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Next Generation Energy Green Hydrogen: Critical Review

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Abstract

The transition to a sustainable and low-carbon energy system has become a global imperative, driven by the need to mitigate climate change and reduce reliance on fossil fuels. Green hydrogen, produced through the electrolysis of water using renewable energy sources, has emerged as a promising solution to address these challenges. This critical review paper presents a comprehensive analysis of the next generation energy green hydrogen, focusing on its production, storage, transportation, and applications. The paper begins by discussing the various methods of green hydrogen production, including alkaline electrolysis, polymer electrolyte membrane (PEM) electrolysis, and solid oxide electrolysis. It examines the advancements in electrolyzer technology, catalysts, and materials, as well as the integration of renewable energy sources such as solar and wind power. The review also explores the scalability and cost-effectiveness of green hydrogen production, highlighting the need for continued research and innovation to drive down costs and increase efficiency. In addition to production, the paper evaluates different storage technologies for green hydrogen, including compressed gas, liquefaction, and chemical storage. It analyzes the advantages, limitations, and safety considerations of each method, emphasizing the importance of reliable and efficient storage systems to enable the integration of green hydrogen into existing energy infrastructure. The review explores the transportation options for green hydrogen, including pipelines, trucks, ships, and blending with existing natural gas networks. It discusses the infrastructure requirements, safety regulations, and energy losses associated with each mode of transport, underscoring the need for a robust and interconnected hydrogen distribution network. The paper also examines the diverse applications of green hydrogen across various sectors, such as transportation, industry, and power generation. It discusses the potential for hydrogen fuel cell vehicles, the decarbonization of heavy industries like steel and chemicals, and the role of green hydrogen in grid balancing and energy storage. The review emphasizes the need for policy support, market incentives, and public-private collaborations to accelerate the adoption of green hydrogen technologies. Paper discusses the current policy landscape and regulatory frameworks for green hydrogen at the national and international levels. It analyzes government initiatives, financial incentives, and research and development programs aimed at promoting green hydrogen as a key pillar of the future energy system. Hydrogen is a useful energy carrier for remote or high-energy density applications. It can also be used as a feedstock for chemical reactions to create a variety of synthetic fuels and feed stocks. This paper is based on a survey and analysis of the development, production, and use of hydrogen energy. It has been suggested that hydrogen will be the future generation of energy for everyone based on the critical review.

Keywords: Energy; Hydrogen; development; renewable source

Introduction

Since it makes up 75% of all stuff, hydrogen is the chemical element that is most prevalent on Earth. However, we never discover it on its own; rather, we discover it with other chemical elements like the carbon that creates organic compounds or the oxygen that forms water. The first element in the periodic table and having an atomic number of 1, hydrogen is the simplest chemical element. It emits no pollution on its own, is lightweight, and can be stored. It is the ideal option for a fuel because of these features.

However, hydrogen is an energy vector and not a fundamental energy source, thus it must be created chemically. Although it is frequently true, hydrogen is not always a renewable fuel. Only when the method used to obtain it is renewable is hydrogen considered renewable. Let's examine the various methods used to produce hydrogen.

Hydrogen that has been stored in particular tanks is directed into a fuel cell when we need to convert it into energy. There, it forms a new bond with airborne oxygen, resulting in the generation of electricity. As a result, the only byproduct of the process is water, creating a clean, sustainable system where no CO2 is released in the process of generating electricity.

Production/Development

Green hydrogen, which is created by splitting water molecules into hydrogen and oxygen using renewable electricity, has the potential to significantly reduce greenhouse gas emissions while assisting in meeting the world's energy needs. By 2050, the demand for hydrogen is projected to increase to 500-680 million metric tons (MT), from an anticipated 87 million MT in 2020. The market for hydrogen production was evaluated at $130 billion between 2020 and 2021, and it is anticipated to expand by up to 9.2% annually until 2030. Nevertheless, there is a resurgence of interest in green hydrogen generating technology. This is due to the fact that hydrogen's potential applications are growing in a variety of fields, including power generation, manufacturing processes in the steel and cement industries, fuel cells for electric vehicles, heavy transportation like shipping, production of green ammonia for fertilizers, cleaning products, refrigeration, and grid stabilization.

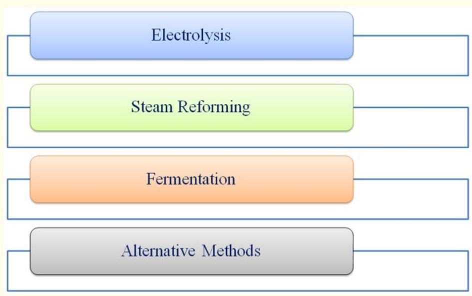

Figure 1: Production of hydrogen.

Hydrogen that is green is unique. It is created by electrolysis, a process that uses machines to completely separate water into hydrogen and oxygen. It was never practical to create hydrogen using electrolysis because it used so much electricity. There are two reasons why the situation is changing. First, a sizable surplus of renewable energy is now accessible at grid scale; rather than being stored in battery arrays, the surplus energy can be used to drive the electrolysis of water, "storing" the energy in the form of hydrogen. The efficiency of electrolyzers is also increasing.

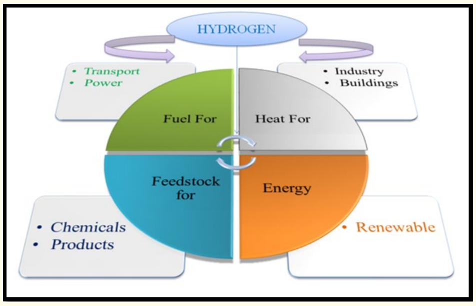

Figure 2: Utilization of Hydrogen.

Literature Review

Discussions over clean, affordable, and sustainable energy sources have grown as a result of the rise in the world's energy demand [1-3]. Pollution of some form is included in the majority of waste disposal methods. Depending on the product or resource in issue, waste originates from consumption; its manner of use determines the portion that is wasted during use and the portion that only becomes waste upon system affordability (Lou and Nair 2009).

When an item is non-biodegradable, it signifies that its constituent parts won't decompose over time. No matter how powerful the creatures, nonbiodegradable garbage cannot melt, decompose, or otherwise change in nature. Recycling is another option for non-biodegradable wastes like plastic, glass, metal, etc. (Venu and Rao 2010).

Researchers and scientists are looking into different ways to produce energy that have no negative environmental effects or very little environmental impact [4-7]. Pollution and waste management are closely related. The act of polluting and its effects are both referred to as pollution. Unwanted byproducts that are typically of low value are referred to as waste. The term "pollution" can be used to describe the introduction of materials, substances, or energy into the environment that endangers human health, harms ecosystems and living things, destroys buildings and amenities, or interferes with the environment's intended functions (Ming-Lang Tseng, 2011).

Hydrogen can transport energy across long distances in the form of liquid fuels via freight ships or pipelines due to its easy electrochemical conversion, light weight, and high mass energy density [8-10]. According to the World Energy Outlook (WEO) 2012 revised policy scenario projections, India's carbon dioxide emissions will rise by 3.5% year between 2010 and 2035, when they would account for 10% of global emissions (IEA 2012). Its primary usage, accounting for 35% of the estimated 50 million metric tonnes generated annually on a global scale, is as a feedstock for the synthesis of ammonia [11-13]. In terms of environmental concerns and the utilisation of organic wastes like solid waste or effluent of the food and fermentation industries, pretreated sewage sludge, market garbage, etc., bacterial fermentation mechanisms for hydrogen production under either dark or light conditions are currently important. Wang et al. (2011), Chu et al. (2012), and Lay et al. (2012).

A summary of current advancements in hydrogen technology and how they are used in power systems for hydrogen production, storage, and re-electrification In order to evaluate how different hydrogen production pathways relate to one another and to other stages of the hydrogen square, Dawood et al. analysed a variety of hydrogen production pathways. Najjar's study [14-17] examined the safety of hydrogen during its production, transmission, and use but did not examine the numerous drawbacks related to the various methods used to produce hydrogen.

Parra et al [18]. assessment of the evolution of hydrogen generation from a cost standpoint lacked a comprehensive analysis of the numerous patterns in the development of the various technologies. In his study of hydrogen in the energy transition, Kovac [19]

The 2015 Paris Climate Accord makes clear that all countries in the world concur that the issue of greenhouse gas emissions requires urgent attention and prompt solutions.

In order to ensure the energy supply and decrease the environmental impact of the most advanced non-renewable energy sources, it is vitally necessary to develop sustainable, scalable energy sources with high energy density (Li et al., 2017).

Maggio et al. [20] examined potential market impacts of hydrogen production from renewable energy sources. The United Kingdom and Australia are two additional nations who have pledged financial support. The COP26 conference demonstrated the significant advances made in green-hydrogen research over the previous two years, including practical innovations for efficiently and inexpensively storing hydrogen fuels to lower the price of hydrogen energy (Ogden et al., 2018). However, it was noted that the main rival in the passenger vehicle market was electric automobiles. A brief review of hydrogen as an energy carrier was also provided by Abe et al. in their paper from year 21. Currently, green hydrogen only makes up 0.1% of all energy produced globally (IEA, 2019), underutilizing one of the most effective technological advancements to combat climate change, which petroleum energy is mostly to blame for. Electrolysis, a specialised technique that also enables hydrogen use in industry, is responsible for improving the production of green hydrogen. According to a recent PwC analysis on corporate demand and possibilities for hydrogen energy, the industry will continue to grow steadily by 2030. (Price water house Coopers, 2019).

Finally, Liu et al. [22] examined current trends and potential obstacles for hydrogen production and storage. They discovered that the photo-catalytic conversion of water to hydrogen during their study period, from 2004 to 2018, was the hydrogen production method that has received the most attention. A current survey of technology used to produce hydrogen, using both renewable and non-renewable resources, was provided by Mengdi and Wang [23]. Additionally, Hosseini and Wahid [24] examined different hydrogen generation systems.

Modern scientists are leading calls for research into hydrogen energy as the next step toward getting rid of petroleum-based energy sources like oil, along with hydroelectric power, solar photovoltaics, nuclear fission, and wind energy. As the COP26 conference in November 2021 demonstrated, political leaders are increasingly in favour of such concepts. Especially in achieving carbon neutrality in industries that are now challenging to decarbonize, the increasingly ambitious climate targets create a crucial role for hydrogen (Ayodele and Munda, 2019).

The economic, technological, and environmental elements of hydrogen production were examined by El-Emam and Ozcan [25]. Green hydrogen energy is a natural replacement for fuel-based energy and it improves the long-term energy security of a nation (Chien et al., 2021).

A study on the potential for producing, utilising, and exporting carbon-free hydrogen from Qatar was done by Okonkwo et al. [26]. From the production of energy to transportation, fossil fuels continue to be the main cause of greenhouse gas emissions in the economy. 6 billion tonnes of CO2 were released into the atmosphere by fossil fuels in 1950. This amount nearly doubled by 1990, topping out at over 22 billion tonnes. Renewable production of hydrogen technology shares was predicted by Lane et al. [27]. It is crucial to remember that industrialization during the 19th and 20th centuries led to tremendous political and economic development, as well as a rise in culture and scientific innovation. However, it was also accountable for high levels of environmental deterioration and widespread meddling with the environment and natural resources (Martinez-Burgos et al., 2019). We now release about 34 billion tonnes of carbon dioxide annually as emissions have continued to increase quickly (Ritchie et al., 2020).

Due to the political, financial, and environmental issues connected to fossil fuels, hydrogen is expected to replace them as an energy vector. 2018 (Gondal et al.). There is easily enough technical capacity for creating green power from wind, solar, and hydro to meet both this increased need for green hydrogen and all present electricity use (Kakoulaki et al., 2021).

Since there have been certain studies, which were mentioned in previous sections, and some of these [28-31] have evaluated one or more types of the processes involved with hydrogen production, it is not the first time that the various hydrogen production technologies have been discussed.

The Paris Agreement reinforces the Sustainable Development Goals of the United Nations to build a more just and equitable society. Knowing how to utilise natural resources without putting them at risk of further depletion or risking the survival of future generations is crucial for achieving this aim (Ueckerdt et al., 2021).

The start-up of Carbon Capture, Utilization, and Storage (CCUS) resulted in a 15% increase in production capacity [32]. It will be necessary to transition away from petroleum-based energy systems and toward new energy carriers in order to reduce and eventually eliminate human-caused greenhouse gas emissions (Armaroli and Barbieri, 2021). In response, the UN developed the Sustainable Development Goals (SDG) 2030, a set of objectives meant to direct mankind toward a more sustainable future while fostering the technological and engineering advancements that have made life and work simpler for everyone (Falcone et al., 2021).

Although a low-carbon economy must quickly transition to ensure environmental sustainability, the UN SDGs are broad in scope and take equality, well-being, and justice into account. As a result, problems like accessibility and price are crucial for establishing a "fair" transition. The use of green hydrogen could help attain these objectives. The phrase "green hydrogen" or "renewable hydrogen" was first used by (NREL, 1995). They referred to hydrogen produced from renewable sources as renewable hydrogen, which is another word meaning green. Electrolysis with renewable energy sources (RES) produces renewable hydrogen, often known as green hydrogen, and is a method of production with almost no carbon emissions (IRENA, 2019). By promoting responsible production and consumption, the realisation of green hydrogen satisfies SDG 7 (Affordable and Clean Energy). Its implementation enables people to benefit from energy and power without endangering the environment, which is what responsible consumption entails (Armaroli and Barbieri, 2021).

According to reports, the overall global demand for hydrogen has significantly expanded over the past seven years, rising from 255.3 billion cubic metres in 2013 to approximately 324.8 billion cubic metres in 2020 [33-36].

The world's atmosphere has a lot of naturally occurring hydrogen, which makes the development of green hydrogen a workable solution to the energy dilemma. It also complies with SDG 13 (Climate Action), which promotes climate action through the regulation of carbon energy emissions and the adoption of renewable energy sources. In the future, hydrogen will not dominate the world's energy infrastructure; rather, a green-hydrogen economy is anticipated, in which hydrogen will play a supporting role as the foundational element required to enable a society powered entirely by renewable energy sources (de Oliveira et al., 2022).

Out of the 228 large-scale industrial, infrastructural, and transportation hydrogen projects worldwide, reports by the Hydrogen Council and McKinsey & Company [37] stated that. The extensively used method is referred to as "steam reforming." Due to its high hydrogen-to-carbon ratio within the hydrocarbons group, methane is the fuel that is most frequently employed in this process, which reduces the amount of byproducts that are produced [38, 39].

Investigating green hydrogen also has implications for how it can help society become Net-zero by 2050. "Reducing net CO2 emissions from energy and industrial processes to zero, after accounting for carbon capture and sequestration," is the definition of net-zero (Rogelj et al., 2015). It is a concept that describes the establishment of a balance between the quantity of greenhouse gases supplied to and those withdrawn from the atmosphere (Sridhar et al., 2021). When the amount of greenhouse gases emitted to the environment is equal to or less than the amount removed, net-zero emissions occur (PricewaterhouseCoopers, 2019). In order to achieve the UN SDG objective of lowering global temperatures below 2°C by 2100, experts on climate change and concerned authorities believe that the world must attain net-zero by 2050. To prevent severe climate impacts, worldwide CO2 emissions must be reduced by 45% by 2030 and must be completely eliminated by 2050. (Bhagwat and Olczak, 2020). According to research projections, if the current target is not met, the globe could suffer from severe and negative effects of global warming and experience climate conditions that are either unsustainable or perhaps unlivable. More important causes for the rise in interest in green hydrogen include the recent success of electric vehicles and hydropower. Success in both instances demonstrates that, with additional research, there is a chance of realising less expensive and more accessible ways of producing energy that are safe for use and kind to the environment. This optimism provides the drive to step up research on the creation and application of green hydrogen.

Interest in sustainable energy production practises has always existed, even before the threat of global warming and increased focus on sustainability (Chanchetti et al., 2020). As alternatives for producing energy and electricity, there have always been resources like hydroelectric power and wind energy. Even nuclear energy has used as an alternate energy source in some cases. Because of the numerous catastrophic instances, nuclear energy is a risky option for generating electricity. Without the help of petroleum-based energy sources, wind and hydropower have become unstable and unable to adequately supply enough power to power the modern world.

However, the global demand for green hydrogen will rise beyond 2035. But by 2050, there might be a demand for 150-500 million tonnes annually for the same time frame. There are many good reasons to produce hydrogen energy, and current global trends indicate that stakeholders are eager to enhance production. Hydrogen-based fuels can be produced in a variety of ways, including electrical, thermal, biochemical, photonic, electro-thermal, photo-thermal, photo-electrical, thermal-biochemical, and photonic (Dincer, 2012).

Rapid decarbonization of the industrial sector and many chemical transformation processes depends on green hydrogen production employing renewable energy-powered, low-temperature water electrolyzers (Lagadec and Grimaud, 2020). Concerns exist, though, regarding its application. It should be mentioned that bibliometrics is a crucial indicator for placing the growing relevance, significance, and study in clean and renewable energy in its proper historical context. The research on published works in this area of bibliometrics was first introduced by Garfield's groundbreaking work on citation index in the 1950s (Hood and Wilson, 2001). Bibliometrics is the term for the quantitative analysis of bibliographic data (Broadus, 1987). Through various citation statistics and bibliometric indicators, it is used to examine the effectiveness of different research themes (Ramos-Rodrguez and Ruz-Navarro, 2004), to map the relationships between research themes (Cobo et al., 2011), and to examine the evolution and thematic structure of a research field (Valtakoski, 2020). The two categories of bibliometrics are performance analysis and scientific mapping analysis (Noyons et al., 1999). Science mapping analysis is the use of publications and citation data to analyse numerous scientific aspects, including countries, institutions, and performance (Narin and Hamilton, 1996). It also evaluates the social and cognitive makeup of the research field (Small, 1999).

The other method that produces hydrogen using fossil fuels is coal gasification. With the help of steam and oxygen, the coal is put through a partial oxidation in this process at a high pressure of around 5 MPa and temperature to produce a mixture of CO, methane, CO2, and other chemicals [40-44].

In terms of research on the production, storage, and use of hydrogen as a fuel, the US, Japan, and China are some of the top nations, with a concentration on hydrogen fuel storage in particular (He et al., 2019). Fuel made of hydrogen is difficult to store due to its volatility and high reactivity with other substances. Because of this, numerous research projects on hydrogen storage, as attested by the bibliometric analysis (He et al., 2019). The publication's contents state that future trends are determined by a rigorous examination of present systems' storage levels and processes. In addition, the report claims that although being conducted since the 1990s, research on hydrogen storage has only resulted in roughly 300 articles annually. But as time went on, interest in this subject exploded, and by 2018, there were an average of 1500 articles per year (Liu et al., 2020). Tan et al. (2021) report that the United States, Japan, China, Germany, and South Korea are the countries with the highest concentrations of hydrogen energy research.

Given the limitations on the eligibility of pathways to renewable sources, the definition of renewable hydrogen is somewhat more inclusive. Renewable energy sources can be described using existing terminology, such as those found in the EU Directive 2018/2001/EC (commonly known as RED 2). (European Commission, 2018). The various interpretations adopted by governments and standardising bodies can be distinguished (from a legal standpoint) by additional eligibility criteria, such as a carbon intensity threshold.

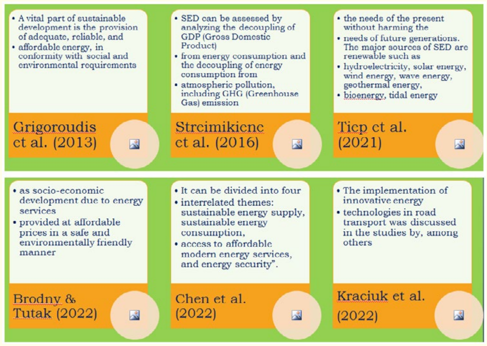

Figure 3: Critical Reviews.

In the related fields of hydrogen energy (Tsay, 2008), the green economy (D'Amato et al., 2017; Loiseau et al., 2016), blockchain and energy (Ante et al., 2021), hydrogen production and storage, etc. (Liu et al., 2020), emerging technologies (Xu and Feng, 2021), and sustainable development, previous authors' bibliometric studies were found (Raman et al., 2022a,b). However, no studies that examine and assess the research trends and possibilities of green hydrogen have been discovered. Our study fills that gap by introducing a fresh viewpoint and analysis based on key terms, the contribution of open access, prominence percentile, altmetrics, and alignment to UN SDG.

The world is totally dependent on energy and power nowadays. The sustainability of the world is frequently threatened by the methods used to produce it.

7 Keys to scale up hydrogen

Determine hydrogen's place in long-term energy plans. Future expectations can be set by the federal, state, and local governments. Companies must to have distinct long-term objectives. Refining, chemicals, iron and steel, freight and long-distance transportation, construction, and electricity generating and storage are important industries.

Boost the market's demand for clean hydrogen. Although there are clean hydrogen technologies, costs are still a problem. To support investments made by suppliers, distributors, and users, policies that enable sustainable markets for clean hydrogen are required, particularly to limit emissions from hydrogen derived from fossil fuels. These investments, whether in low carbon energy or fossil fuels with carbon collection, utilization, and storage, can result in cost reductions by scaling up supply chains.

Address the first-movers' investment risks. The most dangerous part of the deployment curve is where new applications for hydrogen, clean hydrogen supply projects, and infrastructure projects are located. The private sector can invest, learn, and share risks and gains with the use of targeted and time-limited loans, guarantees, and other measures.

Encourage R&D to reduce costs. R&D is essential to lowering prices and enhancing performance, including for fuel cells, hydrogen-based fuels, and electrolysers, in addition to cost savings through economies of scale (the technology that produces hydrogen from water). Setting the research agenda, taking calculated risks, and enticing private money for innovation are all important functions of government action, including the use of public monies.

Harmonize standards and remove pointless regulatory hurdles. Regulations and permit requirements that are ambiguous, unsuitable for new uses, or inconsistent across industries and nations present challenges to project developers. It is crucial to share expertise and harmonise standards, especially for equipment, security, and certifying emissions from various sources. Governments, corporations, communities, and civil society must frequently consult because of the complexity of the supply chains for hydrogen.

Engage globally and monitor development. All areas of international cooperation need to be strengthened, but standards, the exchange of best practises, and cross-border infrastructure in particular. To monitor progress toward long-term objectives, hydrogen production and consumption must be tracked and reported on a regular basis.

To further build momentum over the coming ten years, concentrate on these four crucial chances. These opportunities, which are mutually beneficial, can help to scale up infrastructure development, improve investor confidence, and reduce costs by building on existing policies, infrastructure, and skills.

Review Analysis

There is growing agreement that practically every industry that relies on fossil fuels today and is challenging to decarbonize could employ green hydrogen. In order to fulfil the Paris Agreement's climate obligations and the zero-emission goals necessitated by the climate emergency, it is crucial to promote it. Efforts to build a transportation network, instal hydro-generation for the road, and manufacture more competitive electrolyzers are just a few of the initiatives that are already being supported in Europe along the entire hydrogen value chain. A study by the International Renewable Energy Agency claims that over time, the cost of installing hydrogen systems might drop by 40% to 80%. This means that green hydrogen could be economical starting in 2030, especially given the declining cost of renewable energy.

By 2030, the market for green hydrogen production is anticipated to increase at a compound yearly growth rate of 6.4%, reaching 225.55 billion USD. The increased demand for cleaner fuel and the expansion of governmental regulations guiding the decarbonization of petroleum products are the main drivers of this rise. It is very well explained that hydrogen the fuel for our next generation. Its development and utilization played a vital role in the growth of country. The key initiatives to quicken decarbonization between now and 2030 are:

1. Energy conservation.
2. Renewable energy for Electrification.
3. Rapid expansion of the production of renewable energy (which will further reduce the already low cost of renewable electricity).
4. Scaling up sustainable, contemporary bio-energy is necessary, among other things, to create CO_2-based green fuels.
5. Green hydrogen could be produced by de-carbonizing grey hydrogen. This would increase scale, lower electrolysis costs, and make green hydrogen competitive and ready for further expansion in the 2030s, with the goal of achieving net zero emissions by 2050.

The Future of Hydrogen is a thorough and unbiased analysis of hydrogen that outlines the current state of the industry, the ways in which hydrogen can contribute to the development of a clean, secure, and cost-effective energy future, and how to go about achieving its potential. One energy source that has the potential to reduce global greenhouse gas emissions (GHG) caused by the world's reliance on fossil fuels for energy production is hydrogen. As a result, this study provides an in-depth analysis of the various technologies available for the generation of clean hydrogen, as well as their flaws and obstacles to the expansion of the hydrogen economy. In addition to being environmentally friendly, RS hydrogen production has the potential for a distributed hydrogen supply network paradigm. The scaling up of the hydrogen economy is hampered by a number of issues, as shown in this study, in addition to the technical difficulties involved with the various technologies. The lack of a value chain for clean hydrogen, hydrogen storage and transportation, high production costs, a lack of international standards, investment risks, and flammability are among the most important of these. Future study can also examine the different reactors, materials, and industrial applications of the various technologies to inform stakeholders about the direction of research and development in the hydrogen industry.

Conclusion

This critical review paper provides a comprehensive examination of the next generation energy green hydrogen. It highlights the technological advancements, challenges, and opportunities associated with its production, storage, transportation, and applications. The paper underscores the importance of continued research, policy support, and international cooperation to unlock the full potential of green hydrogen in driving the transition to a sustainable and low-carbon energy future.

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