IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)
e-ISSN: 2319-2402,p- ISSN: 2319-2399.Volume 15, Issue 9 Ser. II (September 2021), PP 21-26
www.iosrjournals.org

Methods of Preparation of Grey, Blue, Green and Yellow Hydrogen

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***Abstract**: It has been observed and concluded, over years of research that, hydrogen is one of the most unparalleled energy carrier of this century, having said that, it still has a lot of untapped potential when it comes to commercial usage. It is evident that an ample amount of research is being carried out to obtain an efficient method for the production of different types of hydrogen, under the clean energy initiative, which has been a prime focus across the globe.There would be no useful organic compounds to form the building blocks of life without it. This study focuses on types of hydrogen and its specialties which has ample real world mapping in areas like petroleum refining, power generation and as an energy carriers. The one in more abundance is grey hydrogen but in the not so distant future green hydrogen will be the hot topic. Outstanding methods do not have any specifications regarding carbon capture but we can have plants which will absorb carbon or conservation of CO_2 can be stifled by chemisorption. New strides are being made in this field everyday with discoveries of new ways of storing the hydrogen.*
Keywords

Date of Submission: 01-09-2021 Date of Acceptance: 15-09-2021

I. Introduction

While the tech geniuses, industrialists and entrepreneurs have been successful in bringing about mammoth change in the lifestyle in terms of a variety of factors, the most important being the healthcare, which in turn has increasing the life expectancy by 45.7years to 72.6years as of 2019[11], somewhere while working for a better change we might've ignored the wellbeing of our planet. Climate change is one of the biggest threats faced by the mankind in the 21st century. One of the major causes of the human-induced climate change is carbon dioxide which is emitted by the burning of fossil fuels. These fossil fuels are majorly used as a source for the production of energy, but while we are effectively producing a massive amount of energy, this in turn is heating up the entire planet. The major focus at the moment is the production of clean energy and most importantly the application of it. The upturn of hydrogen, the most uncomplicated closed-shell molecule to ever exist on this planet, has created countless avenues to approach the most important problem at this instant of time.

1.1 Applications of Hydrogen

) Petroleum Refining: Petroleum products like gasoline and diesel are produced by using the process of hydrocracking where hydrogen plays an important part. It also plays an important part in removal of contaminants like sulphur in the production of methanol. Hydrogen is also used for hydro-isomerization, which the process in which normal paraffin is converted to iso-paraffin.[12] Besides that, it is used to convert aromatic to cycloalkanes and in the process of hydrocracking as well.

2) Power Generation: Hydrogen, along with providing promising means of electrical grid stabilization, is already being used to cool the power plant generators. Electrical energy can be turned into hydrogen through electrolysis, then stored and used in an end-use application like transportation.

3) For energy: Hydrogen plays a vital role in the production of clean energy, which can be used for a range of applications, which not only offers a palpable benefit but, it also meets an immediate need. This is the case for power supply to isolated regions that aren't connected to the facility grid, sensitive sites that need reliable back-up energy systems, captive fleets, and portable power generators used for outdoor events.[14]

4) Energy Carrier: A colossal amount of energy can be delivered and stored by hydrogen but having said that, hydrogen is not an energy source but is an energy carrier[13]. Hydrogen are often utilized in fuel cells to get electricity, or power and warmth . Today, hydrogen is most ordinarily utilized in petroleum refining and fertilizer production, while transportation and utilities are emerging markets.

II. Handling of Hydrogen

Hydrogen, being a highly inflammable and explosive gas, has wide flammability limits with a low minimum ignition energy and a fast burning velocity. Despite of its flammable mixture with air, its deflagration in a partially or completely confined space is accompanied by a severe pressure impulse and a potential transition to detonation. Hydrogen gas also has the ability to embrittle metals and due to this property, safe handling of gaseous hydrogen is absolutely essential. The safe handling procedures must include attention to the following aspects:

1) Any possibility of leakage should be dealt with on an immediate basis.
2) Avoidance of formation of a flammable mixture.
3) Avoidance of ignition sources from the gas.
4) Selection of appropriate container materials, which cannot be embrittled by the gas.
5) Inertisation of the operation vessels.

The same considerations have to be applied for liquid hydrogen and hydrogen in the combined state such as, metal hydrides. Liquid hydrogen is accompanied by additional hazards due to its low temperature, rapid vaporisation, solidification due to moisture and air, embrittlement of construction materials. Although it is possible for metal hydrides to be stored at moderate pressure and ambient temperatures, the fine particles produced during the repetitive cycles of hydrogen absorption and desorption are pyrophoric, and can cause internal stress that cause the container to rupture.[6]

III. Process Descriptions for Production of Hydrogen

Hydrogen production still remains one of the largest industrialized processes worldwide. In 2020, roughly 87 million tonnes of hydrogen was produced worldwide. This level of industrial production largely pertains to the fact that hydrogen is required for many essential chemical processes. As we can relate from the applications of the gas mentioned above, this level of production is justified by the gargantuan role it plays in the vast chemical industry; in oil refining, production of ammonia from Haber's process, as a fuel in transportation and so on. [3]

The methods for commercial production of hydrogen can mainly be bifurcated into major divisions:

1) Production of hydrogen from fossil fuels. (Steam-Methane Reforming Reaction)
2) Production of hydrogen from water using electrolysis.

Majority of the commercial hydrogen produced today is by using the method of steam methane reforming of natural gas. The second method specified above involves the electrolysis of water which produces hydrogen and oxygen as its products. [3]

3.1 Steam Methane Reforming Reaction

The reaction involves production of hydrogen by exposing high temperature steam to a methane source such as natural gas. The exposure of steam at a very high temperature of 700-1000°C causes the carbon atoms of methane to separate and after two successive reactions, they reform separately to produce hydrogen (H2) and carbon dioxide (CO2).[1]

Steps involved:

1. Water enters the furnace, producing steam at a very high temperature.
2. Steam reacts with natural gas, producing hydrogen and carbon monoxide.
3. In the water shift reactor, carbon monoxide and steam react to form carbon dioxide and more hydrogen gas.
4. The hydrogen gas is purified to the customer's specifications, removing contaminants.
5. Pure hydrogen is delivered to the customer. Remaining gases are recycled back into the process or recovered for other uses. [3]

In a "water-gas shift reaction," the product carbon monoxide and steam are reacted using Cu-ZnO as a catalyst, at a temperature of 150-250°C to produce carbon dioxide and more hydrogen. In a final process step called "pressure-swing adsorption," carbon dioxide and other impurities are removed from the gas stream, leaving essentially pure hydrogen.

The steam methane reforming reaction proceeds as follows:

Steam-methane reforming reaction

$$CH_4 + H_2O \xrightarrow{\Delta} CO + 3H_2$$

Water-gas shift reaction

$CO + H_2O \rightarrow CO_2 + H_2$ (+)[4] Δ

The reaction also requires a catalyst to proceed. The most common catalyst used for the reaction is nickel. The reaction takes place at a pressure of 3-25 bar and because of its endothermic nature, enthalpy must be supplied to the reaction for it to be successful.

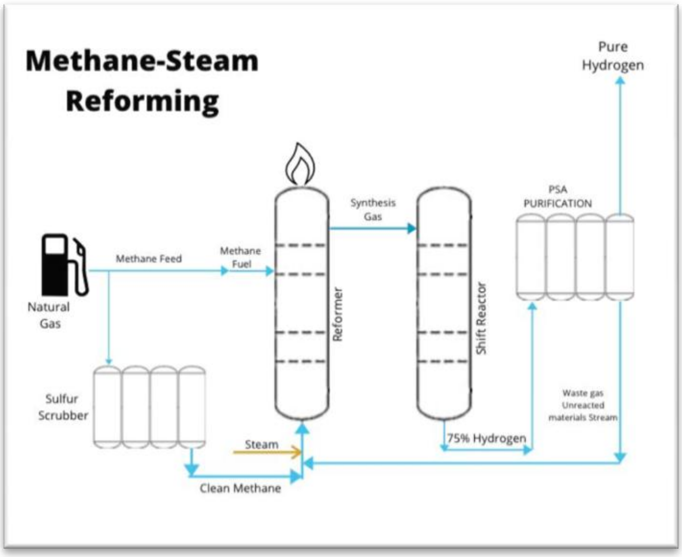

Fig 1. Steam-methane reforming reaction

3.2 Electrolysis Of Water

The process of electrolysis can be defined as splitting water into its components, hydrogen and oxygen using electricity. Electrolysis is less efficient than a direct chemical path but offers virtually no pollution or toxic by-products if the electric current is generated using renewable energy. It is the purest way of synthesis as the hydrogen produced is clean and can be produced anywhere where there is renewable energy. The energy efficiency of hydrogen synthesis by electrolysing water is 60% to 70% only. This is a major issue in large scale production of clean hydrogen gas for the longer run.

The electrolysis reaction takes place as follows:
Reduction at cathode: $2\ H^+(aq) + 2e^- \rightarrow H_2(g)$
Oxidation at anode: $2\ H_2O(l) \rightarrow O_2(g) + 4\ H^+(aq) + 4e^-$

3.3 Synthesis of Grey Hydrogen

Grey hydrogen is made from fossil fuels such as natural gas.
It makes up for almost 95% of hydrogen currently produced around the world today. Its production leads to carbon waste and hence releases CO2 into the atmosphere. It isprimarily used in chemical industry for making ammonia and fertilizer. Produced at a temperature of 750-990°C. The reaction is endothermic in nature.ΔH = 206 kJ/mol.The cost of production ranges from $1-$1.80 /kg[7]

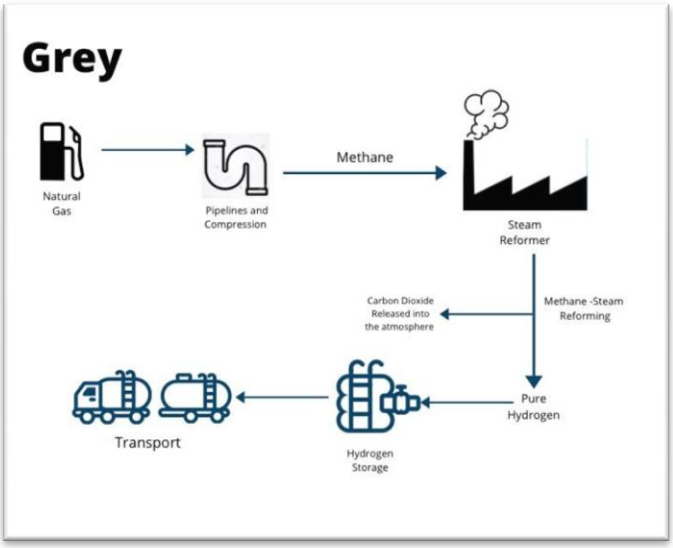

Fig 2. Production of Grey Hydrogen

3.4 Synthesis Of Blue Hydrogen

Process much less harmful for the atmosphere.Blue hydrogen is derived from natural gas through the process of steam methane reforming. The wavelength of this light gives a value of 486.3 nm. Carbon di oxide is captured as a by-product using **CCS technology**.

The issues in large scale synthesis of blue hydrogen are 1. Supply Chain 2. Underdeveloped CCS technology. The cost of operation would be $1.40-2.40 per kg of hydrogen gas produced.[8]

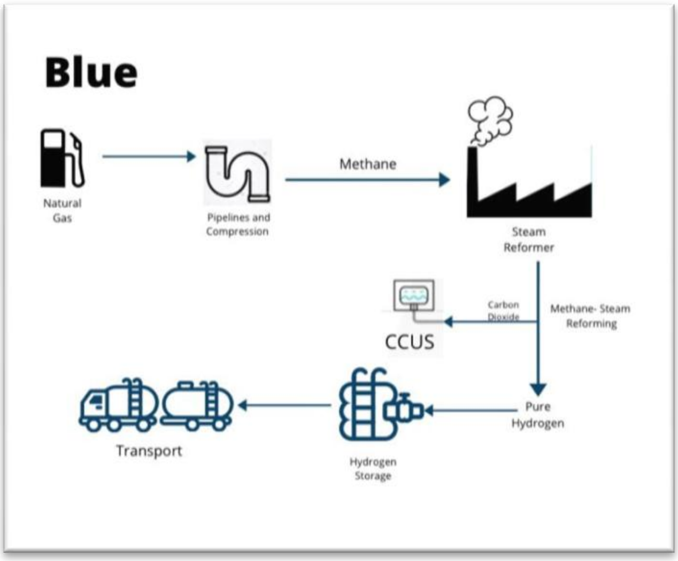

Fig 3. Production of Blue Hydrogen

3.5 Synthesis of Green Hydrogen

It is produced by electrolysing water to its components. Electrolysis is less efficient than a direct chemical path but offers virtually no pollution or toxic by-products if the electric current is generated using renewable energy. It is the purest way of synthesis as the hydrogen produced is clean and can be produced anywhere where there is renewable energy. The primary use of green hydrogen is in manufacturing fuel cells.

Humanity is facing an upward battle with preserving the resources of our planet with climate change and many other manmade disasters ,if we want to avert future disasters then the global carbon emission level has to drop to zero before 2050 and a promising solution for this is **Green Hydrogen** as it is a clean burning molecule ,which means it can help us to decarbonize a range of sectors which have been hard to clean up in the past.

Reduction at cathode: $2\ H^+(aq) + 2e^- \rightarrow H_2(g)$
Oxidation at anode: $2\ H_2O(l) \rightarrow O_2(g) + 4\ H^+(aq) + 4e^-$
The Minimum required potential for operation would be 1.2V and the cost of operation at the moment would be 3/kg-$6.55/kg and will eventually drop to 2$/kg by the year 2030.[9]

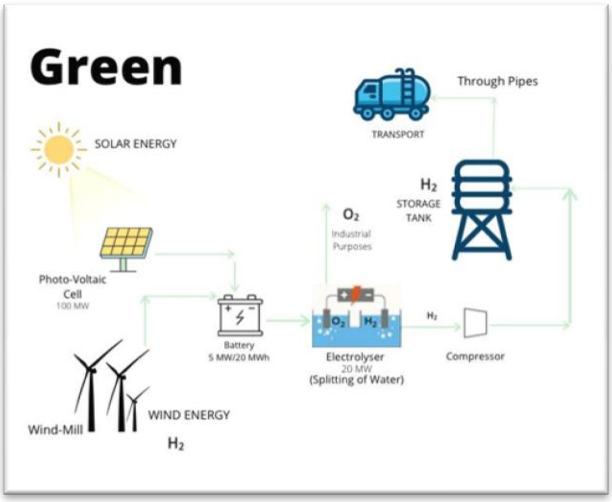

Fig 4. Production of Green Hydrogen

3.6 Synthesis of Yellow Hydrogen
Has the potential to be efficient and economical in the future. In this method of production of hydrogen, the electrolysis of water is achieved from the energy obtained through solar energy.
Challenges faced in the manufacture of Yellow hydrogen are1)Underdeveloped solar technology and2)High cost for processand the cost of operation would rangefrom$3.4-5 per kg of hydrogen gas produced.[10]

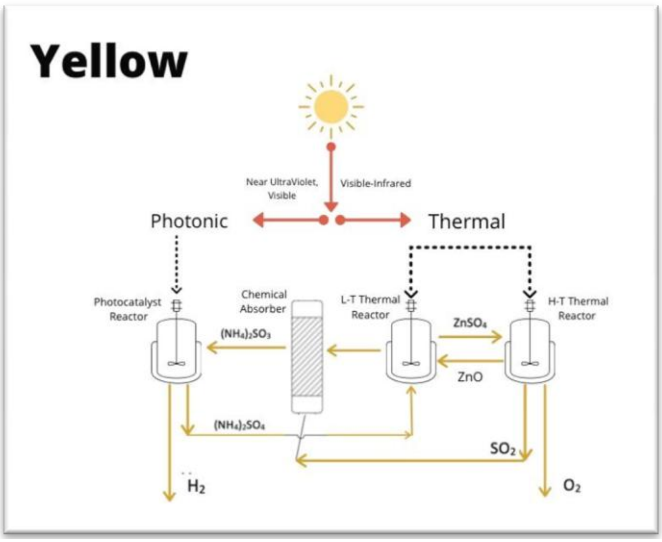

Fig 5. Production of yellow hydrogen

IV. Conclusion

Cleaner and environment-friendly hydrogen is the pathway to a productive future. With fewer emissions and renewable sources of generation, hydrogen can be an effective and economical source of energy as compared to the exhausting fossil fuels.

The methods of production, of different types of hydrogen have been studied so as to gain a thorough insight on how the methods of preparation differ according to the different source of energy, and in turn study the dynamics behind each process. It has been observed that green hydrogen is the most environment friendly but the cost of production is high, whereas grey and blue hydrogen are economical but the method of production were less environment friendly in comparison to the green hydrogen. The information on yellow hydrogen is scarce, hence it is still a subject for further study.

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