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Hydrogen as Fuel of Tomorrow

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***Abstract*— As well know that carbon-based fossil fuels are a non-renewable resource and these are depleting at an alarming rate. The unmonitored explicit usage of fossil fuels certainly demands for an alternate type of fuel which could replace it in the future because not today but in the near future there will come a time when we will be short on carbon based fuels and need for an alternative type of fuel will the demand of the day. The increasing global demand for sustainable and clean energy sources has finally demanded the exploration of alternative fuels. Hydrogen, with its high energy density and zero carbon and greenhouse gas emissions during combustion, has emerged as a promising fuel of the future. Hydrogen is a potential fuel which can change our fossil fuel based dependency for energy generation to hydrogen economy. The various properties of hydrogen make it excellent alternative and soon to be primary source of fuel in the future. The various techniques of hydrogen production such as electrolysis and coal-based extraction will be discussed as well as the storage methods. Hydrogen is a better fuel in every term. There will be comparative study as well which compares the versatility, the combustion properties, electrical generation efficiency, thermal usage efficiency and also that it's extraction methods are certainly more eco friendly as compared to other fossils fuels. Researchers are still going to make hydrogen as feasible as fossil fuels are today and soon in the upcoming years, we will see hydrogen economy booming.**

Keywords*—*Hydrogen, electrolysis, fuel, efficiency, fuel cell

I. INTRODUCTION

Hydrogen is the fuel of future to come. Hydrogen is a major component of environment that can be utilized in ICE (internal combustion engines) or power devices and produces or emits no ozone depleting substance when combusted with oxygen. The main thing to notice is that it produces energy water as a byproduct. Hydrogen production and storage are under broad research under supervision of major companies. A solar-energy based hydrogen framework can provide us with options for an absolute zero-emission planning for creating hydrogen. Despite the fact that steam reorganization of methane is one the most popular and significantly used methods of hydrogen production, the byproducts included can be controlled. Environmental climate change is a major problem for major fraction of the global population. Rising carbon dioxide (CO_2) levels have legitimately added to an unusual climate change. The feasibility of hydrogen as a fuel lies in its abundant availability and versatility. Hydrogen can be manufactured through various methods, including electrolysis of H_2O (water), reforming of hydrocarbons, and biomass conversion. Additionally, hydrogen can be utilized in a variety of applications, such as fuel cells for electricity generation, transportation in hydrogen-powered vehicles, and industrial processes. However, the extensive adoption of hydrogen as a primary fuel faces several challenges. One key obstacle is the efficient and cost-effective production of hydrogen. Traditional methods for manufacturing of hydrogen often rely on fossil fuels and can be energy-intensive, limiting their sustainability. Moreover, the storage and transportation of hydrogen present significant hurdles. Hydrogen's low density and high reactivity require specialized storage and distribution systems. Hydrogen offers a variety of advantages when produced using "clean" resources, and these advantages are drawing more and more attention as governmental goals. In order to manage pollutants and ensure the dependability of the power system, a large market for hydrogen as an electrical source needs to be developed. Shipping-related emissions of CO2 and air pollutants are avoided because hydrogen emits no emissions at the point of very last use. In contrast to other alternative fuels, which can only be created from electricity, hydrogen offers the long-term option of being totally made of renewable energies. It can also help diversify the sources and components of vehicle petrol. Any (regionally available) number one electricity source can produce hydrogen. Additionally, electricity produced by intermittent renewable sources like wind and solar should be stored in hydrogen. Clean electricity production from fossil fuels may be possible if CCS is implemented successfully on a big scale. Additionally, IGCC facilities may present the opportunity to co-produce hydrogen and power.

II. HYDROGEN PRODUCTION

Extraction of hydrogen comes out as a key aspect to use it as a fuel. Multiple processes are available at the given time to extract hydrogen from naturally available form of it but efficiency of processes determines the cost effectiveness and feasibility of accepting hydrogen as fuel. [1] In a fully developed hydrogen economy, hydrogen might create electricity, replace fossil fuels as a source of fueling mobility in cars and trucks, in addition to providing portable electricity for use in private devices and other applications, it also supplies electricity for grid distribution. At the moment, electricity uses 12% of global energy and transportation 20%. By 2030, all vehicles and light trucks will require around

600Mt/year of hydrogen, as opposed to just 50Mt/year today, where the imbalance is significantly high.

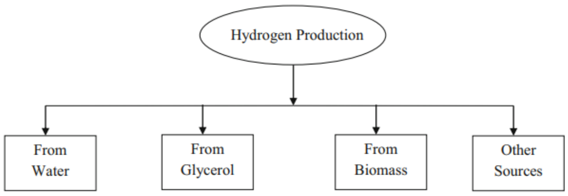

Fig1 Overview of hydrogen production methods

A promising production method for hydrogen as a future fuel is water splitting with only renewable energy inputs. The earth's surface is covered in water, which is much more widely dispersed geographically than fossil fuels. [2] Contrary to the "once-through" life cycle of the fossil fuel energy chain, the water-hydrogen cycle is closed. Reserves are being used up at the site of production and leaving behind undesired CO2 and pollutants when they are used. On the contrary, the hydrogen and oxygen is created when water splits and are united once more at the site of usage to produce energy, refilling the water used in its manufacture while providing energy. Since no chemical components are formed or destroyed once the cycle has ended, this cyclic chemical reaction is a requirement for a sustainable energy system. However, there is a resultant energy flow within water-hydrogen cycle, with energy is utilized for water splitting and and energy is produced for water creation. So one of the most feasible options appear to be splitting water using a renewable energy source which leaves the least impact on the environment and driving towards the sustainable growth.

A. *Electrolysis*

Each stage in the conversion of power results in a reduction in efficiency. The three main processes in the generation of hydrogen are manufacturing, utilisation, and storage. The water electrolysis process now operates with an efficiency of 86% when using the heat recovery method. Around 97% of the global hydrogen is made by steam reforming fossil fuels like natural gas along with other main energy sources.[3] However, there are some cutting-edge production methods for hydrogen that use renewable energy. The extraction of the primary energy carrier, delivery to the hydrogen production facility, conversion to hydrogen, and liquefaction prior to use are the first steps in the researched process chains. One of the most popular procedures is electrolysis, which also produces biogas. Through a process called electrolysis, oxygen and hydrogen may be separated from water. An electrolyzer, which functions somewhat similarly to an energy module in reverse, is where electrolytic processes take place. Rather than producing hydrogen from water atoms, as an energy unit does, an electrolyzer creates hydrogen from hydrogen atoms. Since it is the sole technique that does not require fossil fuels, electrolysis is frequently regarded as the preferred method of producing hydrogen. Additionally, it is practical on both small and big scales and has a high product purity. An electrolyser, which consists of a number of cells, each having a +ve and -ve electrode, is the central component of electrolysis. [4] The electrodes are submerged in water that has been treated with hydroxyl ions to make it electrically conductive, typically in the form of alkaline potassium hydroxide. The anode (+ve electrode) is usually composed of nickel and copper and is covered in metal oxides like ruthenium, manganese, and tungsten. At the electrode surface, the anode metals enable rapid pairing of atomic oxygen into oxygen pairs. The cathode (-ve electrode) is commonly composed of nickel and is catalystized with a thin layer of platinum. The catalyst facilitates the rapid pairing of atomic hydrogen into pairs at the electrode surface, speeding up the synthesis of hydrogen. Hydrogen would accumulate on the electrode without the catalyst, preventing current flow.

B. *Coal-based Extraction*

Between the existing technique of natural gas reforming and the prospective technique of renewable water splitting lies a step called coal-based hydrogen generation. Coal is the most accessible fossil fuel that can generate a sizable amount of hydrogen without depleting its reserves or increasing its retail cost. Carbon monoxide and hydrogen are both present in the direct syngas produced during the gasification of coal, and during the water-gas shift procedure, CO reacts with steam to produce even more hydrogen. Coal may be used to make hydrogen using a variety of techniques that also capture CO2 and retain roughly 80% of the coal's initial energy content.

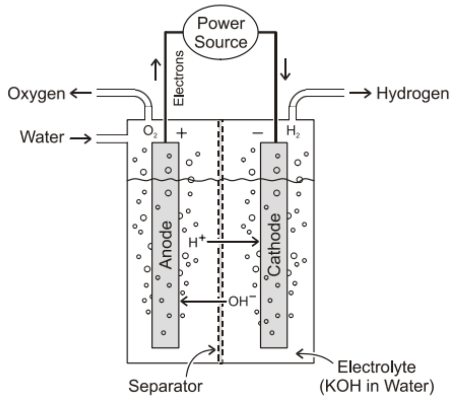

Figure 2 An Electrolysis Cell [2]

A crucial material issue is the creation of membranes for separating hydrogen from CO and CO2.[5] As compared to the regular efficiency of 34% for current electricity manufacturing from coal without carbon dioxide, coal gasification and the water-gas shift are industrial technologies that are in position to be deployed in Integrated Gasification Combined-Cycle (IGCC) power plants.
The two popular manufacturing methods for producing hydrogen from fossil fuels are hydrocarbon reforming and pyrolysis. These methods are the most cutting-edge and frequently employed, providing nearly all of the hydrogen need. More specifically, upgraded hydrogen was produced in a 48:1 coal : natural fuel ratio. Due to the production costs being closely tied to fuel prices that are still kept at reasonably lower

levels, fossil fuels continue to dominate the world's supply of hydrogen at the moment. Membrane reactors, like many other areas of the chemical and biological industries, provide fresh approaches to the production of H2 from conventional fuels. A membrane is a form that permits mass to move when subjected to a gradient of driving forces (such as attention, electric potential, etc.) and is often much thicker lateral to its thickness. Membranes are divided into three categories: dense, porous, and ion change depending on the separation regime. Organic and synthetic membranes are the two main types, with synthetic membranes being more common in both organic and inorganic systems. Strong hydrogen selectivity, high permeability to operate with high flows and constrained surfaces, and excellent chemical and structural durability are all necessary characteristics of a membrane that is ideal for manufacturing H2. Therefore, important components for include an appropriate (porous) support that allows gases to pass through, as well as a barrier that prohibits inter-diffusion inside the steel support.

Numerous studies have been conducted and remarkable solutions for hydrogen production are now being studied. The provision of high hydrogen charge at a low cost is the primary driving force behind those investigations. The production of hydrogen has unique challenges. Aluminum and H2O, for instance, can combine to form hydrogen. The inclusion of OH- in this case speeds up the reaction. However, it has been found that doing so shortens the equipment's useful life by causing corrosion in the hydrogen device.

3. HYDROGEN STORAGE

In recent years, hydrogen energy has grown significantly in favour as a clean substitute for fossil fuels. It provides more energy and presents less environmental risks.

Hydrogen, being less dense than air, actually possesses a gravimetric density that is approximately seven times greater than fossil fuels. This noteworthy disparity positions hydrogen as a promising and viable energy source for the foreseeable future. Nevertheless, there exist a number of critical concerns that demand our attention, particularly pertaining to storage and transportation. In the forthcoming years, the expectation is that hydrogen energy will gradually replace oil as the primary energy source across various modes of transportation, such as cars, trains, planes, and ships. It is even predicted that by the year 2040, hydrogen energy will power more than 35% of vehicles in Europe. There are 447 hydrogen fueling stations that are running right now. Table 1 gives an idea of number of active hydrogen filling stations around the country world.

Table 1 Top 10 countries with active hydrogen filling stations

Country	Active H_2 stations	Country	Active H_2 stations
Japan	133	England	11
Germany	83	Norway	10
North Korea	37	Canada	8
China	18	Denmark	8
France	11	Scotland	6

A. *Compressed Tanks*

The most common type of hydrogen storage device used in gasoline mobile cars is compressed gasoline tanks. In fact, a number of prototype vehicles equipped with these tanks are currently being evaluated on the market. The Toyota Mirai, Mercedes-Benz F-Cell, and GM Equinox have all had their fuel economy evaluated by the manufacturers using EPA inspection methods. The most important component for compressed petrol is the fabric that makes up the tank. It must be compact, affordable, and robust enough to meet the necessary strain, pressure, and safety requirements. The material's thermal conductivity also needs to be very high in order to withstand the exothermic heat generated during tank filling. The pressurized fuel tank could be made of carbon fibre reinforced plastic in light of these specifications. The plastic tanks reinforced with carbon fibre are durable and strong while still being light in weight. However, due of their incredibly poor thermal conductivity, development is required. Currently, a composite high-strain tank is installed in the majority of vehicles in the on-street inspection segment. This is because of its simple structure and charge-discharge design. The regulation allows for the division of high-pressure tanks into four groups. The carbon composite Version 3 and Version 4 is the material of choice for the hydrogen tank. The compressed natural gas vehicle, on the other hand, favours type Version 1 and Version 2 batteries. This is because the hydrogen car operates under better stress than the natural gas vehicle, which is normally compressed to 20–25 MegaPascal. Recently, it has been popular to transport 70 MPa tanks in order to carry more hydrogen and increase the diversity of vehicles. The relationship between hydrogen quantity and pressure is not linear, though, due to the strain present in this range. Double pressure can only result in a 40–50% increase in volume and cannot store twice as much hydrogen. For the same automobile, fabric and winding method optimization has increased hydrogen storage by 65%. If the fabric's durability is assured, there may be more opportunity to reduce the tank's weight. High-stress tanks, however, cannot be shrunk similarly due to their physical characteristics. To increase the car's range, the excessive-stress tank's volumetric assets must be compromised with the architecture of the mobile vehicle. . When hydrogen gets reduced to 20 K under atmospheric pressure, it takes on a liquid state with a much higher density than when it is in the state of a gas. Liquid hydrogen is attractive for the expansion of the variety of vehicles that people can ride in due to its high density and capacity to store a sizable amount of hydrogen on board. From an infrastructure standpoint, the ability to store and transmit a significant amount of hydrogen is also quite appealing. According to certain research, the ease of distribution and storage can offset the liquefaction's increased energy use. Because hydrogen is stored in hydrogen-absorbing alloy tanks more densely than it is in liquid form, the tanks can be built more compactly and have reversible hydrogen charge and discharge capabilities. It has a low gravimetric density, though—the weight of the hydrogen is comparable to the weight of the tank. The density has been boomed on numerous occasions. Materials with the capability of two, such Titanium-Vanadium-Manganese and Titanium-Chromium), are being developed. However, vehicle evaluations revealed a few issues, such as managing a noticeable quantity of heat when absorbing hydrogen (which needs cooling for the speedy rate), and limited hydrogen release in the environment.

B. *Metal Hydrides*

At the considerably lower temperatures and pressures required for fuel cells, some steel hydrides may be able to store and release hydrogen from onboard the vehicle in a reversible manner. LaNi5H6, for instance, may also release hydrogen under PEM fuel mobile working conditions, but it is not suitable for use in automobiles due to its low gravimetric capacity and high price. When compared to conventional metallic hydrides, complex metal hydrides have the ability to boost the gravimetric hydrogen capacity of substances. With the assistance of Ti dopants, the chemical sodium aluminium hydride (NaAlH4) can also retain and release hydrogen in a reversible manner at low temperatures (1508C). [7] Complex metallic hydrides continue to exhibit poor hydrogen capacity and delayed hydrogen absorption and release kinetics. Since the maximum theoretical fabric gravimetric ability of sodium aluminium is 7.4 wt% hydrogen, practical material capabilities at the time are only simplest 3-4 wt%. Additionally, hydrogen emission's kinetics are too slow to be used in cars.

Because of amides' high hydrogen storage capacity, amides and imides have recently received attention. The Lithium amide (LiNH2) and hydride (LiH) total dehydrogenation is represented as:

$$LiNH_2 + LiH \rightarrow Li_2NH + H_2 \quad (1)$$

which includes two steps:

$$2LiNH_2 \rightarrow Li_2NH + NH_3 \quad (2)$$

$$NH_3 + LiH \rightarrow LiNH_2 + H_2 \quad (3)$$

4. A BETTER FUEL

Any type of fuel is considered to be a better form of fuel if it has some or the other type of improvement over other available resources. We shall discuss some of those properties in the upcoming texts and conclude why is it a better form of fuel.

A. *Versatility*

All fuels must be converted to another form of energy, such as mechanical, electrical, chemical and thermal energy, at the user's end through a process or a chemical reaction like combustion which can be utilized for energy production needs. A fuel becomes more adaptable and usable and easier to use if it can convert directly to different types of energy forms at the consumers' side. The types of fuels and forms to which they can be transformed into other types of energy forms at the consumers' end are listed in the table 2. As can be shown, combustion is the only mechanism that can combine all fuels—apart from hydrogen.

Table 2 Versatility of Fuels

Conversion Methods	Hydrogen	Typical fossil fuels
Fire based Combustion (rxn. with O_2)	Possible	Possible
Direct hot water vapour production	Possible	Not possible
Chemical Conversion	Possible	Not possible
Catalyst assist-based combustion reaction	Possible	Not possible
Electro-Chemical conversion	Possible	Not possible

[10] However, there are five ways that hydrogen can be connected to other sources of energy: in addition to fire based combustion, it can be instantly changed into steam, thermal energy and power via electrochemical processes, and it can also serve as a warmth source and/or sink through chemical reactions. All engines can run on hydrogen fuel, which can also be used for heating and cooking. Warmth is created when hydrogen chemically combines with a metal, alloy, or detail to form a hydride. In other words, exothermic energy is used during the charging or soaking up process. However, the discharging or resorption process is endothermic, necessitating the application of heat to a hydride in order to release hydrogen from it. The heat produced during the charging process and the heat needed for discharging are determined by the hydriding substance, the hydrogen stress, and the temperature at which the heat is removed or supplied. By combining various metals to form alloys, different hydriding houses can be operated.

B. *Efficiency*

1) Thermal generation efficiency - In the chemical industry, hydrogen is used extensively to create heat combustion. In comparison to flame combustion, catalytic hydrogen combustion is more effective. As most of the energy from the catalytic reaction stays inside the heated space and negligible polluting gases are produced, catalytic combustion reactions are up to 99% efficient in some applications, such as space heating. Kitchen ranges can also use catalytic burners. The Aphodid steam generator produces prisine steam at very high temperatures when hydrogen and oxygen are burned together.

[11] The temperature is then lowered by adding the proper amount of water. German Aerospace Research Establishment (DLR) engineers designed and tested the H2/O2 steam generator. This steam generator is incredibly straightforward, small, and highly effective (about 99%). Conventional water vapour generators are normally close to 78% efficient.

2) Electrical generation efficiency - Fuel cells have substantially higher efficiency for converting hydrogen to electricity than are thermal power plants that burn fossil fuels. While realistic efficiencies for hydrogen fuel cells are approximately are about 50-70%, conversion efficiencies for the latter are approximately about 37%. Even increased efficiency (up to 85%) can be anticipated from the sophisticated hydrogen fuel cells now under development. This is yet another significant and distinctive quality of hydrogen that can improve conversion rates in motor vehicles and, as a result, lower fuel usage. Combinations of a hydrogen fuel cell with an electric motor , popularly known as hybrid vehicle setup would produce conversion efficiencies that are more than twice as high as those of an internal combustion engine powered by petrol or diesel. Numerous studies have been conducted and remarkable solutions for hydrogen production are now being studied. The provision of high hydrogen charge at a low cost is the primary driving force behind those investigations. The production of hydrogen has unique challenges. Aluminium and H2O, for instance, can combine to form hydrogen. The inclusion of OH- in this case speeds up the reaction, but it has been discovered that doing so causes corrosion in the hydrogen device, shortening the equipment's useful life. Although the battery and gas mobile structures are related to one another in many ways, a comparison between the two is noticeably minor, especially when it comes to finances. In addition to the variations in rate, there are many types of batteries. Assuming that the battery charges and discharges at a rate of 61a per degree Celsius, the cost of the lithium-ion battery may be reasonably predicted to be around 270 $/kWh. As per a report from 2019, the cost of fuel cell stacks and tanks for compressed hydrogen ranges from $15 to $100 per kWh. As a result, a hydrogen-powered car is more affordable than a battery-powered one. Government subsidies for hydrogen prices are common, which further lowers the cost of hydrogen at the pump station to about $8/kWh. The cost of producing energy using hydrogen fuel cells is typically around $0.24/kWh, which is less than the price of electricity in many nations.

5. CONCLUSION

In several nations up to the 1960s, hydrogen was utilized as city petrol for both residential electricity (for cooking, heating and lighting) and for lighting up the streets. Hydrogen also serves as a crucial chemical feedstock in the synthesis of ammonia and other compounds, including the hydrogenation of crude oil, among other processes. The development of fuel cell technology in the latter part of the 1990s is the primary factor behind the rebirth of interest in hydrogen. As noted in the preceding paragraphs, the transportation industry will be essential for the possible adoption of hydrogen, despite the fact that hydrogen can be utilised in a number of applications (mobile, stationary, and portable). under addition, compared to internal combustion engines, gas cells can attain their best conversion efficiency under this situation. Because of hydrogen's availability and potential for zero greenhouse gas emission, it has emerged as a possible future fuel. You recognize the necessity of shifting to a hydrogen economy as a dedicated scientist and aspiring scientific student. Hydrogen can be produced in a number of processes, highly popular the method of electrolysis of water, hydrocarbon reforming, and biomass conversion. However, efficient and cost-effective hydrogen production remains a difficulty. The most widely accepted and used methods for producing hydrogen is electrolysis, which uses renewable energy sources rather than fossil fuels. Electrolysis is the process of separating oxygen and hydrogen from water using an electrolyzer. This approach is considered the preferred way of hydrogen production because it produces no greenhouse gas emissions. It is practical on both small and large scales and offers high product purity. [13] By optimizing electrolysis processes using machine learning techniques, such as identifying optimal operating conditions and catalyst performance, the efficiency and cost-effectiveness of hydrogen production can be improved.

Another approach to hydrogen production is coal-based extraction, which lies between the current method of natural gas reforming and possible efficient method of renewable water splitting. Coal, as a readily available fossil fuel, can supply a significant amount of hydrogen without depleting its reserves or significantly impacting its market price. Coal gasification and the water-gas shift methodcan be utilized to produce hydrogen from coal while capturing CO2 emissions. However, the development of membranes for separating hydrogen from CO and CO2 remains a critical material issue in this process.

Storage and transportation are vital aspects of a hydrogen economy. Compressed gas tanks and metal hydrides are two potential storage options. Compressed gas tanks are commonly used in fuel cell cars and require lightweight and robust materials, such as carbon fiber reinforced plastic. Metal hydrides offer reversible on-board hydrogen storage but face challenges related to gravimetric capacity and kinetics. In terms of fuel properties, hydrogen exhibits versatility, as it can be directly converted into different forms of energy, including steam, heat, and electricity. Its efficiency is notable, with catalytic combustion and fuel cell systems offering high conversion rates and electrical generation efficiencies compared to traditional thermal power plants.

Hydrogen exhibits promising characteristics such as zero emissions, adaptability, and high efficiency, making it an appealing alternative for various applications, including transportation, electricity generation, and industrial processes. However, the widespread acceptance of hydrogen as a mainstream fuel requires addressing challenges in production, storage, and transportation. Overcoming these obstacles necessitates dedicated research and development efforts, utilizing advancements in machine learning and material science. By leveraging these technologies, we can pave the way for a sustainable future powered by hydrogen. If we are to accomplish a major penetration of hydrogen into future electrical networks, the techniques for hydrogen generation, distribution, storage, and consumption must be significantly enhanced beyond their current levels of performance, dependability, and cost. The following is a list of some of the most difficult conditions for the hydrogen economy: the creation of a CO2-free method for mass producing sustainable hydrogen at a fair price, the development of a reliable national infrastructure for hydrogen distribution and transportation, the development of practical hydrogen storage systems for both mobile and stationary applications, a sharp drop in costs, and a significant increase in the durability.

Up to 2020, it is projected that the electrolysis of water using grid energy and the creation of hydrogen from fossil fuels will be the two main sources of hydrogen. During this transitional time, better and more efficient reformation/gasification processes, CO2 collection and sequestration, and new efficient and affordable electrolysers will need to be created. The reforming and gasification of fossil fuels must be gradually replaced over time by ecologically benign hydrogen generation techniques that are mostly powered by renewable electricity sources. Hydrogen has the potential to be the straightforward, ecologically beneficial, and weather-independent power source of the future, which can eventually eliminate the conventional greenhouse gas emitting fuel based power production from the mainstream energy generation.

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