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HYDROGEN: THE BOOMING TECHNOLOGY

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***Abstract*— The rising population and pollution alarms the need for adoption of renewable technologies over fossil fuels for meeting the increasing energy demands and achieving net zero emissions. However, being intermittent in nature, these renewable sources are highly weather and location dependent which causes a gap between demand and supply of energy. This gap can be filled by hydrogen which is an environment friendly fuel and can be produced from both renewable and non-renewable energy sources. It does not cause GHG emissions and is a promising future energy carrier. Hydrogen has a potential to achieve the target of green economy for the betterment of the future and is gaining popularity nowadays. This paper gives a description of the various types of hydrogen, production processes, applications and challenges faced while adopting hydrogen economy for a safe and sustainable future.**

***Keywords*— Hydrogen economy, Green Hydrogen, energy carrier, net zero emission, renewable energy, hydrogen production**

I. INTRODUCTION

With a rapid growth in population, the world experiences an increase in energy demand and a significant decline in the availability of fossil fuels. Since conventional energy sources are at the verge of extinction in upcoming decades and also the fact that the use of such sources pollutes the environment that can pose a threat to the future generations and the earth, the world now focuses on renewable energy sources for meeting the energy demands while saving the environment.

Global warming is a major issue caused by continuous greenhouse gas emissions into the environment from human activities carried out to meet the rising demands for energy. In 2021, the global CO_2 emission was around 36.3 Gigatonnes (Gt) [11]. Therefore to tackle this issue, countries are aiming at generating energy with no or minimum adverse impact on the environment. One of the alternatives to achieve this goal is by using green hydrogen.

In order to achieve the target of limiting global warming below 2°C by reducing GHG emissions, green hydrogen is receiving major attention globally [3]. The availability and properties of hydrogen make it the key focus and is seen to have the potential to meet the energy needs of the future. Green hydrogen is produced through electrolysis of water using renewable energy as a source [8]. Adoption of a hydrogen based economy for achieving net zero emissions and sustainable energy transition can bring out a positive impact.

However, green hydrogen is not gaining a rapid growth because of the various challenges faced by it including storage, cost, safety, lack of policies and commercial acceptance [1]. Although green hydrogen finds wide applications in industries and transportation, it has still a long way to go.

The following sections of the paper cover the types of hydrogen produced, production methods, and applications of green hydrogen, advantages, and the barriers faced by the technology followed by the concluding remarks at the end.

II. TYPES OF HYDROGEN

Hydrogen is a carrier of energy and not a source of energy. Different energy sources or technologies can be used to produce hydrogen [9]. Depending upon the type of source used for hydrogen production, hydrogen is classified into various types identified by color coding.

When bituminous coal is used as a source to produce hydrogen, it is called black hydrogen whereas when lignite coal is used for hydrogen production, it is termed as brown hydrogen. Gasification process involving steam, heat and oxygen is used for producing hydrogen without combustion. It is the most environmentally damaging type of hydrogen as it gives out twice the amount of CO_2 than the one produced using natural gas [7-9].

The most common method of producing hydrogen is by using natural gas or methane. It uses steam methane reformation process where the reaction between methane and steam at high temperature and pressure in the presence of a catalyst produces hydrogen and carbon monoxide. Additional water is then supplied to produce pure hydrogen and carbon dioxide. The hydrogen so produced is called gray hydrogen as it leads to GHG emissions [10].

The next most common method of hydrogen production is blue hydrogen. It adopts the same process as gray hydrogen with an additional technology of carbon capture by trapping about ninety percent of the GHG emissions. The captured carbon is then either stored under the ground or reused in industries as a feedstock [10]. Hence CO_2 emissions in the environment are reduced.

Another type of hydrogen is green hydrogen. It is the key focus nowadays to achieve net zero emission targets and reduction in global warming. When hydrogen is produced using clean and renewable sources of energy like solar, wind, etc. it is called green hydrogen. The process of electrolysis of water is used for producing green hydrogen where water is split into oxygen and

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hydrogen by providing electricity through renewable sources of energy [8]. Various electrolyte systems such as alkaline water electrolysis, proton exchange membrane electrolysis, solid oxide water electrolysis, and anion exchange membrane can be used [7]. Since the method for green hydrogen production uses renewable energy sources, there are no CO_2 emissions in the environment which brings it to the central focus. However, the production cost of green hydrogen poses a challenge for wide range adoption.

Table -1 Hydrogen types [1]

	Gray Hydrogen	Blue Hydrogen	Green Hydrogen
Derived from	Natural Gas	Natural Gas	Water splitting and renewable power
Method	Steam methane reforming	Advanced gas reforming	Electrolysis
GHG Emissions	High	Low	Zero
Carbon Capture	CO_2 emitted in atmosphere	CO_2 captured and stored	No CO_2 emissions

When the process of electrolysis is powered by nuclear energy, the hydrogen so produced is called purple hydrogen. This method has an advantage as the extremely high temperatures from the nuclear reactors can be used to produce hydrogen through other techniques by producing steam for natural gas based steam methane reformation [15].

Turquoise hydrogen is a novel entry among the existing hydrogen types and lies between blue and green hydrogen. It is produced by a process called methane pyrolysis. Here, methane is used as a feedstock but the heat is produced using electricity rather than combustion of fossil fuels. Methane pyrolysis produces hydrogen along with solid carbon and not CO_2. Hence there is no need for carbon capture technology and the solid carbon can be used in manufacturing of materials like tyres. Moreover, if the electricity for producing heat is generated using renewable sources, there are no GHG emissions [15].

Hence among the variety of hydrogen and corresponding production methods, green hydrogen finds a huge scope as the future fuel with zero emissions leading to a cleaner, better and sustainable environments.

III. HYDROGEN AS A FUEL FOR THE FUTURE

In order to tackle global warming and achieve a sustainable future, renewable energy sources like wind, solar, geothermal, etc. are being used for generation of electricity to meet the rising energy demands. Though these sources are clean and environment friendly, they are dependent on factors like weather, time or location which causes a misbalance between demand and supply of energy. The cost of renewables are declining which increases their expected share in the energy mix of the future. But the uncertainty in their output is a major challenge which needs to be addressed [9]. Hence an alternative needs to be considered to ensure continuous supply of energy without causing any harm to the environment. Hydrogen is one of such alternatives because of its properties and availability. Some of the properties are given in the table below:

Table -2 Properties of Hydrogen at ambient conditions [4]

Atomic number	1
Atomic mass	1.00784 amu
Molecular mass	2.01568 amu
Energy density	10.05 MJ/m^3
Volumetric density	0.08376 kg/m^3
Boiling point	-252.87 °C
Melting point	-259 °C
Critical point	-240.2 °C at 12.7 atm
Triple point	-259.3 °C at 0.07 atm
Higher heating value	141.86 MJ/kg
Lower heating value	119.93 MJ/kg

Hydrogen can be used as a carrier of energy which can successfully bridge the gap between demand and supply. It is also referred to as a sustainable energy carrier as it is non-exhaustible, pollution free and does not cause any adverse effects on human health [4].

Hydrogen is available in the environment in abundance but not in free form. It is often found with other atoms in the form of a compound like water. Hence to extract hydrogen from water, water electrolysis is used which produces hydrogen and oxygen without any CO_2 emissions. This hydrogen thus produced is the most environment friendly and will help to achieve net zero emission targets. Hydrogen is also non-toxic and the lightest element [1]. As compared to other fuels, it has the highest content of energy. Being an energy carrier, it can be produced using other renewable sources which adds to its advantages as its production is easy.

Hydrogen can be stored and transported too. It is used in transportation where vehicles are driven by fuel cells and hence do not produce any pollution as the only by-product is water with zero contaminants. At present, nearly about 11,200 cars powered by hydrogen are on the road [9]. However, since electric vehicles are gaining a lot of popularity nowadays in

spite of having issues like long time of charging and short mileage, since it is environment friendly and comparatively cheaper than fuel cell driven vehicles, hydrogen economy in transportation is lacking a consistent growth [13]. But in the future, transportation sector will be an eminent application of hydrogen as there would not be any GHG emissions [4].

Another notable application of hydrogen is in the industrial sector. It is used for production of methyl alcohol and ammonia in the chemical industry. In fact, 60 percent of hydrogen in the world is used in ammonia preparation followed by oil refining. It is also used in steel processing industry for the production of steel [13].

With hydrogen already being put to use in these sectors, it still has more opportunities to explore. Since hydrogen is strongly linked with the concern of climate change, it is definitely going to remain the central focus in the future. The dependence of energy users on specific sources of energy is reduced when hydrogen is utilized along with electricity. Hence hydrogen ensures energy security. Moreover, the local air pollution is reduced by deploying hydrogen in various applications instead of fuels containing carbon which produce GHG emissions. Since governments and energy policies aim at reducing air pollution and enhancing the quality of air, hydrogen will be one of the alternatives along with other renewable sources in the future.

Hydrogen economy involves the development of hydrogen technology and relevant infrastructure. It generates a scope for the countries to develop expertise in the technology for the energy transition and move towards a sustainable future with zero carbon emissions. This ultimately leads to the economic development of the countries as it creates new job opportunities in the new sector [9].

Keeping in mind the potential of hydrogen for becoming the next generation no emission fuel, countries like India estimate the demand for hydrogen to increase from 6 Megatonnes (Mt) per annum today to at least five-fold by the year 2050 and increase ever after. The demand for particularly green hydrogen is expected to grow beyond 2050 with major applications in steel and transport sectors. India is predicted to produce green hydrogen as 80 percent of the total hydrogen by 2050 using electrolysis and renewable energy. To manage the variability in renewable energy, energy storage is required. Long term storage can be achieved by deploying hydrogen. By 2040, it is expected that hydrogen will become a cost effective way to provide inter-seasonal storage in the power sector [8].

Therefore hydrogen has a great scope for becoming the fuel for the future in all the countries across the world.

IV. CHALLENGES TO OVERCOME

Every technology comes with its own benefits and drawbacks. These barriers need to be overcome for making the technology a success. Every new concept faces several challenges in the initial stages but by making appropriate efforts, the technology can compete with the existing similar ones.

Although hydrogen has multiple advantages that makes it a potential fuel for the future, it is yet to reach perfection. The concept of hydrogen economy is broad as it includes everything from its production to distribution. The major challenge faced in the production of hydrogen is the cost. Producing hydrogen from renewable energy is a costly process as compared to hydrogen produced using fossil fuels [1]. Because of green hydrogen being expensive, its acceptance is low.

As compared to electric vehicles, hydrogen driven vehicles are costly due to the high cost of fuel cells. Currently, the commercial cost of a fuel cell is around USD 230/kW [9]. Hence in spite of being environment friendly, the growth of these vehicles in the market is slow.

Storage of hydrogen is possible in gaseous, liquid as well as solid chemical form [4]. However, the volumetric energy density of hydrogen is low. This makes it difficult to handle hydrogen which adds up the cost [1]. Hence it is important to focus on research and development for storage of hydrogen.

One of the concerns related to hydrogen is safety. Hydrogen is an environment friendly fuel as it does not release any greenhouse gases. It is also non-toxic so any leakage would not cause any harm to the environment. Having low density, it quickly disperses and rises thus reducing the chances of fire. However, if the concentration of hydrogen in the atmosphere reaches above 4 percent, a serious fire may occur. In worst cases, it can even lead to explosion [4]. Hence safety being the priority, steps need to be taken to analyze the issue.

As a whole, apart from the safety concern all other challenges point towards high cost either for production of hydrogen, storage or its application. Efforts need to be made to bring down the cost so that hydrogen gets a push and gets adopted quickly. This can be done by reducing the cost of electrolyzers used for production of hydrogen, making fuel cells more efficient and cost effective, and exploring better storage methods. With the motive of achieving net zero emissions and decarbonisation, overcoming the challenges related to hydrogen is important.

V. CONCLUSION

Most of the world's energy demands are fulfilled by fossil fuels like oil, coal and natural gas. However, as the demand rises rapidly, fossil fuels alone cannot meet them. Also they cause environmental pollution which is not desirable. Hence there is a need for a shift to renewable energy sources like solar, wind, geothermal, hydrogen, etc.

Considering the intermittent nature and location dependence of most of the renewable sources, hydrogen stands out of them. It is an energy carrier and can be produced using various sources. It has the potential to reduce GHG emissions for a sustainable future.

A number of methods are available for the production of hydrogen like steam methane reformation, coal gasification, electrolysis, pyrolysis, etc. Among the various types of

hydrogen produced, green hydrogen is the cleanest and ensures achieving the target of net zero emissions.

Hydrogen finds its application in various industries, transportation and storage because of its properties. However, the greatest barrier for adopting a hydrogen economy is the high cost with the major share from production methods. For achieving a sustainable future with no GHG emissions, this cost needs to be brought down.

As the world slowly moves towards adopting hydrogen economy and invests in research and development for enhancing the technology, decarbonisation and net zero emissions are likely to be achieved soon ensuring a sustainable and healthy future.

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