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# Green Hydrogen as a Low Carbon Alternative.

***Shravani Wagh[1], Adarsh Singh[2], Humaera Gadkari[3], Dr. Pratibha Gawande[4]***

[1,2,3]Student, Datta Meghe College of Engineering, Airoli, India

[4]Asst.Professor, Datta Meghe College of Engineering, Airoli, India

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**ABSTRACT:**

This review highlights the significance of the subject of renewable hydrogen. According to a study, one of the newest areas in the domain of research and development is green hydrogen. This paper reviewed the many growth processes in the hydrogen field. Globally, many nations are searching for profitable and commercial applications for green hydrogen. In this review, the development and difficulties surrounding green hydrogen have been covered. Due to the expense of electrolysis and storage space, one of the primary issues with H2 is its production. Numerous research publications have provided strategies for lowering the cost of equipment. It has been predicted that green hydrogen will exceed until 2050 with overcoming its every difficulty. The topic of the electrocatalyst to be utilized is covered, along with the expense of the procedure and storage. Another significant role for electrocatalyst is shown in the production of molecular hydrogen. Utilizing green hydrogen would protect the environment from greenhouse gas emissions while also promoting economic growth.

Keywords: Green Hydrogen Production, Electrolyzers , Cost Reduction, Environmental Impact .

## Introduction

The globe is currently seeing a significant shift in the use of green hydrogen energy. There are two main techniques to manufacture hydrogen: using renewable and non-renewable resources. Green hydrogen is hydrogen generated from renewable resources. It is created by a procedure known as electrolysis. Alkaline Water Electrolysis (AWE), Solid Oxide Electrolysis (SOE), Microbial Electrolysis, Proton Exchange Membrane (PEM) or PEMFCs are just a few of the several forms of electrolysis. There is no dependency on traditional fossil fuels in this procedure. Green hydrogen has been emphasized as being important in this research. It has provided information on its capacity, cost, storage, and production. It has also provided insight into the electrocatalyst that is employed in the procedure.

It has also provided insight into the electrocatalyst that is employed in the procedure. It is anticipated that the field of green hydrogen would undergo significant transformation till the year 2050. There are still a lot of problems that need to be solved. In the fields of industry, research, environmental, economic, and commercial development, green hydrogen has proven instrumental. Green hydrogen use will lower carbon emissions and the need for foreign fuel imports. As a result, there needs to be greater discussion about sustainable energy sources, and this is motivating research.

## Literature Review

Biraj Singh Thapa et al [1], examined of the creation, application, and potential economic growth of green hydrogen in the coming years. They have provided a quick overview of the study comparing Nepal's growing need for green hydrogen to the country's anticipated need for hydrogen. Several graphs, such as the one showing the increase in Nepal's power generation capacity, indicate that the country will require 34.4 GW of energy by 2045 due to accelerated power trade, as opposed to the basic scenario's 8.9 GW. When considering the country's increased economy rate, the graph also shows that petroleum products will be in high demand to meet energy needs, and the cost of producing green hydrogen will rise significantly by 2050. The University of Kathmandu is building a centre for green hydrogen (CGH), where it will conduct the most advanced research on GH and the need for it in Nepal in the years to come. According to studies, Nepal might earn up to USD 3 billion year in 2030 if it uses its excess 3000MW of renewable power for H2H production, which creates sustainable hydrogen.

Ujwal Sontakke et al [2] has studied the issues surrounding the production, storage, and growing demand for renewable energy in India. There are two ways to manufacture hydrogen: using renewable resources or non-renewable ones. However, India is exploring more environmentally friendly ways to produce hydrogen because of the depletion of fossil fuels and the acceleration of global warming. After providing information on Proton Exchange Membrane Fuel Cells (PEMFCs), automakers Toyota, Honda, and Hyundai are eager to see fuel cell technology advance. The concept of mixing hydrogen with compressed natural gas, or HCNG, improves engine performance and significantly reduces emissions. According to the Energy and Research Institute of India, demand for hydrogen would soar from 6 million to 28 million metric tons by 2050, and prices will drop by as much as 50% by 2030. India is set to commence the production of electrolysers soon. The main obstacles are the high cost of the equipment needed to produce, store, and distribute hydrogen from renewable sources. India wants to lessen its impact on the environment pollution and stop importing petroleum to use as a fuel replacement for vehicles. Funding for research and development in the field of renewable hydrogen is being provided by Indian organizations.

The topic of green methods for producing hydrogen has been covered by S. Shiva Kumar et al. [3], with a particular emphasis on proton exchange membrane electrolysis, or PEMFCs. According to their statement, water electrolysis is one of the most recently developed methods for producing hydrogen. It may be broadly classified into four categories: Alkaline Water Electrolysis (AWE), Solid Oxide Electrolysis (SOE), Microbial Electrolysis Cell (MEC), and Proton Exchange Membrane (PEM). They discussed the PEM process, its elements, the electrocatalyst employed in this process, and how calculations are aided by the laws of thermodynamics. The authors also focused on the electrocatalyst, namely on the oxygen evolution reaction (OER) at the anode and the hydrogen evolution reaction (HER) at the cathode. The graph below illustrates the number of reports on HER and OER, with 2017 recording the highest number. They have focused on the PEM process and made sure that future studies on renewable processes would be conducted. They have also made sure that the PEM procedure is more affordable and applicable to the next years.

| Electrolysis | Advantages | Disadvantages |
|---|---|---|
| Alkaline water Electrolysis | Well established technology non-noble electro catalyst.<br>low-cost technology.<br>The energy efficiency is (70-80%) commercialised | Low current densities<br>Formation of carbonates on the electrode decreases the performance of electrolyser, Low purity of gases,<br>Low operational pressure |
| Solid Oxide Electrolysis | Higher efficiency (90-100%)<br>Non-noble electro catalyst<br>High working pressure | Low durability |
| Microbial Electrolysis | Use different organic waste waters under development | Low hydrogen production<br>Low purity of hydrogen |
| Proton exchange Membrane | High current densities<br>Compact system design<br>Quick response<br>High hydrogen production rate with high purity of gases<br>High energy efficiency<br>High dynamic operation | New and partially established<br>High cost of components<br>Acidic environment<br>Low durability<br>Commercialization is in near term |

Table No.1 The benefits and drawbacks of various water electrolysis techniques

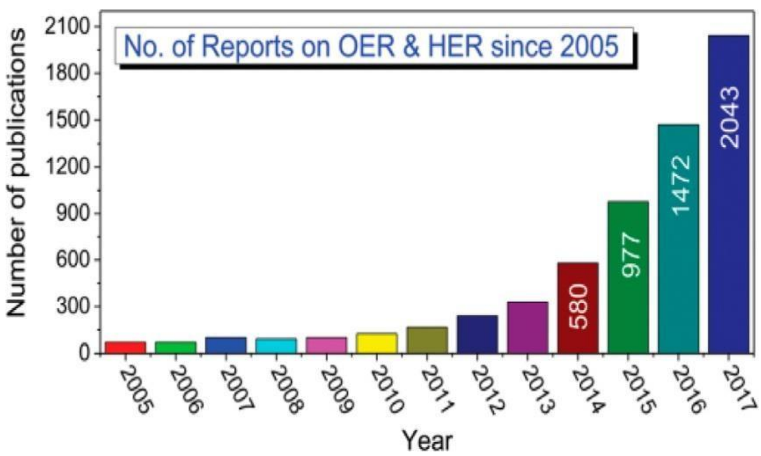


Fig 1. Number of scientific reports on OER and HER from 2005 to 2017 (Reprinted from (Ref 4))

Prabhukhot Prachi R. et al [5] explore the subject of three types of solid hydrogen storage and its conveyance. Nowadays, the most important concern is the hydrogen repository. Firstly, the properties of hydrogen, its use as a fuel, and its uses were covered. The storage of hydrogen demands a larger volume than that of gasoline-powered cars. The deposition of hydrogen in both gravimetric and volumetric platforms has been examined by the US Department of Education (DOE). These goals are shown in the table below. When dealing with solid-state hydrogen, it can be kept intact by combining it with either chemically or physically bound hydrogen.In physically bound hydrogen, H2 adheres to the solid surface of the material; this is studied in detail for materials such as carbon nanotubes (CNT), zeolites, metal organic frameworks, and polymers. In contrast, in chemically bound hydrogen, H2 reacts with the material to form various hydrides, including metal hydrides, complex hydrides, and the most recent type, clathrate hydrates. In their review, they covered both methods in great detail and concluded that alternative materials should also be considered for hydrogen storage because numerous variables, such as a substance's size and form, will affect its storage capacity.Thus, the main obstacle for hydrogen accumulation is to identify the material that has the capacity to store a significant amount of H2.

| Storage Parameter | Units | 2010 | 2015 |
|---|---|---|---|
| System gravimetric capacity | kWh/kg<br>(kgH2/kg system) | 2(0.06) | 3(0.09) |
| System Volumetric Capacity | KWh/L (KgH2/L System) | 1.5(0.045) | 2.7(0.081) |
| Storage system cost (and fuel cost) | $/kWh net ($/kg H2) | 4(133) | 2(67) |
| Durability | °c | -30/50(Sun) | -40/60(sun) |
| Min/Max delivery temperature | °c | -40/85 | -40/85 |
| Cycle life (1/4$^{th}$ tank to full) | Cycles | 1000 | 1500 |
| Min. Pressure delivery from tank.<br>FC= Fuel Cell<br>ICE= IC Engine | Atm | 4FC/<br>35ICE | 3FC/<br>35ICE |
| Max delivery pressure from tank | atm | 100 | 100 |
| Charging/Discharging rates.<br>System fill time (5kg) | Min | 3 | 2.5 |
| Fuel purity | %H2 | 99.99 (Dry basis) | |

Table 2. US DOE targets for hydrogen storage

G. K. Housley et al [6] aiming to produce hydrogen at temperatures between 800 and 900 degrees Celsius, the US Department of Energy's Nuclear Hydrogen Initiative emphasizes the use of high-temperature electrolysis (HTE) and the sulphur-iodine (SI) approach. Focusing on larger-scale demonstrations employing Integrated Laboratory Scale (ILS) systems, the program aims to produce 5000 Nl/hr via HTE and 200 Nl/hr via SI. Critical challenges including heat management and material performance are addressed by this program, which was developed at Idaho National Laboratory (INL) and Ceramatec. Operating at 830°C, the HTE ILS plant was initially intended to produce 4735 NL/hr (14.1 kW) of hydrogen. Its modular architecture allows for scalability and reliability up to 7103 NL/hr. Potential for large-scale nuclear-powered hydrogen generation is reinforced by future-plans to include heat recovery for increased efficiency.

Qusay Hassan et al [7], their study emphasizes the critical role that hydrogen plays in renewable energy systems while concentrating on how the gas may reduce greenhouse gas emissions and advance sustainable development. Among the renewable energy sources that are investigated in connection with hydrogen production are solar, wind, geothermal, biomass, solid municipal waste, food waste, algae, and lignocellulosic biomass. It is commonly known that solar and wind energy use environmentally friendly electrolysis methods. Geothermal energy is widely recognized for its efficacious high-temperature electrolysis capabilities.As potential sources, biomass, food waste, algae, lignocellulosic biomass, solid municipal trash, and biomass are all listed; each offers unique advantages and challenges that necessitate further technological advancement. The evaluation emphasizes hydrogen's versatility as an energy carrier in addition to its importance for balancing out variable renewable energy sources like solar and wind and for stabilizing energy systems. Despite storage and distribution challenges, green hydrogen is positioned as essential for achieving sustainable energy futures globally. Efficiency and economic feasibility are increasing due to ongoing technological advancements.

Alexandra M et al [8] illustrates the potential of green hydrogen to decarbonize sectors and the dominance of fossil fuels in worldwide CO2 emissions as of 2019. Based on US and Japanese initiatives to incorporate hydrogen into transportation and heating, it projects a large increase in the use of green hydrogen by 2050.The conversation covers several forms of hydrogen and their differing carbon footprints. Green hydrogen is anticipated to become more affordable by 2030 and may significantly lower industrial CO2 emissions. Heavy-duty trucks are expected to be largely replaced by fuel cell electric cars by 2050, highlighting the importance of hydrogen in the decarbonization of transportation. A fully renewable energy future, encompassing storage, e-fuels for transportation, and the phase-out of fossil fuels in microgrids, is positioned to benefit greatly from hydrogen's ability to reduce emissions associated with building heating and decarbonize high-temperature industrial operations

Gaetano Squadrito et al [9], this assessment highlights how important green hydrogen is to the transition to renewable energy sources and carbon-neutral economies. It is made by electrolysis with renewable resources, and when combined with biomass, it produces no carbon dioxide emissions. The use of green hydrogen is increasing gradually despite obstacles including exorbitant prices and continuous discussions about what constitutes green hydrogen. Importantly, if fossil fuels are substituted, worldwide electrolysis producing green hydrogen is expected to utilize only 1.8% of the world's water supply. It is recommended to utilize seawater for electrolysis in order to reduce the amount of freshwater used, however problems such as corrosion from chloride must be overcome. For water-scarce regions like Saudi Arabia and parts of Africa, investments in desalination are essential. Wastewater electrolysis is a different strategy that has been proposed. It is advantageous in areas where freshwater resources are scarce since it lessens competition and stress on them. Strict storage regulations, significant capital expenditures for small-scale electrolysis, and appliance adaptation for hydrogen consumption are some of the regulatory and financial obstacles. For adoption to become widely accepted, these obstacles must be removed. The evaluation calls for inclusive policies that support polygeneration and by-product value-adding in order to create a sustainable green hydrogen economy. It also promotes a balanced approach between dispersed and centralized production.

G. Kakoulaki. et al [10] emissions reduction by 2050 is the goal of the European Green Deal, with clean hydrogen being given priority. Utilizing 40 GW of renewable energy-powered electrolysers, the EU intends to manufacture 16.9 million tons of hydrogen by 2030. According to the report, the EU has enough renewable energy resources in the form of wind, solar, and hydropower to cover its needs for hydrogen generation as well as its present electricity consumption. Many regions have sufficient capacity to manufacture green hydrogen; however, some might need to transmit electricity across regions. The results verify the energy policies of the European Union and emphasize the necessity of more investigation into techno-economic evaluations and green hydrogen infrastructure.

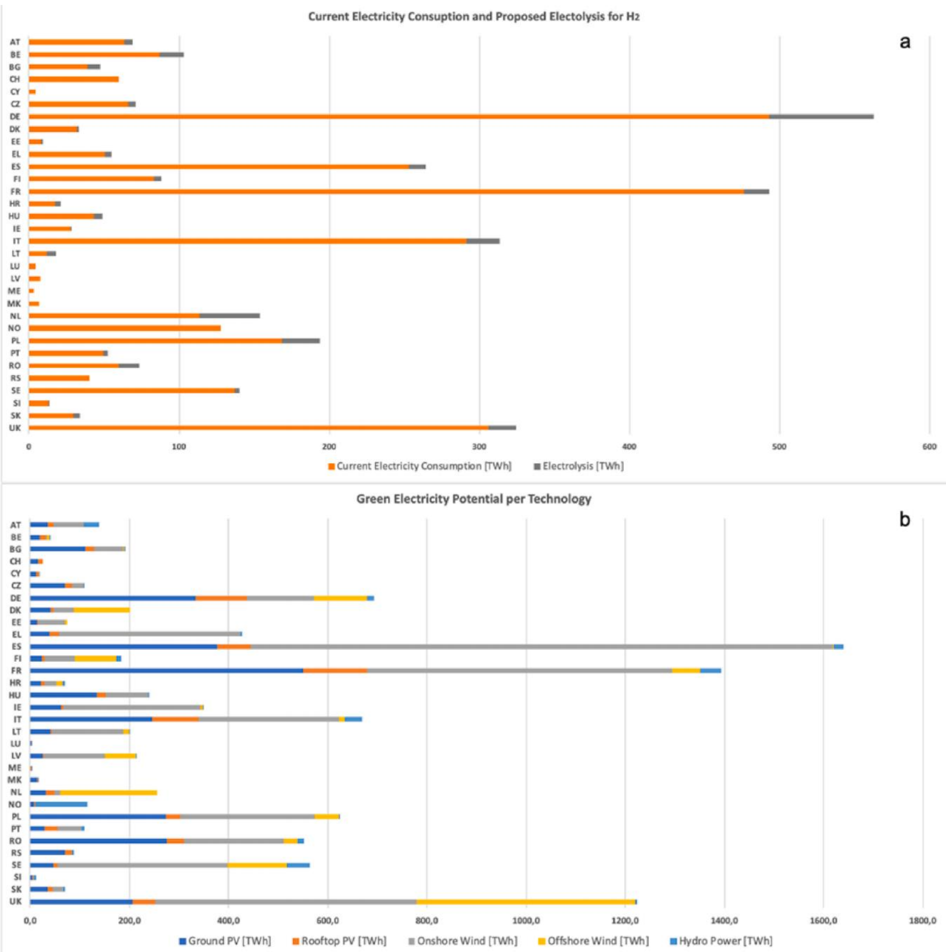


Fig 2. A breakdown of the nation's current power usage and the estimated amount needed for electrolysis is provided in (a);(b) The total national green energy potential, expressed in terawatt hours, for each technique.(Reprinted from (Ref 12))

Harshal V. Patel et al [11], the first part of the paper highlights the increasing need for energy because of population expansion and development, and it goes over the drawbacks of using traditional energy sources. Since hydrogen storage has a better power density, a lower self-discharge rate, and is more versatile than battery storage, the introduction promotes the integration of energy storage systems, particularly hydrogen storage. The two primary subsystems of the system—generation and storage—are described in the methodology section. It demonstrates how to generate hydrogen using a commercial electrolyser that converts 230 VAC to 5 VDC while maintaining compatibility with goods that are readily accessible on the market. The use of power converters to align voltage levels throughout the network and guarantee seamless operation via a single bus-bar is described in the article. It describes the suggested micro-grid architecture, which combines battery storage and PV emulators to create green hydrogen by connecting PV arrays to cascaded boost and buck-boost converters.A forward-thinking strategy is demonstrated by the emphasis on power converters, the analogous electrical electrolyser model, and control techniques using an advanced digital twin (MATLAB/SIMULINK). The authors' dedication to furthering green hydrogen generation and renewable energy is demonstrated in this section, which also provides a clear roadmap for future study and development.

Ismail Marouani et al [12], the paper's introduction skill-fully captures the attention of readers on the increasing interest in green hydrogen as a sustainable and eco-friendly energy source. It highlights the greater environmental advantages of green hydrogen by clearly differentiating it from grey and blue hydrogen. The many uses of green hydrogen are covered in detail in this study, including aviation, industrial applications, transportation, and energy generation. Every use is clearly explained, showcasing green hydrogen's adaptability as a clean energy source. The mention of certain areas in which green hydrogen can be advantageous highlights the technology's potential to displace fossil fuels in a wide range of industries. Techniques for water analysis, hydrogen storage, fuel cells, and infrastructure construction are all covered. Because it highlights current research and development initiatives that are essential to the future of green hydrogen, this section is especially beneficial. The paper's conclusion succinctly outlines the main ideas and emphasizes the promise of green hydrogen as a potential future energy source. It highlights how investment and international cooperation are required to fully reap the benefits of green hydrogen. This compelling call to action is in line with the main point of the paper and serves as a good conclusion.

## Conclusion

One possible way to lessen the production of dangerous gasses is to produce hydrogen using the electrolysis process. Electrolysis is powered by sustainable energy sources like sun, wind, and hydroelectricity. Since the market for renewable hydrogen is expanding, a lot of study has been done in this area. On the H2, there have been ideas and experiments. The PEM process of electrolysis has been developing over the past few years, and several new developments are being made. Its production methods, equipment costs, storage, capacity, and the electrocatalyst employed have all been discussed. Businesses such as Toyota, Hyundai, and Honda are eager to switch from petroleum fuel to hydrogen fuel. The field of H2 will expand significantly by the year 2050. Green hydrogen will help all nations achieve their economic and commercial goals in the coming years, as well as the global climate goals. Government regulations should be stringent, and businesses and academic institutions should work together to play a strong role. Green hydrogen will therefore contribute to a sustainable and wholesome environment for coming generations.

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