Feasibility Study on Production of Hydrogen from Renewable Sources

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Abstract - *Hydrogen is considered to be a clean fuel. It can be obtained from various domestic resources, such as biomass, natural gas, nuclear power, and renewable energies like solar and wind. Due to the growing need for hydrogen, the hydrogen economy is rising on the political agenda. The natural occurrence of hydrogen cannot satisfy the present need. Hence there is a wide gap between hydrogen present on earth and the current hydrogen requirement. Hydrogen energy is the zero carbon emission energy at the end but, it depends on the production pathway and the energy used for its production. Commercial Hydrogen is produced in industries through various methods. Most hydrogen in India is produced through reforming methane, resulting in significant carbon dioxide emissions. This paper examines the current world hydrogen energy scenario, the methods of production of hydrogen using non-renewable sources, and the economic aspect of hydrogen production through various ways like biomass gasification, Pyrolysis, fermentation, bio photolysis, and electrolysis process.*

Key Words: Hydrogen, Renewable Sources, Biomass Gasification, Pyrolysis, Fermentation, Bio Photolysis.

1. INTRODUCTION

Hydrogen is the most widespread chemical element on the earth and is molecular di-hydrogen (H2). It is expected to be an important fuel in the future that will positively affect the quality of atmospheric air. It can be deployed as an energy carrier to store, move, and deliver energy produced from other sources. It can be obtained from several sources, both renewable and non-renewable, by various processes. Today's most common methods are natural gas reforming (a thermal process), electrolysis, and other methods include other thermal methods and biological processes.

Developing energy systems for the future will be based on emission-free and low carbon sustainable energy sources. Hydrogen as a fuel will play a significant role in solving climate change and energy usage problems.

1.1 World Hydrogen Energy Scenario

Global hydrogen production and consumption is over 55 million tonnes per year [1]. Hydrogen technologies intensified in 2019, is awakening keen interest among policymakers. The fuel cell and electric vehicle markets are almost doubled owing to notable expansion in China, Japan, and Korea. The World Development strategy comparison of fuel cell vehicle and hydrogenation station (Table 1) depicts the current scenario and future development goals of the USA, Japan, China, and Europe.

1.1.1 Hydrogen Energy Scenario in the USA

Demand for hydrogen in the USA could reach around 22-41 million metric tons per year (MMT/yr) by 2050, approximately 10 MMT/yr at present. This would reduce US petroleum use by 15%, and 12 MMT/yr of hydrogen would fuel 18% of cars and 26% of light-duty trucks, with a further 5 MMT/yr fueling 22% of the medium- and heavy-duty vehicle [2]. Nearly all the hydrogen produced in the US is used for refining petroleum, treating metals, producing fertilizer, and processing foods.

1.1.2 Hydrogen Energy Scenario in Japan

In 2020, Japan declared that by 2050 Japan would reduce greenhouse gas emissions to net-zero and achieve a carbon-neutral, decarbonized society. Hydrogen is supposed to play a significant role in Japan's clean energy transformation. Japan was one of the first countries to launch a national hydrogen strategy to make hydrogen cost-effectiveness comparable to natural gas. As per their goals, by 2030, Japan aims to have more than 5 million residential fuel cells, 800,000 hydrogen fuel cell vehicles, and to set up a global hydrogen supply chain. This will result in providing valuable lessons to the international energy community. Japan is well-positioned to push for an internationally shared vision on making hydrogen an excellent energy source [3].

1.1.3 Hydrogen Energy Scenario in China

China is one of the world's largest hydrogen producers. They produce around 22 million tons of hydrogen per year, equivalent to one-third of the world's total. However, most of focus on using green hydrogen to power its fuel cells. Nevertheless, at present, only 3 % of China's hydrogen is made from renewable resources. China is considered a pioneer, and they are aiming for 5,000 fuel-cell vehicles by 2020 and 1 million fuel-cell vehicles by 2030 [4].

TABLE 1

World Development strategy comparison of fuel cell vehicle and hydrogenation station. [4]

Country/Region		Current Scenario	Future Development Goals			
		2018-2022	**2025**	**2030**	**2040**	**2050**
Japan	Hydrogen fuel cell vehicle	2,839	200,000	800,000	6,000,000	
	Hydrogenation station	113	320	900		
United States	Hydrogen fuel cell vehicle	5,899		1,000,000		
	Hydrogenation station	41		200		
EU	Hydrogen fuel cell vehicle	1,033	300,000	1,200,000		5,3000,000
	Hydrogenation station	152	1,500	3,700		15,000
South Korea	Hydrogen fuel cell vehicle	900-67,000			2,900,000	
	Hydrogenation station	14-310			1,200	
China	Hydrogen fuel cell vehicle	2,836	100,000	1,000,000		
	Hydrogenation station	61	350	1,000		

1.1.4 Hydrogen Energy Scenario in Europe

The EU consumes around 8 million tonnes of hydrogen every year, mainly produced from fossil gas rather than renewable power. Therefore Hydrogen technologies will play an essential role in reaching the Green Deal's 2050 net-zero targets by decarbonizing hard-to-abate sectors, according to a study by Hydrogen4EU.

The study states that allowing low-carbon hydrogen to contribute at its full potential and renewable hydrogen could save Europe over €2 trillion ($2.42 trillion) through 2050 [5].

1.1.5 Hydrogen Energy Scenario in South Korea

South Korea unveiled a hydrogen roadmap in 2019 that outlined a goal of producing 6.2 million FCEVs and rolling out at least 1,200 refilling stations by 2040 and announced "Green New Deal" in 2020, which includes investment and construction of three hydrogen cities by 2022, with a further three such cities to be added by 2025. These selected hydrogen cities are expected to provide hydrogen production and shipping infrastructure to serve residents as a primary energy source. Therefore, Korea plans to become Northeast Asia's largest hydrogen hub and further achieve carbon neutrality by 2050 [6]. "In the hydrogen transition, South Korea has strong positions in FCEVs and stationary fuel cells," law firm Clifford Chance said in their report.

1.2 Indian Hydrogen Energy Scenario

The Indian hydrogen market was valued at approximately ₹350 crores in 2017 and is projected to reach about ₹590 crores by 2025, growing at a Compound Annual Growth Rate (CAGR) of 6.3% from 2018 to 2025 [7]. Hydrogen is already used extensively in India, mainly as an industrial feedstock in creating ammonia-based fertilizers.

1.2.1 Methods Used for the Production of Hydrogen

Most hydrogen in India is produced through reforming methane, resulting in significant carbon dioxide emissions.

An alternative means of production is electrolysis, where water is split into its component using electricity. India claims to be one of the first large-scale alkaline electrolysis facilities globally, which produced hydrogen from electricity at the Nangal Facility from 1962.

1.2.2 Ministry of New and Renewable Energy

The Ministry of New and Renewable Energy (MNRE) had seen hydrogen as an area of strategic interest since 2006 when the first Hydrogen and Fuel Cell Roadmap was launched(MNRE, 2006).

More recently, in 2016, MNRE published a report laying out a comprehensive plan for increasing the R&D activity. This included significant funding for different electrolysis technologies and their integration with renewable electricity sources, which has strong potential in India, given the cost and availability of renewable electricity.

1.2.3 Investment Requirement in India

In terms of the investment requirements, if India is to deploy green hydrogen as a clean energy solution for crucial sectors, including transport, industry, and power, by 2050, this would require significant investment in electrolysis. The potential scale of hydrogen use in India is vast, which increase 3 to 10 times by 2050 [8].

2. LITERATURE REVIEW

Production of hydrogen is possible in many ways from the spectrum of initial raw materials available. Presently, hydrogen is mainly produced by the steam reforming of natural gas, leading to massive emissions of greenhouse gases. Around 50% of the global demand for hydrogen is currently met via Steam Reforming Process(SPR), about 30% from reforming chemical industrial off-gases, 18% from coal gasification, 3.9% from water electrolysis, and 0.1% from other sources [11]. Plasma and Electrolyte processes yield a high efficiency for hydrogen production, but unfortunately, they are considered energy-intensive processes.

Steam reforming is one of the most widely used and comparatively cheaper processes for hydrogen production [12]. In the near future, biomass is anticipated to become the most viable renewable organic substitute for petroleum. Biomass is available from a variety of sources, such as animal wastes, municipal solid wastes, crop residues, short-rotation woody crops, agricultural wastes, sawdust, aquatic plants, short rotation herbaceous species (e.g., switchgrass), waste paper, corn, and many others. Another promising method of hydrogen production is Pyrolysis or co-pyrolysis. Raw organic material is gasified at a pressure of 0.1–0.5 MPa in the temperature range of 500–900°C [13]. An Important method for the production of hydrogen in the coming future would be the electrolysis of water; at present, approximately only 4% of hydrogen worldwide is produced by this process [10]. Photo electrolysis is one of the renewable ways of hydrogen production that used solar energy in the electrolysis of water, exhibiting promising efficiency and costs, although it is still in the phase of experimental development. Currently, it is the most effective and least expensive method of hydrogen production from renewable resources. Aqueous phase reforming (APR) is an under development technology to process oxygenated hydrocarbons or carbohydrates of renewable biomass resources to produce hydrogen [14, 15].

In the past, there have been some developments in this process that allowed more efficient and less expensive commercial units due to the changes in the material of reformer tubes, better control, and understanding of carbon limits. Better catalyst and process concepts developed over time.

3. MATERIALS AND METHODS

When we look at the various processes for hydrogen production, the question lies in the advancement of alternative technologies for hydrogen generation to those based on fossil fuels. However, it is not feasible to consider only the environmental aspect. The processes to be taken into account for the future must consider environmental concerns and the most favorable economics.

3.1 Biomass Gasification

Gasification is a process in which organic materials get converted at temperatures generally above 700°C, without combustion, with a controlled amount of oxygen and/or steams into CO, H, and CO.

Gasification technology is commonly used with biomass and coal as a fuel feedstock, and it is very mature and commercially used in many processes. It is a variation of Pyrolysis. Therefore, it is based upon partial oxidation of the feedstock material into a mixture of nitrogen, known as "producer gas," carbon monoxide, carbon dioxide, hydrogen, methane, higher hydrocarbons, carbon monoxide, and carbon dioxide [16].

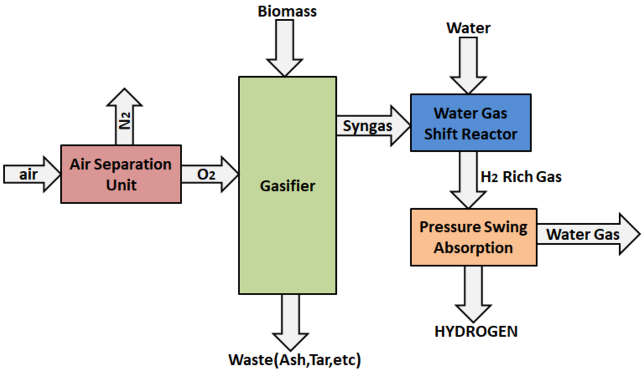

Fig-1: Biomass Gasification (Block Diagram)

3.1.1 Process

A controlled amount of oxygen or/and steam are added into CO, H, and CO. The carbon monoxide reacts with water to form carbon dioxide and more hydrogen via a water-gas shift reaction. The addition of steam or/and oxygen in the gasification process results in the production of "syngas" with an H2/CO ratio of 2/1, the latter used as feedstock to a Fischer-Tropsch reactor to make higher hydrocarbons (synthetic gasoline and diesel) or to a WGS reactor for hydrogen production.

Adsorber or special membranes can separate the hydrogen from this gas stream; the gas may also contain particulate matter, which is removed using cyclones and scrubbers. The particulate-free gas is compressed and then catalytically steam reformed to eliminate the tars and higher hydrocarbons. This is followed by high and low-temperature shift conversion reactions to produce additional hydrogen.

Finally, the hydrogen is separated from other products by pressure swing adsorption (PSA).

The main reactions taking place in biomass gasification are as follows:

$$\begin{array}{ccc} Biomass + heat & \longrightarrow & H_2 + CO_2 + CH_3 + char \quad (1) \\ + & & + \\ steam & & CO + light\ and\ heavy\ HC \end{array}$$

However, the gasification process provides notable amounts of "tars" (a complex mixture of higher aromatic hydrocarbons) in the product gas even operated in the range of 800–1000°C [13]. A secondary reactor, which uses calcined dolomite or nickel catalyst, is used to clean and improve the quality of the product gas using the catalytic action [17].

For hydrogen production, a WGS process can be used to increase the hydrogen concentration, then followed by a separation process to produce pure hydrogen. Superheated steam (more than 900°C) has been used to reform dry biomass to achieve high hydrogen yields.

3.1.2 Challenges with this Approach

One major problem with this technology is that it must use a tremendous amount of resources to gather large amounts of biomass to the central processing plant.

This process typically suffers from low thermal efficiency since moisture in the biomass must also be vaporized. But, it can be performed in a fixed-bed or fluidized-bed reactor, with the latter reactor having typically better performance [17].

Ideally, gasification plants should use oxygen; however, the oxygen separation unit is cost-prohibitive for small-scale plants, limiting the gasifiers to the use of air, resulting in significant dilution of the product and the production of, Low-cost and efficient oxygen separators are required for this technology.

3.1.3 Advantages

Biomass is abundantly available as a renewable source of energy. It is less expensive than fossil fuels. It is clean carbon by-product fuel.

3.1.4 Applications

Currently, removing "tars" to acceptable levels for pure hydrogen production limits the commercialization of biomass-based hydrogen production. Cost-effective hydrogen production may require future development of smaller efficient distributed gasification plants for this technology for cost-effective hydrogen production. Mostly, gasification reactors are built on a large scale, have high logistics costs, and require massive amounts of material to be continuously fed. The efficiencies of the gasification plants are roughly around 70% [18].

3.2 Pyrolysis and Co-Pyrolysis

Pyrolysis is an endothermic thermal decomposition of biomass carried out in an inert atmosphere typically at 450 °C-550 °C. Gasification aims to produce gases, whereas Pyrolysis aims to produce bio-oil and charcoal.

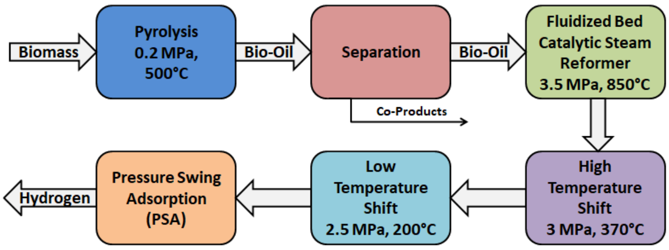

Fig-2: Pyrolysis Process (Block Diagram)

3.2.1 Process

Gasification aims to produce gases, whereas Pyrolysis aims to produce bio-oil and charcoal. Hydrogen can be made by reforming the biomass to a liquid bio-oil in a process called Pyrolysis.

The bio-oil so produced is a liquid composed of 85% oxygenated organics and 15% water. The bio-oil is then steam reformed in the presence of a nickel-based catalyst at 750 °C - 850 °C followed by shift conversion of CO and CO2. The following equation can generally describe the reaction:

$$Biomass \longrightarrow Bio.oil + char + gas \quad (2)$$
$$Bio.oil + H_2O \longrightarrow CO + H_2 \quad (3)$$
$$CO + H_20 \longrightarrow C0_2 + H_2 \quad (4)$$

Here equations (2), (3), (4) are stages of Pyrolysis, reforming, and shift, respectively. Based on the temperature ranges, pyrolysis processes are divided into low temperatures (up to 500°C), medium temperatures (500–800°C), and high temperatures (over 800°C). Fast Pyrolysis is one of the latest processes for transforming organic material into products having higher energy. The products of fast Pyrolysis appear in the entire phases formed (solid, liquid, and gaseous) [13].

3.2.2 Challenges with this Approach

The challenge while using this method of hydrogen production is the potential for fouling by the carbon formed, but some arguments claim that this can be minimized by appropriate design.

3.2.3 Advantages

Some of the Pyrolysis process advantages are relative simplicity, clean carbon by-product fuel flexibility, compactness, and reduction in carbon emissions.

Biomass is abundantly available as a renewable source of energy. It is less expensive than fossil fuels. It is clean carbon by-product fuel.

3.2.4 Applications

The application of co-pyrolysis has received interest in industrially advanced countries, as it should limit and lighten the burden of disposal of waste. Pyrolysis and co-pyrolysis are well-developed processes and could be used on a commercial scale.

Since CO and CO2 emissions are found out to be significantly low, and they can be operated in such that it recovers a significant amount of solid carbon, which is quickly sequestered, Pyrolysis may play an essential role in the future.

3.3 Aqueous Phase Reforming (APR)

Aqueous phase reforming produces hydrogen from biomass-derived oxygenated compounds such as sugar alcohols, glycerol, and sugars. APR is unique in that reforming is done in the liquid phase. The process generates hydrogen without volatilizing water, which represents significant energy savings.

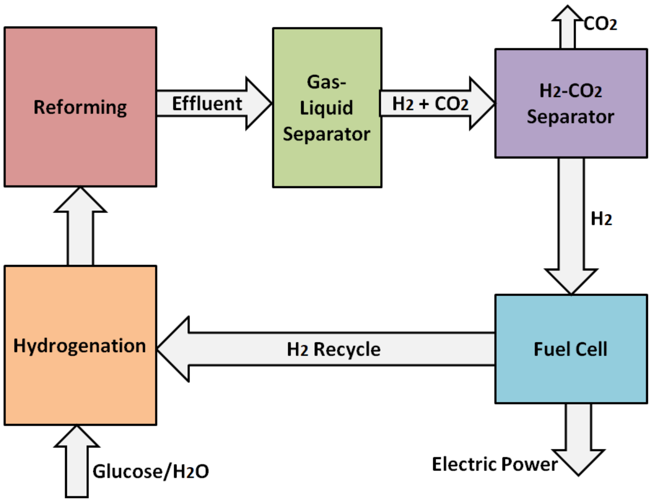

Fig-3: Aqueous Phase Reforming Process (Block Diagram)

3.3.1 Process

APR is a process where hydrocarbons or oxygenates are dissolved in water and react with water molecules in an aqueous phase at substantially lower temperatures (220–270°C) conventional alkane steam reforming (ca. 600°C) and high pressures to form H_2 and hydrocarbons. The low temperatures at which aqueous-phase reforming reactions occur minimize the undesirable decomposition reactions typically encountered when carbohydrates are heated to elevated temperatures. Aqueous feed concentrations of 10–60 wt% were reported for glucose and glycols [13].

APR is unique in itself as in this process, reforming is done in the liquid phase. The basic chemical reactions for APR are presented as:

$$C_nH_mO_n \longrightarrow nCO + mH_2 \qquad (5)$$
$$CO + H_2O \longrightarrow CO_2 + H_2 \qquad (6)$$

Equations (5) and equation (6) depict 'oxidation of oxygenated hydrocarbons' and 'WGS reaction'.

3.3.2 Challenges with this Approach

Catalyst selection is vital to avoid methanation, thermodynamically favorable, along with Fischer-Tropsch products, such as propane, butane, and hexane [14,15]. Most of the researches so far has been focused on supported Group 8 catalysts, with Pt containing solids having the highest catalytic activity. Even though they have comparatively lower activity, nickel-based catalysts have been evaluated due to nickel's low cost [14].

3.3.3 Advantages

It is possible to generate H_2 and CO_2 in a single reactor, as the water-gas shift reaction (WGS) is favorable at the same temperatures as in APR reactions, thus forming low amounts of CO. In contrast, the steam reforming processes require multistage or multiple reactors to achieve low levels of CO in the product gas.

It reduces the need to vaporize water, which provides a significant energy saving compared to conventional vapor-phase steam reforming processes.

3.3.4 Applications

Some researchers claim that this technology is more agreeable for converting biomass feedstock to hydrogen efficiently and selectively.

Recently, Rozmiarek reported an aqueous phase reformer-based APR, which achieved an efficiency of more than 55% with a feed composed of 60 wt.% glucose in water. However, the catalyst was not stable during long-term testing (200 days on stream) [23].

The reactors tend to be somewhat large due to moderate space-time yields. Improving catalyst activity and durability is a domain where significant developments can be made.

3.4 Electrolysis of Water

Hydrogen is produced by the electrolysis of water. In this process, electricity (electro-) is used to break down (negative-lysis) water (H_2O) into oxygen and hydrogen without any harmful or polluting side products. Fig. 4 depicts the Basic representation of the Electrolysis Process.

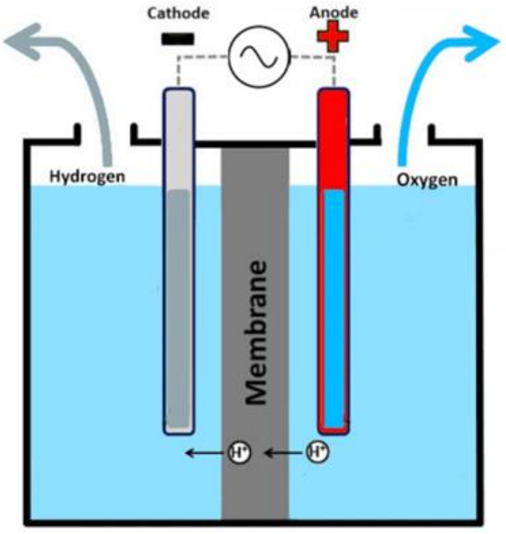

Fig-4: Basic Representation Electrolysis of Water Process

3.4.1 Process

Water electrolysis is when the chemical bonds present in the water molecule break into hydrogen and oxygen using a direct current passing through two electrodes in a water solution. The primary chemical reaction that takes place can be written as:

$$H_2O + Energy \longrightarrow {}^{1}/_{2}\, O_2 + H_2 \qquad (7)$$

At room temperature, the splitting of water is negligible, approximately 10-7 moles/liter, because pure water is a very poor conductor of electricity. Therefore, acid or base is added to improve the conductivity. Sulphuric acid is generally used as the electrolyte in water electrolysis, and the electrodes are of platinum (Pt), which does not react with sulphuric acid. For water electrolysis, the energy is required as electrical energy from a DC power source. In an alkaline electrolyzer, KOH, NaOH, and H2SO, solution is mainly used with water. The solution splits into ions positive and negative ions, and these ions readily conduct electricity in a water solution by flowing from one electrode to the other. Water electrolysis technology can be divided into three subcategories: Polymer/proton electrolyte membrane electrolysis, Alkaline electrolysis, and Steam electrolysis.

3.4.2 Challenges with this Approach

In comparison with the previous methods described, electrolysis is a highly energy-demanding technology.

3.4.3 Advantages

The chemical energy acquired per electrical energy supplied of the electrolysis of water in practice reaches 50–70% [19]. It is essentially converting electrical energy to chemical energy in hydrogen, with oxygen as a valuable by-product.

This process is ecologically very clean because no greenhouse gases are formed, and the oxygen produced has further industrial applications.

3.4.4 Applications

The most common application of electrolysis technology is alkaline-based electrolysis, but proton exchange membrane or polymer electrolyte membrane (PEM) and solid oxide electrolysis cells (SOEC) have also been developed [20, 21]. SOEC electrolysers are the most efficient but still are under-developed. SOEC technology faces difficulties due to corrosion, seals, thermal cycling, and chrome migration. PEM electrolysers are more efficient than alkaline and do not have corrosion problems and seals issues like SOEC; however, they cost more than alkaline systems. Alkaline systems are the most developed and have low capital costs. They have the lowest efficiency; therefore, they have the highest electrical energy cost [13].

3.5 Photo Electrolysis

Photoelectrolysis is also one of the renewable ways of hydrogen production in the phase of experimental development, exhibiting promising efficiency and costs, although it is still in the phase of experimental development. Currently, it is the most effective method and least expensive method of hydrogen production from renewable resources.

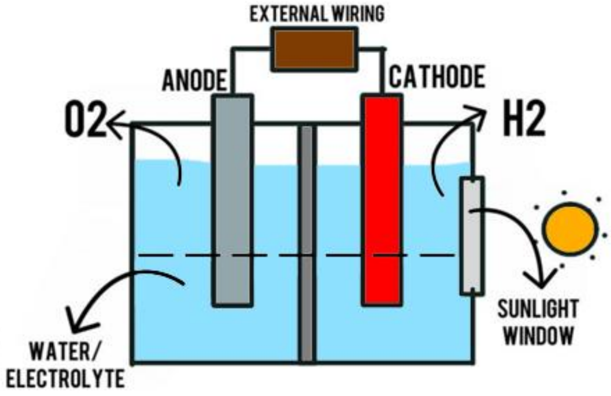

Fig-5: Basic Representation of Photo Electrolysis Process

3.5.1 Process

A photoelectrode is a semiconducting device that absorbs solar energy and creates the necessary voltage and current to decompose water molecules into hydrogen and oxygen. Photoelectrolysis employs a photoelectrochemical (PEC) light collection system for the electrolysis of water to take place. The semiconductor photoelectrode will generate enough electrical energy to support the induced reactions of hydrogen and oxygen if it is submerged in an aqueous electrolyte (exposed to solar radiation).

In the production of hydrogen, electrons are released into the electrolyte, while free electrons are required for the generation of oxygen. Photo-electrochemical (PEC) water splitting is one of the potential techniques for clean solar hydrogen production and has been utilized in small- to large-scale hydrogen generators.

There are three options for the arrangement of photoelectrodes in the assembly of PECS, Photo-anode made of n-type semiconductor and cathode made of metal, photo-anode made of n-type semiconductor, and photocathode made of p-type semiconductor, and Photo-cathode made of p-type semiconductor and anode made of metal.

3.5.2 Challenges with this Approach

The photovoltaic layer is produced from some of the light-absorbing semiconductor materials.

The light absorption of the semiconductor material is directly proportional to the performance of the photoelectrode. Semiconductors with wide bands provide the necessary potential for the splitting of water.

The photoelectrochemical cell is also influenced by the catalytic layers for the performance of the electrolysis and requires suitable catalysts for water splitting. The encased layer is another crucial component of the photoelectrode that prevents the semiconductor from rusting inside the aqueous electrolyte. This layer must be highly transparent to provide the maximum solar energy so that it could reach the photovoltaic semiconducting layer.

3.5.3 Advantages

The photoelectric device eliminates the need for a separate electrolyzer and power generator, which reduces the overall costs and increases the overall efficiency of the system. Photoelectrolysis systems are still in the experimental stage. However, Photoelectrolysis will become an essential means to future hydrogen production because it is powered by renewable solar energy [22]

This process is ecologically very clean because no greenhouse gases are formed, and the oxygen produced has further industrial applications.

3.5.4 Applications

Although This technology is in the experimental and modification stages, it already demonstrates promising efficiency and hydrogen production costs. The Non-renewable hydrogen production methods will only serve as a short-term supply for the hydrogen economy because they offset the benefits of fuel cell vehicles by consuming fossil fuels and emitting greenhouse gases; therefore, methods like Photoelectrolysis are worth investing in.

3.6 Thermo Water Splitting

Thermochemical cycles have been developed since the 1970s and 1980s when they searched for new sources to produce alternative fuels during the petroleum crisis. Hydrogen is widely considered the fuel in the power of nonpolluting vehicles, domestic heating, and aircraft.

The abundant supply of water and sunlight offers us an affordable alternative source to produce hydrogen apart from fossil fuels and biomass.

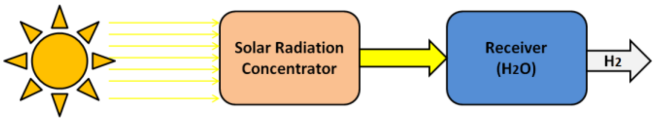

Fig-6: Thermo Water Splitting Process (Block Diagram)

3.6.1 Process

Thermochemical water splitting processes use high-temperature heat (500-2000 °C) to drive a series of chemical reactions that produce hydrogen. The chemicals used in the process are reused within each cycle, creating a closed-loop that consumes only water and produces hydrogen and oxygen. The thermal dissociation of water is described as follows:

$$H_2O + heat \longrightarrow {}^1/_2\, O_2 + H_2 \qquad (8)$$

3.6.2 Challenges with this Approach

An effective technique is needed to separate oxygen and hydrogen to avoid ending up with an explosive mixture. Semi-permeable membranes based on zirconium oxide and other high-temperature materials can be used for this purpose. If the product gas mixture is quenched to lower temperatures, separation can also be achieved. Then, Palladium membranes can be used for effective hydrogen separation.

A material, which satisfies high bandgap and corrosion-resistant, is not available commercially. Therefore, there is a need to process such material. Photo-electrodes should be resistant to undesired reactions.

3.6.3 Advantages

PEC technology depends on solar energy, which is a renewable source.

Photo-voltages are generated on both electrodes in the bi-photo-electrode PEC system interface, resulting in the formation of an overall photo-voltage that is sufficient for water decomposition without the application of a bias. It is environmentally safe, with no harmful by-products. It may be used on both large and small scales.

4. ECONOMICAL ASPECT

In the present scenario, the cheapest and most widely used method for hydrogen production is the steam reforming of methane (natural gas). This method produces about half of the world's hydrogen production, with the cost of production about 7 USD/GJ. Partial oxidation of hydrocarbons provides a comparable price for hydrogen. However, the emission of greenhouse gases generated by these processes must be purified and stored, increasing the hydrogen price by 25–30% must be evaluated [13].

Thus the renewable energy seeks attention that includes thermochemical processes like gasification and Pyrolysis of biomass. The price of hydrogen production from gasification of biomass ranges from 10–14 USD/GJ and that from pyrolysis 8.9–15.5 USD/GJ. The cost of hydrogen obtained is about two to three times greater than the price of hydrogen obtained by the SR process. The final cost of production primarily depends on the equipment, availability, and cost of feedstock [9].

Electrolytic processes can be termed as highly effective when it comes to greener methods of production. It is one of the simplest technologies for producing hydrogen without by-products. Meanwhile, the input electricity cost plays a key role in the price of hydrogen obtained and is relatively high. According to the researchers, "the dominant methods for hydrogen production by the year 2030 will be 3716 catalyzed biomass gasification and steam reforming of natural gas. The use of solar energy in the given scenario is also a possibility. The role of solar energy is predicted to increase by 2050 [9].

5. CONCLUSIONS

Hydrogen is widely considered the fuel for the power of nonpolluting vehicles, domestic heating, and for aircraft. The abundant supply of water and sunlight offers us an affordable alternative source to produce hydrogen apart from fossil fuels and biomass. The development of hydrogen (H2) generation technologies is the topic on which a tremendous amount of research is going on. At present, the most developed and used technology is the reforming of hydrocarbons. Also, Significant developments in other hydrogen generation technologies from renewable resources such as biomass, water, and solar are the current focus to decrease the dependence on fossil fuels. Many processes are under development with minimal environmental impact.

Hydrogen is produced from various feedstock available almost everywhere. These technologies may reduce the world's dependence on fuels that comes primarily from unstable regions. The increase of hydrogen production within the country might increase economic security and national energy. The ability of hydrogen to be produced from a wide variety of feedstock and using various processes may make every region of the world able to have hydrogen energy. Hydrogen may prove to be the most ubiquitous fuel available.

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[7] India Hydrogen Market by Delivery Mode (Captive and Merchant), Technology (Steam Methane Reforming, Partial Oxidation of Oil, Coal Gasification, Methanol Reforming, Ammonia Cracking, and Electrolysis of Water), and End User (Chemical, Petroleum Refining, Metal Processing, Glass Industry, Edible Fats and Oils, Energy, and Others) - Global Opportunity Analysis and Industry Forecast, 2018-2025 at: https://www.alliedmarketresearch.com/india-hydrogen-market accessed on 09/05/2021

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