WORLD ENVIRONMENTAL CONSERVATION CONFERENCE
2023

CLIMATE CHANGE PARTNERSHIP ACTIONS FOR SUSTAINABLE FUTURE AND RESTORING LIFE ON EARTH

Proceedings of the 6th edition of World Environmental Conservation Conference

18th – 21st October, 2023

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Production of Proceedings
Netlink Environmental Conservation Organisation
Room 21 Abubakar Adamu Bulding
Federal University of Technology, Akure.
Design amd Printing of Proceedings
Maryj Printing Press
ACAD Fagbote Filling Station Akure-Ilesha Expressway
Phone number: +23407063411658

Copies of Proceedings
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ISSN: 2705-2850

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PREFACE

There is a growing concern on the adverse impacts of climate on biodiversity. This phenomenon is greatly manifested in form of shifting weather patterns threatening global food security, health and species existence. Humanity is at the receiving end of the consequences of climate change hence there is a need to step up actions on all fronts- overtime, everywhere all at once.

This calls for collaboration, partnership and networking to strengthening synergy among relevant stakeholders in a bid to tackling climate change menace. This forms the basis for the theme of this year world Environmental conservation conference: **CLIMATE CHANGE PARTNERSHIP ACTIONS FOR SUSTAINABLE FUTURE AND RESTORING LIFE ON EARTH.** The theme is conceived with a view to create an interface for information sharing and offer opportunities for participants to refine their commitments and pledges in the quest to achieving Sustainability in the face of climate change.

This year World Environmental Conservation Conference is memorable in the sense that it received overwhelming funding from the host - West African Science Service on Climate Change and Adapted Land use). WASCAL is posed to provide information and knowledge at the local, national and regional level to cope with the adverse impacts of climate change. Thus, this conference will offer opportunities for participants to learn from good practices demonstrated and showcase by WASCAL during the course of the conference. It will also strengthen staff-student exchange and provide prospect for Doctorate Research Doctoral Research in West Africa Climate System Programme (DRP WACS) – WASCAL among others.

Special appreciation goes to the management of The Federal University of Technology, Akure the host institution, National Park Service and African Regional Center for Space Science and Technology Education-English (ARCSSTE-E) that co-host this conference. We equally acknowledge other private, individual and corporate organizations that have contributed towards the success recorded in this event.

All the submitted articles were subjected to strict double blind peer-review process by the reviewers that are experts in the area of the particular submitted manuscript. The accepted manuscripts are published in WECC 2023 proceedings and also available for download on the organization website (www.necorng.org).

The accepted manuscripts fall within the underlisted subthemes:

- Climate change adaptation strategies in Agriculture, Forestry and Other Land Use (AFOLU)
- Climate smart city and architectural landscape design
- Retrofitting and decarbonization in tourism and hospitality industry
- Indigenous knowledge and local innovation in climate change adaptation
- Climate risk management, health, safety and hygiene
- Carbon credit-offset marketing/circular economy
- ICT development in environmental conservation (image processing and acquisition, computer vision, graphics, speed, interface technology, HMD devices, GIS: Body Tracking, AI and IOT, VRT, IVE).

We commend our keynote speaker Prof. Douda Kone Director Capacity Building Department, WASCAL Headquarter, Ghana and other guest speakers Prof. Babatunde Rabiu, Director General, Chief Executive Office, African Regional Centre for Space Science and Technology Education-English (ARCSSTE-E) and Dr. Goni I. M., Conservator General National Park Service.

It is hoped that researchers, students and policy makers will find the papers in this book very useful. Even though all the papers were reviewed and edited, the content and option expressed remain essentially that of the authors and not necessarily that of Netlink Environmental Conservation Organization.

Dr. Oladeji S. O.

President Netlink Environmental Conservation Organization

Convener World Environmental Conservation Conference

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GREEN HYDROGEN: A SUSTAINABLE ENERGY SOLUTION IN NIGERIA

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ABSTRACT

Green hydrogen, created by electrolyzing water with renewable energy, has emerged as a crucial component in the shift to a more ecologically friendly and sustainable energy landscape. Concerns about climate change, air pollution, and energy security are fueling an increase in the demand for clean and sustainable energy sources worldwide. Fossil fuels, which make up the majority of the existing energy sources, have intrinsic drawbacks and difficulties that call for a switch to cleaner substitutes. Green hydrogen provides a dependable and resilient energy supply because of its adaptability as an energy storage medium and its ability to stabilize the energy system. It also lowers greenhouse gas emissions, reduces climate change, decarbonizes industrial processes and generates economic opportunities. In addition to these benefits, green hydrogen lessens reliance on fossil fuels, promoting energy security and independence as well as global sustainability. This review paper emphasizes the many benefits of green hydrogen in its conclusion and shows how it has the ability to transform the Nigeria's energy system. Its importance in the pursuit for a more sustainable and secure energy future is reinforced by its role in lowering emissions, improving grid stability, and promoting economic growth.

INTRODUCTION

Hydrogen is the most abundant element in the universe, and has gathered interest as a promising candidate in the pursuit of sustainable energy solutions. It is available in nature in its association with oxygen in form of water, and its association with carbon – in plant and animal tissue such as methane. Hydrogen holds the potential to revolutionize the way we power our world. Although hydrogen is a product historically used in the chemical sector, hydrogen has a uniqueness and is essential in the transition to a more sustainable energy landscape because of its capacity to serve as an energy carrier and store clean energy generated from renewable sources, such as wind, solar, and hydropower which makes it an alternative to using fossil fuels (Lebrouhi *et al.*, 2021).

Hydrogen is the lightest gas in nature and it is considered non-toxic to the environment and to animal and plant health. Although true, it is essential to note that hydrogen generation from fossil fuels, such as natural gas and coal, leads to the emission of greenhouse gases and is therefore not environmentally friendly (Janusz & Nejat, 2011). The commercial technologies for hydrogen production involves steam reforming of natural gas and pyrolysis. These technologies have been able to provide for the hydrogen demand over the years but has itself added to the emission of carbon dioxide into the environment (Pedro *et al.*, 2021).

Hydrogen has a higher energy density that is 2.2 times more energy than natural gas, 2.75 times more than gasoline and 3 times more than oil making it among the best options for energy generation in the world. Hydrogen is broadly deliberated as the most feasible future energy carrier that is carbon-free and has a wider implementation range without environmental pollution (Sazali, 2020). Moreover, hydrogen represents 73.4% of the sun's mass, being responsible for 85% of its energy, that comes from hydrogen atoms fusion, forming helium and releasing a huge amount of energy (Germscheidt *et al.*, 2021). With the increase in energy demands across the nations of the world, the demand for hydrogen as an energy source is bound to increase also. This would require that the production of hydrogen to meet these demands would need to be sustainable and be has a significantly less negative impact on the environment.

There are many ways to create hydrogen gas, but the carbon footprint of these processes varies significantly. The hydrogen economy today is not yet green having a global energy-related carbon emission of over 1 Giga-tons produced during hydrogen production. Gray hydrogen uses steam reformation of natural gas and uses the natural gas as feedstock which breaks it down to methane, carbon dioxide and hydrogen. This hydrogen is collected while the carbon dioxide is released. A similar method is used in production of brown hydrogen, but this time uses gasification of solid fossil fuel such as coal, and then steam reforms the methane to produce hydrogen. Blue hydrogen which combines gray hydrogen with carbon capture and storage technologies is a low-carbon alternative (Alexandra *et al.*, 2021). This technology is currently at the experimental state. Green hydrogen is produced by electrolysis of water, which involves splitting the water in to oxygen molecule and hydrogen molecule using an electric current inside an electrolyzer. The electricity used is exclusively of renewable origin – produced from solar, wind or hydroelectric installations- for the hydrogen to be clean and qualified as "green". If it is produced by a significant portion of nuclear electricity (as in France), it will be labelled yellow (Rabiee *et al.*, 2021; Scamman & Newborough, 2016).

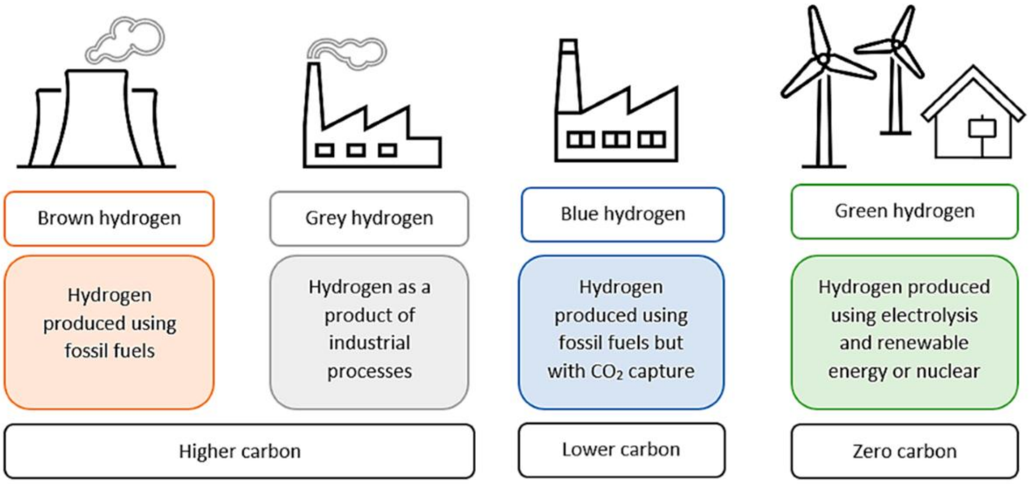

Figure 1: Different colors of hydrogen

Hydrogen produced from other sources have carbon footprint that influence its environmental factor negatively. This is because the technology most un use is the Steam methane reforming of natural gas. Steam methane reforming of natural gas is a mature technology, operating at or near the theoretical limits of the process that is used to produce nearly all the hydrogen (in the form of a mixture of hydrogen and carbon monoxide) in the chemical industry and the supplemental hydrogen in refineries (Barelli *et al.*, 2008). Steam methane reformation is a catalytic process that includes the interaction of natural gas or other light hydrocarbons with steam. In a succession of three reactions, a combination of hydrogen, carbon monoxide, carbon dioxide, and water is formed.

$$CH_4 + H_2O \leftrightarrow 2CO + 3H_2 \quad (1)$$

$$CH_4 + 2H_2O \leftrightarrow CO_2 + 4H_2 \quad (2)$$

$$CO + H_2O \leftrightarrow CO_2 + H_2 \quad (3)$$

The reforming reaction is highly endothermic and a large amount of heat is provided by feeding supplemental natural gas to the furnace. Conventionally the gas is passed through a water-gas shift reaction whereby the carbon monoxide is further converted into carbon dioxide and hydrogen gas. This process is used for over 85% of the world hydrogen production process and accounts for a higher percentage of carbon emission into the atmosphere. Hydrogen produced by this processes alone viz Brown and Grey hydrogen have a larger carbon emission and higher carbon footprint. Although the process is predominant, the consequence is still large in comparison to the benefits. However, in bid to reduce the carbon emissions to the environment, technologies have been developed to capture the carbon.

Carbon capture and storage is a technology used to complement the steam methane reforming process by capturing the carbon either before or after the production process. The technology for capturing and storing carbon widely depends on the process or part of the process for capturing the carbon. Capturing carbon during the pre-combustion process is done by physical or chemical methods after the water-gas shift reaction takes place, these methods incudes absorption, adsorption or membrane techniques are very high pressure of about 2 – 7 mega Pascals, leaving hydrogen as a fuel for combustion. This process significantly lowers the performance and increases the expenses of the hydrogen production process (Dubey & Arora, 2022).

Post combustion carbon capture process involves capturing carbon from the flue gas before it is emitted into the atmosphere. This process is considered more feasible for coal plants and is comparatively more economical, has flexibility in operation but is less efficient than the pre-combustion technology. This process is more preferable and can be retrofitted into plants without much disturbance, and is also commercially proven at a small scale.

The hydrogen produced with the utilization of carbon capture and storage technologies have lesser carbon emissions and a lower carbon footprint, but takes into account a lower efficiency in the hydrogen production process as well as increase in the cost of producing the hydrogen. With the above challenges on environment and commercialization, renewable energy sources for use in hydrogen production proves to have zero carbon emissions as well as having advancements in the technologies that can optimally produce hydrogen from other sources such as water.

Green Hydrogen

The depletion of the conventional energy sources has led the world in the direction of a more reliable and abundant source of energy while also combating the problems associated with environmental pollution which is mostly gotten from the burning of coal and natural gases.

The world's view of a carbon-free solution is the use of hydrogen which is produced from splitting water. This process when done with only renewable energy as input produces green hydrogen which is completely carbon-free as compared to other colors of hydrogen gotten from non-renewable energy sources. Although the world is steering towards this environmentally friendly solution, hydrogen produced by renewables has historically contributed a negligible proportion of total hydrogen production – green hydrogen made up 1% of the total hydrogen produced in 2018 (Gielen *et al.*, 2019).

Green hydrogen production involving splitting of water can be done through several different methods with most of them being in their early research and development stages while a few have pilot projects currently running.

Water electrolysis is one of the least complex methods of producing green hydrogen. This method uses the conventional electrolysis principle of having two electrodes placed in an electrolyte and electricity passed through it. When the electricity is passed through water, the covalent bond between the hydrogen and oxygen atoms in the water is broken and they are separated to each one of the electrodes (Ture, 2007). The positive atom which is Hydrogen is deposited at the cathode (positive electrode) and the negative atom of Oxygen is deposited at the anode (negative electrode). The energy requirement to split water increases with temperature of the water so it is preferable to use a high temperature electrolysis process.

Alkaline electrolysis follows the same principle as water electrolysis but uses aqueous KOH solution (caustic) as an electrolyte that usually circulates through the electrolytic cells. Alkaline electrolysis is a mature technology with a significant operating record in industrial applications that allows remote operations.

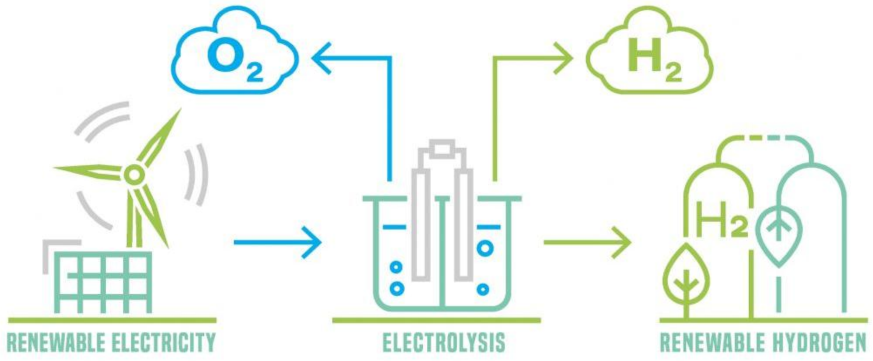

Figure 2: Electrolysis of water to produce green hydrogen

Thermochemical water splitting converts water into hydrogen and oxygen by a series of thermally driven chemical reactions. This process of water splitting is highly dependent on thermal energy over electrical energy. The technology does not require the utilization of membrane and only consume low voltage electricity. Although one of the oldest known method of splitting water, it has been of little interest over the past decade (Sazali, 2020).

Photo-electrolysis (also known as photolysis) is a more modern method of splitting water into its constituents. The process incorporates the photovoltaic system coupled to electrolyzers. The system offers some flexibility; as the output can either be hydrogen from the electrolyzer or electricity from the photovoltaic cells. Direct photo-electrolysis represents an advanced alternative to a photovoltaic electrolysis system by combining both process in a single apparatus. With the lowering cost of solar PV and electrolyzers, hybrid solar-hydrogen energy systems have considerable potential for energizing rural populations while reducing their carbon impact (Collera, 2021).

Polymer electrolyte membranes electrolyzers require no liquid electrolyte, simplifying their design significantly. The electrolyte is an acidic polymer membrane. This electrolyzer is designed to operate at pressures up to several hundred bar, and is suitable for most industrial applications. The alkaline electrolyzer and the proton exchange membrane electrolyzer have reached advanced commercial status in the hydrogen processing sector. Unfortunately, both approaches have several critical concerns, such as hydrogen management, huge structure, and expensive materials required during cell construction (Zakaria & Kamarudin, 2021).

Green hydrogen production must stay "green" in order to protect the environment from the dangers of greenhouse gases and noxious gases that are produced when fossil fuels are used as feedstock in energy production. With develop countries delving into renewable energy sources, it is becoming very feasible for the production of green hydrogen to be widespread as more improved technologies are developed to harvest natural occurring phenomenon such as wind and solar and convert them into useful energy either as electricity or heat (Rejeb *et al.*, 2022).

Greenhouse gases has over the years increased the temperature on the earth's surface which research has found out would have an adverse effect on climate, sea water level and biodiversity. These gases are mostly emitted from grey and brown hydrogen which uses fossil fuels as their feedstock in hydrogen production. For drastic natural occurrence to be avoided, the net carbon emission to the atmosphere must be kept at near zero. The use of renewable energy sources is in view to serve the purpose of achieving this shortcoming in the other colors of hydrogen.

Need for Green Hydrogen

Nigeria's energy technology over the years have been majored on hydropower and burning of fossil fuels to generate electricity. The use of both of these technologies have not been able to meet the energy demand of the country, hence the need to import energy from neighboring countries. For instance, in Nigeria, the gap between energy production and consumption had been on the increase from 75,424.168 kilo tons in 1971 to almost 139,641.359 kilo tons in 2010 (World Bank, 2015). This caused the country to diversify in their means of generating energy to meet the demand. Nigeria focuses on two major source of energy generation; hydroelectric and burning of fossil fuels.

However, with the growing demand being more rapid than the generation, the country has also employed importation of energy from neighboring countries. This would imply that the countries power generation causes concern for environmental values as well as meeting the people's energy requirement. Importation of energy adds to financial implications on economy and in many cases does not substitute for the energy deficit in the country, and this also incurs huge bills for the electricity tariff (Ebohon, 1996). With concerns about climate change, air pollution, and energy security have fueled unprecedented worldwide demand for clean and sustainable energy sources in the twenty-first century. With rising global temperatures, harsh weather events, and the depletion of finite resources, the repercussions of relying primarily on fossil fuels for energy generation have become increasingly obvious (Maganza *et al.*, 2023).

Renewable energy sources including wind, solar, and hydropower have made significant strides in lowering carbon emissions. However, because these sources are intermittent and location-dependent, maintaining a constant energy supply is difficult. Nigeria has been involved in renewable energy sources in the modern times such as the solar and hydropower, but not prominent in the wind power generation but with limited applications and utilizations. The country's involvement in renewable energy sources has only majorly been for small scale generation, and no focus on integration with the national electricity grid (Ozoegwu *et al.*, 2017). Green hydrogen, created by electrolysis of water using renewable power, emerges as a viable alternative in this context.

Current energy sources, dominated by fossil fuels such as coal, oil, and natural gas, are associated with a range of environmental, economic, and geopolitical limitations and challenges. Some of these challenges are:

i. Greenhouse Gas Emissions: Fossil fuel combustion is a primary source of greenhouse gas emissions, contributing to global warming and climate change.
ii. Air Pollution: The combustion of fossil fuels also releases harmful pollutants, leading to air quality issues and negative health impacts.
iii. Resource Depletion: Fossil fuels are finite resources, and their extraction can result in environmental degradation and geopolitical conflicts.
iv. Energy Security: Reliance on fossil fuel imports can undermine a nation's energy security and economic stability.
v. Energy Transition: Transitioning from fossil fuels to renewables requires extensive infrastructure changes and investment, posing economic challenges.

The widespread concern of energy and environment has been in the forefront of the energy industry across the world. With the developing technology behind green hydrogen production, the world is starting to see it as a vital energy carrier capable of overcoming these constraints and problems and so also in Nigeria. The splitting of water into hydrogen and oxygen using renewable power offers:

i. Zero Emissions: Green hydrogen production generates zero carbon emissions, contributing to efforts to combat climate change.
ii. Energy Storage: Hydrogen can store excess renewable energy, enabling a stable and reliable energy supply, even during periods of low renewable energy generation.
iii. Versatility: Hydrogen can be used in various sectors, including transportation, industry, and power generation, offering a versatile solution to decarbonize multiple industries.
iv. Energy Independence: Green hydrogen reduces dependence on fossil fuel imports, enhancing energy security.

The worldwide need for clean and sustainable energy has never been greater, driven by environmental imperatives and a commitment to a low-carbon future (Mali *et al.*, 2021). Current energy sources have limitations and constraints that need a shift to greener alternatives. Green hydrogen, as an energy carrier derived from renewable sources, promises a compelling answer to these difficulties while ushering in a more sustainable and ecologically responsible energy future for Nigeria and other countries at large.

Benefits of Green Hydrogen

Nigeria would gain significantly from adopting energy production from green hydrogen. Green hydrogen has several advantages, ranging from environmental advantages to energy storage solutions and industrial decarbonization. It has the capacity to cut greenhouse gas emissions, improve grid stability, and contribute to energy independence places it at the forefront of the transition to a more sustainable and secure energy future for the country. The process of water electrolysis through renewable energy sources generates hydrogen without emitting greenhouse gases like carbon dioxide. By replacing fossil fuels in their various applications, green hydrogen would help in the reduction of overall net carbon emissions which would contribute to climate change (Devbalan & Yadav, 2022).

Green hydrogen contributes significantly to climate change mitigation by providing a clean energy alternative to fossil fuels. Its broad implementation in areas like as transportation, heating, and industrial operations has the potential to greatly reduce the carbon footprint, hence assisting in the limitation of global temperature rise and the accompanying climate implications (Megía *et al.*, 2021). It would favor the country in utilizing a more energy efficient means for transportation and domestic use as hydrogen is a better energy source for electricity and heating.

Green hydrogen production through electrolysis can potentially use wastewater or brackish water contributing to water conservation efforts. The process of directly producing hydrogen from biological processes can greatly influence the waste management efforts in countries while having hydrogen that can serve as energy carrier (Gaetano *et al.*, 2023). The utilization of wastewater as a feedstock can allow on-site treatment for water recycling and reuse, as well as hydrogen generation (Germscheidt, 2021). The waste management in the country would be more valuable towards a clean environment and a clean energy supply.

Green hydrogen benefits in their potential in energy storage and demand. It is a versatile energy storage medium capable of generating more energy than the conventional fuel sources. Excess electricity generated from renewable sources during periods of low demand can be used to produce hydrogen through electrolysis. This stored hydrogen can then be converted back to electricity when needed, providing a reliable and flexible energy storage solution (Takach *et al.*, 2022). Green hydrogen's capacity to store and release energy can improve grid stability by balancing supply and demand. Hydrogen-based energy storage devices can assist regulate changes in renewable energy supply, lowering the danger of blackouts and increasing grid dependability (Agbossou *et al.*, 2001).

In various industries such as transportation, manufacturing and agriculture, green hydrogen’s versatility allows for a broad range of clean energy solutions. Vehicles can use fuel cells for power generation which would eliminate the carbon generation and deposition. Hydrogen as feedstock in manufacturing process or in producing ammonia for land use highlights some of the values that hydrogen provides in the various industrial sectors. In high-temperature operations, hydrogen is employed as a reducing agent. Green hydrogen may dramatically cut emissions and help the shift to greener industrial practices by replacing conventional hydrogen generation technologies (typically produced from natural gas). The adoption of green hydrogen can therefore lead to decarbonizing industrial processes and practices (Genaro *et al.*, 2021).

Green hydrogen generation is not dependent on fossil fuels, lowering a country's reliance on imports and exposing it to energy price swings (Krane & Idel, 2021). This increased energy independence improves economic stability and security. The availability of green hydrogen produced domestically can improve Nigeria’s energy security by diversifying its energy sources. This decreases susceptibility to supply outages, geopolitical conflicts, and global fossil fuel market volatility.

CONCLUSION

In an era defined by the urgency to combat climate change, decrease emissions, and shift to cleaner, more sustainable energy sources, green hydrogen emerges as a light of hope and opportunity. This analysis has shone light on the urgent need for green hydrogen and its many advantages, providing a picture of a transformational energy carrier set to change our global energy environment. Climate change, air pollution, and the limited nature of fossil fuels need a fundamental shift in our energy paradigm. Green hydrogen, created by renewable energy-powered electrolysis, provides a clear way to decreasing greenhouse gas emissions, mitigating climate change, and building a more sustainable future.

Current energy sources have obvious limitations and constraints, ranging from environmental deterioration to energy security issues. Green hydrogen serves as a flexible energy carrier that can store excess renewable energy, improve grid stability, and decarbonize industries such as transportation and manufacturing. It holds the possibility of energy independence by decreasing dependency on fossil fuels, minimizing geopolitical concerns, and contributing to economic stability. It serves as a catalyst for innovation, job growth, and technical improvement, while also encouraging global collaboration and diplomacy. In order to transform the energy landscape and leave a lasting legacy of environmental responsibility and energy security for our world, it is now more important than ever to invest in, develop, and embrace green hydrogen.

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