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Review On Techniques for Hydrogen Generation

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Abstract— **In terms of energy storage medium, energy vector, and fuel for industry, transportation, and other uses, green hydrogen is thought to be the best option for the next energy market. The development of green hydrogen technologies has received more attention over the past 20 years, but even now, a variety of arguments are made to support the hold-up in their widespread use and the depletion of their market. Furthermore, some fresh inquiries are prepared to be made in order to rationalize the postponement of the implementation of green hydrogen technologies. In order to determine the true status of the play, a critical review of recent literature and institutional reports is conducted in this essay. Specifically, the distinct benefits and drawbacks of various green hydrogen technologies (water electrolysis, biomass pyrolysis, gasification, etc.) have been examined and contrasted, with an emphasis on the electrolysis process as the most promising technique for the widespread and large-scale production of hydrogen. Numerous analyses and discussions have focused on the geopolitical and economic factors related to the shift towards a green hydrogen economy, including the potential escalation of the water problem. The aim is to find strategies and resolve issues to expedite this transition.**

Keywords—Hydrogen production, Renewable energy sources (RES), Green hydrogen, Production technologies

1. INTRODUCTION

In methods for producing hydrogen, hydrocarbons, steam, and occasionally air or oxygen are heated before being mixed together in a reactor. Hydrogen can be obtained from both water and hydrocarbons. The process involves breaking down water molecules and hydrocarbons to form H2, CO, and CO. Another approach involves decomposing hydrocarbons into hydrogen and carbon through heating, without the presence of steam or air. It's important to note that hydrogen production requires alternative primary energy sources [1]. As a fundamental necessity to mitigate global greenhouse gas emissions, the transition of energy has emerged as a significant challenge for the coming three decades. Hydrogen holds the promise of being efficiently converted into energy for transportation and industrial applications, devoid of Co_2 emissions. It's regarded as a clean energy source with vast potential for widespread utilization, thereby contributing to sustainable energy systems. As one of the most promising solutions, it offers a pathway to address the urgent challenges posed by contemporary climate change issues [2].

Approximately 50% of the global hydrogen production originates from natural gas, predominantly through steam methane reforming. The remaining hydrogen comes from oil (30%), a significant portion of which is utilized in hydro-processing within petroleum refineries, from coal (19%), mainly for ammonia production, and the remaining 4% is generated through water electrolysis [1]. The future of environmental security and economic growth hinges significantly on meeting the ever-growing energy demands across various sectors, including commercial and residential buildings, transportation, and industry. While energy consumption experienced a decline during the global pandemic until 2020, it rebounded with a 5% growth in 2021. With dwindling energy resources and increasing demand, various approaches have been proposed to tackle this challenge.

The availability, environmental impact, sustainability, and costs of energy have significantly influenced human life over the past century. A wide array of energy sources has been explored, ranging from fossil fuels to nuclear power, hydropower, wind energy, biomass, solar energy, and more [3]. Even now, a considerable portion of the global population resides in circumstances characterized by energy deprivation, with many relying on heavily polluting fuels and technologies. The necessity of a significant reduction in global greenhouse gas emissions (GHG) has been highlighted in the 2018 Intergovernmental Panel on Climate Change (IPCC) special report on the effects of global warming of 1.5°C. Over pre-industrial levels and on these emissions. To effectively counteract climate change, greenhouse gases emission needs to be reduced by at least 45% by 2030[4]. Hydrogen can be produced by different paths, each having a different environmental impact, that is usually associated with a colours attribute. Today, a number of different colours are used to classify the hydrogen according to the $C\,o_2$ emission related to the productions path [5]. Hydrogen is becoming more and more popular among all new clean energy system as shown in Fig. 1. since it is a carbon-neutral substitute that can meet the world's rising energy needs while also taking the environment into account. The intense curiosity about the development of hydrogen production technologies is primarily motivated by its advantageous properties, which include being the most energy dense and lightest chemical element, as well as its high efficiency, renewable nature, high conversion, fast recovery, versatility, cleanliness, large total storage capacity, zero emissions [3].

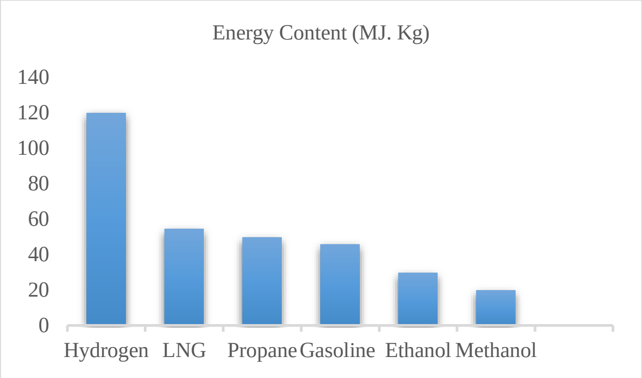

Fig. 1. Energy content of several fuels [3].

The production, transformation, and use of energy have resulted in or are related to a number of environmental problems, such as acid rain, stratospheric ozone depletion, and global warming. Numerous viable remedies for the present environmental issues brought on by the release of dangerous pollutants have emerged recently. Systems using hydrogen energy seem to be among the best options, and they can have a big impact on improving sustainability and the environment. Now days, the primary application is as a chemical rather than a fuel; with 40Mt of yearly production, it represents worth about fifty million US dollars. The majority of its these days, it’s used as a processing agent in chemical manufacturing processes (like methanol, ammonia, and medicines) and oil refineries (like desulphurization and upgrading traditional petroleum) [6]. In nature, hydrogen is not easily accessible. It can, however, be created from any primary energy source and utilized as fuel, either directly in an internal combustion engine or indirectly combustion engine or in a fuel cell, with the only byproduct being water. Being the only fuel that is carbon-free and has the largest energy content of any known fuel, Worldwide recognition exists for hydrogen as a secondary renewable energy source that is less harmful to the environment than fossil fuels [7]. Hydrogen is essential in numerous chemical sectors like petroleum, ammonia production, and oil sand extraction, among others. Additionally, it serves as a clean fuel for transportation, aids in the production of nitrogen fertilizers, and plays a role in semiconductor manufacturing, pharmaceuticals, aerospace technology, and more. Fig. 2. outlines the current and future uses of hydrogen. The historical shift from traditional fossil fuels to emerging fuel sources highlights hydrogen's significant potential in meeting present and future needs for clean energy. This potential is due to its high "greenization factor" (GF = 0–1, where higher values indicate lower greenhouse gas emissions) along with its other advantageous properties [3].

While hydrogen is considered "green" when produced without Co_2 emissions, the most advanced and widely adopted technology for this is electrochemical water splitting, also known as electrolysis. Therefore, the prevailing definition of "Green Hydrogen" refers to hydrogen created through electrolysis using renewable electricity. This particular definition is commonly found in documents and articles that view electrolysis as the preferred and primary method for future hydrogen production [5]. Green hydrogen, or hydrogen produced from renewable resources, is one potential source of zero-carbon hydrogen. Short-term geopolitical concerns associated with oil and gas are reduced by renewable energy. New opportunities for hydrogen have evolved as a result of the intermittent nature of solar and wind power, which has increased electricity generation from renewable sources and its momentarily cheap spare capacity. This is particularly true given the growing need to find a long-term solution to the issue of excess electricity storage [2].

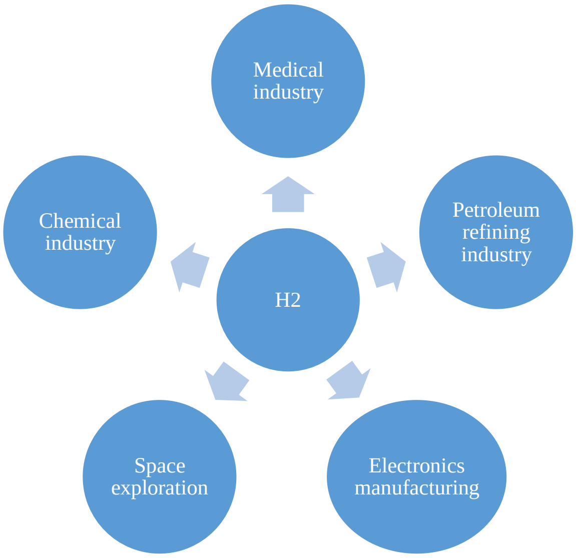

Fig. 2. Wide application of hydrogen in the industry.

2. Green hydrogen production technology

Different techniques and technologies can be used to manufacture hydrogen from both renewable and fossil resources. As previously stated, "green hydrogen" is typically thought of as hydrogen produced using a renewable energy system (RES). While the absence of Co_2 emissions—that is, hydrogen produced by carbon-neutral or renewable-source technologies—is the general definition of green hydrogen [5]. The two most developed methods for producing hydrogen from renewable energy at the moment are biogas steam reforming and water electrolysis. The creation of hydrogen can be based on biofuels like biogas or electrolysis using renewable energy sources like solar, hydropower, and wind. Electrolysis using hydro or wind power is one of the best hydrogen production technologies when looking at life cycle assessments [2].

A. Steam reforming of bio-feedstocks

Using methane as a fuel, the well-known process of steam reforming produces a significant portion of the hydrogen needed for industrial uses today. It is a hydrocarbon, and water vapor reacts catalytically. When methane is present, the process can produce reforming gas, which is a gas combination of carbon monoxide, hydrogen, and carbon dioxide. The foundation of most industrial systems is a tubular reactor filled with catalyst particles, such as nickel particles, supported on alumina silica, activated by $K2_o$. The reactant stream laps the catalytic particles at a temperature of around 850–870 °C on average. The method works with a variety of hydrocarbons, including glycerol, methanol, ethanol, and methane.

The most common feed material is methane, and steam methane reforming (SMR) is a low-cost technique available today. for extensive industrial uses. To boost the hydrogen yield in accordance with the process to be fed, steam reforming and the water gas shift reaction are frequently combined. For instance, the manufacturing of methanol and synfuel mostly uses reforming gas. However, there is a net Co_2 emission when using natural gas (methane) and other fossil fuels to make hydrogen, which is known as "grey hydrogen." With this procedure, pure hydrogen must be produced by separating it from the other reforming gas constituents. Through this process of separation, it is also possible to record the generated Co_2 and to use a procedure known as Co_2 sequestration to get rid of it in some way (such as in an exhaust oil field). A clean type of hydrogen known as "blue hydrogen" can be produced through Co_2 sequestration; however, doing so will require managing Co_2 in any case and adding expenses to production. It will be carbon neutral when using biogas, bio alcohols, or biooils, and the hydrogen produced can be referred to as "green hydrogen"[8-10].

TABLE 1. PRIMARY ENVIRONMENTAL FEATURES OF GREEN HYDROGEN TECHNOLOGY

Production Technology	Advantages	Drawbacks
Steam Reforming of bio-feedstocks	Excellent conversion efficiency, no need of oxygen and established technology utilized in natural gas production.	There are Co_2 and CO emission despite being carbon neutral.
Biomass Pyrolysis	Utilizing waste biomass and low-water-content leftover as feedstock, no oxygen is required.	Despite being carbon neutral, emission of Co_2 and CO exist; tar formation must be treated, and management is difficult.
Water Electrolysis	No direct emission; the only byproduct is oxygen.	Green energy must be inexpensive and have a low conversion efficiency of roughly 60%
Direct production by biological processes	Maney different type of garbage could be utilized as feedstock; potential applications Co_2 as a cofeedstock has the potential to yield beneficial byproduct.	Low manufacturing density, low level of development of technology, and pre-treatment of the feedstock needed to meet the requirement of the microorganisms used.
Biomass Gasification	Biomass residue and wastes are used as feedstocks	Despite being carbon neutral, Co_2 emission occur; exit gases are post-treated, and the remaining funds are asked for.

The technology of steam reforming has been extensively evaluated and is still in use; however, there is a need for improvement. The least expensive method for producing hydrogen these days is methane steam reforming, although the grey hydrogen is the end product. Though not entirely prevented, emissions can be significantly decreased by absorbing Co_2 . Additionally, this type of hydrogen is unsuitable for use in fuel cells and other applications that call for extremely pure hydrogen, necessitating further procedures for separation. Steam reforming, which uses bio-hydrocarbons as feedstock, can be regarded as environmentally friendly, but in order to achieve pure hydrogen, a variety of purification processes, including hydrogen separation, will be necessary. Metal membrane reactors are one way to address this issue. When using metal membrane reactors for the process, the reactor itself actually separates the hydrogen from the other reforming gases [11].

B. Biomass gasification

The chemical process of gasification transforms carbon-rich materials, such as coal, oil, or biomass, into a gas mixture known as "syngas" that contains carbon dioxide, carbon monoxide, hydrogen, and other gaseous materials. The method has been known and employed since the 19th century, when it was mostly utilized to provide the city with gas, which is a mixture of roughly 50% hydrogen, 3-6% carbon monoxide, and the balance such as carbon dioxide and methane. Extreme circumstances were met to manufacture city gas from coal: 30 bar or higher and temperature as high as 1200°C [12]. The process involves burning the feedstock with low oxygen levels (referred to as "partial oxidation") and steam; it is typically done at temperatures between 700 and 800 °C [12, 13]. In this instance as well, blue hydrogen can be created by using fossil fuels that have been properly cleaned. The method is carbon neutral if biomass is utilized as feedstock, and the green hydrogen is produced during the purification of effluent gases. Due to the exothermic nature of combustion, which releases a lot of energy as heat, cogeneration processes make this technology extremely intriguing [14]. Cogeneration of heat and power is of particular relevance when considering the release of high-temperature heat during the process [15, 16]. Furthermore, the biomass feedstock cannot be dried because steam is required. Ref provides a schematic and in-depth study of the various gasification reactor technologies [17]. The regulation of biomass quality and water content, ash management, and syngas quality are among the problems preventing the technology for producing hydrogen by biomass gasification from spreading. control, hydrogen production through syngas purification, hot gas management, and reuse. In addition, the reforming of liquid residuals yields a variety of oxygenated, chlorinated, and sulfurized compounds in relation to the starting material (commonly referred to as TAR), as well as paraffins, isoparaffins, olefins, and aromatic hydrocarbons. The management of these residuals gives rise to socio-environmental problems [18].

C. Biomass pyrolysis

Pyrolysis is a heat treatment method that involves thermal breakdown without the use of oxygen. Many organic compounds can be converted into energy using it, provided that they have less than 15% water by volume. The pyrolysis reaction is typified by extremely intricate chemical reactions that transpire within the 400–800 °C temperature range. The following are the by-products of the breakdown reaction:

- solid fraction: 20–30% of the original material's weight, primarily carbonaceous. It can be used as fuel since it has a good calorific value of 8000 kcal/kg.
- Weight-based liquid fraction (TAR): 50–60%. About 22–23 MJ/kg of energy are present when dry, and 16–18 MJ/kg when 20% water is present;
- The gaseous fraction, also known as pyrolysis gas, is made up primarily of light hydrocarbons, carbon dioxide, hydrogen, and carbon monoxide. It makes up 15–30% of the total weight. Its calorific value is medium-high.

The balance between the production of carbonaceous residue, syngas, and bio-oil is determined by how the pyrolysis process is carried out

- Conventional pyrolysis takes place at moderate temperatures (around 500 ◦C), with long reaction times, and it results in a balance of the three fractions;
- Vegetable charcoal has been produced by carbonization, the earliest and most well-known pyrolysis technique, since approximately 2500 years ago. Temperatures between 300 and 500°C are when it happens, and only the other fractions are reduced while the solid fraction is recovered.
- In order to minimize the reforming of intermediate compounds and promote the synthesis of the liquid fraction up to 70–80% by weight of the product, fast pyrolysis is carried out at temperatures between 500 and 650 °C.
- With contact periods of less than one second and temperatures above 650 °C, flash pyrolysis is performed to encourage the creation of the gaseous fraction.

Despite being well-known and extensively researched, there are a number of problems that prevent this technology from being widely used. First and foremost, a well-characterized biomass feedstock is essential for a well-regulated system and goods caliber. The simplest feed characteristics—particle size, density, and humidity, for example—have an impact on the system's efficiency as well. This highlights the requirement for proper pretreatments, which must be customized to the biomass being used, whether they be chemical, physical, or biological. Moreover, heat, bio-oil, biochar, and gases are the byproducts of pyrolysis. The products must be post-treated by a reforming process in order to obtain hydrogen in the gas and liquid phases procedure. Last but not least, storing biomass creates serious fire hazards for huge plants, and collecting biomass requires a sizable area. This final point raises new expenses and problems with regard to the pre-treatment, storage, and transportation of biomass [19,20].

D. *Electrolysis*

Direct electric current (DC) is used in the electrochemical process of electrolysis to propel a chemical reaction down a non-spontaneous reaction path. Specifically, water electrolysis makes it possible for water to divide into oxygen and hydrogen ($H2_o$). There won't be any Co_2 emissions if the water electrolysis is completed only with RES electricity. Additionally, this technology has been around for a while and is used in industry [21-23]. mostly for manufacturing procedures needing extremely pure hydrogen. Approximately 8 kg of oxygen are created for every kg of hydrogen produced by electrolysis, requiring 50–55 kWh of power and about 9 kg of pure water (depending on the electrolysis process). However, oxygen is typically not taken into account when evaluating costs for hydrogen; only in the last few years has the valorization of oxygen been taken into account[24,25,26,27]. Water electrolysis is becoming more and more popular as a result of the widespread use of PV and wind technologies that transform solar and wind energy into electricity, as well as plans to move to 100% renewable energy sources for energy. is said to be the best method for producing hydrogen [5].

E. *Direct production by biological processes*

Although the use of microorganisms for waste treatment and biomass transformation dates back thousands of years, it has only been thoroughly researched and developed in the last few centuries. Currently, considering energy, petroleum fuels, biogas, alcohol, and biofuels rank as the main products. Green hydrogen can be produced directly from organic feedstocks using certain microbes, as previously documented, or by reforming these products [28-30]. Technologies such as dark-fermentation, photo-fermentation, photolysis, and Co_2 gas-fermentation are applicable based on the particular microbe. When fermenting, Anaerobic microbe metabolism leads to the evolution of hydrogen. Furthermore, this method of carbon dioxide capture and conversion can be applied in situations where Co_2 serves as a feed for the culture. Both bacteria and algae are used in photolysis, in this instance under anaerobic conditions, to either directly photolyze water or to fix Co_2 while releasing hydrogen. These technologies are intriguing because they provide a means of producing hydrogen from waste materials that contain organic components such as sugars, starches, cellulose, acetate, and wastewater. However, they have some problems with large-scale application, such as the size of the bioreactors, the rate at which hydrogen is produced, the management of the population of microorganisms against infection by rival microorganisms and mutation, and the need to pretreat wastewater before using it [28-30]. Apart from the aforementioned methods for producing green hydrogen, several approaches, such as direct solar water splitting and electrochemical reforming of biocompounds, are being investigated [31-34]. These procedures are not covered here because, despite their potential, they are still in the early stages of development and will need additional study to be ready for commercialization. It's noteworthy to note that, when discussing green hydrogen, water electrolysis is typically the sole method taken into account. This is because electrolysis depends on the availability of electric power, a requirement that strengthens the connection between electrolytic hydrogen and RES [5].

CONCLUSION

The objective of this study was to examine all currently existing and large-scale application-ready technologies in order to find potential strategies and solutions for the widespread deployment and usability of green hydrogen. The focus was not on analyzing the infrastructure requirements or the cost of hydrogen, in contrast to other assessments that have been done in the literature. Rather, a technical-economic and social examination of potential challenges associated with the green hydrogen economy was carried out.

There are other techniques to make green hydrogen besides electrolysis. This links markets and social concerns that are currently only loosely connected and appear to be independent of one another, introducing a revolution to current energy and social policies. This is due to the fact that hydrogen is both a feedstock and an energy source that, when oxidized, produces water. Therefore, it is essential to have a very wide view of all the available technologies and how these can correlate with each other in order to manage politically the transition from the existing fossil fuel-based economy to one based on hydrogen and energy from renewable sources.

Analogously, a limited perspective while articulating the potential consequences of the hydrogen economy may cause one to concentrate on incidental issues while disregarding actual and prospective issues. Taking into account the aforementioned factors, the authors contend that a proper green hydrogen economy necessitates striking a balance between distributed and centralized production, as well as between local and global environmental interests and social concerns.

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