

# A CRITICAL REVIEW ON THE ROLE OF HYDROGEN AS A CLEAN FUEL SOURCE

## Abstract

Due to population growth and increased human activity, the world's energy requirements have significantly increased. In the modern world, fossil fuels play a significant role in providing energy, but they also contaminate the environment by releasing greenhouse gases into the atmosphere. Hydrogen is a well-known efficient energy carrier and is found in both renewable and non-renewable sources. This review article gives a general overview of the biomass (biological and thermochemical) and water splitting (photolysis, thermolysis, and electrolysis) processes that are used to create hydrogen from renewable sources. Discussions about these methods' shortcomings are present. The study also looks at a number of important obstacles to the global development of the hydrogen economy. The paper concludes with some recommendations for further research for scientists to aid in improving the efficacy of specific production construction mechanisms and policy direction to lessen investment risks in the sector to scale up the hydrogen economy.

**Keywords:** Biomass, Hydrogen production, Dark fermentation, Hydrogen Power system Renewable energy

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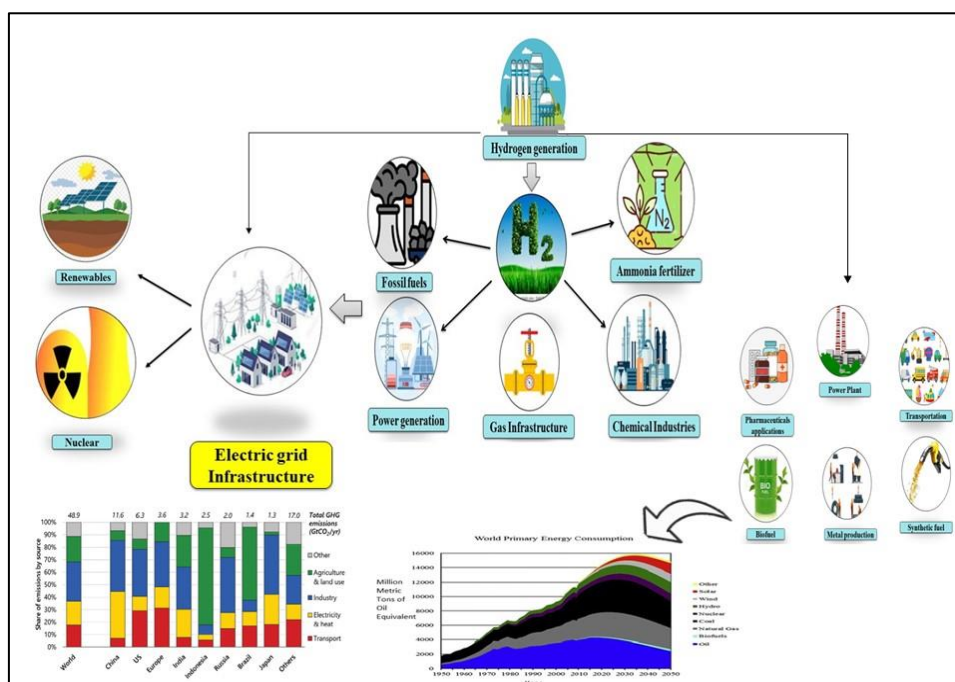
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## I. INTRODUCTION

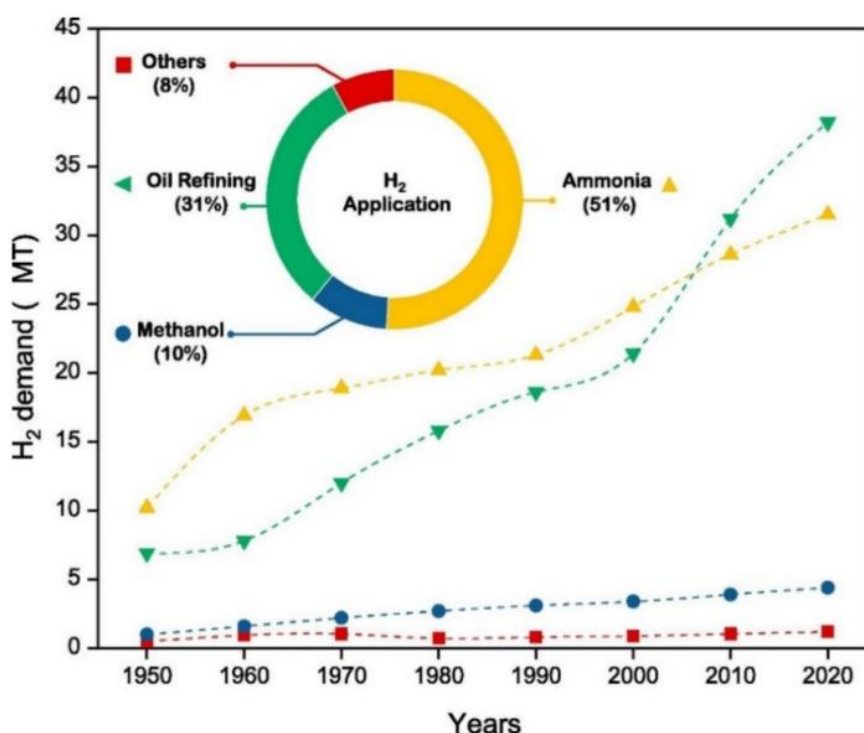
Despite the fact that fossil fuels today satisfy a large fraction of global energy demand, the negative impacts of fossil fuel combustion are unavoidable such as greenhouse gases, acid rain, and other environmental and human health implications. To that aim, global energy transformation is gaining traction, which is aided by the fast growth in the field of renewable energy. To boost this momentum and reduce pollutants, hydrogen has been investigated as an alternative energy carrier, while producing power from hydrogen by using a fuel cell which produces no local pollution because the sole waste is clean water [1]. Furthermore, hydrogen may be generated locally, reducing a country's reliance on external energy supplies [2]. The availability of water on Earth, in particular, ensures that hydrogen may be produced in a somewhat sustainable manner. Water splitting using electrolysis presents intriguing prospects for synergy with renewable energy. Because of the intermittent nature of some renewable energy supplies, hydrogen may be created before it is required, making it appropriate for distributed and centralised production that is directly connected to remote renewable resources. An electrolyzer's hydrogen is ideal for use with fuel cells. Presently, energy executives consider hydrogen to be the least impactful and least definite issue confronting the global energy system. Hydrogen products are now utilised in the various industrial sector as raw materials. However, if we realise its full potential as a complete energy carrier, it has the potential to play a significant role in many more sectors. The majority of the estimated 50 million metric tonnes generated annually on a worldwide scale is used as a feedstock for ammonia synthesis, with oil refining accounting for 35% [2-3]. When it realises its role as a flexible energy carrier, as shown in **Figure 1**. Extensive descriptions of current development may be found elsewhere, and a number of research are attempting to characterize current progress in hydrogen system integration using unique methodologies [3]. There is broad agreement that creating hydrogen from renewable energy sources (solar, wind, etc.) has significant potential for global sustainability [4-6].



**Figure 1:** Representation of the various Hydrogen production routes.

## II. STATUS OF THE GLOBAL HYDROGEN PRODUCTION

According to the International Energy Agency IEA study, 2020 was a record year for policy action and low-carbon output, with 10 countries worldwide adopting hydrogen policies. **Figure 2** depicts the growth in demand for H<sub>2</sub> over time; it can be observed that the generated hydrogen is largely utilised in the manufacturing of 51% of NH<sub>3</sub>, while remaining roughly 31% is used in oil refining, rest 10% is used in the production of methanol CH<sub>3</sub>OH, and the last remaining 8% has various applications [8]. Hydrocarbon steam reforming is now the most widely used method for producing hydrogen on a global scale, accounting for more than 90% of industrial hydrogen production plants[7-8]. According to the same research, 75 nations throughout the world have implemented net-zero carbon aspirations, accounting for more than half of global GDP, and over 30 have hydrogen-focused programmes.



**Figure 2:** Hydrogen demand worldwide and its share on various uses

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## III. HYDROGEN TECHNOLOGIES

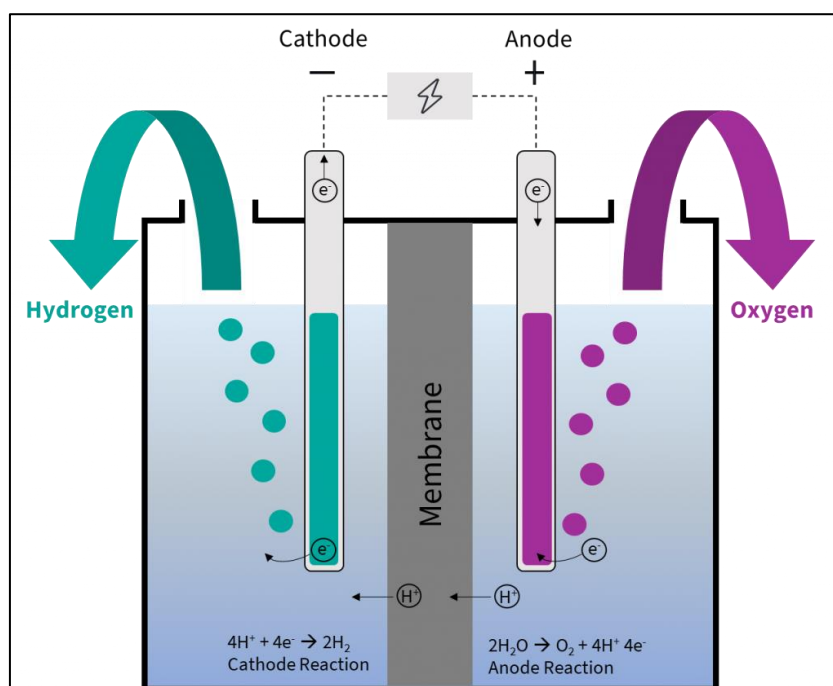
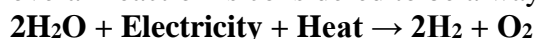
This section introduces some hydrogen technologies often utilized in hydrogen power plants. They include electrolytic hydrogen generation, hydrogen re-electrification via fuel cells, hydrogen storage, and converter technologies. The properties of these technologies are given and proved by certain experimental findings.

#### IV. ELECTROLYTIC HYDROGEN PRODUCTION

Water electrolysis, coal gasification and Steam reforming etc are the most common industrial generation technologies of hydrogen today. Other hydrogen generation technologies, for example reforming  $C_2H_6O$  ethanol and  $C_{12}H_{22}O_{11}$  sugars, [9-10]. Decreasing amount of renewable power, there is an increasing interest in water electrolytic hydrogen production, which uses electricity to extract hydrogen from water while emitting no carbon byproducts such as Carbon dioxide  $CO_2$ .

#### V. WATER ELECTROLYSIS PRINCIPLE

Two electrodes (Cathode and Anode) are placed in the electrolyte solution which is linked to the power source which helps to conduct current in the water electrolysis cell, as illustrated in **Figure 3**. Degraded water helps to create hydrogen  $H_2$  on the cathode which has negative charge and oxygen on the anode which has positive charge with a sufficiently enough voltage is been placed between the two electrodes [11]. The inclusion of an electrolyte increases the conductivity of the water, allowing it to conduct electricity continuously. In the process of water electrolysis, solid polymer electrolytes and acids are often utilised, and ions diverse are considered as charge carriers:  $OH^-$ ,  $H^+$ ,  $O_2$ , etc. Water electrolysis reactions at various charge carriers' electrodes may change, Meanwhile, the overall reaction is considered to be always the same

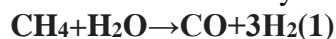


**Figure 3:** Representation of the Water electrolysis principle.

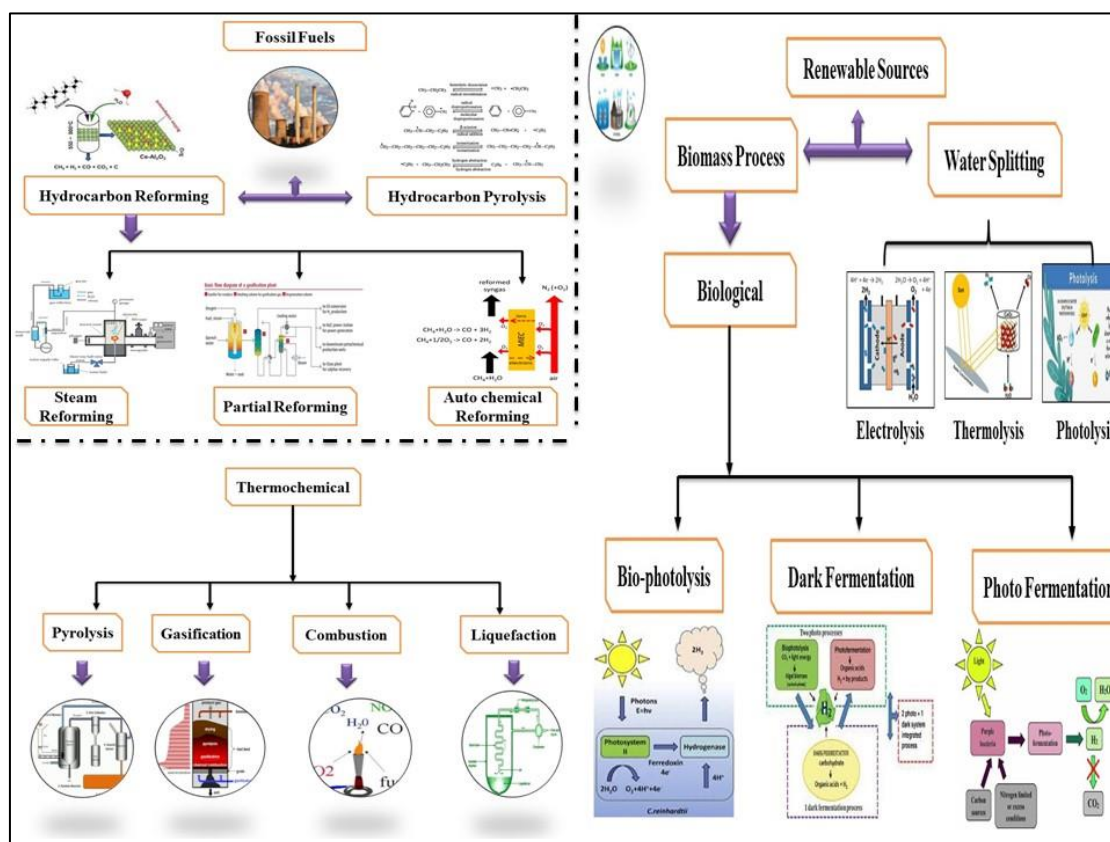
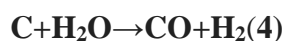
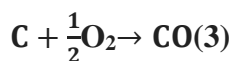
#### VI. HYDROGEN PRODUCTION PATHS

Hydrogen production is mostly done by using either fossil fuels or through RS, which is presented in **Figure 4**. The most common method is known as "steam reforming." Because

of its high hydrogen-to-carbon ratio within the hydrocarbons group, methane is the most commonly employed fuel in this process; hence, the created byproducts are minimized [12]. **Table 1.** The reformation process begins with the mixing of methane  $\text{CH}_4$  with steam, which is then forwarded over a catalyst bed at a high pressure of approximately 1.5-3 MPa and a temperature which is ranged from 600-800 °C to form a mixture of carbon monoxide (CO) and hydrogen  $\text{H}_2$ , as shown in below Equation [1]. The second phase comprises with the shift reaction, which involves the interaction of extra steam with the CO from the previous phase to create additional hydrogen  $\text{H}_2$  and  $\text{CO}_2$ , as shown in below Equation [2]



The further method for producing hydrogen which involves fossil fuels is coal gasification. In this technique, coal is partially oxidized at high pressure, roughly 4 MPa, and T°C with the help of oxygen and steam to produce CO, methane,  $\text{CO}_2$ , and other chemicals [13]. At temperatures above 1000 °C and pressures above 1 bar, hydrogen and CO are usually stable [Table 3]. The procedure is depicted in Equations (3) and (4) [13-16].



**Figure 4:** Representation of various Routes to hydrogen production.

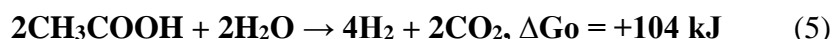
<b>Table 1: Representation of the hydrogen production technologies involves from biomass</b>			
<b>Technology</b>	<b>Principle</b>	<b>Source as a energy</b>	<b>Operating Condition</b>
Dark fermentative	Biological	Carbohydrate-rich substrates	Anoxic conditions
Photo fermentative	Biological	Small organic molecules	Anaerobic Conditions
Pyrolysis	Thermochemical	biomassin dry form	300-1000°C in the absence of oxygen
Gasification	Thermochemical	biomassin dry form	800-900°C
Hydrothermal Liquefaction	Thermochemical	biomass wet	250-370°C and 4-22 MPa
Steam reforming	Thermochemical	Biomass-derived liquids	800-1000°C

## VII. HYDROGEN PRODUCTION

Despite the hydrogen generation potential of the various biomass technologies outlined in the preceding section, the various processes have significant constraints that may prevent them from being used for hydrogen production. **Table 4** provides an overview of current research approaches.

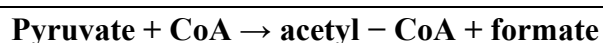
## VIII. BIOLOGICAL PROCESS

- 1 Photo-fermentation:** Photo-fermentation method has a modest yield in comparison to H<sub>2</sub> generation; it is also essential for bacterial control. Furthermore, it necessitates a large surface area and has a significant energy need. H<sub>2</sub> output is expected to be between 10 and 49 grammes per kilo gramme of feedstock [17-19].The chemical reaction for the production of hydrogen by using photo fermentative mechanism with combination of acetate is conferred in Equation (5).

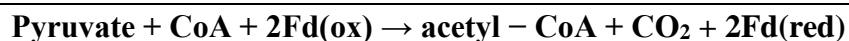


- 2 Dark fermentation:** Dark fermentation procedure necessitates pre-treatment and has a significant number of by-products, as well as a poor rate of generation and yield of H<sub>2</sub>. The H<sub>2</sub> output is expected between 4-43 g/kg feedstock [19]**Figure 5**.

1. Pyruvate: formate lyase:



2. Pyruvate: ferredoxin oxido reductase:

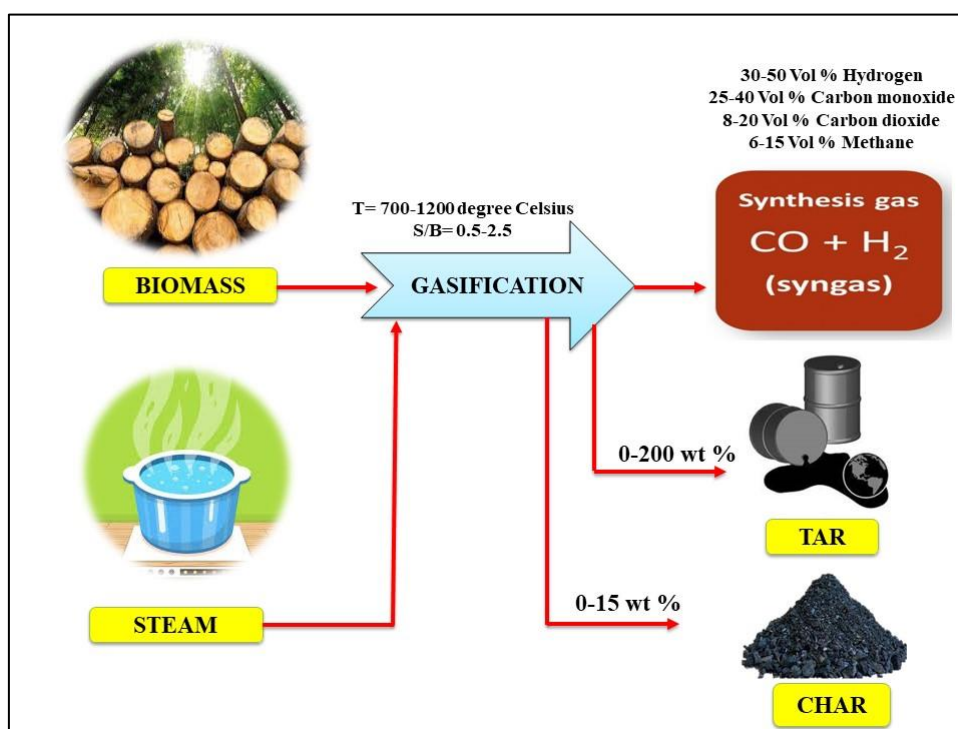






## X. BIOMASS GASIFICATION

One of the most feasible, sustainable, and possibly carbon-neutral hydrogen generation processes is biomass gasification. Biomass is a renewable resource that absorbs CO<sub>2</sub> from the atmosphere as it grows, resulting in a far lower net carbon footprint than fossil fuels. However, the viability of hydrogen generation from biomass must be directly tied to the region's raw material availability and cost. The physicochemical qualities, distribution, and hydrogen concentration of the starting material are the most important aspects. The structural composition and morphology of feedstocks of biomass vary widely, and all of these features must be addressed when mixing feedstocks with suitable conversion methods [22]. Moisture, energy, and ash are thus the most significant characteristics to consider when evaluating biomass utilisation using this technique. Techno-economic research accompanied by competent life cycle evaluations are so critical in this area. Because of the low density of biomass, the transportation and storage expenses of biomass feedstock or generated hydrogen must be effectively justified in terms of economies of scale. The technique will be tough to compete with. Similar to coal, the most viable approach for biomass feedstock is gasification. It produces the most at high temperatures (usually 500-1300 °C), as demonstrated in the equation below. Surprisingly, combining biomass gasification with carbon capture and storage can produce negative carbon emissions (**Figure 6**).

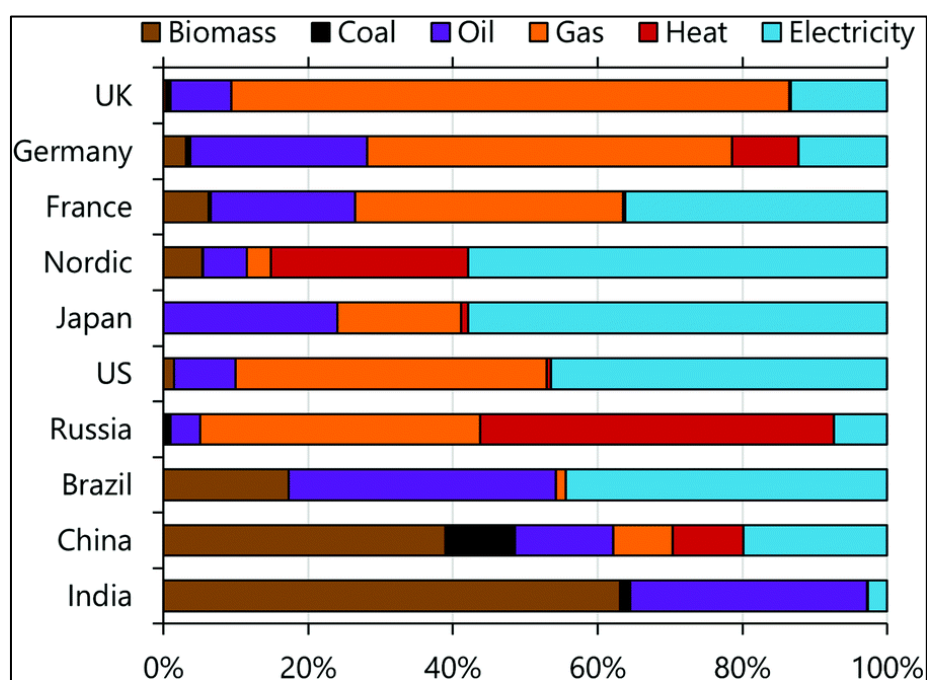


**Figure 6:** Representation of the procedure for biomass steam gasification.



## XI. HYDROGEN UTILIZATION

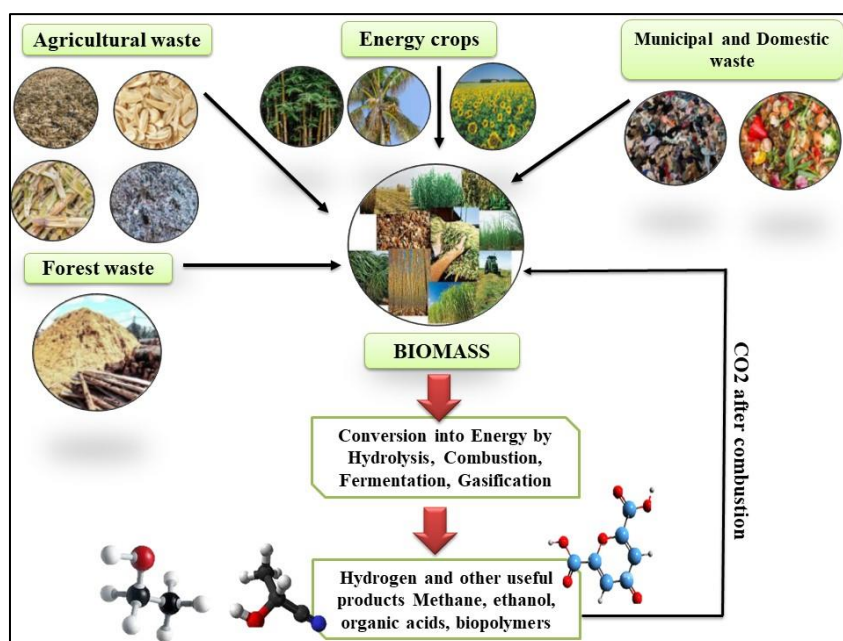
**1 Fuel and Power Systems:** Domestic and industrial heat comprise 33 and 50% of global carbon dioxide emissions and universal energy consumption rate, respectively. The bulk gases generated by the typical burning method of natural gas which are implicated in several environmental pollution concerns (i.e. greenhouse gaseous emissions). In contrast, using H<sub>2</sub> gas as an alternative fuel to natural gas has proven to be an effective strategy to minimize greenhouse gas emissions. Because of its reactive nature, it may immediately contribute in the decarbonization process in the energy sector after it is created from renewable energy sources, as illustrated in **Figure 7**. The hydrogen is currently generated by conventional i.e. non-renewable sources at a rate of 19%, 31%, and 49% from coal, heavy oil/naphtha, and natural gas, respectively, resulting in the release of about million 560 tonnes of CO<sub>2</sub> each year [23]. Furthermore, excess electricity generated by power plants may be turned into hydrogen, which can be either directly consumed or chemically processed into chemicals utilised in other industrial aspects [24-25].



**Figure 7:** Representation of fuels used for domestic heating in ten countries.

- 2 Power-to-gas:** Power-to-gas is a technique that uses electrical energy to produce a flammable gas. Power-to-hydrogen methods are becoming increasingly popular due to the assumption that hydrogen is a combustible gas with a high-power density[23]. According to the literature, multiple pilot projects have begun globally, with Europe having the greatest establishment rate of 85%, followed by the United States and Japan [24].
- 3 Fuel cells:** Fuel cells have recently attracted international interest for their efficiency and environmental friendliness as energy producers. In practice, they are integrated electrochemical devices that are commonly utilized to transform given chemical energy into electrical energy via redox processes [25]. In terms of energy generating efficiency, they can act as energy carriers.

**4 Process of Biomass in Hydrogen Production:** Biomass is viewed as more promising than fossil fuels in terms of hydrogen generation due to its enormous reserves and supply, ease of oxidation, and high yearly output. As seen in **Figure 8**, hydrogen may be created in a variety of ways in connection to biomass. Despite the fact that CO<sub>2</sub> is released during the creation of hydrogen from biomass, the number of gaseous emissions is equivalent to the amount absorbed by organisms during their lifetime. [14]. The two ways that may be employed to manufacture hydrogen from biomass are biological and thermochemical processes. These will be covered in following sections. In comparison to coal&biomass has a relatively high hydrogen-to-carbon ratio. C<sub>6</sub>H<sub>10</sub>O<sub>5</sub> (pure cellulose) is thought to have a hydrogen-to-carbon of about 1.7, compared to 0.7 for typical bituminous coal [14]. Biomass using help to reduce reliance on hydrocarbons. Through a technique known as photosynthesis, biomass may restore CO<sub>2</sub> equilibrium in the atmosphere [24].



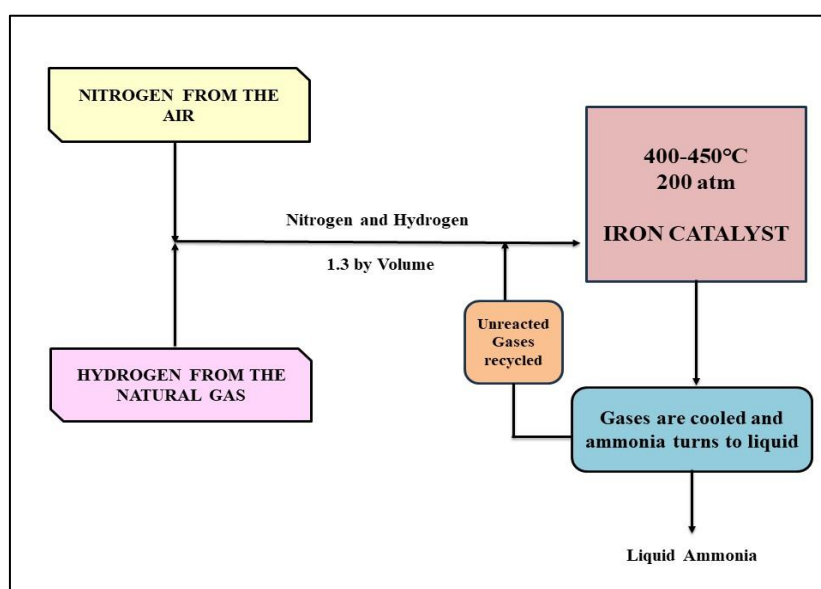
**Figure 8:** Representation of the various Biomass sources which are conversion into hydrogen and other beneficial products.

## XII. TRANSPORTATION SECTOR

Cars based on hydrogen fuel provide a possible alternative to outperform traditional battery-powered powertrains. Globally, hydrogen-fueled vehicle sales are expected to be 3% in 2030 and 36% in 2050. Different kinds of hydrogen (liquid and compressed) is used to power hydrogen-powered vehicles. The aviation industry is recognised as the quickest transportation option, with yearly growth in air traffic expected. Kerosene is the most popular aeroplane fuel. Various aviation fuels frequently exhibit a requirement, i.e., resistance to corrosion and extreme temperature fluctuations [22]. It's worth remembering that petroleum accounts for the vast bulk of aviation fuel. Alternative, less hazardous fuels such as liquid hydrogen (H<sub>2(l)</sub>) are being created and are expected to be eco-friendly in order to increase energy preservation and lessen the negative environmental consequences of fossil fuels. As an aviation fuel, chilled hydrogen fuel has the potential to outperform kerosene.

### XIII. AMMONIA (NH<sub>3</sub>) PRODUCTION

Ammonia (NH<sub>3</sub>) is regarded as one of the most important compounds, with massive global production rates. Brightling (2018) projects that the largest ammonia manufacturing facility will have a daily capacity rate of 3200 metric tonnes. Ammonia which is used as a fertilizer in agriculture. It is also used in polymer manufacturing, explosives, refrigerants, medicines, gas sensors, and fuel cells. It is carried out in the as-designed reactor at pressure and temperature operating parameters of 20-30 Mpa and 300-500 °C, respectively, using potassium carbonate KOH-promoted finely split iron catalysts and the needed energy of 2.4 EJ. [25]. Furthermore, the H<sub>2</sub> used in the synthesis of ammonia process is generally generated from steam gas reforming, which is not considered ecologically favorable. **Figure 9** The energy sources used determine the distinctness of the electrochemical ammonia production processes. Hydrogen may be created from water using an electrolysis technique that uses sustainable green energy sources and so reduces harmful greenhouse gases emissions [25].



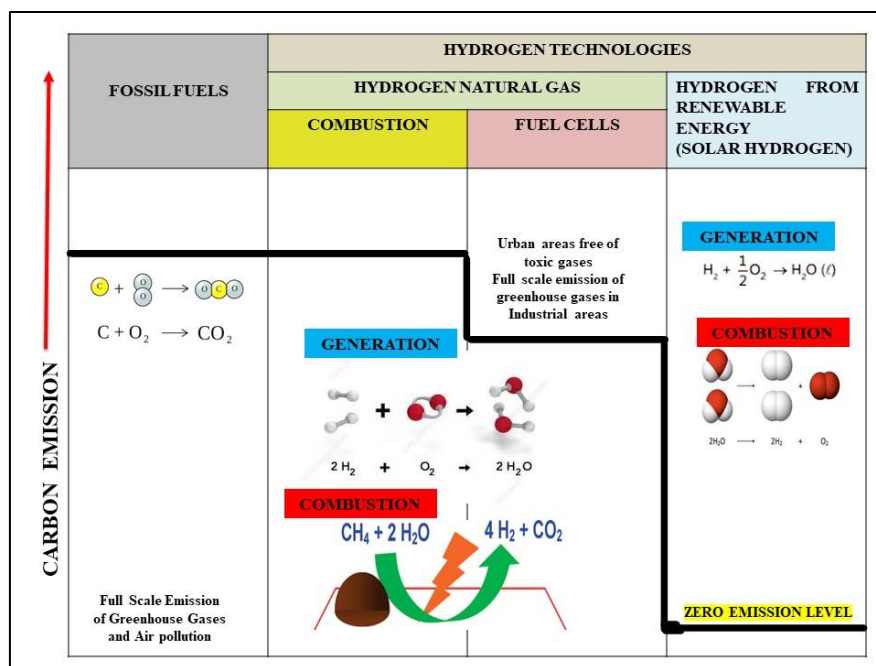
**Figure 9:** Flow chart scheme for the process of production of ammonia.

### XIV. METALLURGICAL INDUSTRIE

In general, hydrogen may form oxy-hydrogen flames & function as a reducing agent in industrial metallurgical processes to extract metals from their respective ores. During the process synthesis of oxy-hydrogen flames which is known as exothermic reaction, hydrogen is permit to combine with oxygen at very high temperatures approximate 3000 °C to form oxy-hydrogen flames, which are then utilised for various welding & cutting on different non-ferrous metals. The metals can be pulverised and used in metallurgical applications later on, or they can be included into a composite material.

## XV. HYDROGEN ROLE IN THE WORLD'S ENERGY GENERATION IN FUTURE

As previously said, hydrogen energy has the ability to act as an carrier to energy, and this has become critical in terms of sustainable growth in global, both in developing and developed nations [12-25]. Energy consumption is predicted to rise considerably higher in emerging nations, reduction [22-25]. Hydrogen and Fuel cells are widely regarded as critical future energy-supply technologies. It is predicted that RS shares of 35% and 70% by 2050 on total energy consumption might 10% and 33% by 2050 [25]. Hydrogen which can be transported and stored, and converted into electrical energy which is used as a fuel cells.  $H_2$  is environmentally beneficial, depending on the energy source used to produce it. The fundamental reason is that it is a supplementary energy carrier to electricity [15-20].  $H_2$  is viewed as a possible energy source creation which might help reduce  $CO_2$  emissions. **Figure 10** depicts a comparison between hydrogen technology and fossil fuel. It is projected that using hydrogen produced through traditional methods can reduce carbon emissions by roughly 20% when utilised in fuel cells. As a result, carbon emissions may be greatly decreased by employing RS to produce hydrogen [24-25]. As a result,  $H_2$  can be considered a possible powerful rival in the world's energy system in the future [18].



**Figure 10:** Impact of hydrogen production and combustion on emission of carbon

## XVI. CONCLUSION

In this review article it stated to ensure the long-term production of clean and green hydrogen, it is necessary to perform a comprehensive review of potential production methods and their environmental consequences, as well as seasonal storage and utilization choices. Hydrogen may be produced using either fossil-based or renewable feedstocks; however, each process has advantages and disadvantages. The existing hydrogen colour coding is inaccurate, presuming that green hydrogen always has fewer carbon emissions than blue or

grey hydrogen, which is not necessarily true. Water electrolysis is gaining traction; nonetheless, fulfilling 24% of energy demand with hydrogen under a 1.5-degree scenario of climate change mitigation will entail vast quantities of extra renewable electricity generation. In this scenario, essentially 31,320 terawatt-hours of electricity would be required to power electrolyzers, which is more than is presently generated globally from all sources combined.

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