Nigeria's Green Hydrogen Pathway: A Strategic Framework for Climate Neutrality and Energy Security

K. O. LAWAL[1], S. O. GIWA[2], I. K. MURITALA[3], J. ADIGHIJE[4]

[1,2] Faculty of Engineering and Engineering Technology, Abubakar Tafawa Balewa University, Bauchi, Nigeria.

[3] Lone Star College, Houston Texas, United States.

[4] Niger Delta Power Holding Company, Abuja, Nigeria.

Abstract- Nigeria faces a dual challenge of energy poverty and the imperative to decarbonize its fossil fuel-dominated economy in alignment with its 2060 net-zero commitment. This paper explores the potential of Green Hydrogen (GH) as a cornerstone for a sustainable and secure energy future for Nigeria. Utilizing a comprehensive desk review methodology, we analyze Nigeria's abundant but underutilized renewable energy resources—solar, wind, and hydro—as a foundation for cost-competitive GH production. The study identifies significant barriers, including high capital expenditure, infrastructural deficits, and a nascent policy framework. Conversely, it highlights strategic opportunities in export markets, domestic decarbonization of hard-to-abate sectors, and local economic development through green ammonia and fertilizer production. We propose a multi-stakeholder pathway involving robust policy formulation, international collaboration, and substantial investment in research, development, and capacity building. The findings posit that a concerted national strategy towards a GH economy can simultaneously address Nigeria's energy trilemma: inequitable energy access, energy insecurity and environmental sustainability; foster industrial growth and solidify its role as a future leader in the global green energy market.

Keywords: Climate Neutrality, Green Hydrogen, Nigeria, Renewable Energy, Decarbonization

I. INTRODUCTION

The global energy sector is undergoing a profound transformation driven by the urgent need to mitigate climate change and achieve the goals of the Paris Agreement. Hydrogen, particularly green hydrogen (GH) produced via water electrolysis powered exclusively by renewable electricity, has emerged as a critical enabler for decarbonizing sectors where direct electrification is challenging, such as heavy industry, shipping, and long-haul transport [1]. For developing nations like Nigeria, which is concurrently grappling with energy access deficits and a commitment to reach net-zero emissions by 2060 [2], GH presents a unique dual opportunity: to enhance domestic energy security and to position itself as a key player in the emerging global hydrogen market. It is a known fact that the country's energy sector faces hurdles in meeting the growing energy demands of its population and industries while transitioning to a low-carbon economy. The potential of renewable energy resources, especially solar energy, remains largely untapped [3]. Studies, such as [4], have highlighted the growing interest and investment in hydrogen, a key precursor to other renewable fuels production, across various industries.

This paper argues that Nigeria's immense renewable energy potential provides a strategic advantage for capitalizing on the GH economy. The following are the objectives of this study:

(a) To contextualize Nigeria's energy landscape within the global GH discourse

(b) To evaluate the technical and economic feasibility of domestic GH production

(c)To identify the critical barriers and opportunities; and

(d) To propose an actionable, multi-stakeholder pathway for integrating GH into Nigeria's national energy strategy.

II. GLOBAL CONTEXT OF GREEN HYDROGEN

The international momentum behind GH is unmistakable. Major economies have launched ambitious national hydrogen strategies, recognizing its role in deep decarbonization. Germany, for instance, has invested €9 billion to attain global leadership in hydrogen technologies, while Japan aims to become a hydrogen-based society by 2050 [5]. [6,7] projected that hydrogen could satisfy up to 18.5% and 22% of global final energy demand by 2050, respectfully, in a deep decarbonization scenario, abating up to 80 gigatons of cumulative

CO_2 emissions. Figure 1 shows the Global Hydrogen Demand in 2025 with power, transport and industry sectors having significant GH demands.

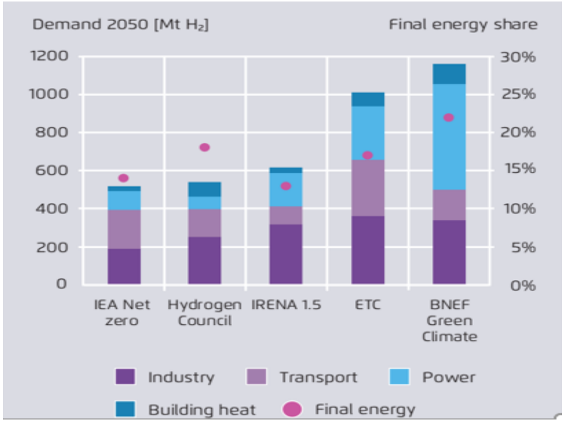

Figure 1: Estimated Global Hydrogen Demand in 2050, [8].

GH is increasingly seen as the only viable solution for "hard-to-abate" sectors. Aviation, maritime shipping, and industries like steel and cement manufacturing require high-density energy carriers or high-temperature heat, which GH and its derivatives (e.g., green ammonia) can provide [9]. This global demand creates an export opportunity for countries with rich renewable endowments, such as Nigeria.

III. NIGERIA'S ENERGY LANDSCAPE AND RENEWABLE ENERGY POTENTIAL

Nigeria's current energy mix is overwhelmingly dependent on fossil fuels. With an installed capacity of approximately 10.4 GW, natural gas dominates at 79.5%, followed by hydropower at 20.4%, while solar PV accounts for a negligible 0.1% [10]. This reliance contributes significantly to national carbon emissions and results in chronic energy poverty, with over 90 million citizens lacking access to reliable electricity [11].

Paradoxically, Nigeria possesses some of the world's most abundant renewable resources. The country enjoys a high solar irradiation averaging 5.5 kWh/m²/day, translating to a solar power potential exceeding 200GW [12]. Significant wind potential exists in coastal and northern regions, with speeds ranging from 4–6 m/s, and its hydropower capacity is estimated at 14 GW, including untapped small-scale potential [13]. This vast, underutilized potential forms the bedrock upon which a Nigerian GH industry can be built.

IV. TECHNICAL AND ECONOMIC FEASIBILITY OF GH PRODUCTION IN NIGERIA

Nigeria is blessed with an abundance of renewable sources including solar and wind power [14]. The impressive solar irradiation in many regions in the nations can make large-scale GH hydrogen feasible which can translate to a great economic impact as the demand for GH in many sectors is fast increasing and the green pathway towards environmental sustainability is not negotiable [15].

GH is produced through the electrolysis of water (H_2O), splitting it into hydrogen (H_2) and oxygen (O_2) using electricity from renewable sources. This process results in zero carbon emissions. The core technology is the electrolyzer, with three primary types being developed: Proton Exchange Membrane (PEM), Alkaline, and Solid Oxide Electrolyzer Cells (SOEC), each with differing efficiencies, cost profiles, and operational requirements [16]. An electrolyzer operates on the principle of a redox reaction which occurs following splitting of water to hydroxyl and hydrogen ions on passage of electric current (Equation 1). These reactions are involved when insoluble (non-sacrificial) electrodes are used.

$$2H_2O_{(l)} \rightarrow 2H^+{}_{(aq)} + 2OH^-{}_{(aq)} \quad \ldots (1)$$

Anode reaction

$$2OH^-{}_{(aq)} \rightarrow O_{2(g)} + 2H^+{}_{(aq)} + 2e- \quad \ldots (2)$$

Cathode reaction

$$2H^+{}_{(aq)} + 2e- \rightarrow H_{2(g)} \quad \ldots (3)$$

The reaction occurring at the anode is oxidation where hydroxyl ion loses its previously gained electron to form oxygen gas and hydrogen ion (Equation 2). While the one at the vicinity of the cathode is reduction, in which 2 molecules of hydrogen ion gain two electrons to form a molecule of hydrogen gas (Equation 3). When the source of electricity is green in nature, as in case of solar powered electrolytic system, this is referred to as green hydrogen already given the acronym, GH.

One of advantages of GH production system is that the electrolytic reactions lead to purification of the aqueous medium (electrolyte) which is water, when it is characterized with pollutant loads. For a case when sacrificial electrodes are used the mechanism of clean coagulant synthesis and hydrogen formation can be illustrated as shown in the following reactions.

$$M_{(s)} \rightarrow M^{3+}{}_{(aq)} + 3e^{-} \quad \ldots (4)$$

$$3H_2O_{(l)} \rightarrow 3H^{+}{}_{(aq)} + 3OH^{-}{}_{(aq)} \quad \ldots (5)$$

$$M^{3+}{}_{(aq)} + 3OH^{-}{}_{aq} \rightarrow Al(OH)_{3(aq)} \quad \ldots (6)$$

$$3H^{+}{}_{(aq)} + 3e^{-}{}_{(aq)} \rightarrow 1.5H_{2(g)} \quad \ldots (7)$$

$$3OH^{-} \rightarrow 1.5O_{2(g)} + 3e^{-} + 3H^{+} \quad \ldots (8)$$

There is simultaneous dissolution of anode electrode (Equation 4) and splitting of water (Equation 5) in the aqueous medium which lead to formation of metallic hydroxide (aluminium hydroxide) shown in Equation 6, which is believed to be the clean coagulant [17;18]. The in-situ-synthesized coagulant destabilizes pollutants in the aqueous medium via chemical and physical mechanisms. For this case the green-gas formation reactions occurring at anode and cathode are respectively given in Equations 7 and 8 [17;18].

The versatility of GH is one of its greatest assets. It can be utilized directly in fuel cells for clean power generation, particularly in transportation (PEMFC) and stationary applications (SOFC). It can be blended into existing natural gas networks, combusted in turbines, or serve as a critical feedstock. Its derivative, green ammonia (NH_3), is essential for producing sustainable fertilizers and is emerging as a promising zero-carbon fuel for maritime shipping [19]. This concept of "sector coupling" – integrating power, industry, and transport – is central to GH's value proposition.

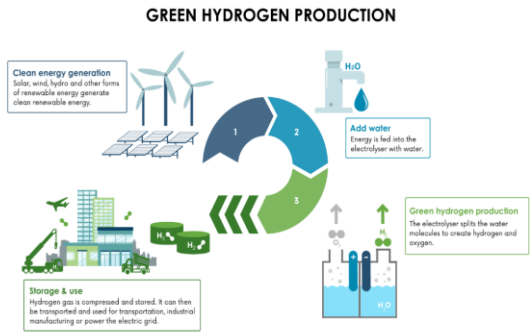

Figure 2: Green Hydrogen Production [20].

V. CHALLENGES AND BARRIERS TO ADOPTION IN NIGERIA

Despite the promise, significant hurdles must be overcome for Nigeria to develop a GH economy.

(i) High Capital Costs: The upfront investment for electrolyzers, storage systems (e.g., compressed gas, liquefaction, ammonia carriers), and refueling infrastructure remains substantial. Current GH production costs range from \$3.74-\$6/kg, though global efforts aim to bring this below \$2/kg by 2030 [7].

(ii) Infrastructural Deficits: Nigeria's electricity grid requires significant modernization to handle the intermittent and large-scale integration of renewable energy needed for GW-scale electrolysis. Furthermore, a dedicated pipeline network for hydrogen transport is non-existent.

(iii) Policy and Regulatory Vacuum: A clear national strategy, safety standards, and incentives (e.g., carbon pricing, tax breaks) are crucial to de-risk investments and attract private capital. The current policy landscape is underdeveloped.

(iv)Technological and Human Capacity Gaps: The domestic expertise in hydrogen technologies is limited. A skilled workforce specializing in electrolyzer maintenance, fuel cell technology, and project management is urgently needed.

VI. A STRATEGIC PATHWAY FOR NIGERIA

A successful GH economy requires a coordinated, long-term strategy involving both public and private sectors.

A. Formulate a National Green Hydrogen Strategy: The government must lead by developing a comprehensive roadmap with clear targets, R&D priorities, and an investment framework. This strategy should be integrated into the broader Energy Transition Plan.

B. Foster Public-Private Partnerships (PPPs): Collaborations between government agencies (e.g., NNPC, Ministry of Power), international oil companies, and renewable energy developers are essential to finance and deploy large-scale pilot projects.

C. Leverage International Collaboration and Finance: Partnerships with countries like Germany and institutions like the World Bank can facilitate technology transfer, knowledge sharing, and access to climate finance.

D. Invest in Capacity Building and Local Content: Academic curricula must be updated, and vocational training programs established to build a domestic talent pool. Local manufacturing of components should be encouraged to maximize economic benefits.

E. Develop Enabling Infrastructure: Prioritize investments in grid modernization and repurpose existing natural gas infrastructure for hydrogen blending to create an initial market.

VII. CONCLUSION

Green hydrogen is not merely a niche alternative but a strategic imperative for Nigeria. It offers a viable pathway to reconcile economic development with climate action, turning the nation's renewable resource curse into a powerful advantage. By harnessing its solar, wind, and hydro potential, Nigeria can produce GH for domestic use—decarbonizing industry, strengthening grid stability, and enhancing energy security—while also tapping into lucrative export markets for green ammonia and other derivatives.

REFERENCES

[1] IRENA. (2021a). Green Hydrogen: A guide to policy making. International Renewable Energy Agency.

[2] Federal Government of Nigeria. (2021). Nationally Determined Contributions (NDC). UNFCCC.

[3] K. O. Lawal, H. S. Miya, G. A. Bakare, and U.O. Aliyu (2024). "Load Frequency Control Strategy Using Hybrid Adaptive Particle Swarm-Spiral Dynamic Optimization Algorithm for Stand-alone Renewable Rural Network". *Nigerian Journal of Tropical Engineering (NJTE),* Vol 18, 21 29 ISSN: 1595-5397, DOI: 10.59081/NJTE.18.1.003

[4] Ibrahim K. Murtala, Dortyya Guban, Martin Roeb and Christian Sattler (2019). High-Temperature Production of Hydrogen: Assessment of Non-renewable Resources Technologies and Emerging Trends. International Journal of Hydrogen Energy. Vol.25, pp26022-26035

[5] IEA. (2023a). Global Hydrogen Review 2023. International Energy Agency.

[6] Hydrogen Council. (2023). Hydrogen Insights 2023: A perspective on hydrogen investment, market development and cost competitiveness.\

[7] Bloomberg New Energy Finance, BNEF. (2023). Hydrogen Market Outlook: H2 2023. Bloomberg New Energy Finance.

[8] Agora Energiewende (2023). Training Material on the P2X and The Value Chain. Berlin

[9] IRENA. (2021b). A Pathway to Decarbonize the Shipping Sector by 2050. International Renewable Energy Agency.

[10] IEA. (2023b). Africa Energy Outlook 2023. International Energy Agency.

[11] Johnson, O. N., Ereh,R. E., Agboola, P.O., Okhirebu, D. I. (2025). The Role of Renewable Energies for Sustainable Energy Governance and Environmental Policies for the Mitigation of Climate Change in Nigeria. *IIARD International Journal of Geography & Environmental Management*. Vol. 11 No. 2 2025 E-ISSN 2504-8821 P-ISSN 2695-1878 www.iiardjournals.org Online Version.

[12] Oluwatoyin A. Somoye (2023). Energy Crisis and Renewable Energy Potentials in Nigeria: A Review, *Renewable and Sustainable Energy Reviews,* Volume 188, 113794, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2023.113794.

[13] Olayinka S. Ohunakin, Olaolu O. Akinnawonu (2012). Assessment of Wind Energy Potential and the Economics of Wind Power Generation in Jos, Plateau State, Nigeria, Energy for Sustainable Development, Volume 16, Issue 1, Pages 78-83, ISSN 0973-0826, https://doi.org/10.1016/j.esd.2011.10.004.

[14] K. O. Lawal, G. A. Bakare, and U. O. Aliyu (2022). "Intelligent Load-Frequency Control System for Micro-hydro Power System for Evboroho II Community, Edo State, Nigeria". *Nigerian Journal of Tropical Engineering (NJTE)*. Vol 16, 635-643 ISSN: 1595-5397.

[15] Remus Prăvălie, Cristian Patriche, Georgeta Bandoc (2019). Spatial Assessment of Solar Energy Potential at Global Scale. A Geographical Approach, Journal of Cleaner Production, Volume 209, Pages 692-721, ISSN 0959-6526, https://doi.org/10.1016/j.jclepro.2018.10.239.

[16] IRENA. (2020). Green Hydrogen Cost Reduction: Scaling up Electrolyzers to Meet the 1.5°C Climate Goal. International Renewable Energy Agency.

[17] Giwa, S. O., Kamran, P., Hale, H., (2012) The Effects Of Operating Parameters On Temperature And Electrode Dissolution In Electrocoagulation Treatment Of Petrochemical Wastewater, International Journal of Engineering Research & Technology (IJERT), 1(10) 968-976

[18] Giwa, S.O., Giwa, A., Toprol, H and Hapoglu, H. (2013). Effects of Operating Parameters on Electrode Dissolution and Energy Consumption during Electrocoagulation Treatment of Petroleum Refinery Wastewater International Journal of Engineering Research & Technology (IJERT), 2(8), 639-647.

[19] Lloyd's Register. (2021). Zero Ready Framework: Ammonia as a Marine Fuel.

[20] Clean Hydrogen in New Jersey (2025). https://dep.nj.gov/hydrogen/hydrogen-energy/)