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A review of Green hydrogen production and the obstacles to hydrogen green economy

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Abstract

The Energy sector, a significant contributor to greenhouse emissions due to its reliance on fossil energy sources, is on the brink of a significant transformation. However, there is hope on the horizon. Hydrogen is leading the charge in the energy industry's decarbonisation processes with its cleaner and more sustainable features. The adoption of Hydrogen could pave the way for a global energy transition towards a carbon-neutral society. Green Hydrogen, in particular, holds immense promise. It can facilitate the shift to clean and renewable energy while ensuring the reliability and sustainability of power grids, inspiring a sustainable and carbon-neutral future for the energy industry.

Moreover, Hydrogen, with its potential to displace fossil fuels in various industries as an energy source, has sparked a growing demand for hydrogen supply chain management structures. This versatility is the recipe for economic development. However, there are significant obstacles to implementing a cleaner Hydrogen economy in Nigeria, such as the high production costs of green Hydrogen and the need for substantial development of specific technologies. This review article will delve into these obstacles and assess potential solutions.

Keywords: Greenhouse; Sustainability; Hydrogen infrastructure; Obstacles and energy transition

1. Introduction

The revolution in the energy industry is not just a global effort to reduce greenhouse gas (GHG) emissions but also a crucial and urgent task to maintain people's living standards. Energy is extensively used in every human activity, and SOX, NOX and CO2 emissions from the energy generation processes affect global climate change. Many countries have continued to deploy renewable energy sources at different levels to solve society's carbon emission problems. According to the International Energy Agency's recent forecast, a $2.5\ ^{\circ}C$ increase in global average temperature is expected by the end of this century under the present conditions (Stated Policies Scenario), which is $1\ ^{\circ}C$ above the Net Zero Emissions Scenario [1]. Hence, the development and expansion of renewable energy sources is required. In its effort to combat decarbonisation and the achievement of Sustainable Development Goal 7, the United Nations has requested organisations and countries to deploy available energy transition solutions rapidly. However, this rapid deployment must be accompanied by proper policies and regulations to ensure its effectiveness and sustainability by 2050 [2]. Each nation's role in this transition is crucial, and implementing appropriate policies and regulations is not just a necessity but an urgent call to action. Every nation desires clean fuels for production because of lower greenhouse gas emissions. However, the production of Hydrogen, the primary candidate for clean fuel, is a through-based fossil fuel for most developing nations, resulting in carbon emissions challenges. Hydrogen can also be produced from Biomass. This is a major attractive route, as the feedstock can be residue from forestry and agricultural industries. Green Hydrogen's high production costs are the main barrier to developing a clean global market in many countries.

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2. Materials and methods

2.1. Processes for hydrogen production

Steam methane reforming is a promising technology that uses natural gas to produce Hydrogen. This process is advanced, and many industrial investors provide infrastructure to support the activity. However, this technology is not considered as environmentally friendly as water electrolysis, as it produces greenhouse gas emissions (Zhang et al., 2022)[3]. Steam Methane Reforming (SMR) is the production of Hydrogen on a large scale through chemical interaction in gas manufacturing. This process contains two chemical reactions that convert water and methane (usually natural gas) into pure Hydrogen and carbon dioxide. Depending on the end-use application, this hydrogen gas must be purified to meet specific quality standards. According to Du et al. [4], there are two types of purification methods: chemical and physical. Their difference is in the methods of removal of impurities. Chemical elements, such as O2 and N2, are removed through physical. SMR is the most common and economical process of Hydrogen production, where the natural gas is heated and mixed with superheated steam. At the same time, the reformer converts natural gas into carbon monoxide and Hydrogen by reacting it with water. A chemical reaction that produces further Hydrogen and carbon monoxide occurs during reforming. Some common responses are given in the endothermic reaction below [5]. External heat is supplied by burning natural gas, which produces carbon dioxide as a greenhouse gas emission.

$$CH_4 + H_20 \longleftrightarrow CO + 3H_2 \text{ ---------------[1]}$$

$$CO + H_20 \longleftrightarrow C0_2 + H_2 \text{ ----------------[2]}$$

$$CH_4 + 2H_20 \longleftrightarrow C0_2 + 4H_2 \text{ -----------------[3]}$$

2.2. Production of Hydrogen through Water Electrolysis

A water electrolysis cell consists of two electrodes, an anode and a cathode, in contact with the electrolyte. The process involves a renewable energy source delivering current to the cell. Due to high voltage application, water breaks into Hydrogen and oxygen and moves towards the cathode and anode. Different reactions occur at the electrodes subject to the electrolyte and electrolysis technology. However, the total response is always $H_2O \rightarrow H_2 + 1/_2\, O_2$. The three primary electrolysers that can be used for this process are alkaline (AEL), proton-exchange membrane (PEMEL), and solid oxide (SOEL). However, since SOEL is the most minor technological advancement [6], it requires substantial development before being used commercially. However, PEMEL's compact design makes PEMEL electrolytic plants more attractive for industrial applications [7]. With future research and development on sustainable material-based catalysts, PEMEL production costs are anticipated to reduce and, therefore, be readily available. According to Risco-Bravo et al. (2024), AEL remains the leading technology for water electrolysis because of its accessibility for larger-scale applications, use of low-cost electrode materials, and lower CAPEX.[8]

2.3. Production of Hydrogen through Biomass Gasification

Biomass gasification is an advanced technology pathway that has existed for many years. It is a reaction process of heat, steam, and oxygen that converts Biomass to Hydrogen and other products without incineration. Since increasing Biomass removes carbon dioxide from the atmosphere, this process lowers carbon emissions with long-term carbon capture, utilisation, and storage. Hydrogen production from biomass gasification comprises pre-treatment, syngas generation, and hydrogen production. Biomass is pre-dried before gasification, reducing a reduction of less than 5% of Biomass's moisture content. Since gasification converts organic material at high temperatures (> 650Oc) into carbon monoxide, Hydrogen, and carbon dioxide, separating the Hydrogen using an Absorber or special membrane is essential.

Example reaction

$$C_6H_{12}O_6 + O_2 + H_2O \rightarrow CO + CO_2 + H_2 + \text{other species (Cellulose component of Biomass).}$$

Pyrolysis is the gasification of Biomass without oxygen. The gasification process of Biomass is regarded as slow compared to coal-producing hydrocarbon compounds. Hence, applying catalysts such as Zeolites aluminosilicate to reform the hydrocarbon will generate a mixture of Hydrogen and Carbon dioxide. The gasification process of hydrogen production ensures the release of carbon dioxide from carbon monoxide as the Hydrogen is separated and purified.

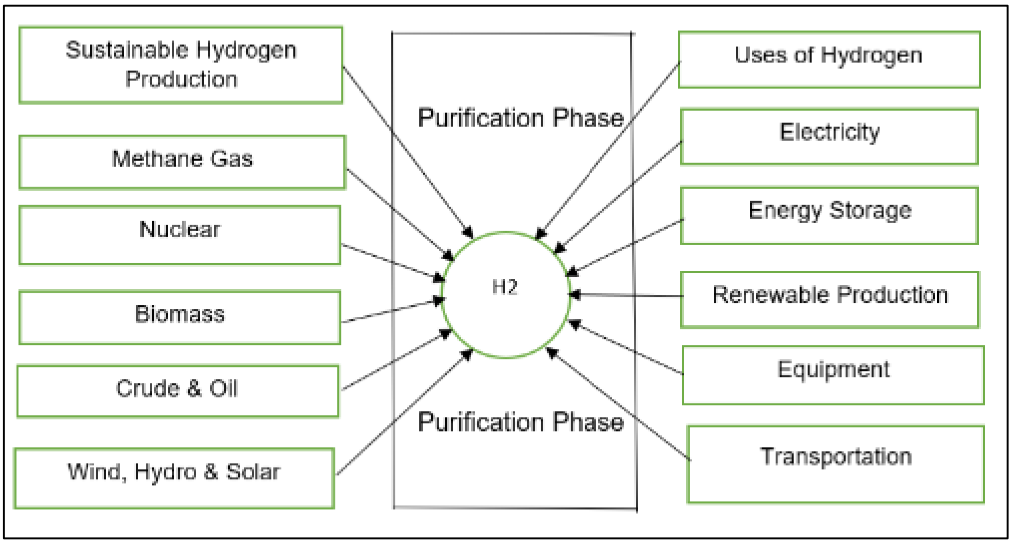

Figure 1 Source: Author's perspective of Hydrogen generation and usage

3. Types of Hydrogen

3.1. Grey Hydrogen

The most prevalent form of Hydrogen. Grey Hydrogen: Grey Hydrogen is the most prevalent form of Hydrogen created from natural gas from the chemical reaction of methane. Grey Hydrogen is mainly produced form of Hydrogen from our fossil power plants. Hydrogen produced through this process contributes more to carbon emissions, while only about 2 % of Hydrogen is generated through electrolysis [9]. Hence, considering Grey hydrogen as a killer and not a low-carbon fuel is the submission of Yu et al. (2021)[10].

3.2. Blue Hydrogen

Blue Hydrogen is generated through natural gas reforming or gasification. However, it is very similar to grey Hydrogen. However, the carbon generated during the hydrogen production process is captured and stored in Carbon Capture Usage and Storage. While the process is not considered perfect, above 75 % of carbon can be captured as CO_2 is produced, according to [11]

3.3. Green Hydrogen

According to Prosst (2020), producing green Hydrogen involves water electrolysis. It is known as a product of electrolysis using a renewable energy source [12]. Without causing any harm, we can use green Hydrogen and release oxygen into the environment [13]. Consequently, this expensive hydrogen production technique is best for a sustainable and friendly ecosystem. [14]. Green Hydrogen is the cleanest of all forms of Hydrogen and is critically needed in an eco-friendly and sustainable environment.

4. Economic Obstacles to the Hydrogen-Green Economy

According to an IEA analysis (2019), hydrogen production from fossil fuels will remain the cheapest form of energy until 2030. Low-carbon or green Hydrogen is indeed much more costly than grey Hydrogen. Moreover, the hydrogen supply has been considered expensive irrespective of the carbon-free emission to end users. Hydrogen with a low density makes it difficult to transport and store, thus increasing its cost.

Elevated production costs, the lack of an existing value chain, and the need for international standards are three primary obstacles to implementing clean Hydrogen in the Nigerian economy. While green Hydrogen remains the cleanest energy source for sustainability, the high production costs constitute the main barrier to the global hydrogen market. Compared to other fossil fuels, the cost of green hydrogen production is economically hindering a global clean hydrogen market.

Due to the high cost of hydrogen production, it also encounters efficiency losses, which are attributed to its cost, making it less viable than other energy sources. According to the International Energy Agency (2019), converting Hydrogen to electricity after shipping and storing reduces energy efficiency by below 30 %. Hence, using electricity directly is more convenient than converting it to Hydrogen.

Furthermore, since water electrolysis represents less than 0.1% of global hydrogen production, its likelihood of growth is very high due to declining costs for renewable electricity, mainly from solar PV. Proximity to abundant renewable energy sources for electrolyte manufacturers will drastically reduce the cost of production and even the cost of transporting Hydrogen from the production sites to end-users [15]. According to Xiang et al., 2021, the production of green hydrogen costs about 2 dollars per kg (based on current US prices) [16]. Khan et al., 2021 concluded that blue Hydrogen produced from natural gas is between $5 to $7 per kg in the US and other western world. [17]

4.1. Inadequate value chain for Hydrogen

The need for a clean value chain represents one of the primary challenges in developing a free carbon economy. The fossil fuel value chain dominates the hydrogen value chain. This is technically not commendable since fossil fuels and Hydrogen have opposite impacts on climate change. A complete value chain is required for a sustainable hydrogen market. The major challenge in designing a sustainable value chain for the green hydrogen market lies in the choice of value pathway.

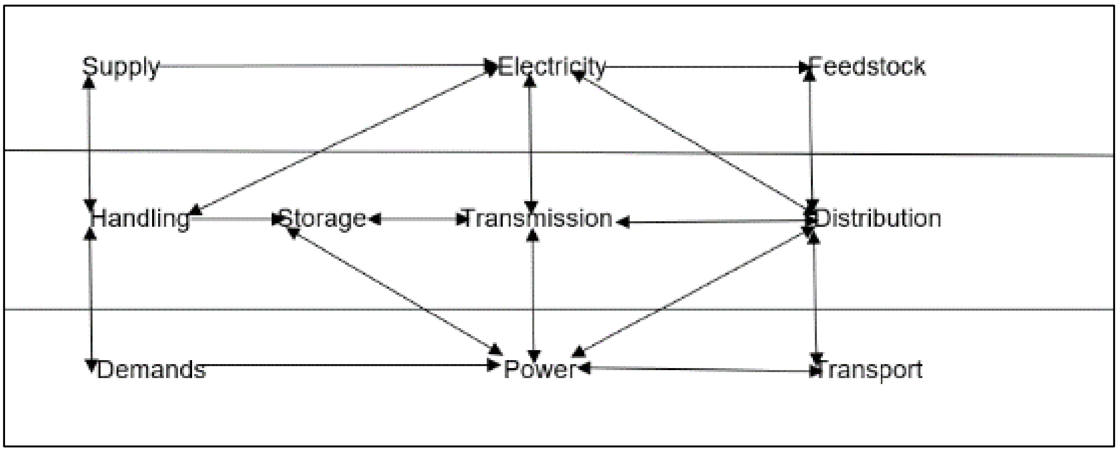

Figure 2 Source: The author elaborated on data from IEA (2019), Hydrogen Value Chain

From Figure 2 above, it is clear that the hydrogen value chain interconnects and links various aspects of our lives. Hence, the need for a sustainable hydrogen economy can always be emphasised. While all these paths have the same result, producing low-carbon Hydrogen and sustaining the environment, clean energy has many advantages regarding infrastructure, industry, and, most significantly, environmental impact. Due to the global call on climate change in our society, the flexibility of Hydrogen as a solution is gaining acceptance from a broader range of governments and businesses. For instance, green hydrogen offers hope for investors in transport, where it plays a substantial role in decarbonisation policy goals. Significant stakeholders in the energy industry, automobile manufacturers, and oil and gas companies are pushing their support for the advancement of the hydrogen value chain. No doubt, hydrogen investment can positively drive the industrial evolution of many third-world countries, creating skilled jobs. (IEA, 2019)[18].

4.2. Hydrogen Safety

Hydrogen is a fuel with a shallow boiling point (253 ∘C at 1 atm) and a density of (10.8 MJ/Nm3). Hydrogen dissolves in many metals, forming different metallic compounds. Comparing Hydrogen with other fuels, such as propane and gasoline, could be the best way to determine its safety and sustainability. Daseh et al.,2022 concluded that Hydrogen is safer than conventional fuels, as every fuel has little safety and operational concerns [.19]. As Hydrogen remains environmentally friendly, if it accidentally explodes, the fire extinguishes faster than an oil or gas fire. According to Najjar, 2023, Hydrogen will not linger outside the container during burning and can be contained quickly.[20]

As a light gas, Hydrogen faces challenges in improving its sustainability. It can diffuse through many membranes, including gas turbines, pipelines, storage tanks, etc. Hydrogen stored in metallic tanks can degrade the mechanical properties of the storage vessel or tank, leading to hydrogen embrittlement. This embrittlement due to hydrogen reaction with the surface of the storage vessel happens at low-stress levels, leading to brittle fractures, according to (Lix. et al. 2020) [21]. Continuous metal reactions with Hydrogen cause severe effects on metals despite their high strength.

Abbreviation

ALL	Alkaline Electrolyzer
CAPEX	Capital Expenditure
CO2	Carbon-dioxide
IEA	International Energy Agency
NOS	Nitrogen Sulphite
PEMEL	Proton-exchange Membrane Electrolyzer
PV	Photo-voltaic
SMR	Steam Methane Reforming
SOX	Sulphuric oxide

5. Conclusion

Hydrogen will continue to play a substantial role in the global energy market and the transition toward a green economy. Its emission-free nature and adaptability make it the energy for the future. However, hydrogen development has remained insignificant in many developing nations due to the dominance of fossil fuels, which has remained dangerous to the environment. Hence, it must be considered for rapid development if the environment is free from carbon emissions and sustainability is attained. Hydrogen investors must be prepared for technological advancement through hydrogen production and infrastructural development. Since a large quantity of Hydrogen is required to generate a small quantity of energy, the future will depend on the investment and commitment of industry players. Finally, governments of different nations must create a Global awareness of the economic importance of Hydrogen for a greener economy and sustainability.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare they have no conflicts of interest or financial conflicts to disclose.

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