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Potential of Green Hydrogen with its Various Generation Methods

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ABSTRACT

Understanding the Contribution of Hydrogen and its potential future low carbon society. Making availability of Hydrogen at the domestic and commercial level, by making its extraction easier by converting renewable energy into hydrogen fuel using atmospheric Electrolysis or Biomass method. Enriching the hydrogen society for by adopting the various efficient and most economical ways of generation of hydrogen. One of the best way is to put back all Hydrocarbons and petroleum fuels with green hydrogen as industrial fuel. Hydrogen plays a key role in many industrial applications and is currently seen as one of the most promising energy vectors. Many efforts are being made to produce hydrogen with zero CO2 footprints via water electrolysis powered by renewable energies. The conventional coal gasification and steam methane reforming (SMR) process for hydrogen production are undesirable due to huge emissions of CO2. Thus, cleaner technology based on Thermal decomposition of Biomass or Electrolysis of water, are the need of today's Hydrogen Revolution. Also then making the proper storage and utilization of hydrogen by best suitable methods to get optimum results is essential to complete the hydrogen cycle. One of this way is by using the solar energy to extract the water molecules from the atmospheric moisture and powering it for electrolysis to extract the green hydrogen from moisture collected with maximum solar to hydrogen (STH) efficiency, just like plants do in nature through photosynthesis

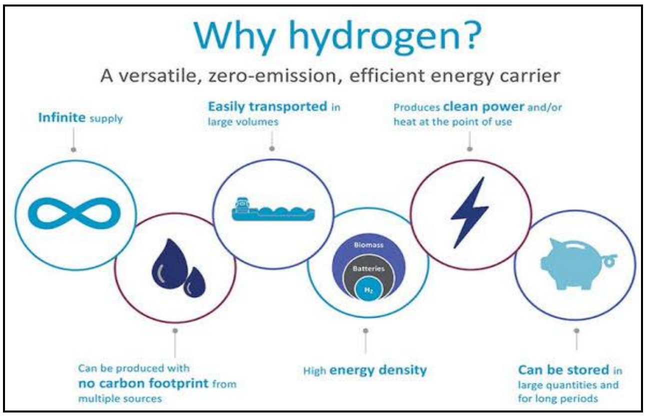
Keyword –Atmospheric moisture, Biomass, Electrolysis, Hydrogen, Low carbon society, STH efficiency, SMR (Steam methane reforming).

I. INTRODUCTION

Hydrogen is an excellent secondary form of energy source that stores and transports energy produced from other primary sources such fossil fuels, water, biomass, renewable and others. And So, Hydrogen is never found in its purestate without being produced from the other primary sources, and so it is known as an energy carrier. Hydrogen is very clean burning fuel and when combined with oxygen in fuel cells to produce the heat and electricity with only the water as a by-product. But today we are using it with combination carbon to form hydrocarbons as a easy fuel, but only drawback is that, presence of carbon produces harmful greenhouse gases.

Hydrogen can be directly made from the fossil fuels or the biomassusing various Thermochemicalprocesses or it can be made by passing electricity through the water to separate the basic elements of it, i.e.hydrogen and oxygen. Its broaden vision of future low carbon society is to enrich the "Hydrogen economy" where Hydrogen is produced from variety of energy sources, mainly renewable, stored for later us,transported to where it is needed, and then converted cleanly into heat or electricity.Energy carriers are the important element of the energy system that allow the storage and transport of energy in the usable form, from one place to another just like electricity, has the energy carrier. Hydrogen can be procure by the separation of hydrogen atom from variety of energy sources using the Thermal or the electrical energy.

Main reason for only Hydrogen is used, is its highest energy density among any common fuel by weight. (about 3 times more than gasoline). But Ittakes enough energy to make synthesis of the energy source to extract Hydrogen, but if we use renewable energy for it, then energy is not any concern. So, Hydrogen is useful as an energy source/fuel because it has highest energy content per unit weight, due to which its is used has rocket fuel and in fuel cells to produce electricity on spacecraft. Hydrogen is not widely used as a fuel now, but it has the potential for greater use for Sustainable future. Hydrogen is best form of energy carrier as well as energy fuel with lowest carbon footprints,easy transportation (not likeelectrical transmission losses), Produce clean and efficient energy with highest energy density.



II. SOME SALIENT FEATURES OF HYDROGEN :

A. Most abundantly available element in the universe

The Hydrogen element, which is the building blocks of the universe, were created after the Big Bang. Hydrogen has single proton and electron and is the only element with no neutrons, making it the simplest element in the universe. Because of this, Hydrogen is believed to be the most prevalent element, consisting for about 90% of the known universe. Hydrogen is the simplest and most abundant element in the universe, but it rarely exists as a gas on Earth, it requires to be separated from other elements.

B. Lightest element among all

It is the most light or flimsy element ever and is colorless, inodorous, and tasteless. It's also in many of the organic compounds. Since hydrogen atom has only single electron and single proton and we know -

Mass of an electron is 9.109×10^{-31} kg

Mass of proton is 1.67×10^{-27} kg

Also, hydrogen is having the smallest atomic number and so no other have the less mass than hydrogen. Thus, total mass of hydrogen is smallest. So, hydrogen is the lightest element in the universe.

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C. Hydrogen can never be found in pure state on earth

Hydrogen exists as in its pure state on Earth as a diatomic gas, H2, but it's very rare in Earth's atmosphere because it is light enough to escapeearth's gravity and drain into space. The element remains common at the Earth's surface as well, but it is bound into water and hydrocarbons to be the third most prominent element. Although, Hydrogen element is the also most common element in the human body in terms of numbers of atoms of the element, it's only 3rd in abundance by mass, after oxygen and carbon, because hydrogen is so light and exist only with another element.

D. Hydrogen the only element that can have atoms without any neutrons

There are the three main isotopes of hydrogen: protium, deuterium, and tritium. The most usual isotope of hydrogen is protium, which has single proton but zero neutronsand 1 electron. Due to which hydrogen is the only element that can have atoms without anyneutrons. Deuterium has all single proton, neutron, and an electron. Although this isotope is denser in weight than protium, deuterium is not radioactive. However, tritium does emit radioactivity. Tritium is the isotope with single proton, two neutrons, and single electron.

E. Hydrogen gas is extremely flammable

Hydrogen gases are believed to be the natural burners. Itdoesn'tconsist of any flashpoints as it can catch on fire in all temperatures above its boiling point of 20 k. It is also exceptional for the ability to burn at lower concentrations. Its periodic position also makes it the highly reactor to nearby elements and can be burned or reactedat very lower concentrations.

Hydrogen is very volatile by nature and without any external effects, it can readily react very quickly with other near elements and be oxidized. This oxidized form is the main cause of the burning of hydrogen.Hydrogen is continuously carrying out combustion reaction, which is another reason for its extreme flammability.

F. It can be in Gaseous form and also in alkali metal form.

The natural form of hydrogen at room temperature and pressure is a colorless and odorless gas. The gas and liquid are generally nonmetals, but when hydrogen is Crushed down into a solid, the element becomes an alkali metal. Solid crystalline metallic hydrogen is having lowest density of any crystalline solid.

G. Hydrogen is the only atom for which the Schrödinger equation has an exact solution.

The hydrogen atom has special importance in quantum mechanics and quantum field theory as a simple two-body problem physical system which has yielded many simple analytical solutions in closed-form is very much relative to it. The Schrödinger equation allows the individual to figure out the stationary states and also the time evolution of quantum systems. Exact analytical answers are available only for the nonrelativistic hydrogen atom due its simplicity.

H. Sun, the continuous energy source produces energy from Hydrogen fusion chain reaction

The Sun is a main harbinger star, and as a such energy source, by generating its energy by nuclear fusion of hydrogen nuclei into helium. The core of the Sun hydrogen iscontinuously converted into the helium due to process called nuclear fusion. It takes four hydrogen atoms to fuse into each of the helium atom. During the process some of the mass is converted into energy and released in the form of heat. It fuses about 600 million tons of hydrogen every fraction of second, for generating 596 million tons of helium. The remaining four million tons of hydrogen is transform to energy, which makes the Sun shine.

J. Hydrogen use by nature, through photosynthesis

Across the billions of years transform, nature has been making quite impressive evolutions, and humans have been mimicking these in their modern-day technologies is the most effective way to find eco friendly and most efficient solutions. When theplants photosynthesis, they use sunlight to break apart water into hydrogen and oxygen, and then combine the resulting hydrogen with carbon dioxide from the air to create carbohydrates or ATP molecules. In this way plants releases us oxygen and becoming carbon sinks, by utilizing hydrogen from waterto create their fuel.

We can see easily Figure out the similarity between this natural and artificial process of Hydrogen separation from water:

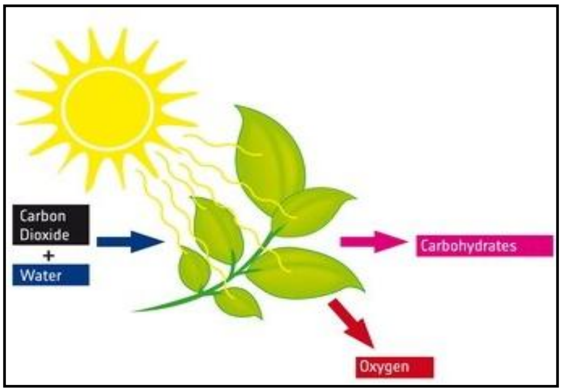

Fig. 1: Photosynthesis by plants

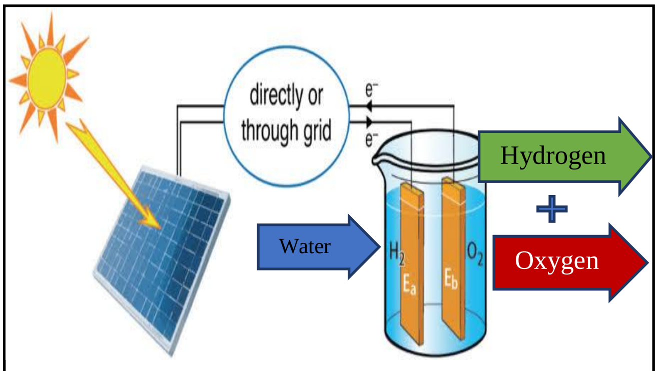

Fig. 2: Electrolysis of water

III. DIFFERENT HYDROGEN EXTRACTION METHODS :

Hydrogen can be Extracted using a number of different processes. Thermochemical process possesses heat and chemical reactions to generate hydrogen from organic materials, such as fossil fuels and biomass, or from materials like water. Water (H2O) can also be split into its fundamental elements hydrogen (H2) and oxygen (O2) using electrolysis or solar energy. Microorganisms such as bacteria and algae or any other produce hydrogen through biological processes.

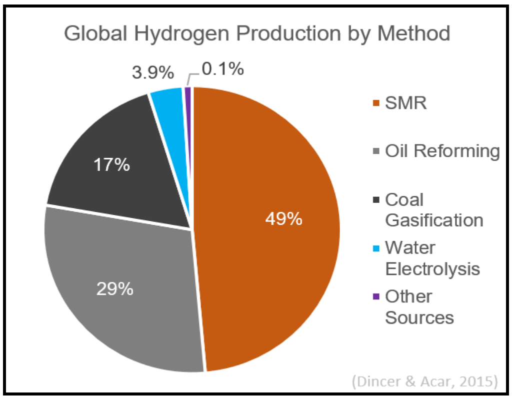

Fig. 3: Synthesis of Methane

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As of 2020, the larger part of hydrogen (~95%) is produced from fossil fuels by steam reforming process of natural gas and other light hydrocarbons,while partial oxidation of heavier hydrocarbons, and coal gasification is done. Other methods of hydrogen procurement include biomass gasification, Zero-CO2-emission methane pyrolysis, and electrolysis of water. The synthesis processes of, methane pyrolysis as well as water electrolysis can be done directly with any source of electricity which may be renewable, such as solar power.

1) Thermochemical Processes

Some Thermal processes use the energy in different resources, such as natural gas, coal, or biomass, to release hydrogen from their main molecular structure. Hydrogen can be produced by reacting metals with acids (e.g., zinc with hydrochloric acid). In other processes, heat, in combination with closed-chemical cycles of the hydrocarbons, produces hydrogen from feedstocks such as methane or water. The various Thermo- Chemical processes are:

- Natural gas reforming (also called as steam methane reforming or SMR)
- Biomass gasification (for coal)
- Biomass-derived liquid reforming
- Solar thermochemical hydrogen method (STCH).

A. Steam Methane Reforming

Steam methane reforming (SMR) is a method of producing hydrogen from natural gas, which is generally methane (CH4). It is currently cheapest source for the industrial hydrogen. Nearly half of the world's hydrogen is being produced by this method. The process includes of heating the gas to between 700–1,100 °C (1,292–2,012 °F) in the presence of steam and a nickel catalyst which results in endothermic reaction to breaks upmethane molecules and forms carbon monoxide and molecular hydrogen (H2). The carbon monoxide gas can then furtherpass with steam over iron oxide or other oxides films substances andthen undergo a water-gas shift reaction to obtain further quantities of H_2. The drawback to this process is that its byproducts are major atmospheric release of CO_2, CO and other greenhouse gases.

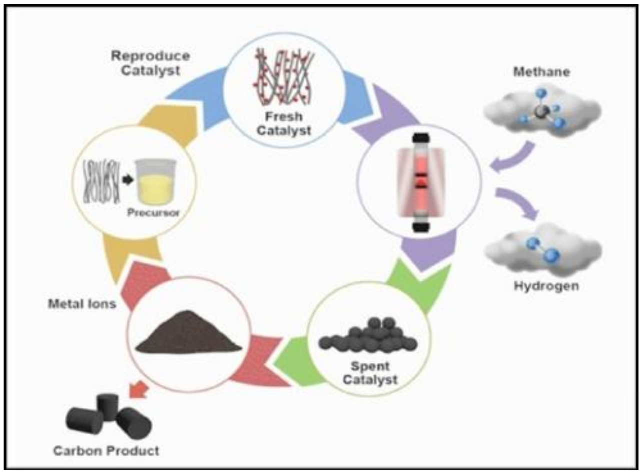
For this process, Steam at hightemperature (H_2O) reacts with methane (CH_4) in an endothermic reaction to generate the syngas

$$CH_4 + H_2O \rightarrow CO + 3H_2$$

In a second stage, additional hydrogen is produced through the low-temperature, exothermic, water-gas shift reaction, performed at nearly about 360 °C :

$$CO + H_2O \rightarrow CO_2 + H_2$$

Essentially, the oxygen (O) atom is drain rom the additional water (steam) to oxidize CO to CO2. This oxidation also provides energy to maintain the reaction. Additional heat required to drive the process is generally generated by burning some part of the methane or also we can use renewable energy sources like solar to power this process.



Source: - International journal of hydrogen energy, 40(34), 11096

B. Pyrolysis or Thermal decomposition

Pyrolysis of methane or other hydrocarbons is a hydrogen procurement process from natural gas. Hydrogen separation occurs in single step viapass through a molten metal catalyst in a "bubble column". It is a "no-greenhouse-gas" approach for potentially very low-cost hydrogen generation being measured for its capability to scale up and for operation at scale. The process is conducted at very higher temperatures (1065 °C or 1950 °F). Other forms of methane pyrolysis, such as the thermo-catalytic decomposition of methane, however, are able to set off at a reduced temperature between 600 °C - 1000 °C depending on the selected catalyst.

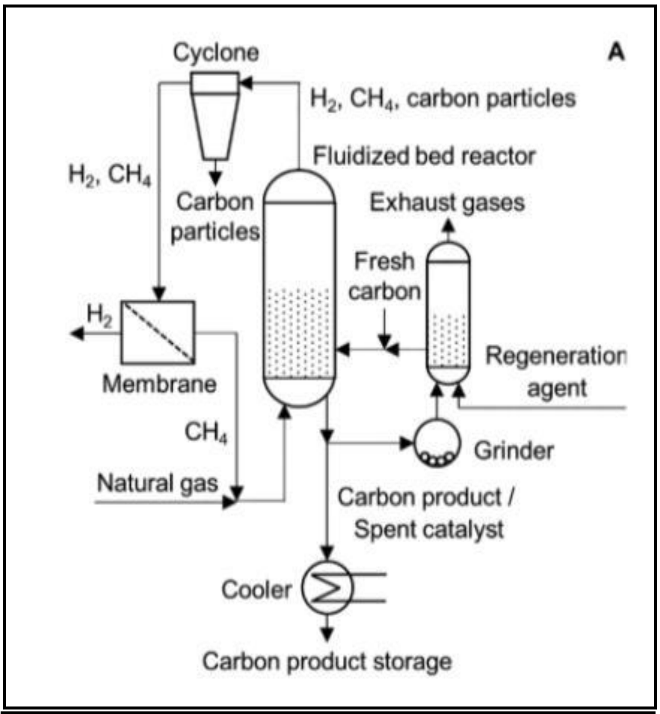


Fig. 4: Industrial implementation of methane Pyrolysis

C. Partial oxidation or Reduction reaction

Hydrogen production from heavy and large hydrocarbons, which are unsuitable for catalytic steam reforming, is achieved by partial oxidation process. A fuel-air or fuel-oxygen mixture is partially combusted, resulting in a hydrogenand the carbon monoxiderich syngas. More hydrogen and carbon dioxide gases are then obtained from carbon monoxide (and water) via the water-gas shift reaction. Carbon dioxide can be co-fed to lower the hydrogen to carbon monoxide ratio generated in the first step.

D. Coal Gasification or carbonization

For the production of hydrogen from coal fuel, coal gasification method is used. The process of coal gasification uses steam and oxygen to break down the molecular bonds in coal and form a gaseous mixture of hydrogen and carbon monoxide syngases. Carbon dioxide and all other pollutants may be more easily removed from gas obtained from coal gasification compare to coal combustion method. Another method for conversion of coal is low-temperature and high-temperature coal carbonization.

Coke oven gas which are made from pyrolysis (oxygen free heating) of coal has about 60% hydrogen left, the rest being methane, carbon monoxide, carbon dioxide, ammonia, molecular nitrogen, and hydrogen sulfide (H_2S). Hydrogen can be separated from other these impurities by the pressure-swing adsorption process.

2) Electrolytic Processes

Electrolysis is a prominent option for carbon-free hydrogen production from renewable energy resources. Electrolysis is the process of using electricity to synthesis water into its fundamental molecules hydrogen and oxygen. This reaction takes place in a closed unit called as an electrolyzer. Electrolyzers can range in size from minor, appliance-size equipment that is well-suited for small-scale distributed hydrogen production to the major large-scale, central production facilities that could be tied directly to renewable or other non-greenhouse-gas-emitting forms of energy resources that can produce electricity. Methods to produce hydrogen without the use of fossil fuels or natural gas involve the process of splitting the water molecule (H2O) into its fundamental components oxygen and hydrogen using the electrolysis method. When the source of energy for this water synthesis is renewable or low-carbon, the hydrogen produced is referred to as green hydrogen. Electrolyzersor electrodes used here consumes electricity to split water into hydrogen and oxygen. This technology is well developed and now available commercially, and systems that can efficiently use this intermittent renewable power are being developed.

Today in 2020 around 8 GW of electrolysis capacity is installed worldwide, accounting for around 4% of global hydrogen generation. Electrolysis of water is 70–80% efficient process. There are three main types of electrolytic cellsused:

- Solid oxide electrolyser cells (SOEC)
- Polymer electrolyte membrane cells (PEM cell)

- Alkaline electrolysis cells (AEC)

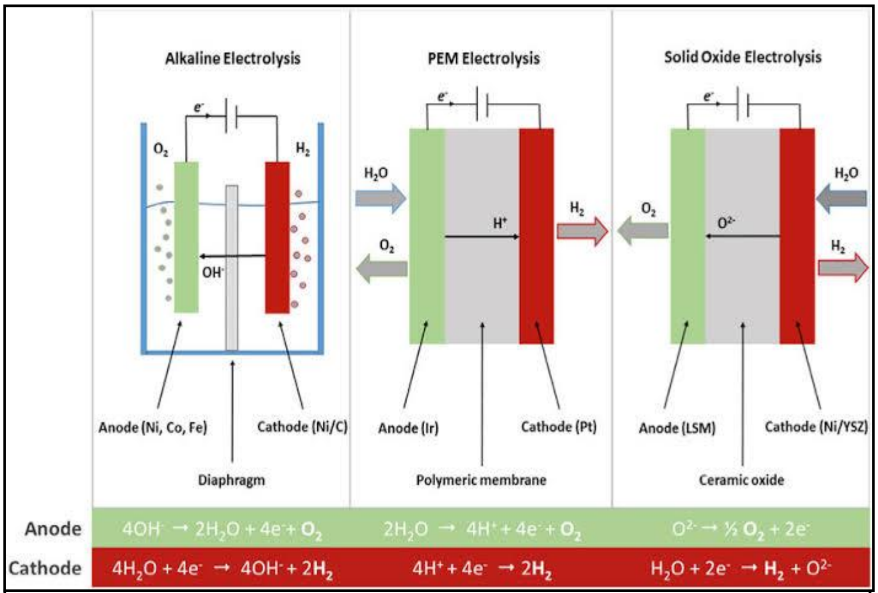


Fig. 5: Different types of Electrolysers

Traditionally, alkaline electrolysers are cheaper in terms of initial cost andgenerally use nickel catalysts), but are less-efficient. PEM electrolysers, conversely, are more expensive (they generally use expensive platinum group metal catalysts) but they are more efficient and can operate at higher current densities, and can therefore be possibly cheaper and its initial cost can be forbided if the hydrogen production is large enough.

3) Direct Solar Water Splitting Processes

Direct solar water synthesis, or photolytic, processes use light energy to split water into its molecules of hydrogen and oxygen, just like plants. These processes are currently in various prior stages of research but offer long-term potential for sustainable hydrogen production with lowest environmental impact. For this technology to be economically competitive, it is essential o develop water splitting systems with highest solar-to-hydrogen (STH) efficiencies.

In photoelectrochemical (PEC) water splitting, hydrogen is produced from the water using sunlight and some specializedsemiconductors called photoelectrochemical such as perovskite materials, which use light energy to directly separate water molecules into its hydrogen and oxygen molecules. The semiconductor materials used in the PEC process are similar to those used in photovoltaic solar electricity generation used in solar panels, but for PEC applications the semiconductor is immersed in a water-based electrolyte, where sunlight energizes the water-splitting process. The following are the solar water splitting processes:

- Photo electrochemical (PEC)

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- Photo biological

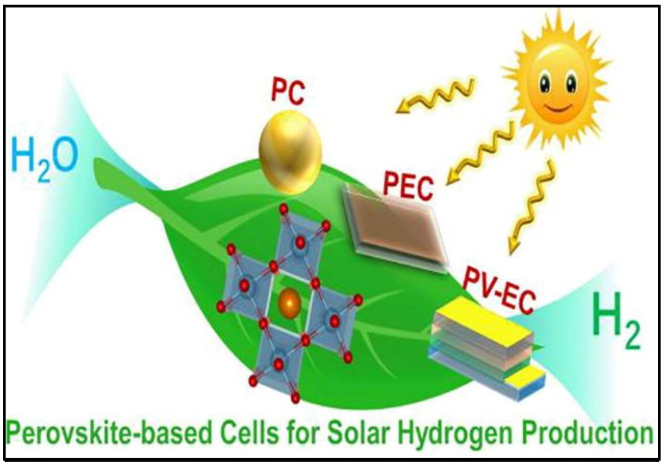

Fig. 6: Photo-Electrochemical cells

4) Biological Processes

Microbes such as bacteria and microalgae and others can produce hydrogen through biological reaction processes, using sunlight or organic matter. These technology pathways are in early stagesof research and development, with pilot demonstrations occurring, but in the long term have it also has potential for sustainable, low-carbon hydrogen production for infinite time.

In photolytic biological systems, microorganismssuch as green microalgae or cyanobacteriause Photolytic energy to split water into oxygen and hydrogen ions naturally. The hydrogen ions can be combined through direct or by the indirect routes and produced as a hydrogen gas. Some photosynthetic microbes use sunlight as the driver to break down the organic content, releasing hydrogen into the atmosphere. This process is known as photofermentative hydrogen production. Researchers are nowworking on methods to allow the microbes to produce hydrogen for larger extent of time and to increase the rate of hydrogen production. The following are the two biological processes commonly used:

- Microbial biomass conversion
- Photobiological.

IV. HYDROGEN STORAGE AND UTILIZATION METHODS :

Hydrogen is an excellent energy carrier with respect to weight. 1 kg of hydrogen contains 33.33 kWh of usable energy, whereas petrol and diesel only hold about 12 kWh/kg. In terms of volumetric energy density however, hydrogen is outperformed by liquid fuels. This poses a challenge when hydrogen must be transported from the place of its generation to a refuelling station. Petrol and diesel carry around 8.8 and 10 kWh/litre, respectively. Pressurised hydrogen contains about 0.5 kWh/litre at 200 bar, 1.1 kWh/litre at 500 bar and 1.4 kWh/litre at 700 bar. Hydrogen can be stored physically as either a gas or a liquid. Storage of hydrogen as a gas typically requires high-pressure tanks (350–700 bar [5,000–10,000 psi] tank pressure). Storage of hydrogen as a liquid requires cryogenic temperatures because the boiling point of hydrogen at one atmosphere pressure is −252.8°C. High density hydrogen storage is a challenge for stationary and portable applications and remains a significant challenge for transportation applications which also make utilization of Hydrogen little complex.

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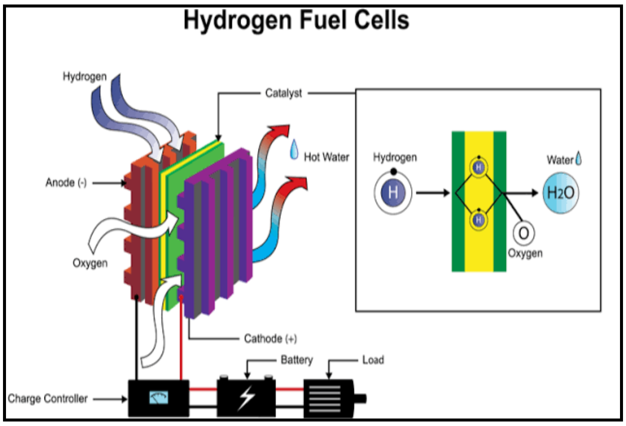
A. Hydrogen Fuel cell

Hydrogen fuel cell is an electrochemical cell that converts the chemical energy of ahydrogen fuel and an oxidizing agent (often oxygen) into electricity through a pair of redox reactions. The first fuel cells were invented by Sir William Grove in 1838. The first commercial use of fuel cells came more than a century later following the invention of the hydrogen–oxygen fuel cell by Francis Thomas Bacon in 1932. The alkaline fuel cell, also known as the Bacon fuel cell after its inventor.Fuel cells are different from most batteries in requiring a continuous source of fuel and oxygen (usually from air) to sustain the chemical reaction, whereas in a battery the chemical energy usually comes from metals and their ions or oxides, that are commonly already present in the battery, except in flow batteries. Fuel cells can produce electricity continuously for as long as fuel and oxygen are supplied.



There are many types of fuel cells, but they all consist of an anode, a cathode, and an electrolyte that allows ions, often positively charged hydrogen ions (protons), to move between the two sides of the fuel cell. At

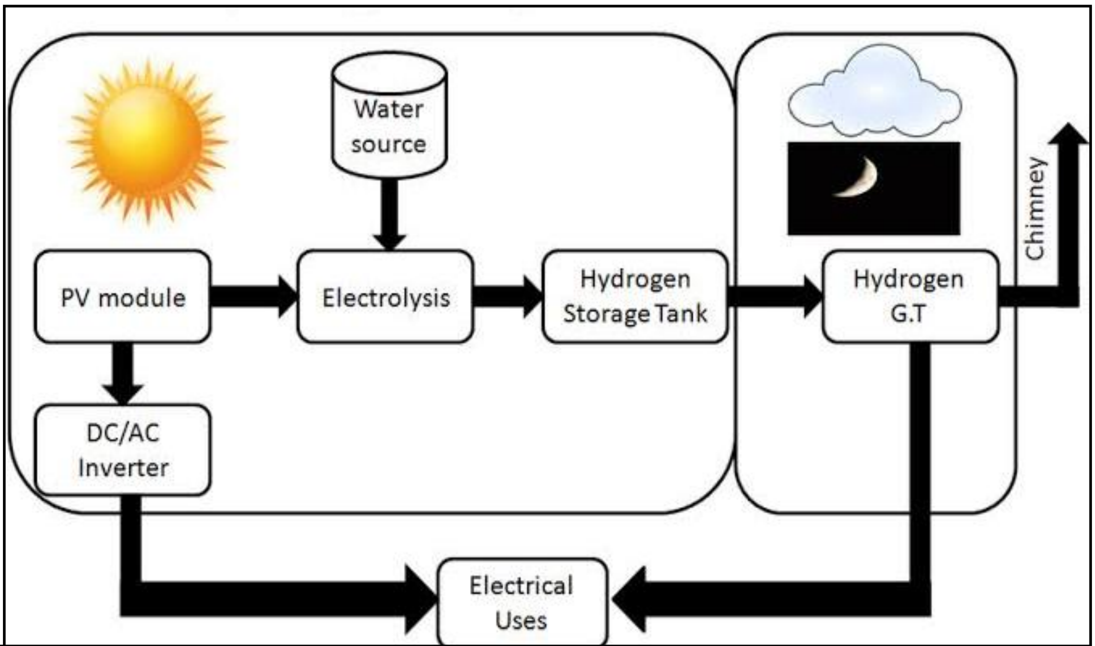


Fig. 7: Block Diagram of Solar green hydrogen generator using atmospheric moisture

the anode a catalyst causes the fuel to undergo oxidation reactions that generate ions (often positively charged hydrogen ions) and electrons. The ions move from the anode to the cathode through the electrolyte. At the same time, electrons flow from the anode to the cathode through an external circuit, producing direct current electricity. At the cathode, another catalyst causes ions, electrons, and oxygen to react, forming water and possibly other products. In addition to electricity, fuel cells produce water, heat and, depending on the fuel source, very small amounts of nitrogen dioxide and other emissions. The energy efficiency of a fuel cell is generally between 40 and 60%; however, if waste heat is captured in a cogeneration scheme, efficiencies of up to 85% can be obtained.

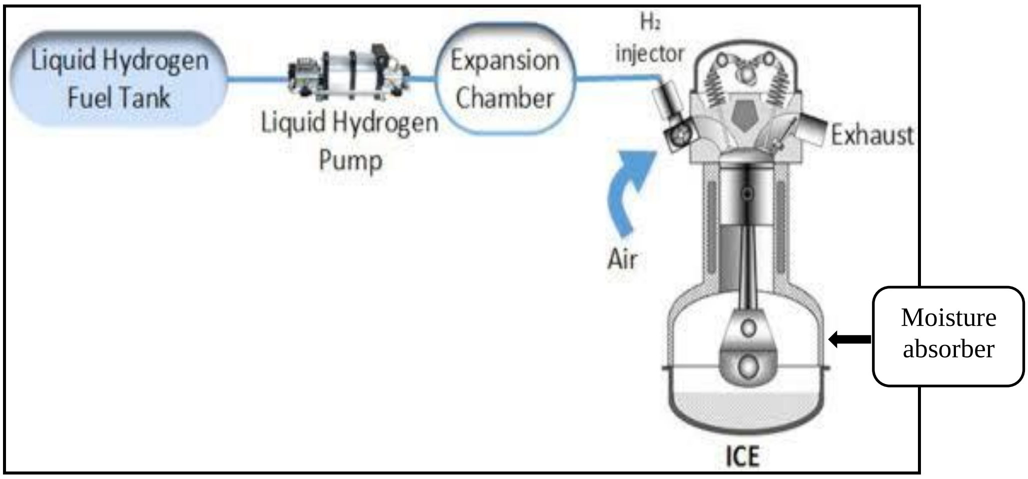


Fig. 6: Hydrogen combustion engine

B. Hydrogen Combustion method :

Hydrogen has since been used extensively in the space program since it has the best energy-to-weight ratio of any fuel. Liquid hydrogen combustion is the fuel of choice for rocket engines, and has been utilized in the upper stages of launch vehicles on many space missions. Hydrogen engines burn hydrogen in an internal combustion engine, in just the same way gasoline is used in an engine. Hydrogen internal combustion engines (Hydrogen ICE) are nearly identical to traditional spark-ignition engines. Due to large energy density, hydrogen combustion is used in heavy torque and load vehicles, trucks and spacecrafts.Due to more space and time for combustion rotary engines are more preferred for Hydrogen Internal Combustion engines.

Hydrogen has a wide flammability range in comparison with all other fuels. As a result, hydrogen can be combusted in an internal combustion engine over a wide range of fuel-air mixtures. Hydrogen has very low ignition energy. The amount of energy needed to ignite hydrogen is about one order of magnitude less than that required for gasoline. This enables hydrogen engines to ignite lean mixtures and ensures prompt ignition. Hydrogen has very low density. This results in two problems when used in an internal combustion engine. Firstly, a very large volume is necessary to store enough hydrogen to give a vehicle an adequate driving range. Secondly, the energy density of a hydrogen-air mixture, and hence the power output, is reduced.

V. GREEN HYDROGEN GENERATION FROM ATMOSPHERIC MOISTURE:

Solar panels are multiplying on rooftops and in the domestic surroundings worldwide as communities blaring for renewable energy sources. But the panels could do more than only keeping the electrical charge onthey could also produce hydrogen gas on site, allowing domestic users to heat, refrigerate and power their homes without expanding their carbon footprints.A solar panel that converts solar energy and stores it in the form of electrical energy through the help of battery, which can be utilized for powering the moisture absorption process and also electrolysis which directly produces hydrogen using water contentof the air.

Here, Source is a completely off-grid, solar powered and self-contained device that first creates the water from sunlight and atmospheric moisture. For this, Air is drawn into the unit with thefan, then special hygroscopic material(such as sodium chloride combined with silica (SiO_2))absorb the water. The water vapor is collected in the reservoir as the airflow passes through a condenser, then flows into a reservoir. Here, a standard array (2 panels) averages 4-10 liters of water production each day depending on the sunlight available and humidity conditions.Here,we only need sunlight and water vapor and all energy would be generated automatically. And all over the world you have water vapor in the air, even in the driest places in the world, humidity is never zero or absolute. Then we have to generated Hydrogen from that storedwaterusing the common Electrolysis process and stored that hydrogen gas in a pressurized container, just like we would do with CNG. It is similar to natural gas, except that we do not produce greenhouse gases when we use it. When hydrogen is used with the help of generators or fuel cells, it recreates only water. The particularity of this module is that hydrogen is produced at the rate of the discharge of the sunlight, at much weaker electric currents. So we can optimize each step and minimize the losses for conversion and generation. Also best advantage is to generate Hydrogen at any remote places for commercial as well as domestic purposes.

The solar panel can be utilized measuring about 1.65 meters long, roughly the height of 4-5 feet and has a rated power output of about 210 watts. The system can convert the renewable 15% of the solar energy it receives into hydrogen.A traditional solar panel converts between 18 to 20% of the solar energy into electricity using the battery system, that also can be used in sunny days only.If same system is installed with all available efficient method the system can produce 250 liters of hydrogen per day on average for a full year. Then, this Hydrogen can be used for heating, refrigeration and powering the domestic and commercial purposes and can also used has fuel to power our FCEV vehicles.

VI. CONCLUSION :

Hence, we have seen the potential and the impact of the green Hydrogen on the sustainable society. We have seen different methods of generation, utilization and application of the green Hydrogen and its deep impact on the net-zero carbon mission or low carbon society. Here is a need for new low-carbon technologies to encounter the net-zero targets. One of the options is to put back all Hydrocarbons and petroleum fuels with green hydrogen as industrial fuel. Currently, hydrogen is widely used across the refineries, forproduction of urea, steel and other chemical industries only

The time is right to tap into hydrogen’s potential to play a leading role in intercepting critical energy challenges. The latest successes of renewable energy technologies and electric vehicles have shown that policy and technology revolution have the power to build global clean energy industries. Hydrogen is come out as one of the leading options for storing energy from renewables with hydrogen-based fuels potentially convey energy from renewables over long distances – from regions with plentiful energy resources, to energy-hungry areas thousands of kilometers away.

Green hydrogen featured in a number of effusion reduction pledges at the UN Climate Conference, COP26, as a means to decarbonize heavy industry, long haul freight, shipping, and aviation. Now governments and industry

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across worldwide have both acknowledged hydrogen as an important pillar of a net zero economy. The Green Hydrogen Catapult, a United Nations initiative to bring down the cost of green hydrogen announced that it is almost doubling its goal for green electrolysers from 25 gigawatts set last year, to 45 gigawatts by 2027. One day we would definitely achieve this flight of Hydrogen ecosystem for sustainable and healthy future.

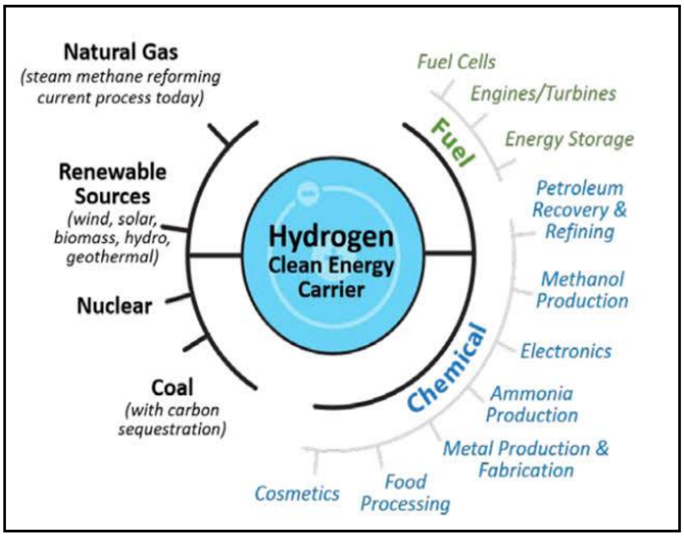

Fig. 8: Hydrogen generation to application has a clean energy carrier

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