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Green Hydrogen - An Overview

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Abstract
The global demand for Green Hydrogen is expected to reach 130 MT by 2030. Green Hydrogen is steadily emerging as an alternative energy source because it generates high enthalpy required for powering energy-intensive industrial processes, without emitting greenhouse gasses. Green hydrogen has the enormous potential to decarbonize heavy industries. This paper aims to understand the ecosystem of Green Hydrogen, the challenges around it, the ideas and technological innovations related to it, and how it can emerge as a leading technology to drive the world to a net-zero carbon status and aid in decarbonization while reducing demands of fossil fuels from various sectors.
Key Words: *Green Hydrogen, Renewable energy source, Decarbonization, Net-zero status*

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I. Introduction

In the global era defined by industrial and technological innovations, we face a pressing humanitarian crisis - Climate Change. Escalating heat waves, frequent droughts, melting of ice caps, worsening of air quality, rising of ocean levels, the collapse of the global food and fishing industries, biodiversity loss, exacerbated refugee crisis, uninhabitable land, raging forest fires, storms and increasing temperatures of the earth are many adverse effects of Climate change, some of which are visible very frequently across many different parts of the world. Despite deliberations aimed at combating Global Warming, the pace of actionable measures remains notably sluggish, significantly impacting the planet's well-being. It was projected that the decade of 2020 would be pivotal in tackling Climate Change mitigation and reversing the aging of the Earth, however, the action on the ground level seems to have been very slow due to numerous factors like wars, refugee crises, pandemics, etc. According to the UN estimates 2030, the time frame remaining to avoid irreversible and permanent one-sided damage to our planet is only 6 years.

Powerful and leading global economies, encompassing, both developed and developing, as well as high-income and low-income are aligning their efforts and working on saving this planet. Nations such as the USA, China, The European Union, India, and many others have announced their target to achieve net zero emissions within this century and substantial work has begun. Countries like Bhutan and Suriname have already announced that they have achieved their net-zero status well before time. A notable technology that these countries aim to pivot to is Green Hydrogen. The global demand for Green Hydrogen is expected to reach 130 MT by 2030. It is steadily emerging as an alternative energy source due to its capability of generating high temperatures and heat, both are critical for powering enormous energy-intensive industrial processes, without emitting greenhouse gasses. Green hydrogen has the enormous potential to decarbonize heavy industries, one of those who have found it very difficult to decouple from the emission of greenhouse gasses. Anchored in sustainable development, Green Hydrogen's distinction lies in its production through entirely renewable energy methods, devoid of coal or natural gas remnants. Consequently, it performs a critical function in combating climate change and heralds a potential replacement for fossil fuels.

II. Hydrogen - Differentiation and Production

Hydrogen is classified based on the methods of its production. Hydrogen is not a Primary Energy Source but it is rather considered as an Energy Vector. An Energy Vector is an element/molecule/compound that does not produce energy and it requires a chemical reaction to take place for its production. The renewability of Hydrogen is also defined by the way it is produced. Hydrogen is only renewable if renewable sources of energy produce it. Hydrogen is characterized in different categories by colour codes assigned to the final product based on the feedstock and raw pathway used.

Different Types of Hydrogen

1. Grey Hydrogen - Produced by reforming Natural Gas without CCUS (Carbon Capture, Utilisation and Storage)

2. Blue Hydrogen - Produced by using Natural gas and reforming it with CCUS.
3. Green Hydrogen - Produced by electrolysis using the mediums of renewable electricity.

Production Methods of Hydrogen

1. Steam Methane Reforming (SMR) - This is the most widely used and mature method to produce Hydrogen. This process involves the reformation of natural gas where methane is made to react with steam at very high temperatures, usually 700 - 1000 degree Celsius. This is considered a method that pollutes the environment as it generates 10 kilograms of Carbon Dioxide (CO_2) for every 1 kg of hydrogen generated and accounts for almost 830 million tonnes of Carbon Dioxide generation. Steam reforming is also an alternative to producing hydrogen from other fuels, such as ethanol, propane, or gasoline.

   Steam-methane reforming
   $CH_4 + H_2O \leftrightarrow CO + 3H_2$ …. (1)
   Water-gas shift
   $CO + H_2O \leftrightarrow CO_2 + H_2$ …. (2)

2. Partial oxidation - This method produces Hydrogen by reacting Methane and other hydrocarbons present in Natural gas with a limited amount of oxygen. In this case, the oxygen is not enough to completely oxidize the hydrocarbons and hence this method produces Hydrogen, Carbon Monoxide with Carbon Dioxide, and other compounds.

   Partial oxidation of methane reaction
   $CH_4 + \frac{1}{2}O_2 \rightarrow CO + 2H_2(+heat)$ …. (3)
   Water-gas shift reaction
   $CO + H_2O \rightarrow CO_2 + H_2(+a\ small\ amount\ of\ heat)$ …. (4)

3. Biomass Gasification - This is a mature process that uses thermo-chemical and biological routes to produce Hydrogen from Biomass. This process utilizes controlled procedures involving steam, oxygen, and heat to convert biomass into hydrogen and other compounds without utilizing combustion. This method is very sustainable and attractive because it leads to a lower level of carbon dioxide emissions, especially when coupled with the CCUS technique.

   Simplified example reaction
   $C_6H_{12}O_6 + O_2 + H_2O \rightarrow CO + CO_2 + H_2 + other\ species$ …. (5)
   Water-gas shift reaction
   $CO + H_2O \rightarrow CO_2 + H_2\ (+a\ small\ amount\ of\ heat)$ …. (6)

4. Bio-liquid reforming - This method manufactures hydrogen from liquid biofuels like ethanol and methanol. This method is similar to Natural Gas Reforming (Method #1).

   Steam reforming reaction (ethanol)
   $C_2H_5OH + H_2O\ (+heat) \rightarrow 2CO + 4H_2$ …. (7)
   Water-gas shift reaction
   $CO + H_2O \rightarrow CO_2 + H_2\ (+a\ small\ amount\ of\ heat)$ …. (8)

The above methods are the traditional methods for the production of hydrogen and they majorly result in the production of Grey and/or Blue Hydrogen. Some of the methods for the production of Green Hydrogen are described below.

1. Electrolysis of water - This process utilizes renewable energy sources for heat generation that are further utilized to produce almost pure (100%) hydrogen. Electrolysis is the electrochemical reaction that occurs within the cell when electricity is passed from the anode to the cathode across the membrane. This results in the splitting of the water molecules into hydrogen and oxygen. Hydrogen is procured in this method by the electrochemical conversion of water into hydrogen and oxygen.
   $2H_2O + electrical\ energy \rightarrow O_2 + 2H_2$ …. (9)

2. Alkaline Electrolysis - This is the most widely used and commercially established technology used primarily by the fertilizer and chlorine industries. In this method, the electrodes are made to operate in a liquid alkaline solution of potassium or sodium hydroxide. A membrane separates the electrodes through which the hydroxide ions travel. The temperature and pressure range for this procedure is between 60 - 80 degrees Celsius and 1 to 30 bar pressure. The efficiency of this method is close to 70%. Metals that have good alkaline resistance are used as cathodes. E.g. Nickel.

3. Polymer Electrolyte Membrane Electrolysis - In this method, water is split into oxygen and hydrogen electrochemically by using electricity obtained from renewable energy sources. Hydrogen and oxygen take the position of cathode and anode respectively. The membranes used in this method are made up of polysulfonated materials. This method is widely used as it has several advantages like low carbon footprint, high purity, small and compact design, and high efficiency. This method can also take place at low temperatures ranging from 20 to 80 degree Celsius which is helpful in the production of ultra-pure high-grade hydrogen and oxygen. These two materials have a great deal of industrial demand.

4. Solid Oxide Electrolysis - This method is a relatively newer method for the production of green hydrogen and it can still be considered as a method that is not widely adopted and is under research and development. This method uses a solid ceramic membrane as the material for electrolytes which aids in separating hydrogen and oxygen from water by transferring oxygen ions through its conductive membrane. This process operates at high temperatures like 500 to 800 degree Celcius utilizing metals as catalysts.

5. Anion Exchange Membrane - This process works in an alkaline environment. The membrane requires non-noble metals like Nickel, Cobalt, and Iron as catalysts. The temperature range for this process to work is between 50 to 60 degree Celsius. This method produces hydrogen with a high purity level of 99.99%. This is also a new method for producing green hydrogen and can be considered a method that is not widely adopted and is under research and development.

6. Microbial Electrolysis Cell - This method is also called Dark fermentation. This is an important technology to manufacture hydrogen from renewable materials like food and livestock waste and residual materials from crops. This method can be described as the fermentative conversion of organic substrate to bio-hydrogen when light is unavailable. Recently, this method has been gaining a lot of traction due to its cost-effectiveness along with its functioning independent from sources of light energy. This method is also considered as the simplest process for producing bio-hydrogen.

III. Green Hydrogen in Industrial Processes

The industrial demand for hydrogen has grown three-fold since 1970 which shows the growing significance of utilizing green hydrogen. Green Hydrogen has several industrial applications across various industrial sectors. Some of the examples of industrial output of green hydrogen are:-

1. Electricity production: The usage of green hydrogen for power generation using fuel cells or by combusting in turbines is a viable and clean option that can be utilized by power plants. This method would result in being classified as a zero-emission method for the production of electricity and would decarbonize the electricity sector.

2. Transportation: Green hydrogen can be used as a source of generating electricity for vehicles as it has emerged to be a zero-emission fuel. Green hydrogen can be used by storing it in the fuel tanks and then converting it into electricity. Major automobile companies are venturing into research and development of fuel cell-based electric vehicles, where the fuel cells would be powered by Hydrogen. The initial plan is to implement these on cars followed by other vehicles.

3. Manufacturing and production industries: Industries like ammonia production industries, steel-making industries, methanol production, and oil refining industries would utilize green hydrogen to a great extent. Hydrogen is being explored as a cleaner alternative and is gaining prioritization over fossil fuels in processes like desulfurization and hydrocracking. Industries like glass making, fertilizer, and chemicals would require green hydrogen as raw feedstock and green hydrogen finds industrial applications there as well. Hydrogen can also be used as a heat-

providing source or a reducing agent in these industries. Adoption of green hydrogen by these industries would help them immensely to reduce their carbon footprint.

4. Aviation: The aviation industry is reportedly considering implementing green hydrogen as a viable means of fuel. Experiments are being conducted on aircraft, powered solely by hydrogen, or by a mixture of hydrogen with various other fuels through combustion or utilizing fuel cells. This would significantly reduce greenhouse gas emissions.

IV. Green Hydrogen - Challenges and Ideas

While the prospect of harnessing Green Hydrogen in different industries@ has been gaining a lot of traction over the once many decades, there are still some challenges that should be resolved for Green Hydrogen to surface as a proper discretion to different fossil energies being exercised presently. Some of the challenges that Green Hydrogen faces presently are -

1. High Product Price - Hydrogen is one of the most abundant rudiments set up on earth. still, it's frequently set up in a combined state with different rudiments. This makes the birth of hydrogen veritably delicate and it also increases the cost of Hydrogen products. Green hydrogen costs nearly 4 times the price of Grey Hydrogen and nearly double the price of Blue Hydrogen to produce. This is because there's a substantial investment demanded for three factors that are essential for the product of Green Hydrogen- -water electrolyzers, the Cost of running the outfit, and the cost of Renewable energy needed to power the outfit. While the prices of renewable energy have dropped to a great extent over time, the prices of electrolyzers as well as the cost of running the outfit are still high which contribute to high product price for Green Hydrogen.

2. Hydrogen storehouse and Transportation Price - These factors are driven by the cost of hydrogen product prices. The development of the structure to produce, store, and transport green hydrogen is more advanced than what's being spent at the moment on other indispensable accouterments. The development of hydrogen structure is consumer-dependent and it's greatly driven by the presence of several refueling stations and the price that the consumers have to pay for the application of these stations. Research states that over to$ 300 BN is needed for the development of these architectures related to hydrogen. There's also a need to develop artificial sectors, and parts and enable anchorages across the world to be ready to make use of green hydrogen sustainably so that the eventual cost of girding Green hydrogen drops and it becomes a sustainable result to use. The lack of technical channels for the transportation of green hydrogen will drive the functional costs of exercising green hydrogen up.

3. Impact on coffers - We're formerly witnessing an impact on land and water coffers. Green hydrogen requires a substantial quantum of renewable energy and water used by electrolyzers for products. Setting up these shops across the world could lead to strain on these formerly strained coffers and this can be disastrous. However, coordinated, and executed, if not duly designed.

4. Lack of professed labour - To support a hydrogen frugality, there needs to be the presence of professed labour that can help in supporting this frugality. A lot of time would be spent in training and handling these labourers.

5. Energy loss - It's reported that there are veritably high energy losses involved in the overall process of Green Hydrogen. There's a loss of 35% energy during the process of electrolysis to produce green hydrogen. The process of fluxing green hydrogen to convert it to other composites like ammonia so that it becomes suitable for transportation takes a loss of 25. There's an estimated 15 energy input or energy loss in transporting hydrogen. The loss of energy during the use of green hydrogen within different energy cells is approached to be around 50. These inefficiencies, if not optimized, will bear significant renewable energy deployment to feed green hydrogen electrolyzers that can contend with end-use electrification.

6. Lack of domestic and transnational norms - Indeed though green hydrogen is considered an emerging technology, there are no regulations in place to ensure that this resource is being employed judiciously and there are no malpractices involved with it. The absence of common transnational regulations limits the fashionability of hydrogen among countries and limits the eventuality of fleetly turning green hydrogen into a global energy frugality. Thus, a common transnational frame has to be developed as it's essential to limit illegal competition in the development process.

7. Safety - Hydrogen is a largely ignitable gas. However, there needs to be a result of the hydrogen leaks that along with other goods of hydrogen-like cause the sword to brittle, If it has to be employed in the future. These challenges need to be dived for hydrogen to crop as a safe and sustainable technology to be used.

Some results that can be enforced to enable wide-scale acceptance of green hydrogen are -

1. Addition of hydrogen to plans - Governments around have been mentioning that they plan on using Green Hydrogen as a technology. Still, the ground relinquishment of this has been extremely slow. It's now time to establish long-term growth strategies for hydrogen. prospects should be defined and developed at global, public, indigenous, and original clusters. Companies working should be incentivized for this purpose to speed up the embracement of this technology. Transnational cooperation is needed to enable this transition, especially on the subjects related to norms, sharing of good practices, and cross-border structure. Hydrogen products and operations should be covered and reported regularly to keep track of progress toward long-term pretensions.

2. Produce a demand for green hydrogen frugality - Herbage hydrogen technologies that are present at the moment aren't feasible financially. The preface of programs that stimulate the creation of sustainable requests for clean hydrogen, especially to reduce emigrations from reactionary energy-grounded hydrogen, is needed. This would enable investment to flow up. This action will also ultimately gauge up force chains. This would drive cost reductions and increase demand.

3. Exploration and development - Increased support towards R&D is needed. This would enable the technology to mature to a great extent and would prop in bringing down costs. Governments and transnational agencies should promote and incentivize this to enable a great degree of R&D to be initiated for the development of Green Hydrogen. Digital technologies like the development of digital halves to model multiple designs and scripts, including variables similar to rainfall, off-takers demand volatility and original structure (current and unborn) would help optimize each design to maximize return on investment and minimize threat. This can optimize the expenditure related to the operation of Green Hydrogen. Exercising advanced business analytics grounded on Artificial Intelligence and Machine Learning ways can help to transfigure data into business intelligence with practicable perceptivity. These analytics will help maximize yields.

4. Conformation of guidelines and norms - Enabling knowledge sharing for technologies to drive friendly competition for green hydrogen should be promoted. participating knowledge and harmonizing norms for outfit, safety, and certifying emigrations from different sources should be a precedence.

5. Establishment of a devoted ecosystem - A devoted ecosystem for driving the wide relinquishment of Green Hydrogen is needed to maximize the investments. Artificial anchorages can be turned into capitals for lower-cost, lower-carbon hydrogen. exercising gas structures to transport new clean hydrogen can be an option. The transport sector related to the diligence involved with green hydrogen needs to borrow the operation of energy cells and green hydrogen-grounded energies to make this a success. wide transnational trade routes need to be established to feed the growth in demand and force related to Green Hydrogen.

V. Conclusion

Despite the challenges that Green Hydrogen possesses, it has emerged as a leading technology for countries to look into as a sustainable approach to their net-zero targets. Hydrogen already has a wide presence in many industries. Green hydrogen provides an opportunity to decarbonize many industrial, chemical, and transportation sectors. To realize its potential to support clean energy, ambitious, targeted, and near-term action is needed to overcome barriers and reduce costs. Increased investment, support by governments, technological and engineering advancements, and a skilled workforce would help to transition towards green hydrogen which will aid the cause of global decarbonization. If properly planned and implemented, Green Hydrogen can emerge as the new big technology that can revolutionize us. This would create innumerable jobs and drive economies. Our future generations would not be burdened by our wrongdoings of the past and this beautiful planet will not have life on it come to a premature end.

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