

An Efficient method to produce Green Hydrogen by Electrolysis Method

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Abstract

Green hydrogen is called the fuel of the future as it has the ability to power the hard to electrify sectors like industries, transportation and building contributing around 65% of yearly greenhouse gas emission. The process by which Green Hydrogen is produced is called Water Electrolysis. The technique involves “breaking” of the water molecules using electricity in an electrolyser to extract the dihydrogen (H₂). The electricity used must be carbon-free to consider the hydrogen produced as green. Green hydrogen is a clean energy source that emits only water vapor and leaves behind no residue in the air, like coal and oil. The produced hydrogen is ready for use in direct applications like transport and steel production and in direct power applications like fuels, fertilizers and is a great replacement for natural gas. India is well positioned to be a major green hydrogen production center considering the ample amount and the low-cost of the renewable resources that would allow for some of the lowest green hydrogen prices in the world.

Keywords: Green hydrogen; electrolysis; renewable; dihydrogen; electricity; electrolyser

1. Introduction

In the early decades of the 21st century, the world finds itself at a crossroad, where the confluence of escalating climate concerns and the escalating demands for energy drives us to explore innovative, sustainable solutions. Traditional fossil fuels, the lifeblood of our industrialized societies continue to deplete and the consequences of greenhouse gas emissions become increasingly apparent, the need for innovative and sustainable energy solutions has never been more pressing. In this transformative moment, Green hydrogen, often referred to as "the fuel of the future," a versatile and promising energy carrier, has emerged as a frontrunner in the pursuit of a cleaner and more sustainable energy future. We delve deeply into the enigmatic realm of electrolysis, unravelling its inner workings that may drive green hydrogen toward economic viability and scalable

implementation. In an epoch defined by the necessity to confront climate change, green hydrogen shines as a symbol of innovation and a cornerstone of a sustainable future. Moreover, we survey the landscape of its applications, from fuelling zero-emission transportation to forming the linchpin of integrated energy ecosystems in a world that increasingly values environmental stewardship.

Nevertheless, the voyage of green hydrogen is not without its share of challenges and opportunities. This paper thoroughly investigates the economic facets, assessing the investment requirements for a hydrogen-based future, the cost dynamics of renewable energy integration, and the policy frameworks required to facilitate this transformation. Concurrently, we delve into the manifold environmental dividends of green hydrogen, from its role in mitigating

greenhouse gas emissions to its potential to enhance global energy security.

Our aim for this research has been to produce Green Hydrogen through the electrolysis of water which splits water molecules into hydrogen and oxygen using renewable energy sources, creating a clean energy carrier with a multitude of applications. It holds the potential to revolutionize the global energy landscape. This versatile energy vector not only serves as a means to store and transport renewable energy but also provides a clean alternative for sectors traditionally reliant on fossil fuels, such as heavy industry, transportation, and energy storage. Its role in reducing greenhouse gas emissions and mitigating climate change cannot be overstated.

This research paper seeks to explore the multifaceted realm of green hydrogen, delving into its production technologies, applications, economic viability, and environmental benefits. Through a comprehensive examination of the current state of green hydrogen research, this paper aims to shed light on the opportunities and challenges that lie ahead. By understanding the science and engineering behind green hydrogen production, assessing its potential applications, and evaluating its economic feasibility, we can better appreciate its role in a sustainable, low-carbon future.

In a world increasingly beset by the consequences of unchecked carbon emissions, green hydrogen is more than a novel concept; it is a pivotal catalyst for change.

2. Methods to produce Green Hydrogen:

Green hydrogen is hydrogen produced through a process that generates little to no greenhouse gas emissions. It is considered

a key element in the transition to a sustainable energy future. Various methods for green hydrogen production are being researched and developed. Here is an in-depth overview of some of the most prominent methods for green hydrogen production:

i. Water Electrolysis: Electrolysis is the most widely used and accepted method for producing green hydrogen. In this process, water with the help of electricity is split into hydrogen and oxygen. There are three main types: alkaline electrolysis, solid oxide electrolysis and proton exchange membrane (PEM) electrolysis.

ii. Alkaline Electrolysis: Alkaline electrolysis uses an alkaline electrolyte solution, often potassium hydroxide (KOH), to facilitate the electrolysis process. It operates at a higher temperature than PEM electrolysis, typically around 70-100°C. Alkaline electrolyzers are known for their durability, and they have been used in industrial applications for decades. They are often chosen for their ability to produce large quantities of hydrogen.

iii. Solid Oxide Electrolysis: Solid oxide electrolysis operates at much higher temperatures, typically above 800°C. These high temperatures enable faster reaction kinetics and higher efficiency. Solid oxide electrolyzers are particularly well-suited for integration with high-temperature heat sources, such as concentrated solar power or advanced nuclear reactors. This technology is efficient but also more complex and typically requires specialized materials.

iv. Proton Exchange Membrane (PEM) Electrolysis: In PEM electrolysis, a solid

polymer electrolyte membrane, often made of a perfluoro sulfonic acid polymer, separates the anode and cathode compartments. The membrane allows the transport of protons (H^+ ions) while preventing the crossover of gases. This method operates at relatively low temperatures (typically between $50-80^{\circ}C$), which reduces energy consumption, and is well-suited for smaller-scale applications. PEM electrolyzers are valued for their rapid response time and ability to adjust to variable loads, making them suitable for applications where responsiveness is critical.

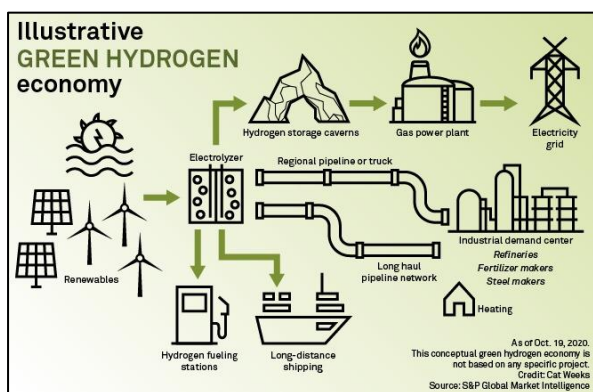


Figure 1: Green hydrogen economy illustration

3. Materials used:

- i. 2 Carbon rods (Electrodes)
- ii. Beaker
- iii. Demarcated test tubes
- iv. Power supply source
- v. R.O. Water
- vi. 98% Concentrated Sulfuric acid
- vii. Copper wires

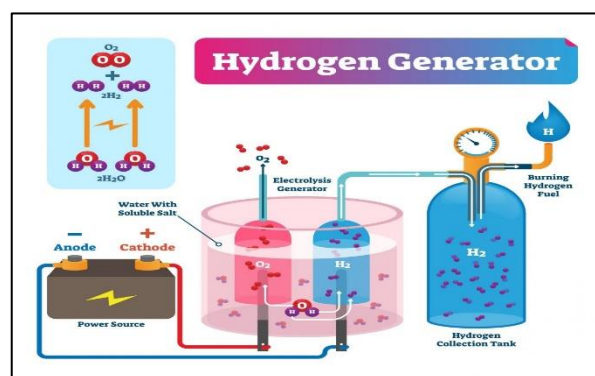
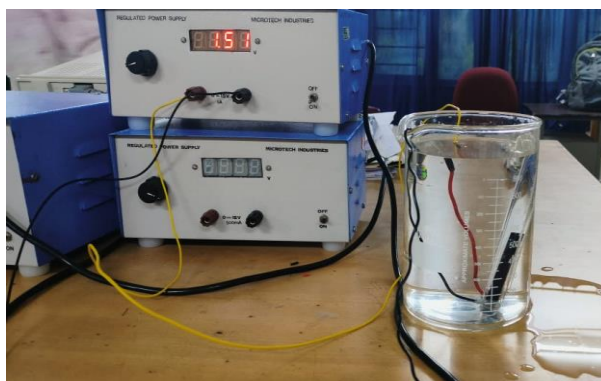
4. Experimental procedure:

- i. At first our aim was to bring all the materials together and make a setup with the help of which we could clearly assess the formation of the hydrogen and could also easily replace certain parts if needed.

- ii. In the beaker we poured 1000ml of R.O. water and then filled up two 10ml test tubes with R.O. water which we overturned and put in the beaker full of water. Next, we managed to slide in both the carbon rods in each of the test tubes ensuring that no water bubble entered in the test tubes. Before inserting the carbon rods in the test tubes, we had wound one side of a wire to both the carbon rods and with the help of a glue gun, had stuck the wires to the rods. Next, we wound the other sides of the wires to the positive and negative sides of the power supply respectively. This was the initial setup that we had made.
- iii. Initially the following readings were taken:
Level of water in both test tubes = 10ml
Water level in beaker = 1000ml
- iv. Next, we poured 2ml of 98% conc. Sulfuric acid in the water in the beaker to ensure that the water would conduct the electricity easily because the acid would increase the degree of ionization of water.
- v. Now we started doing the experiment with a voltage of 1.5V initially. We conducted experiment with this voltage for 30 minutes. After 30 minutes we observed that 0.3ml of Hydrogen was produced at the cathode.
- vi. We conducted the 'Pop' test to confirm the presence of Hydrogen and following that also conducted the lime water test to confirm the lack of the presence of carbon. The lack of carbon was needed to be checked to ensure that there was no

carbon emission which directly ensured the formation of “Green Hydrogen.”

vii. The similar test was conducted for different voltages: 3V, 6V, 9V and 12V. Green Hydrogen formed was The similar test was conducted for different voltages: 3V, 6V, 9V and 12V. Green Hydrogen formed was 1ml, 2ml, 2.5ml and 4.7ml respectively. The time for all the other four readings was also set at 30 minutes and all the water of the test tubes and the beaker were replaced (2ml Sulfuric acid was always added to the beaker whenever the water was replaced) before starting the process to take a reading.



viii. From the experiment we can conclude that the generation of the Hydrogen gas is directly proportional to the voltage supplied and plotting which we received almost a linear graph.

Figure 2: [A] Our Setup [B] Representation of our setup

5. Observations:

The following observations were recorded during the experimental procedure:

Time = 30 minutes

| Sl. No. | Voltage (V) | Volume of water (ml) | Volume of hydrogen produced (ml) |
|---------|-------------|----------------------|----------------------------------|
| 1. | 1.5 | 1000 | 0.3 |
| 2. | 3 | 1000 | 1 |
| 3. | 6 | 1000 | 2 |
| 4. | 9 | 1000 | 2.5 |
| 5. | 12 | 1000 | 4.7 |

Table 1: Volume of Hydrogen produced at different voltages.

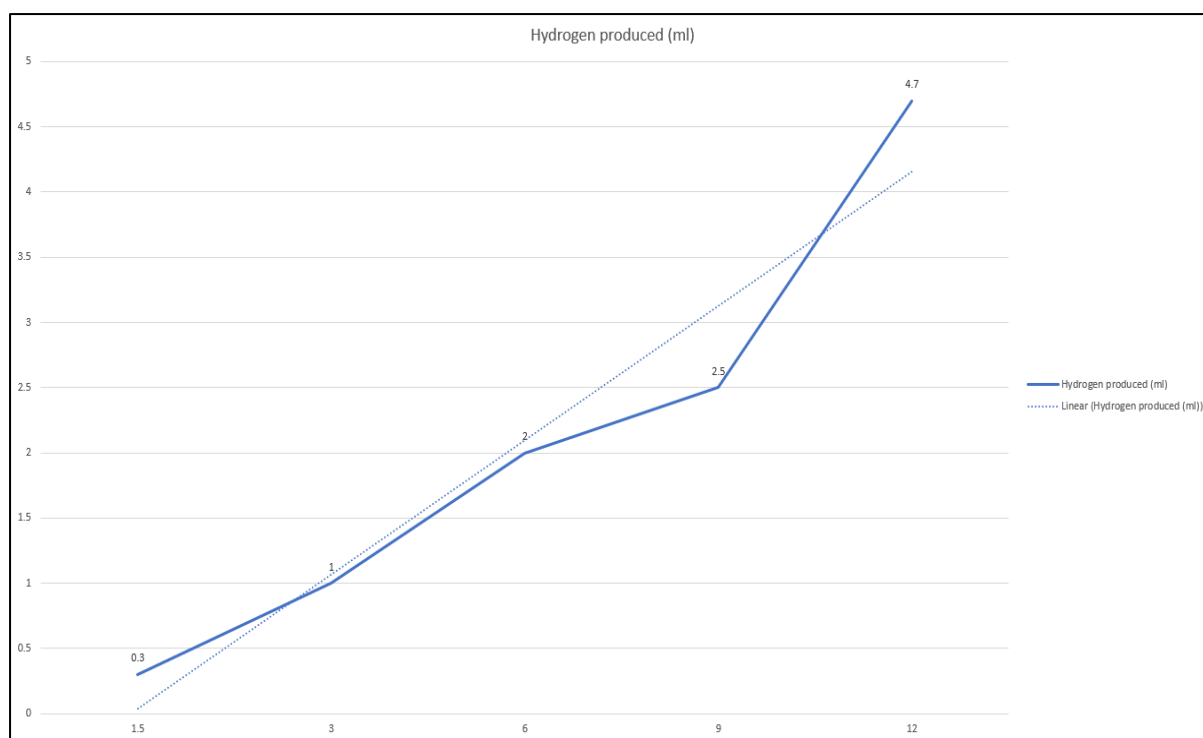


Figure 3: Volume of Hydrogen produced V/s Voltage graph

Confirmatory Test:

For confirmation of Hydrogen: Pop Test -

The "pop test" is a simple and qualitative method for confirming the presence of hydrogen gas. It is a rapid and often visually striking way to detect hydrogen. When hydrogen gas comes in contact with an open flame, it rapidly combusts, producing a distinctive "pop" or "explosion" sound. This reaction is due to hydrogen's high flammability and its ability to burn in the presence of oxygen, which is present in the air.

For detection of Carbon: The limewater test -

The limewater test, also known as the calcium hydroxide test or the "miliness test," is a straightforward experiment used to detect the presence of carbon dioxide (CO₂) gas by observing a chemical reaction. It relies on the reaction between carbon dioxide and calcium hydroxide (Ca(OH)₂) to form calcium carbonate (CaCO₃), which is only slightly soluble in

water. The result of this reaction is a cloudy or milky appearance in the limewater.

6. Experimental results:

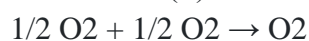
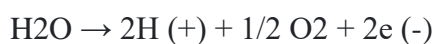
A colourless and odourless gas was formed in the cathode (Hydrogen) and another colourless and odourless gas was formed in the anode. On bringing a burning splinter near to the gas in the cathode, the burning splinter got extinguished with a pop sound ensuring the presence of hydrogen gas. But when the extinguished splinter is brought near the gas in the anode, the splinter rekindles ensuring the presence of oxygen gas. Since, our aim is to produce green hydrogen, so it is very important to check that there is no carbon emission in the entire procedure. In the following method that we had opted for, carbon could only be emitted in the form of carbon dioxide gas from the anode because carbon dioxide gas in order to be formed needed depleted carbon and oxygen gas that were only present in the

anode. So, in order to check that no carbon dioxide gas was present, at first we sealed the opening of the anode with a cork and then make a seizure in the cork through which we can pass a tube and the other part of the tube we insert in another test tube which has lime water in it. Now, the gas from the test tube of the cathode flows to the other test tube and there is no effect on the lime water in the other test tube which ensures the lack of the presence of carbon dioxide. If carbon dioxide was present, there would have been a colour change in the lime water, the lime water would have turned milky. The chemical reactions for the electrolysis process are given below:

Reaction at cathode:



Reaction at anode:



7. Efficiency of Green hydrogen:

Increasing the overall efficiency of green hydrogen production involves optimizing various aspects of the process, from the generation of renewable energy to the conversion of that energy into hydrogen. Here are some key strategies to improve the overall efficiency of green hydrogen production:

i. High-Efficiency Renewable Energy Sources: Use of high-efficiency renewable energy sources such as advanced solar panels and wind turbines. Investing in the latest technology can maximize the electrical energy output for a given amount of sunlight or wind.

ii. Load Management: Implementation of load management and smart grid technologies to match hydrogen production with renewable energy availability helps

avoid curtailment of excess energy and ensures that the electricity used for electrolysis is generated from renewable sources.

iii. Electrolyzer Selection: Choice of the most efficient electrolysis technology available, such as proton exchange membrane (PEM) or solid oxide electrolyzers. These technologies typically have higher electrical efficiencies compared to older alkaline electrolysis methods.

iv. Operating Conditions: Optimization of the operating conditions of the electrolyzer, including temperature, pressure, and flow rates. Running the electrolyzer under optimal conditions can improve its efficiency.

v. Heat Recovery: Implementation of heat recovery systems to capture and utilization of excess heat generated during the electrolysis process. This can enhance overall efficiency and reduce the energy input required.

vi. Hydrogen Compression and Storage: Selection of efficient methods for hydrogen compression and storage, considering factors like energy losses during compression and the choice of storage materials. Advanced materials and techniques can reduce energy losses during these processes.

vii. Co-Generation and Co-Production: Exploring opportunities for co-generation, where the heat produced during hydrogen production is used for other industrial processes or for district heating. Co-production, where hydrogen production is combined with the production of other

valuable chemicals, can also improve overall process efficiency.

viii. Grid Integration: Integration of green hydrogen production facilities with the local energy grid and other energy systems to optimize energy flow and balance supply and demand.

ix. Life Cycle Assessment: Conducting a life cycle assessment (LCA) to evaluate the environmental impact of the entire hydrogen production and utilization process helps identify areas for improvement and ensures that the overall system is sustainable and efficient.

x. Technological Advancements: Staying informed about the latest advancements in hydrogen production technologies, materials, and system design. Continuously adopting new innovations can lead to efficiency gains.

xi. Regulatory Support: Advocative support from government policies and incentives that encourage green hydrogen production and promote efficiency. Policy measures can include carbon pricing, subsidies, and renewable energy targets.

xii. Economies of Scale: Considerations in scaling up hydrogen production facilities can often lead to cost savings and efficiency improvements.

8. Challenges:

Green hydrogen, produced through the electrolysis of water using renewable energy sources, holds great promise as a clean and sustainable energy carrier. However, there are several challenges that need to be addressed to realize its full potential:

i. High Production Costs: One of the primary challenges is the high cost of green hydrogen production compared to hydrogen produced from fossil fuels. The cost of renewable energy equipment, such as solar panels and wind turbines, as well as the cost of electrolysis equipment, needs to come down significantly to make green hydrogen economically competitive.

ii. Intermittent Renewable Energy: The variability and intermittency of renewable energy sources like wind and solar can lead to fluctuations in green hydrogen production. Addressing this challenge requires effective energy storage and grid management solutions to ensure a stable hydrogen supply.

iii. Electrolyzer Efficiency: Improving the efficiency of electrolysis technology is essential to reduce energy losses during hydrogen production. Researchers are working on developing more efficient and cost-effective electrolyzers.

iv. Scale-up and Infrastructure: Building the necessary infrastructure for green hydrogen production, distribution, and utilization is a massive undertaking. It requires significant investment and coordination among various stakeholders.

v. Hydrogen Transportation and Storage: Developing efficient and safe methods for transporting and storing hydrogen is a challenge. Hydrogen is a low-density gas and can be challenging to transport over long distances. Methods such as pipeline networks, liquefaction, and solid-state storage are being explored.

vi. Competing Technologies: Other clean energy carriers and technologies, such as

batteries for energy storage and direct electrification, are in competition with green hydrogen. Deciding which technology is most suitable for different applications is an ongoing challenge.

vii. Regulatory and Policy Frameworks:

The development of supportive policies, regulations, and standards for green hydrogen production and use is critical. Governments need to provide incentives and create a favorable business environment for green hydrogen to thrive.

viii. Public Acceptance and Awareness:

Building public support and awareness for green hydrogen can be a challenge, as many people are still not familiar with its benefits and potential applications.

ix. Material Availability: The production of electrolyzers and other hydrogen-related technologies may require specific materials, some of which could face supply challenges. Efforts to diversify material sources and develop alternative technologies are essential.

x. International Collaboration:

Collaboration among nations and regions is crucial for scaling up green hydrogen production. Cooperation in research, development, and investment can help overcome the global nature of the challenge.

xi. Environmental Impact: While green hydrogen is cleaner than hydrogen produced from fossil fuels, there are still environmental considerations, such as water usage and land use for renewable energy installations. Sustainable practices must be employed to mitigate these impacts.

Addressing these challenges requires a multi-faceted approach that involves technological innovation, policy support, infrastructure development, and international cooperation. As technology and knowledge continue to evolve, green hydrogen has the potential to play a significant role in the transition to a more sustainable and low-carbon energy future.

9. Environmental impact:

Green hydrogen is often considered an environmentally friendly energy carrier compared to hydrogen produced from fossil fuels. However, its environmental impact can still vary depending on several factors. Here are some key aspects of the environmental impact of green hydrogen:

i. Carbon Emissions Reduction: Green hydrogen is produced using renewable energy sources, such as wind, solar, or hydropower. As a result, the carbon emissions associated with its production are significantly lower compared to hydrogen produced from fossil fuels. This reduction in carbon emissions contributes to mitigating climate change.

ii. Air Pollution Reduction: Since green hydrogen production doesn't involve burning fossil fuels, it doesn't produce air pollutants such as sulfur dioxide (SO₂), nitrogen oxides (NO_x), and particulate matter, which are associated with respiratory and environmental health problems.

iii. Water Usage: Electrolysis, the process used to produce green hydrogen, requires water. While this is generally a low-impact water usage process, it can become a concern in regions with water scarcity. Efforts to minimize water use and develop

water-efficient electrolysis systems are ongoing.

iv. Land Use: The deployment of renewable energy sources like wind and solar to generate electricity for hydrogen production can impact land use. Large-scale renewable energy installations may require significant land area. Sustainable land management practices are important to minimize land use and protect ecosystems.

v. Materials and Resource Use: The production of electrolyzers and other hydrogen-related technologies may require specific materials. Ensuring a responsible and sustainable supply chain for these materials is important to minimize environmental impacts.

vi. Energy Efficiency: The overall efficiency of green hydrogen production, including energy losses in the conversion process, can impact its environmental footprint. Improving the energy efficiency of the entire hydrogen production chain can reduce resource consumption and associated environmental impacts.

vii. Waste Management: Electrolysis and other hydrogen production processes can generate waste materials. Proper waste management and recycling practices are necessary to minimize environmental harm.

viii. Lifecycle Analysis: To fully understand the environmental impact of green hydrogen, a comprehensive lifecycle analysis is essential. This analysis takes into account all stages, from the production of renewable energy to the end use of hydrogen, and evaluates the environmental effects and resource use at each step.

ix. Environmental Regulations and Standards: Implementing and enforcing environmental regulations and standards for green hydrogen production and utilization can help ensure responsible and sustainable practices are followed.

x. Sustainable Practices: Promoting sustainable practices in the development and deployment of green hydrogen technology, including responsible land use, water use, and materials sourcing, is essential to minimize its environmental impact.

While green hydrogen offers significant environmental benefits when compared to hydrogen produced from fossil fuels, it is not without environmental considerations. The goal is to continually improve the sustainability of green hydrogen through innovation, efficient resource use, and responsible practices, ultimately contributing to a more environmentally friendly and sustainable energy future.

10. Discussion:

Green hydrogen has emerged as a promising solution in the quest for sustainable and clean energy. As the world grapples with the urgent need to reduce greenhouse gas emissions and transition away from fossil fuels, green hydrogen offers a versatile and environmentally friendly alternative. Here is a deeper discussion on green hydrogen:

i. Renewable Energy Integration:

Green hydrogen is produced through electrolysis, a process that splits water into hydrogen and oxygen using electricity. What sets it apart is the source of this electricity—renewable energy. By harnessing power from solar, wind, or

hydropower, green hydrogen ensures a zero-emission production process.

ii. *Versatility in Applications:*

Green hydrogen's versatility is a key advantage. It can be used in various sectors, including transportation, industry, and energy storage. In transportation, hydrogen fuel cells can power vehicles, offering a clean alternative to conventional fossil fuel-powered cars. In industry, hydrogen is a vital component for sectors like steel and chemical production, offering a green pathway to decarbonization.

iii. *Decarbonizing Difficult Sectors:*

One of the most significant advantages of green hydrogen is its potential to decarbonize sectors that are challenging to electrify directly. Industries such as heavy manufacturing, aviation, and shipping rely on high-energy-density fuels, where green hydrogen presents a viable solution to significantly reduce emissions.

iv. *Energy Storage and Grid Balancing:*

Green hydrogen can also be used as a form to store energy. Excess energy generated from renewables can be used for electrolysis, creating hydrogen stores that can be converted back to electricity during peak demand periods. This feature makes green hydrogen an essential component in balancing energy grids, especially as renewable sources can be intermittent.

v. *Global Collaboration and Innovation:*

Countries worldwide are investing in research and development to enhance the efficiency and reduce the costs associated with green hydrogen production. International collaboration and knowledge-sharing are driving innovation, leading to the development of more efficient

electrolysis technologies, and increasing the feasibility of large-scale green hydrogen projects.

vi. *Challenges and Considerations:*

While the potential of green hydrogen is vast, challenges remain. These include the high production costs, efficiency improvements in electrolysis, building necessary infrastructure, and ensuring a sustainable supply chain for raw materials. Overcoming these challenges requires concerted efforts from governments, industries, and researchers.

vii. *Policy Support and Market Development:*

Government policies play a crucial role in the adoption of green hydrogen. Subsidies, tax incentives, and regulatory frameworks can stimulate investment in green hydrogen projects. Additionally, creating a robust market for green hydrogen encourages private sector involvement and innovation. In summary, green hydrogen represents a beacon of hope in the transition toward a cleaner and more sustainable energy future. Its potential to decarbonize diverse sectors, coupled with ongoing technological advancements and supportive policies, positions green hydrogen as a vital player in the global efforts to combat climate change and develop a more sustainable world for the generations to come.

10. Conclusion:

The green hydrogen production experiment, it is evident that the use of renewable energy sources, such as wind and solar power, in electrolysis processes is a promising avenue for sustainable hydrogen production. The results demonstrate that the system was able to efficiently convert electrical energy into hydrogen gas, with

minimal environmental impact compared to conventional fossil fuel-based methods.

The experimental setup showcased the feasibility of using electrolysis with renewable energy inputs to generate green hydrogen, contributing to the global efforts to mitigate climate change and transition towards a more sustainable energy economy. The process exhibited good efficiency, and further optimization could potentially enhance the overall yield and reduce costs associated with production.

However, it is important to note that there are still challenges to overcome, such as scalability, cost-effectiveness, and the development of reliable energy storage solutions. Additionally, research should continue to focus on improving the performance of electrolysis technologies and exploring novel catalyst materials to enhance the efficiency of the process.

Overall, this experiment provides valuable insights into the potential of green hydrogen production as a key component of the renewable energy landscape. Further research and development in this field will be crucial to unlocking the full potential of green hydrogen as a clean and sustainable energy carrier.

Furthermore, the experiment underscores the critical role that policy and regulatory frameworks play in accelerating the adoption of green hydrogen technologies. Supportive policies, such as incentives for renewable energy projects and carbon pricing mechanisms, will be instrumental in driving the transition towards a hydrogen-based economy.

Additionally, collaboration between public and private sectors, as well as international cooperation, will be essential in scaling up green hydrogen production and distribution infrastructure. This will help create a robust and interconnected hydrogen ecosystem

that can meet the growing demands of various sectors including transportation, industry, and energy storage.

The green hydrogen production experiment represents a significant step forward in realizing a sustainable and decarbonized energy future. It highlights the potential of harnessing renewable resources to produce a clean and versatile energy carrier. With continued innovation, investment, and policy support, green hydrogen can play a pivotal role in achieving global climate goals and ensuring a more sustainable and resilient energy system for generations to come.

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