated continuously in fed-batch mode for 30 days throughout December 2008 in Ankara. The daily temperature fluctuations decrease the hydrogen production by 50% when compared to cultures grown at a constant temperature. It was proven that even at low light intensities and low temperatures, the acetic acid which was fed to the system can be utilized for biosynthesis, growth and hydrogen production. Photo-fermentation in a pilot scale tubular photo bioreactor can produce hydrogen, even in winter conditions. The technology for anaerobic hydrogen production from waste biomass is well developed.

Yang et al. [5] demonstrated the potential of renewable lipid-extracted micro-algal biomass residues as the feedstock for hydrogen production. Low temperature catalytic gasification technology employed to convert the fowl manure into H_2 rich gas will be a favored route for the efficient and clean utilization of the waste [6]. Today hydrogen is mainly produced from fossil fuels and while fossil fuel is not a sustainable energy source, one highly attractive route for hydrogen production is catalytic transformation of bio-ethanol, obtained from transformation and fermentation of biomass. In theory, hydrogen production from biomass or biomass derived liquids can be a neutral carbon emission process since all carbon dioxide produced can be recycled back to plants, and because of its low toxicity and ease of deliver ability, ethanol lends itself very well to a distributed production strategy. Hydrogen is produced from ethanol over cerium nickel based oxyhydride catalyst. Hydrogen may be generated from ethanol by different technologies such as steam reforming, partial oxidation and oxidative steam reforming at lower temperature of 350ºC [7].

3.4 Production of H_2 from other sources

Researches show that urea can be used as a raw material for H_2 production. A technology was demonstrated for the production of hydrogen and other valuable products (nitrogen and clean water) through the electrochemical oxidation of urea in alkaline media [8]. This oxidation of urea to hydrogen has significant benefits over standard hydrogen production meth-ods. Pure hydrogen (100%) is produced at low temperature, pressure, and energy consumption along with other valuable products, such as nitrogen (96.1%) and clean water [9]. It has been demonstrated that inexpensive nickel is the most active catalyst for the electrochemical oxidation of human urine in alkaline media [10].

Some researchers [11] found electrohydrogenesis is a suitable method for producing hydrogen from organic materials. Electro-hydrogenesis is a bio-electrochemical process where organic material is microbially oxidized to protons and electrons, which in turn are reduced to form hydrogen gas (H_2). The reactor in which these reactions occur is termed a microbial electrolysis cell. There are some studies exploring the potential of biohydro-gen production in continuous bioreactors such as continuous stirred tank reactor [12] or in an upflow anaerobic sludge blanket reactor [13]. The steam-iron process is an important way to produce hydrogen from coal or carbon based fuels by using a redox cycle of iron oxide. The process can produce pure hydrogen based on oxidation and reduction [14].

The sulfur–iodine thermochemical water splitting cycle is proposed for the large-scale for solar hydrogen production. The high temperature solar heat is utilized for decomposition of sulfuric acid (H_2SO_4) in the cycle. The rate of sulfuric acid decomposition can be improved at very high temperatures (in excess of 1000° C) available only from solar concentrators. 100% H_2SO_4 decomposition is achieved at temperatures exceeding 700° C. It is a highly efficient approach for decomposing sulfuric acid with a thermal efficiency of about 77% [15].

The proposed sulfur–iodine thermochemical system appears to be superior to conventional solar-based hydrogen production systems. The electricity produced by solar pannels is used to produce hydrogen in the electrolyser.The homogeneous charge compression ignition engine is operated by using 20% hydrogen, 22.5% ethanol and 58.5% water as a fuel. Maximum power produced by the engine is 4805 kW [16]. The photocatalytic activity of the $Fe_2(MoO_4)_3$/g-C_3N_4 hybrid is utilized in H_2 production under visible light irradiation. The optimal hybrid could produce hydrogen 6.6 times faster than pure g-C_3N_4 from water-methanol solution under visible light irradiation. This study may provide a potential approach to the environmental purification of organic pollutants using sunlight [17].

IV. HYDROGEN STORAGE

The storage device is an important part of the hydrogen energy system. A big challenge regarding large scale use of hydrogen is storage. Hydrogen is quite difficult to store or transport with current technology. Hydrogen has good energy density by weight, but poor energy density by volume compared to hydrocarbons [18]. Properties of good H_2 storing materials are lightweight, low cost, excellent kinetics of adsorption and desorption, and recyclability. There are many ways for storing hydrogen fuel in different forms (Table 3). Metals can be used as a storing medium of hydrogen. Magnesium is considered as one of the most attractive hydrogen storage materials due to its high capacity, low-cost and lightweight. Magnesium can store 7.6 wt% hydrogen [19]. The Mg-based films could be a favorable choice as hydrogen storage materials for fuel cell automobiles. Besides Mg, nickel catalysts supported on active carbon could store significant amounts of hydrogen at room temperature and high pressure (up to 0.53% at 30 bars against 0.1% for the activated carbon) [20]. In fact, the foremost challenge faced by hydrogen society is the hydrogen storage problem. Carbon nanorods (diameter 33 nm) have enhanced hydrogen storage performance. These rods show excellent hydrogen storage properties (7169 µmol g^{-1}) compared with that of commercial carbon (2564 µmol g^{-1}) [21].

Table 3. Hydrogen storage types [18].

Category	Type
Gas storage	Compressed hydrogen
Liquid storage	Liquid hydrogen Chemical storage (metalhydride) Magnesium hydride (MgH2), calcium hydride (CaH2), sodium hydride (NaH)
Physical storage	PCN-6 PCN, porous coordination network

V. ADVANTAGES

The use of hydrogen reduces pollution and improves air quality: When hydrogen is combined with oxygen in a fuel cell, energy in the form of electricity is produced which can be used in several economic sectors. The advantage of using hydrogen as an energy carrier is that when it combines with oxygen the only by-products are water and heat. No GHGs or other particulates are produced by the use of hydrogen fuel cells [22].

VI. CONCLUSION

Due to its exceptional properties and versatility, hydrogen is an increasingly strong option for replacing fossil fuels in the long term. For the utilization of H_2 as an energy carrier following factors to be considered: production from cheap and renewable source, proper storage, government policy, safe handling and refilling station. The optimization of hydrogen technologies is required for commercial production of hydrogen.

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