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Is Green Hydrogen a Potential Sustainable Fuel?

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Abstract – Environmental and anthropogenic factors engendering the rise of environmental carbonization have led to a global growing appetite for introducing the use of sustainable energy in governmental policies. Nowadays Green hydrogen has been brought in the spotlight and recognized as a green alternative to fossil fuels because it is presently enjoying a momentum widespread in Markets, countries, and companies. Hydrogen /energy have shared a long period of history during which hydrogen has gained a great chunk of support from different countries though the wrong starting point. If it is competed by other sources of energy green it has been then adopted as the best energy source in several countries such as Germany, China, the USA, Japan…..because hydrogen is regarded as a 'missing piece in the carbon-free energy puzzle': it is a clean energy career which its sustainability and versatility contributing in decarbonizing the environment due to its near-zero carbon missions, as well as a cost-effective production, and as a cutting edge sustainable and technological production, especially in the domain of mobility. That is why it is used as a fundamental fuel in various applications: energy storage, mobility, and in the industrial field, through three types of processes: thermochemical, electrolytic, and biological Processes. Although green hydrogen is recognized as a promising energy vector, it has some drawbacks that 'should be borne in mind' such as high production costs, and greenhouse gas emissions.

Keywords – Green Hydrogen, Causes, Applications, Processes, Advantages, Challenges

I. INTRODUCTION

Today, the energy matrix becomes of deep humanity concern. Since rising energy demands, erratic fossil fuel prices, and significant greenhouse gas (GHG) emissions from fossil fuel-powered vehicles and industries are the main causes of this global utmost importance (i). In fact, The foreseeable fossil fuel running out and the hazardous pollutant emissions combustion of organic compounds such as COx, NOx, SOx, CxHx, soot, ash, droplets of tar, and others are released into the atmosphere (ii) (ii)), have led the global community to strive to realize 2050 goals aiming at of decarbonizing the planet by adopting new carbon-free energy sources as the green hydrogen. The latter is recognized as the only other carbon-neutral source being seriously considered for use in many countries for low-carbon transportation, industrial decarbonization, and heat (iii).

II. DEFINITION OF GREEN HYDROGEN

There is no unanimous definition of green hydrogen, making adoption of a renewable energy alternative difficult. To describe a sustainable hydrogen source, NREL coined the term “green” or “renewable” hydrogen (1). The term “black and brown” hydrogen refers to hydrogen derived from fossil fuel feedstocks (2) (3) (4) (5) (6) and nuclear power (3) (4). (5). Green hydrogen can be produced from industrial residual gases (7), renewable electricity via electrolysis, and derived e-fuels (8), resulting in reduced gas emissions in sectors where direct electrification is not feasible (9) (10). However, everyone agrees that renewable pathways are necessary to generate green hydrogen.

Green hydrogen can be obtained by utilizing the electrolysis chemical process to produce hydrogen. Using an electrical current, the process separates hydrogen from oxygen in water. If this electricity thus is obtained from renewable sources, it will result in zero carbon emissions into the atmosphere. According to the International Energy Agency, this method of obtaining green hydrogen would save the 830 million tonnes of CO2 emitted annually when this gas is produced using fossil fuels. Similarly, replacing all grey hydrogen in the world would necessitate 3,000 TWh/year of new renewables, which is equivalent to Europe's current demand (22).

III. History of Green Hydrogen

It was expected that hydrogen energy will be fused with the cutting-edge development of computers and telecommunication in the 21st and 22nd centuries (11).

There have been several waves of popularity for hydrogen over the last five decades, but so far they have all ended in failure. Interest in hydrogen's potential began to grow in the 1970s due to oil price shocks, oil scarcities, and growing environmental consciousness, especially concerning car manufacturing and usages pollution.

In the 1970s, several academics and engineers argued that hydrogen produced from coal or nuclear electricity had the potential to become a renewable resource, primarily in the transportation sector. This eagerness resulted in the establishment of new hydrogen projects and organizations, such as the International Energy Agency's Hydrogen and Fuel Cell Technology Collaboration Program, founded in 1977, and the International Journal of Hydrogen Energy, founded in 1976. Nonetheless, as oil prices fell, gas and oil resources became abundant, and air pollution was managed in other ways, the desire for a new energy source faded. As a result, hydrogen adoption has been delayed. (12)

Because of growing concern about climate change, a new great concern for hydrogen adoption arose in the 1990s and early 2000s, focusing primarily on the transportation sector, but with a greater emphasis on hydrogen's environmentally friendly characteristics and a strong emphasis on carbon capture and storage. During this period, nations and corporations began to invest in hydrogen, believing in its long-term viability as a new alternative energy source. In addition, in 1993, Japan invested JPY 4.5 billion in a long-term renewable energy-based international hydrogen trade program. The previous year, in 1992, the EU Commission and the Government of Quebec funded a good deal of hydrogen pilot programs in collaboration with industries and research centers to investigate the potential of this new energy source in urban transportation and international shipments. Several automakers, including GM, Toyota, and DaimlerChrysler, have announced plans for the development of hydrogen cars in the wake of investment opportunities and the ongoing advancement of fuel cells. (13)However, interest in hydrogen has once again faded, owing to disappointment in climate policy implementation, high costs of hydrogen infrastructure, and the development of battery electric vehicles. (12)

‘History teaches us not to repeat the mistakes of the past’. Today's enthusiasm may differ from previous waves, with hydrogen finally gaining long-term traction. Hydrogen has regained popularity. The European Commission recently released a hydrogen strategy, followed by Germany, Japan, Australia, and other countries with their hydrogen national strategies - all of which included specific implementation plans for a hydrogen economy. This eagerness stemmed from the fact that:

- First, larger hydrogen applications are being noticed today than in the past.
- Second, there has never been more public support for renewable energy.
- Third, the Covid-19 pandemic has hastened a geopolitical shift that will necessitate the development of new energy sources.

Fig.1 World's Green Hydrogen Producers

From:Chile and its Potential Role Among the Most Affordable Green Hydrogen Producers in the World,2022

I.V REASONS FOR GREEN HYDROGEN ENERGY ALTERNATIVE

Researchers unanimously agree that there are four main reasons to adopt green hydrogen as a viable sustainable transition energy, which are (14) :

A. Global Commitment to Regulate Climate Change

Owing to a global commitment to finding solutions to the climate change problem, many countries are attempting to meet their energy supply-demand by looking for a new sustainable source of energy as an alternative to conventional energy sources. As a result, world governments, corporations, and investors have agreed toallocate significant funding for addressing the challenges of green hydrogen energy adoption.

B.Price Reduction of Renewable Energy Sources

Renewable energy costs are falling, closing the price gap between electrolysis hydrogen and fossil fuel hydrogen. Furthermore, because it is renewable and always available, green hydrogen has the potential to become a component of the national energy system. Hydrogen and fuel cell technologies are cutting-edge development.

C.Great Strides in Hydrogen and Fuel Cell Technology

Hydrogen and fuel cell technologies have advanced significantly in terms of efficiency, durability, dependability, and cost reduction. Both are already significantly cheaper, more durable, and more efficient than during the previous fuel cell boom cycle in the early 2000s (15) when cost increases were deemed necessary for global expansion. As a result, corporations' focus has shifted from research and development to the ability to increase industrial output. These advancements are actively helping to close the price gap between electricity generated by fuel cells using green hydrogen and electricity generated by fossil alternatives such as diesel in some areas.

D.Worldwide shift toward electric sustainable mobility :

The global shift toward electric mobility has resulted in the use of hydrogen and fuel cells to provide long-range zero-emission applications such as trucks, trains, maritime shipping, buses, commercial vehicles, and possibly aviation. With the use of electric drive train design and providing good quality air emission by decision-makers, hydrogen and fuel cells have the potential to reduce costs while also mitigating heavily loaded pollution in many developing-country cities.

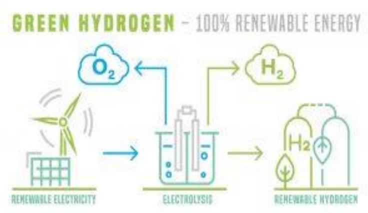

Fig. 2 Green Hydrogen Renewable Energy generation

From : https://www.innovationnewsnetwork.com/

V.APPLICATIONS OF GREEN HYDROGEN

1) A vast array of green hydrogen applications are currently available in different domains. The

following are the five major clean hydrogen usages (16) :

A. Hydrogen Feedstocks

2) Nowadays, hydrogen combustion emits water, but it is very carbon-intensive. That is why switching to hydrogen feedstock has emerged as a new alternative to fossil fuel-based hydrogen production. Green hydrogen production is the result of the electrolysis process of renewable energy power. The total US green hydrogen production could reach around 10 megatons in 2015, with a projected increase of 14 megatons by 2030. The global production of pure hydrogen is estimated to be around 75 MtH2/yr, with an additional 45 MtH2/yr as part of a gas mixture. This amount is equivalent to 3% of global final energy demand and is fairly similar to Germany's annual energy consumption. Green hydrogen is primarily used in the chemical industry and refineries, as part of a gas mixture in steel production, and in the generation of heat and power. The demand for feedstocks is slightly higher in the industrial manufacturing sectors (more than 50 Mt H2). About 45 Mt H2 of the demand is met through chemical processing, which includes three-quarters ammonia and one-quarter methanol, with the remaining 5 Mt H2 used as direct reduced iron (DRI) in the steel-making process(14) (16) (18) (19).

B. Residential and Commercial Heating Systems Applications

3) By combining green hydrogen with natural gas, clean hydrogen can be used to decarbonize residential and commercial heating systems, which are regarded as the most carbon-emitting sources in many countries. This operation can be feasible where natural gas prices are relatively high. In the residential field, green hydrogen focuses on the installation of residential fuel cells that use heat and power units. The latter has recently shifted from PEM to SOFC to benefit from the higher efficiency and operating temperature of SOFC. The Japanese Ene-Farm project has achieved astounding success in the use of clean hydrogen in the residential sector. Over the course of more than ten years, the project resulted in over 300,000 units being deployed domestically, creating the largest Japanese market. Furthermore, while this type of residential system is based on the use of natural gas, the Thailand company « Enapter » is currently the leader in the construction of 100% renewable homes using green hydrogen and fuel cells. Moreover, this new trend is spreading to schools and office buildings, where clean hydrogen and fuel cell systems are being combined with solar PV to provide renewable energy 24 hours a day, seven days a week. SP Group, a Singaporean company, has introduced in its training center a 100% renewable, off-grid, hydrogen-based system (14) (18).

D. Energy applications

Green energy has recently been demonstrated by scientists to be a cost-effective backup power supply option to fuel cells for powering various infrastructures in the event of a power outage. As a result, economies can benefit from long-term energy backup applications, cost savings, and efficiency gains (20) (21). Furthermore, recent studies have revealed that the capacity of green hydrogen storage energy can persist for more than 13 hours (18). In the sector of telecommunication, Continuous telecommunication operations, repeated power access lack of grid power, and security issues relating to diesel theft are issues that have led many developed and developing countries to adopt green hydrogen to store energy by combining green hydrogen with direct air capture/carbon capture techniques to store energy. This feature is essential since ammonia (and methanol) are more easily obtained and stored than hydrogen (14). In remote areas, depending on the mini-grid diesel generators, one can have benefited from the new green hydrogen supplier invented by the Belgian company called Tiger power providing off-grid power by using both hybrid solar PV and green hydrogen solutions. The hydrogen is produced and stored from excess PV for usage by a fuel cell during the evening (14).

E.Transport Applications

Efforts to improve decarbonization mobility are becoming more prevalent these days. As a result, various fuel cells vehicles such as cars, trucks, buses, ships, and planes are now available. They are distinguished by being more efficient in providing a quantity of energy than electric batteries in heavier-duty applications of numerous vehicles due to their lower total system weight and faster fueling time, and they are not greatly influenced by external temperatures, saving them from various reductions due to abnormal conditions as well (14). According to recent statistics, approximately 3000 fuel cell buses and trucks are spread throughout the world (24) with over 12.000 cell passenger vehicles, particularly in Japan and the United States, and only two types of hydrogen trains are operating in China and Germany (25). Geman's hydrogen-powered ship was the first internal vessel in 2006, and the first hydrogen cross-ocean ship was scheduled to launch in 2021 (14). Terms of hydrogen mobility stations, they are becoming more prevalent than in previous years, and they can refuel hundreds of vehicles (14). Haskel confirms that the world's largest hydrogen refueling station is in China, with 1.5 tonnes of hydrogen and the ability to supply 74 fuel cell buses with hydrogen per day (26).

F.Industrial Applications

Today hydrogen is primarily used in the industrial sector. Industries are increasingly interested in using green hydrogen to reduce the carbon footprint of their industrial heating needs (14). such as in ammonia production, steel production, synthesis gas for fuel production, methanol production, and hydrocracking and hydrogenation processes in oil refining (27). Hydrogen industrial and chemical productions are the main hydrogen market productions, particularly with ammonia, gasoline refining, and methanol production. Furthermore, several companies are exploring the use of green hydrogen in steel and glass manufacturing processes (14). Moreover, green hydrogen is presently used in metal processing to reduce iron. According to Air Liquid, the hydrogen consumption in this type of plant ranges between 36 -720 tonnes per year (28).

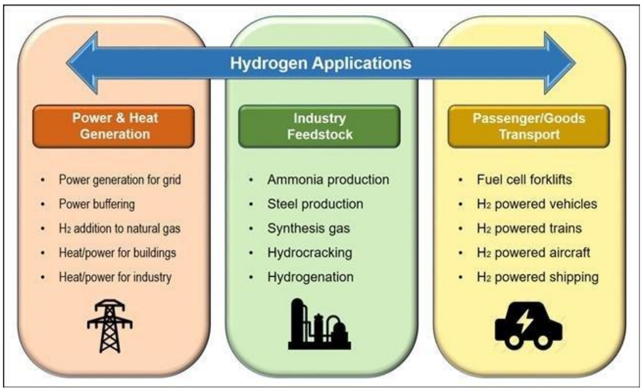

Fig. 3 Green Hydrogen Applications (adpted from Jurie steyin,Christine render,2020)

VI. GREEN HYDROGEN PROCESSES

Though the hydrogen alternative is suggested as the future source of renewable fuel, it is possible if it is processed with eco-friendly methods (29). There are three types of hydrogen: grey, blue, or green(30). Grey and blue hydrogen is produced from fossil fuel but the blue one is less harmful than the grey due to the captured and stored carbon dioxide (31), whereas the green type is the most friendly environmental kind. Several methods are proposed to produce green hydrogen as The steam reformation of fossil fuels, and biomass gasification. But they are found they are not free-carbon emissions (31). The following three pathways are considered 100% sustainable sources of green hydrogen :

A. Thermochemical Processes

The thermochemical water splitting process is set to produce green hydrogen It is a pathway in which thermal energy is generated from two sources: concentrated sunlight solar radiation and renewable electricity, which is required in remote areas for hydrogen production(33) (34). This method is carried out as follows: At temperatures above 2000 degrees Celsius, water thermally decomposes into hydrogen and oxygen. The process employs redox materials, which reduce the required temperature to less than 1000 C (37) (38). This redox-material-based thermochemical water-splitting reaction cycle occurs at temperatures ranging from 900 to 1500 degrees Celsius (34). There are two reactions in the thermochemical water splitting cycle: thermal and oxidation. The first occurs at a higher temperature than the second one (39) (40) (41). As a result, water and reduced redox reactions produce redox material and hydrogen (34). One of this method's main benefits is that no catalysts are needed during the procedure to start or speed up individual reactions. In addition, every thermochemical water-splitting cycle chemical element—aside from water—is recovered and recycled during the production of hydrogen. Other advantages of hydrogen include its ability to produce free-flowing membranes for gas separation, its need for moderate temperatures between 600 and 1200K, and its lower rate of power input requirement (42).

B. Electrolytic Processes

The Hydrogen Electrosis pathway is a promising technique for producing carbon-free hydrogen from renewable and nuclear sources (43). The process uses an apparatus called an electrolyzer to electrically split water into hydrogen and oxygen (43). The electrolyzer ranges from a large or small scale and is a sustainable source of energy (43). Electrolyzers can operate in a variety of ways, including (43) solid oxide electrolyzers, alkaline electrolyzers, and polymer electrolyte membrane electrolyzers. Although it costs money to implement, the hydrogen electrolysis pathway is worthwhile. Especially because many power grids are not ideal for producing electricity due to the high fuel requirements and released greenhouse gases (43). These hydrogen electrolytic processes help to decarbonize the environment and protect it from various harmful pollutants (43).

C. Biological Processes

Today, extensive research is being done on hydrogen processing, particularly in the area of using renewable energy sources (45) (46). Production of hydrogen through biological means is better than production through thermochemical and electrochemical means. Biophotolysis (direct and indirect), photo fermentation, dark fermentation, a combination of dark and photo fermentation, and biocatalyzed electrolysis are all methods for producing biohydrogen. (44). By using a process known as "dark fermentation," anaerobic bacteria can produce hydrogen from biomass-based natural bacterial communities by fermenting carbohydrates and releasing H2. The process is carried out in straightforward fermentation tanks that use direct carbon sources like fermentable sugars, second-generation biomass from crops, or animal byproducts from livestock, ... Although the process degrades natural materials and frequently produces the pollutant elements methane and carbon dioxide (47), hydrogen can be produced efficiently with only carbon dioxide when non-hydrogen-producing bacteria are eliminated through pre-treatment (48). (49). Additionally, unlike with gas reforming PEM fuel cell electrocatalysts, the produced gas mixture, which contains hydrogen and carbon dioxide in a ratio of about 2:1, is useful for a PEM fuel cell process hardly without purification operations and zero carbon monoxide. (50)

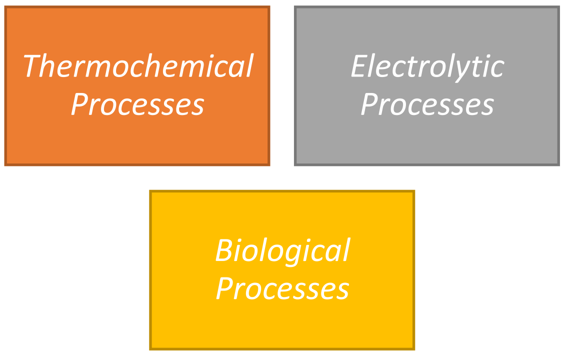

Fig. 4 Green Hydrogen Processes

VII. ADVANTAGES AND CHALLENGES OF GREEN HYDROGEN

A. Advantages

The 2015 Paris agreement recommendations aiming to decarbonize the energy system have led decision-makers to be convinced that green hydrogen is the ' holy grail for decarbonization' and paved the way to consider it as the 'future energy mix (51)'. Namely, certain sectors require heavy energy and are difficult to be decarbonized only by using green hydrogen such as aviation, shipping, long-distance trucking, and concrete and steel manufacturing (52). The following are the advantages of green hydrogen :

Hydrogen is bountiful in supply

The simplest element is hydrogen. Hydrogen atoms only contain one proton per atom. The most prevalent element in the universe is hydrogen. Hydrogen makes up the majority of stars like our sun. In essence, the sun is a huge ball of hydrogen and helium (53). One of the main benefits of hydrogen as a source of energy is its abundant supply. No other energy source is as limitless as hydrogen, despite the fact that it may require a lot of resources to harness (54). Long-term storage of hydrogen offers the possibility of decarbonizing the industrial energy sector and greatly enhancing building energy efficiency. Experts have also noted how hydrogen fuel cell vehicles can be used in conjunction with electric vehicles to assist in decarbonizing the transportation sector (55).

Hydrogen is produced locally

Several domestic energy sources, including natural gas, nuclear energy, biomass, and renewable energy sources like solar and wind, can be used to produce hydrogen. It is a desirable fuel choice for transportation and electricity generation applications because of these characteristics. There are numerous uses for it, including in homes, cars, and portable power(57). Furthermore, On-site production of hydrogen is an option, as is central production followed by distribution. Methane, gasoline, biomass, coal, or water can all be used to make hydrogen gas. Depending on the sources employed, variables such as pollution levels, technical difficulties, and energy requirements change(54). Every country, thus, benefits from locally produced hydrogen because it reduces the need for energy imports and opens up new markets for business expansion and job creation (56).

Hydrogen is a clean energy

Hydrogen is a renewable system that promotes environmental sustainability. Because 1- The process of electrolysis divides water into hydrogen and oxygen. In this situation, renewable energy can be used to run electrolyzers that turn water into hydrogen, creating a system that is nonpolluting and sustainable, and free of emissions. 2- The benefit of using hydrogen as an energy carrier is that the only byproducts of its reaction with oxygen are water and heat.3- It is uncommon for a fuel source because it is non-toxic. This indicates that it respects the environment and does not harm or negatively impact human health(54).

Hydrogen is a far more effective energy supplier

Compared to diesel or gas, hydrogen can transmit a lot more energy per pound of fuel, making it an efficient energy source. This unambiguously indicates that a vehicle powered by hydrogen energy will cover a greater distance than one powered by an equivalent amount of gasoline. For instance, compared to a traditional combustion-based power plant, which typically generates electricity at an efficiency of 33 to 35%, hydrogen fuel cells have a capacity that is about three times higher and is capable of producing electricity at an efficiency of up to 65% (54).

B. Challenges

Despite the growing demand for hydrogen energy due to its promising benefits for the economy and the environment, it is still a source with risky obstacles and is still a lofty objective. The following are some obstacles preventing the adoption of hydrogen as an alternative:

Greehouse Gas Emissions

Several potential distribution routes depend on supply and demand locations, especially when end-users (such as driving patterns in transportation modes) and technological efficiency (such as turbines, internal combustion engines, and fuel cells) are taken into account. As a result, the entire hydrogen supply chain has the potential to produce greenhouse gas emissions from distribution to storage. The use of default values can, to a limited extent, assist in overcoming some of these challenges (57). Although carbon dioxide can be a byproduct of the production of hydrogen, when burned or used in a fuel cell, hydrogen itself does not emit any carbon dioxide. However, when released into the atmosphere, hydrogen causes indirect warming by raising the levels of other greenhouse gases like methane, ozone, and water vapor. This is problematic because it is challenging containing hydrogen's small molecules. Throughout the value chain, it is known to easily leak into the atmosphere. The likelihood of leakage increases with the distance between the point of production and the final destination (58).

Green Hydrogen High Costs

The main impediment to the growth of a clean hydrogen global market is green hydrogen's elevated production costs. In the energy market, hydrogen is indeed competitive with other energy sources and subject to market demand preferences. Because the costs of producing green hydrogen are still too high to be economically competitive with hydrogen made from fossil fuels or other energy sources, there is currently no room for growth in the global market for clean hydrogen. Up until 2030, hydrogen production from fossil fuels will continue to be the most economically advantageous option, according to an IEA analysis (2019). Grey hydrogen is indeed much less expensive than low-carbon hydrogen(57). The following hydrogen costs were registered in 2019: Green hydrogen: $2.5-5 a kilogram, Blue hydrogen: $1.50-3.50 a kilogram, and Grey hydrogen: around $1.50 a kilogram(59). Additionally, the cost of transporting, storing, and supplying hydrogen to end users are also significant factors in the high cost of hydrogen. Since hydrogen has a lower energy density than fossil fuels, it is more expensive and challenging to store and transport (59).

VIII.CONCLUSION AND OUTLOOK

In summary, the objective of this paper is to highlight the significance of green hydrogen as a potential alternative low-carbon energy source in futuristic energy production. As Concerns about greenhouse gas emissions and global warming are increasing and fossil fuel reserves are running out. Green hydrogen provides evidence that it is a versatile and sustainable energy carrier and can meet some sustainable economic and environmental criteria but they are still ambitious goals. To overcome economic and environmental barriers further research and investments in green hydrogen technologies are required.

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