International Journal of Scientific Research & Engineering Trends
Volume 7, Issue 1, Jan-Feb-2021, ISSN (Online): 2395-566X

# A Review Study on Theoretical Investigation of Hydrogen Production Methods

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***Abstract*- This paper present the sustainable, green and zero-carbon emission method of hydrogen production. Depending upon the source of energy used to generate the hydrogen the methods are classified like solar energy, thermal energy, photo-electric. The different process to generate the hydrogen are analyzed and compared in it which give the brief and important description of green and zero-carbon emission method.**

***Keywords*- Clean energy fuel; Production technologies; Hydrogen productivity.**

## I.INTRODUCTION

Various environment problems have been caused by the use of fossils fuels which people prefer to use the most. Starting from the degradation of air people inhale to the global warming, the pollutants emitted due the fuels people use today is the reason behind it. Increment in melting of ice on Antarctica to scarcity of water on South Africa are the effects of carbon and other pollutant emission. Apart from the negative consequences, we know the fossils fuels are non-renewable source of energy. According to Organization of the Petroleum Exporting Countries, the crude petroleum oil output would not be able to meet the energy demands beyond 2045.

Considering the various factors, many researches and studies have been done and still going on for seeking the alternative fuels, including hydrogen energy as the alternative clean fuel. Hydrogen is considered clean energy carrier similar to the electricity. Hydrogen is not only used as the alternative clean fuel but also it is used in many commercial applications from welding metal to dying fabrics to making electronics, plastics, and fertilizers.

The hydrogen generation market size was valued at USD108. 1 billion in 2016 and is predicted to exhibit CAGR of 5.8% by 2025. About 50% of the demand for hydrogen is fulfilled by steam reforming ,close to 30% is fulfilled by oil reforming in refinery, about 17% is fulfilled by the coal gasification, and the remaining is done by the water electrolysis and other sources [1].

Most of the method we are using today is not fully clean method for production of hydrogen as carbon- monoxide is produced in most of the method. There are various methods of producing hydrogen in a clean way without production of carbon. Various researches have been done on various green and clean methods for producing hydrogen. Green and clean technology for hydrogen production has drawn a great attention of the researcher. Currently many developed country and organization are looking forward for the production of hydrogen from clean and green method.

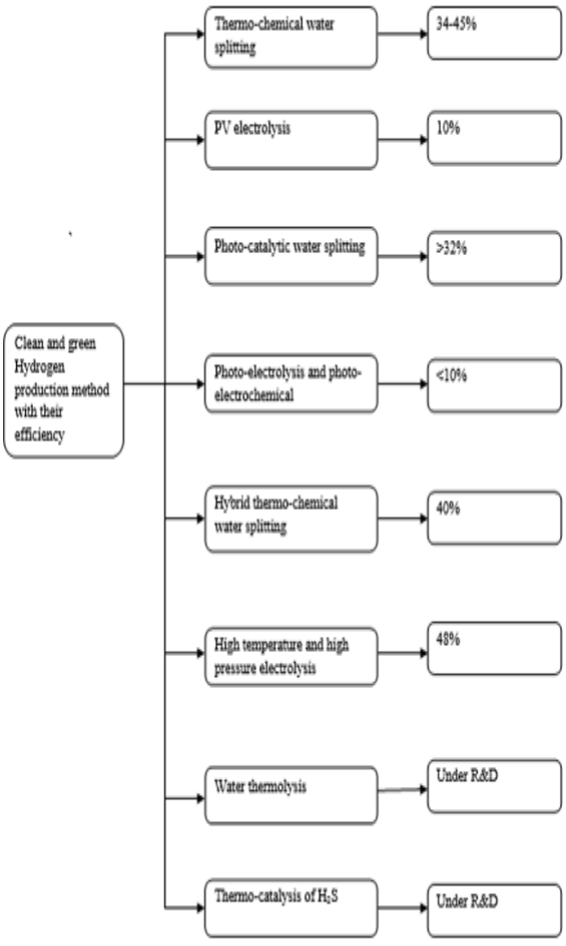


Fig 1. Hydrogen production methods with their efficiency.

Several research papers and reviews had been published regarding the different methods of hydrogen production.

This paper presents the green and clean methods of hydrogen production in a comprehensive manner.

## II. LITERATURE SURVEY

**1. Thermo-chemical water splitting:**
This method is simple among various method of producing hydrogen gas as it includes only water as a material source from which hydrogen is generated. The required other chemicals are reused or regenerated during the process itself so we consider the water as the only material source. Heat is the required energy input for the thermo-chemical water splitting process.

Table 1. Method used for hydrogen production.

| S. No. | Name of cycle | Elements | No. of steps involved | Reactions | Temp. (oc) |
|---|---|---|---|---|---|
| 1 | Mg-Cl | MgCl | 3 | MgCl2+H2O=2HCl+MgO<br>MgO+Cl2=MgCl2+1/2 O2<br>2HCl=Cl2+H2 | 450<br>500<br>80 |
| 2 | Cu-Cl | CuCl | 5 | 2CuCl2+H2O=CuO.CuCl2+2HCl<br>CuO.CuCl2=2CuCl+1/2O2<br>4CuCl+H2O=2CuCl2+2Cu<br>CuCl2(aqu)=CuCl2(sol)<br>2Cu+2HCl=2CuCl+H2 | 400<br>500<br>25-80<br>>100<br>430-475 |
| 3 | Sulphuric acid | H2SO4 | 3 | 2H2O+SO4=H2SO4+H2<br>H2SO4=H2O+SO3<br>SO3=SO2+1/2O2 | 80<br>550<br>450 |

The main reasons of attraction for this method of hydrogen production are:
**1.1** Potentially low or no greenhouse emission.
**1.2** No need of hydrogen-oxygen separation membrane.
**1.3** The electrical requirement is not required or less.

Various cycles such as Mg-Cl cycle, Cu-Cl cycle, Li-NO2 cycles are some of the most used method for the production of hydrogen as summarized from the ref [5].

**2. PV-Electrolysis:**
This method of production of hydrogen has been an area of research because of its feasibility. The electrolysis of water is carried out by an arrangement of system consisting a photovoltaic array, electrolyzer, hydrogen storage.

In this method, simply an electrolysis of water is carried out by driving the solar power as input power.

**At anode;**
4H2O+4e□ 2H2+4OH-
**At cathode;**
4OH□ O2+4e-+2H2O
**Overall reaction;**
2H2O□ 2H2+O2

The efficiency of this method of hydrogen production depends upon the solar cell's efficiency i.e how much the solar power is derived by the solar cells used in it and the efficiency of the electrolyzer [6].

Research into hydrogen production using this method has gained a lot of attention in recent years which has lead to the upgrading of efficiency of the production.

**3. Photo catalytic water splitting:**
This method is also known as artificial photosynthesis which takes place with photo-catalyst in a photo-electrochemical cell. As in natural photosynthesis in plant, sunlight is one of the essence source of energy for this method of hydrogen production. The dissociation of water takes place in the photo-electro-chemical cell. Irradiation of light with suitable energy (equal or more) with respect to band gap of photo-catalyst can generate electrons and

holes in conduction band and valance band of photo-catalyst.

This generated electron results electric charge which is used to influence the valance electrons of the chemical species to conduct the photo-catalytic chemical reaction [7-9].

**Photo oxidation:**

$H_2O + 2h^+ \rightarrow 2H^+ + \frac{1}{2} O_2$

**Photo reduction:**

$2H_2O + 2e \rightarrow H_2$

**Overall reaction:**

$H_2O \rightarrow H_2 + 1/2O_2$

**4. Photo- electrolysis and photo-electrochemical hydrogen production:**

Photo-electrolysis has been an area of great interest for researcher and engineers. Photo- electrolysis consist a photo-catalyst at the one end which is exposed to the sunlight and electro- chemical cell to which electric power are provided. The different research shows that the photonic radiation reduces required electric power. The production of hydrogen is actually in the form of dihydrogen. This process is one of the efficient and convenient process for the sustainable production of hydrogen. Many research have been done in this field for achievement of greater efficiency in the production of hydrogen.

Photo-electrochemical cell use the photonic radiation for the generation of charge which will be followed by the electrolysis of water. One of the most important advantage of photo- electrochemical cell is that it integrates the solar energy absorption and water electrolysis into a unit. This cell consist of photosensitive semiconductor like titanium dioxide ($TiO_2$), NaOH oxide, cadium, sulphide etc [10].

**5. Hybrid thermo-chemical water splitting:**

We have discussed about thermo-chemical water splitting method of hydrogen production in which we split the hydrogen and oxygen at high temperature. But in this hybrid thermo-chemical water splitting method we use electrical energy along with thermal energy for water splitting. Due to the use of electrical energy as input energy the temperature at which splitting occurs decreases which is the beneficial point in this method.

Due to the decrement in operating temperature, other suitable thermal sources can be used like solar, nuclear reactors etc. to drive this process [11].

$2H_2O + Br_2 + SO_2 = H_2SO_4 + 2HBr$

$H_2SO_4 = H_2O + SO_2 + 1/2O_2$

$2HBr = H_2 + Br_2$

**6. High temperature and high pressure electrolysis:**

In this method of hydrogen production, hydrogen is generated from the water by electrolysis at high temperature ranged between 650-1000oC. It is also known as steam electrolysis. Thermodynamically it is more beneficial for carrying out the electrolysis at high temperature because the input energy will be in the form of electrical and heat. High temperature electrolysis is carried out in solid oxide electrolysis cells. In these cells, water are converted into the steam in the expense of thermal energy [12-13].

Some of the benefits of using heat as input energy in electrolysis are:

- It accelerates the reaction kinetics.
- It decreases the energy loss.
- It increases the overall efficiency.

High pressure electrolysis is a technique to produce hydrogen gas due to decomposition of water molecules. This method differs with other electrolysis in the aspect of pressure where 120-200 bar pressure is maintained [14].

**7. Water thermolysis:**

It is the one step thermal splitting of water molecules into atoms is known as water thermolysis. $H_2O \rightarrow H_2 + 0.5O_2$ The reaction occurs at the very high temperature about 3000k which leads to the dissociation of molecules into atoms. However the high temperature would cause the hydrogen and oxygen to react to form the water again which may lead to an explosion.

Various experiments shows that 3% of water molecules break down at 2200oC whereas 50% molecules breakdown at 3000oC .To avoid the explosion separation of product can be done due to which the dissociate atoms cannot react with one another [15].

**8. Thermo-catalytic of hydrogen sulphide to generate hydrogen and sulphur:**

One liter of hydrogen sulphide mixes in the 76g of hydrogen –it is about 1000 times more than the mass of pure hydrogen per unit of volume in the same condition. Hydrogen sulphide can be found in nature in various environments: volcanoes, well water, geo-thermals wells, hot springs, oil wells, lakes or seas.

In recent studies have analysis that black sea have a resources of 4.6 billion tons of $H_2S$ generated by anaerobic bacterial activity which may bring potential of extracting 270 million tons of hydrogen. Over 150m in depth of black sea the concentration of $H_2S$ increases; nearly to sea bottom at 1000-2000 m depth and level of concentration reaches 8-8.5 ml/l.

In presently there is not any commercial available method to generate hydrogen from $H_2S$.Thermo-catalytic cracking of $H_2$ is generate two main products i.e hydrogen and sulphur.

$H_2S \rightarrow H_2 + 0.5S_2$

$H = 20.559 kJ/mol$

Catalytic separation membranes are made by a combination of glass and alumina which permits permeation of H2 from the H2S decomposition rectiar represent the promising cracking process. Molybdenum disulphur (MoS2) catalyst shows good yield; other catalysts are basd on WS2, NiW, NiMo and alumina.

Two process thermochemical cycle extracting H2 from H2S with the help of matels [16].

M + zH2S □ MSz + z H2
MSz □ M + zS
Where (M) represents a metal.

## III. CONCLUSIONS

This paper includes the comprehensive information about the different clean and green methods of hydrogen production. The materials or resources required for the hydrogen production are easily available and mainly these were water, hydrogen sulphide etc. The required input energy for most of the method are driven from renewable source of energy. No any non-renewable source of energy is used in production of hydrogen in any method. In the various experiment performed by researcher on thermochemical cycle (S-I cycle), they were able to generate hydrogen with an efficiency of approximately 45%.

Photo-catalytic water splitting method was able to generate the hydrogen with an efficiency about 32%.High temperature electrolysis is more efficient than room temperature electrolysis which was able to produce hydrogen with an efficiency of 48%. Many of the methods are in developments phases. Researches are still going on for further increment of efficiency of the process. The various factors like cost, efficiency, commercial availability of resources are also considered while selecting any method of hydrogen production.

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