

A Brief theoretical approach on Green Hydrogen Production

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Abstract

Many different technical techniques can be used to manufacture hydrogen from both renewable and nonrenewable feed supplies while reducing greenhouse gas emissions. Hydrogen is employed in upcoming low-carbon energy systems since it emits relatively little carbon. The bulk of the present green hydrogen activities are geared toward the possibility of a green hydrogen market. Green hydrogen and origin guarantees have been defined using various approaches. These vary according on the following: the carbon financial statements' characteristics; the emission threshold at which hydrogen is classified as green; the plan's feedstock and production techniques; and whether or not sustainable hydrogen must be produced through the use of renewable energy. To overcome obstacles and improve green hydrogen production's viability as a sustainable energy source, research is always moving forward. To hasten green hydrogen's integration into clean energy transitions and slow down global warming, research efforts are concentrated on increasing its efficiency, cutting prices, and broadening its applications. A study that focused on the near-zero carbon production method of green hydrogen by electrolysis using renewable energy sources underscored the advancements and prospects of this field of study. This article describes the current techniques for creating hydrogen from sustainable and renewable energy sources.

Keywords: Green Hydrogen, Biomass, Efficiency, Renewable, Hydrogen production.

Introduction

Renewable energy sources are sustainable choices for producing energy since they are natural processes or sources that are continuously renewed. These energy sources include geothermal, biomass, sun, wind, and water (hydropower). Renewable energy has been used historically for a variety of applications, including the production of power, heat, and transportation. The problems with the affordability and dependability of renewable energy sources are still being researched. The goal is to increase the integration of renewable energy sources into the electricity grid and to improve technology. Research examines the state-of-the-art and potential paths for producing green hydrogen by electrolysis with renewable energy sources. Green hydrogen presents a nearly carbon-free generation method that yields substantial environmental advantages. To lessen environmental effects and promote sustainable development, research on renewable energy often focuses on increasing efficiency, cutting costs, and encouraging the wider adoption of clean energy sources^{1,2}. The bulk of the energy used by modernization comes from fossil fuel resources, which is why energy consumption is out of balance. The world's future energy scenario in the absence of fossil fuels has become more pressing due to the continuous consumption of finite fossil fuel resources. In this sense, the world's attention is being drawn to clean and renewable energies due to the alarming evidence of accelerating global warming.^{3,4}

Nowadays, hydrogen finds application in numerous industries such as chemical, food, glass, electrolysis, and refining. Shortly, one of the most important problems facing civilization worldwide will be reducing carbon dioxide emissions from the use of fossil fuels. Increasing renewable energy sources, such as wind, solar, and hydropower, can reduce carbon dioxide emissions.² While fossil fuels can produce energy on demand, the production of electricity from renewable energy sources such as solar and wind power is dependent on the conditions of the surrounding environment. Therefore, when we use renewable

energy sources more frequently, the importance of energy storage increases. Efficient energy storage is very important in the transportation sector.⁵

Hydrogen energy is a zero-carbon option for low-carbon transportation, industrial decarbonization, and heating systems. Both renewable and non-renewable energy sources can produce hydrogen. Renewable energy is now subsidized due to its higher historical cost compared to fossil fuel generation. However, there is a need for a benchmark to determine what qualifies as green power for incentives.⁶ The cost of low-carbon hydrogen is similar to regular hydrogen. Green hydrogen meets specific sustainability standards, but there is no generally accepted definition. The objective is to explore criteria for "green" standards that could be used in future renewable or green hydrogen policies.

Green hydrogen is not a commonly used source of energy, unlike renewable electricity. The majority of hydrogen used in industry is derived from fossil fuels, which results in significant CO₂ emissions.⁶ However, the development of green hydrogen standards has been supported by the commercialization of hydrogen-powered cars, heaters, and other products. It is crucial to prioritize the development of alternative energy sources to address two main issues: the constant increase in energy demand and the decline in the supply of fossil fuels, as well as the global warming caused by excessive use of these fuels. Hydrogen, if produced from renewable feedstock, is an energy carrier that can promote sustainable energy growth. It can efficiently generate power in a fuel cell. Currently, more than 95% of the fuel produced worldwide is made by partially combusting or catalytically steaming hydrocarbons.

One of the biggest hurdles in using renewable energy is the conversion of it into usable electricity and the efficient storage of that electricity. Hydrogen can be produced by using electricity to split water molecules in an electrolyzer, and then used to create synthetic fuels. However, the storage of hydrogen in molecule or atomic form is a significant challenge. The threat of accelerated global warming has led to a worldwide focus on clean and renewable energy sources.⁷

Today, our planet is experiencing various weather-related disasters such as droughts, heatwaves, floods, and hurricanes. These events are clear signs that nature is warning us about the worsening issue of climate change. According to the Fourth Assessment Report (AR4) of the United Nations Intergovernmental Panel on Climate Change (IPCC), the increase in the concentration of greenhouse gases (GHG) since the mid-20th century is responsible for global warming (GW).^{2,4} Today, humanity faces major challenges including the depletion of fossil fuel resources, rising energy demand, and the uncertain future of climate change. To ensure a sustainable and environmentally friendly energy system for the future, we need to develop carbon-neutral energy sources. It is estimated that by the middle of this century, the world will require approximately 10 TW (terawatts) of carbon-neutral power to meet energy demand, support economic growth, and maintain acceptable levels of atmospheric carbon dioxide (CO₂).⁸ As more people become interested in alternative fuels due to economic and environmental concerns, hydrogen is one of the most promising energy carriers. Unlike electricity, hydrogen is not a primary energy source but rather a secondary form of energy generated from natural and bio resources. It is predicted that hydrogen will play a crucial role in the future of the energy sector.¹

Hydrogen: Brief study

Hydrogen is a colorless, odorless, and tasteless gas with great potential as a clean energy source. It can be produced through various methods such as chemical conversion of fossil fuels, water electrolysis, and other processes. Currently, most of the produced hydrogen is used as a chemical feedstock. However, it has the potential to be used as a fuel for vehicles due to its advantages such as rapid burning speed and no toxic emissions. The main barrier to using hydrogen as a fuel is storage due to its extremely low density. In both large and small SMR plants, the cost of NG feedstock accounts for 52-68% and 40% of the final hydrogen price, respectively. The remaining expenses are composed of capital charges.^{3,7}

SIGNIFICANCE AND AIM OF GREEN HYDROGEN

The demand for energy has increased worldwide due to industrialization and economic expansion, and the majority of this demand is currently met by fossil fuels such as coal, crude oil, and natural gas. Many nations have social, political, and economic ties that influence the demand for these fuels. Fossil fuels have a significant impact on society's progress and traditional way of life. The hydrogen economy plays a crucial role in transforming the global economy in terms of finances, society, and politics. Governments are working towards its growth and development, which is a positive sign. However, the world's economic growth is currently strongly associated with the use of fossil fuels for energy.⁹ Researchers are studying the synthesis of hydrogen from water using renewable energy sources such as high thermal water disintegration, gasification hydrogenation, water electrolysis, and water photolysis. Green power sources such as sunlight, ocean and sea energy, runoff waters, winds, and fissionable materials can be used to produce hydrogen. Water, sea water, hydrogen sulfide, and biomass are examples of substances that can be used to extract hydrogen in an environmentally friendly way. Green hydrogen generation techniques are classified based on the source material used to extract hydrogen.^{6,10}

The idea of producing synthetic fuels that don't increase the concentration of carbon dioxide in the atmosphere presents an interesting solution to the energy crisis. Synthetic fuels are chemically similar to fossil fuels, but they are made artificially. Fossil fuels are currently fulfilling most of the world's energy needs, and our modern way of life is heavily reliant on them. However, due to the limited supply of fossil fuels, the way we think about the world's future energy needs has changed. Hydrogen is a safe and clean fuel that doesn't emit harmful pollutants. It can be easily used in fuel cells to produce power, and its use results in only water vapor, with no negative impact on CO₂ emissions or hazardous gas production. Many studies are focused on the potential for future and profitable hydrogen generation, which can be achieved through various energy sources and manufacturing techniques.^{5,11} It is important to note that currently, the vast majority (around 95%) of hydrogen is produced using nonrenewable sources such as coal, oil, and natural gas. Only a very small percentage (4% and 1%, respectively) is created from water using electricity and biomass. Although it is expected that fossil fuels will continue to be used in the creation of hydrogen in the foreseeable future, there is growing interest in the production of renewable hydrogen using abundant renewable energy resources. While biomass is not currently anticipated to play a significant role in hydrogen creation due to other primary concerns such as combined heat and energy generation and the use of biofuels in transportation systems, developing hydrogen production from renewable energy sources may be the best way to achieve a cleaner environment, especially if renewable sources of energy come to dominate the global energy mix shortly.⁸

Currently, 95% of hydrogen is produced from nonrenewable sources. Only 4% and 1% use water and biomass, respectively.² Fossil fuels will continue to be used. However, renewable hydrogen production is gaining interest as abundant renewable energy sources become more important. While biomass is not significant, renewable energy could be the best way to achieve a cleaner environment if it becomes dominant in the future. Hydrogen can be collected in a way that minimizes the release of greenhouse gases and other environmental pollutants. This process is called "green hydrogen". Green hydrogen is intended to reduce greenhouse gas emissions and protect the environment. It can also be used as a direct fuel for transportation and other purposes.

Currently, hydrogen is mostly used as a hazardous material instead of a fuel. Its market value is around \$50 billion USD for the 40 Mt produced annually. Most of its current applications are as a processing reagent in oil refineries and in the manufacture of chemicals, such as methanol, ammonia and medicines. However, the demand for hydrogen is expected to increase due to population growth projections, which will lead to a greater need for food and other commodities.

The rise in energy and food demand is causing an increase in greenhouse gas emissions in the atmosphere. Therefore, methods for producing hydrogen from renewable energy sources, or "green" methods, must be considered to reduce these emissions. At present, natural gas is mainly used to produce hydrogen through steam reforming, which results in significant greenhouse gas emissions.¹

Future hydrogen economies are expected to rely on green hydrogen production techniques to provide hydrogen for fuel, synthetic fuels, the creation of ammonia and other fertilizers, the upgrading of heavy crude, like tar sands, and the production of other chemicals. The importance of hydrogen in reducing environmental harm caused by the burning of fossil fuels has been emphasized since the early stages of the development of the hydrogen energy concept. Several organizations worldwide are developing a hydrogen economy, although the high manufacturing cost is a major obstacle. The US DOE predicts that the market for hydrogen will grow, and production costs will decrease to around \$2/kg by 2025. Green hydrogen is expected to become cost-competitive with existing fuel sources. However, the majority of hydrogen produced globally in 2020 is not green hydrogen.

Green hydrogen standards: The Green Hydrogen Standard is based on a project-level certification and accreditation. It is comprised of seven principles and seven requirements. The Green Hydrogen Standard has seven principles that will be used throughout the accreditation and certification process.⁴ These principles aim to provide a clear global minimum standard, while also accommodating local challenges and opportunities.

Principle 1: Sovereignty and subsidiarity. The GH2 understands that it is the responsibility of sovereign governments to develop natural resources and energy markets in the interest of their citizens and national development. To avoid duplication, meeting credible and comprehensive national requirements is enough to meet GH2's accreditation and certification requirements. Science-based knowledge should be used, referring to peer-reviewed literature and internationally accepted standards.

Principle 2: Proportionality (materiality). GH2 ensures proportionality in the accreditation and certification framework. The process emphasizes the most significant issues and impacts and allows for minor gaps/deviations in meeting the requirements where the broader objective of the requirement is met.

Principle 3: Harmonization. GH2 encourages alignment with international best practices to improve quality and efficiency. GH2 will work to ensure its work's interoperability with organizations with similar objectives.

Principle 4: Consultation. GH2 accreditation and certification require clear evidence of proactive and broad-based stakeholder consultation. All stakeholders have important and relevant contributions to make, including governments and their agencies, companies and their suppliers, local communities that may be affected by the project, financial organizations, investors, and non-governmental organizations. GH2 supports the principle of free, prior, and informed consent.

Principle 5: Transparency. The GH2 expects project operators to provide proactive, comprehensive, and publicly accessible disclosures. Project operators should find out what is of particular relevance and interest to specific stakeholders and share that information in the best possible way. This information should be made available online and in other relevant formats to the community concerned. Free access to open data is of significant value to society.

Principle 6: Independent verification, concerns, and appeals. GH2 relies on project operators to show how they meet the Standard, which will be subject to independent review. GH2 will develop a review and appeal procedure, but stakeholders who have a concern about compliance with the Standard should raise it with the project operator and/or the appropriate national authorities. If this is not appropriate or if the concern remains, the stakeholder may petition GH2 to consider the matter.

Principle 7: The Standard aims to strike a balance between predictability and flexibility in a rapidly growing industry. Project proponents stress the need for clear and stable standards to support long-term planning. All stakeholders agree that GH2 should incorporate emerging best practices, especially as projects scale up from pilots to large-scale operations. GH2 will review the lessons learned from the accreditation and certification process in consultation with all stakeholders. Any subsequent refinements or modifications to the Standard will include transitional arrangements that allow project operators to make necessary adjustments within a reasonable timeframe before coming into force.

Growing energy demand

Fossil fuels continue to dominate the world's energy production, accounting for around 80%. By 2050, global electricity demand is expected to rise by 62% to 185%. India's reliance on imported oil is predicted to reach 90%, and carbon emissions are expected to rise by 50% by 2040. To combat this, the Indian government plans to invest \$1.4 trillion in clean energy and technologies by 2040. While renewable sources provide 18% of India's electricity, coal still accounts for 70%, and it's challenging to meet the increasing energy demand.^{3,8}

Hydrogen - The future energy carrier

Hydrogen was first identified as a distinct element in 1776 by British scientist Henry Cavendish. He discovered it by reacting zinc metal with hydrochloric acid. In 1800, English scientists William Nicholson and Sir Anthony Carlisle discovered that applying an electric current to water produced hydrogen and oxygen. This process is known as electrolysis. In 1839, Swiss chemist Christian Friedrich Schoenbein discovered the fuel cell effect, where hydrogen and oxygen gases combine to produce water and an electric current.¹² In 1874, Jules Verne, in his popular work of fiction titled "The Mysterious Island," prophetically examined the potential use of hydrogen as a fuel. The German engineer Rudolf Erren converted engines to use hydrogen in the 1920s. Francis T. Bacon created the first practical hydrogen-air fuel cell in 1959. Fuel cells based on Bacon's design were used in the Apollo spacecraft. "Hydrogen economy" was coined by John O'M. Bockris in 1970. The development of hydrogen fuel cells for commercial use began in the 1970s. These days, hydrogen finds usage in many different processes, such as the refining of petroleum, the manufacturing of fertilizers, methanol, steel, power generation, backup power, portable power, and the integration of renewable energy sources. The current hydrogen market is mostly dependent on fossil fuels, with approximately 95% of hydrogen originating from non-renewable sources, despite hydrogen's potential as a clean energy source. There is a major push towards green hydrogen, which is created by splitting water into hydrogen and oxygen using renewable electricity, to address climate issues and satisfy sustainability targets.⁷

The hydrogen economy envisions creating hydrogen from different energy sources, storing it for later use, and using it cleanly for power and heat. However, currently, 95% of hydrogen comes from non-renewable sources. There is a growing push towards green hydrogen, produced using renewable electricity, to address sustainability and climate issues. The demand for hydrogen is increasing with traditional industries being the largest consumers, but new uses like fuel cell electric cars, steel manufacturing, and power generation are also gaining popularity. To ensure the sustainability of a hydrogen-based economy, regulatory initiatives and technical advancements are needed to reduce costs. It's crucial to consider the overall energy balance, including the energy demand for production and utilization, and compare it to the energy content of hydrogen. If energy consumption is higher than energy content, hydrogen economy may not result in significant energy savings.

Potential Environmental Impact of Hydrogen Production

Hydrogen production pollutes and causes risks. Synthesizing hydrogen generates hazardous wastewater. Gathering raw materials for hydrogen production causes biodiversity loss. Hydrogen leaks pose serious risks. Extracting minerals and fossil fuels for hydrogen production results in significant waste and depletion. Producing hydrogen from fossil fuels contributes to climate change. Handling hydrogen is a high-risk activity. Clean and sustainable hydrogen production techniques that use renewable energy sources and carbon capture and storage technologies should be prioritized to reduce negative environmental effects. Strict laws, oversight, and reporting procedures can also help control and minimize these effects.¹³

Current Challenges in Hydrogen Production

Scaling up hydrogen production is challenging due to limited market depth, fossil fuel dependence, slow infrastructure development, high production costs, technological limitations, and substantial energy requirements. Addressing these challenges is crucial for successful scaling up of hydrogen production and utilization.¹⁴

GHG emissions accounting

Green hydrogen faces several challenges, including GHG emissions throughout the supply chain, lack of standardization, the need for a comprehensive life cycle analysis, high production costs, infrastructure and storage hurdles, safety concerns, and the need for technological advancements.

Addressing these challenges requires a collaborative effort from industry, policymakers, and researchers. A standardized definition and certification process for green hydrogen needs to be established. Production efficiency needs to be improved, and a comprehensive hydrogen infrastructure needs to be established. Furthermore, safety risks need to be addressed and technological advancements need to be made to improve the scalability and efficiency of green hydrogen production methods.^{15,16}

Hydrogen production methods

Hydrogen can be found in natural sources like water or extracted from fossil hydrocarbons, biomass, hydrogen sulfide, etc. Extracting hydrogen from fossil hydrocarbons requires processing carbon dioxide to prevent greenhouse gas emissions. This process is called "green" hydrogen extraction.¹³

Synthesis Methods

Biomass is renewable organic material from plants and animals, used for fuel in many countries. After greenhouse gas emissions are removed, it's used for transportation and electricity. Agricultural and animal waste is anaerobically processed to produce methane gas and other gases. The biogas is purified using water, cat litter, and iron wool to remove carbon dioxide, moisture, and hydrogen sulfide. Only purified methane is used for hydrogen production.^{10,15}

Methane Pyrolysis

Pyrolysis is a process widely used for cracking natural gas and producing hydrogen. Biomass pyrolysis is another route for energy production in gaseous, liquid, and solid forms. The process requires high temperature in the absence of air and can be slow or fast. Fast pyrolysis is preferred for hydrogen production due to its short residence time and high temperature. In this process, biomass feedstock is heated quickly to form vapor and condensed into a dark brown bio-liquid. For the pyrolysis of biomass, the catalyst, temperature heating rate, and residence duration are all crucial factors that affect hydrogen output. The gas-solid reactor implements the parameter adjustment. Utilizing a catalyst made of zeolite and zinc oxide dramatically increases the amount of hydrogen produced when biomass is pyrolyzed.^{13,17}

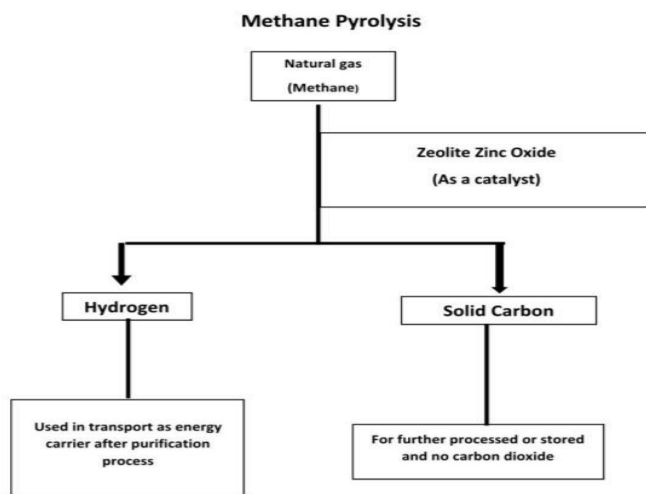


Fig-1 Flow diagram of Methane Pyrolysis

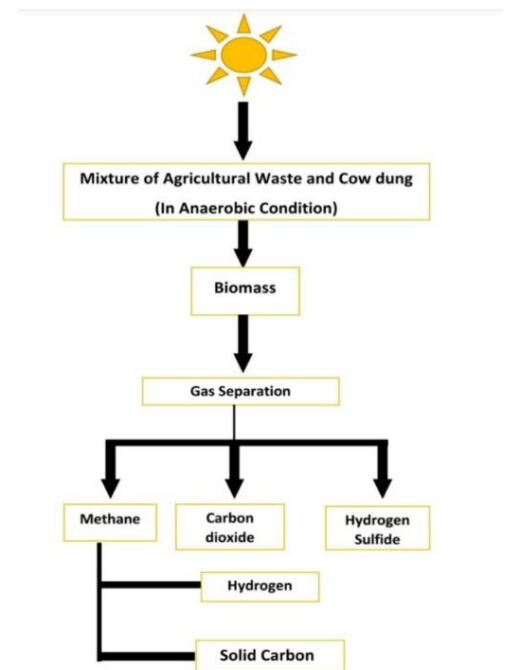


Fig-2 Flow diagram of production of Hydrogen gas from Biomass

Table-2 Hydrogen production technologies summary

Technology	Feedstock	Pressure	Temperature	Efficiency	Maturity
Steam reforming	HC	3-25 bar	700-1000°C	70-85%	Commercial
Auto thermal reforming	HC	30-50 bar	905-1050 °C	60-75%	Near term
Biomass gasification	Biomass	4-7 bar	200-650°C	35-50%	Commercial
Electrolysis	H ₂ O + Electricity	120-200 bar	750-950°C	50-70%	Commercial
Photolysis	H ₂ O + Sunlight	13-28 mm	23-350°C	0.5%	Long term
Thermochemical water splitting	H ₂ O + heat		500-2000°C	NA	Long term

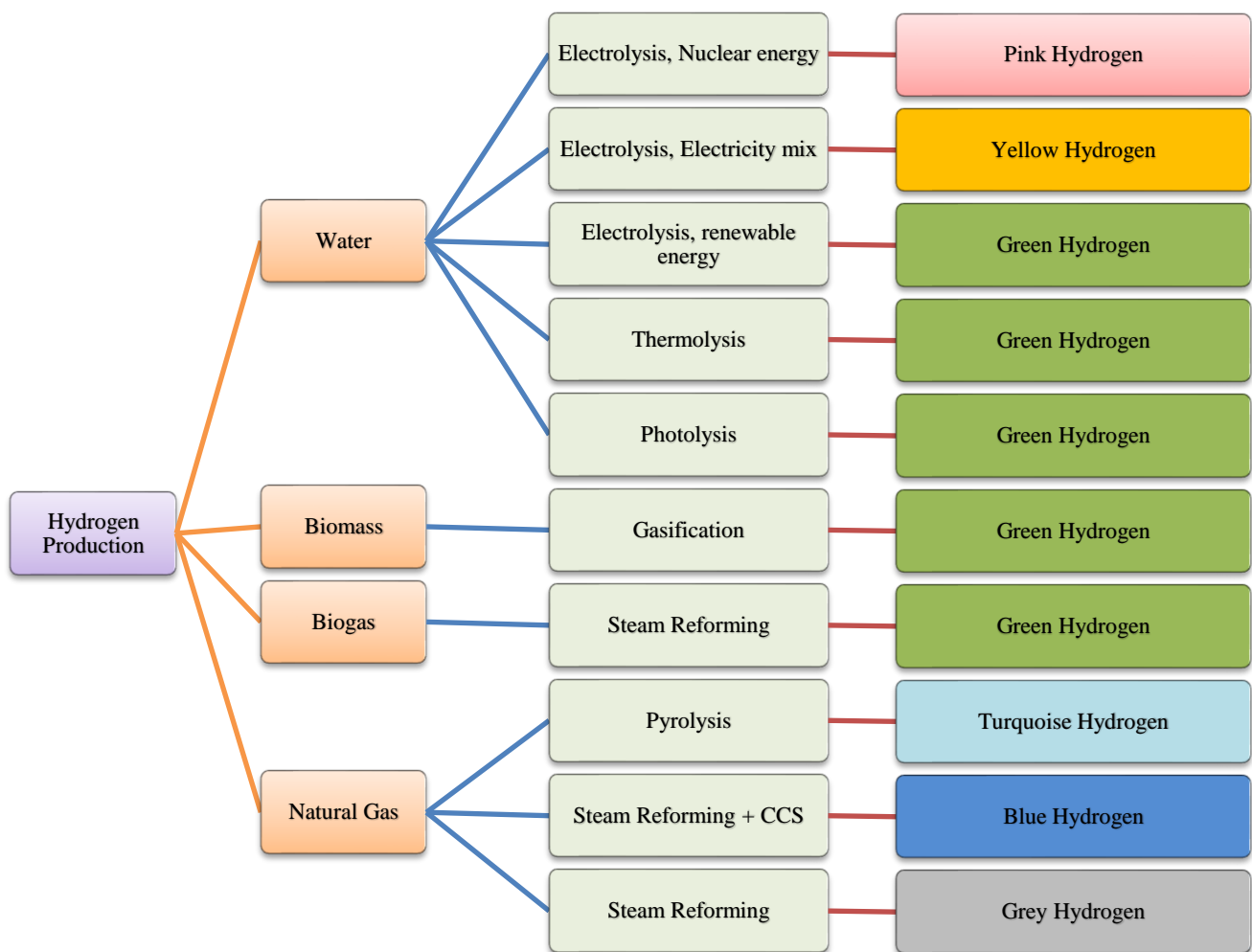


Fig- 3 Different methods of production of Hydrogen as fuel

Application of Green Hydrogen

Green hydrogen is currently receiving more interest than most energy-related concerns. The largest natural gas infrastructure company in Europe just started a new hydrogen business. According to a new McKinsey research released by the Fuel Cell and Hydrogen Energy Association, a hydrogen economy in the U.S. could support 700,000 employment by 2030 and produce an estimated \$140 billion in income annually. There are numerous possible uses for green hydrogen once production begins to scale, despite the high price and handling issues at the moment. Here are five key potential for the fuel, along with some related obstacles, based on research by NREL, McKinsey, and others.

1. Substitution of current hydrogen feed stocks

The most straightforward application of green hydrogen may be to simply replace the huge quantities of the gas currently produced using carbon-intensive techniques to meet industrial needs. According to data from the International Energy Agency, 38.2 million metric tonnes (MT) of hydrogen were used in the manufacturing of ammonia and another 31.5 MT were used for oil refining in 2018. Several companies are developing direct reduced iron techniques that employ the gas to eliminate oxygen from ore, making steelmaking another possible application for green hydrogen, according to NREL. The overall market for

hydrogen feedstock in the United States was 10 MT in 2015, and according to McKinsey, this market might grow to between 13 MT and 14 MT by 2030.

2. Warming

In nations where the primary source of heating is currently natural gas, decarbonizing home and corporate heating systems is a significant problem. Mixing green hydrogen with natural gas to lower the carbon level of the latter is one quick, if only partially effective, solution to the issue. However, only regions with relatively high natural gas prices, like Europe, are likely to find this to be beneficial. Furthermore, the amount of travel is constrained. Although not all natural gas pipeline systems are built of materials that can resist that concentration, blending up to 20 percent hydrogen (on a volume basis) is likely to be practical for natural gas applications, according to NREL researchers in a report published in August.

3. Storage of energy

Utilizing green hydrogen in fuel cells to generate power is one of its most lauded applications. But there are substantial obstacles to overcome.

The AC-to-AC return efficiency drops to about 35% if the water-based fuel is created by electrolysis using renewable energy, which is a significant decrease from the battery-capable efficiency of 95%. However, an NREL research released earlier this year revealed that, even with current technology, deploying green hydrogen for applications that require energy storage with a lifespan of at least 13 hours would be financially advantageous.

4. Non-traditional fuels

Hydrogen is widely employed in industry, but scaling up production for a wider range of uses presents distribution and storage issues. Converting the extremely volatile and combustible gas into a somewhat more flexible fuel, such ammonia or methane, is one technique to get past these problems. However, as energy would be wasted during this conversion, it is most likely only worthwhile to carry out in situations where the value of the final product is high. Because of this, according to NREL, "market opportunities are likely to be driven either by a desire to use carbon dioxide or by the ability to tailor specific products that may be challenging to produce directly from natural gas."

Conclusion

Despite the fact that gasoline and coal are our daily go-to traditional fuels, hydrogen fuel is thought to be the ideal substitute. Carbon emissions will drop significantly if hydrogen is used in conjunction with other renewable energies and is proven to be dependable. This may lead to the ozone layer being repaired, cleaner air, and the health of our planet. Overall, the world will be left in better shape for next generations. By accounting for the production and consumption of green hydrogen, guarantee of origin schemes avoid the need to use green hydrogen in closed systems and hence reduce the transactional costs when producing hydrogen from a range of low-carbon and high-carbon sources. There is much experience in Europe with renewable electricity and biomethane GOs that can be used to inform the development of green hydrogen GOs. A particular challenge is to produce a scheme that enable small hydrogen producers to participate. Green hydrogen standards may require GOs to include carbon intensity details; however, determining those is challenging. Using default values is simpler and cheaper than using actual values, but their conservative nature might exclude some producers unnecessarily. The best approach to defining a green hydrogen standard will depend on policy aims (e.g. the types of public support that are foreseen). It will

also depend on the trade-off between the accuracy of the measuring system and the cost of implementing it, which includes the breadth of the system and the need to avoid unreasonably excluding people from the market due to the scheme being too simplistic. A well-defined and stable policy framework is needed to reduce uncertainty and risks for producers, helping the industry to make better informed investment decisions. Green hydrogen presents opportunities for economic growth and job creation. While international hydrogen trade might maximize economic growth in the future, it will not be possible unless consistent rules and regulations for green hydrogen standards and GOs schemes can be agreed across regions or globally.

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