Green Hydrogen Production - A Potential Sustainable Solution to Zimbabwe's Cooking Fuel Shortage

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Abstract— **Access to clean cooking energy remains a significant challenge, particularly in sub-Saharan Africa, where reliance on traditional biomass fuels contributes to deforestation, health risks, and environmental degradation. This paper investigates the feasibility and advantages of adopting hydrogen-powered cookstoves as a sustainable solution for Zimbabwe. Hydrogen, known for its zero-emission combustion and potential for renewable production, presents a promising alternative to conventional cooking fuels. Utilizing abundant solar resources, solar-powered electrolysis emerges as a viable method for producing green hydrogen. The paper evaluates current cooking technologies, highlighting hydrogen's efficiency and environmental benefits compared to solid fuels, kerosene, and electricity. It emphasizes the necessity for further research and experimentation to establish sustainable hydrogen production. This includes exploring the potential of decentralized hydrogen production through standalone cookstoves capable of on-demand hydrogen generation or centralized production, possibly in the Namib Desert.**

Keywords— Green Hydrogen Production, Sustainable Solution, Cooking Fuel Shortage, Biomass Fuels, Zero-emission Combustion

I. Introduction

Lack of access to clean cooking energy sources globally is a significant challenge attributed mainly to rampant deforestation, significantly contributing to greenhouse gas emissions and posing respiratory illness health hazards, and disproportionately affecting women and children. The World Health Organization [1] estimated that household air pollution from cookstoves that burn biomass fuels was responsible for an estimated 3.2 million deaths in 2020, including over 237,000 deaths of children under five. Furthermore, UNDP [2] records show global deforestation was at a rate of 10 million hectares per year from 2015 to 2020, primarily driven by the unsustainable extraction of wood fuel for cooking and heating, especially in Africa. These numbers are genuinely unrealistic but true. This is so because, in Africa, the World Economic Forum found that women can spend up to 20 hours a week collecting firewood, a crucial fuel source for their traditional stoves [3]. Despite numerous advancements in cooking technologies, access to clean cooking energy remains a significant challenge for remote communities globally, particularly in sub-Saharan Africa. About 2.4 billion people globally lack access to clean cooking technologies, with only 17% of the Sub-Saharan African region having clean cooking energy [4]. Sub Saharan Africa comes just after Asia as a primary hotspot lacking access to clean cooking fuels, accounting for more than 34% of the global use of traditional cooking fuels and technologies from only 15% of the worldwide population [5]. The situation is not expected to improve as over 1.1 billion people in Africa are projected not to have access to clean cooking by 2050 [6]. A current trend as seen in figure 1 by the IEA shows that we are not on track to achieve universal access to clean fuels and technologies for cooking by 2030, and countries with low improvement rates should focus on creating strong momentum to accelerate the rate of improvement.

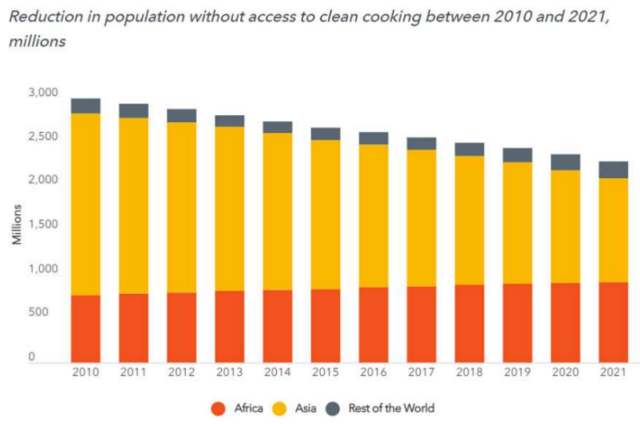

Figure 1: The trends of lack of access to clean cooking

Focusing on Zimbabwe, the World Bank Open Data says that access to clean fuels and technologies for cooking was about 30.40% as of 2020, with its highest value over the past 20 years being 33.60 % in 2001 [7]. These deficient statistics show how big this problem of clean cooking is in the country. It is hard to believe that about 69% of households in Zimbabwe still use wood fuel and charcoal for cooking [8]. Although forests still cover around 45% of the country's land, deforestation is an increasingly pressing issue, resulting in forests disappearing frighteningly [9]. The country's deforestation rate accelerated to 327,000 ha per year (1.9%), currently the highest in Southern Africa [9]. Currently, fuelwood accounts for over 60% of the total energy supply in the country, and almost 98% of rural people rely on fuelwood for cooking and heating [9]. The situation is not improving, as the Forestry Commission reports that up to 11 million tons of firewood is still needed for domestic cooking, heating, and tobacco curing every year in Zimbabwe.

II. Comprehensive Analysis of Conventional Cooking Technologies

Conventional cooking fuels, such as electricity, gaseous, and solid fuels (such as wood, charcoal, etc.), are widely utilized worldwide and have contributed significantly to global climate change challenges. In sub-Saharan Africa, solid fuels have been a significant factor. Figure 2 shows a comprehensive analysis of conventional cooking technologies. The study is based on their performance, availability, and environmental impact.

Figure 2: Lack of clean cooking energy access vs. access in Zimbabwe

A. Solid Fuels

Solid fuels refer to various forms of solid material that can be burned to release energy, providing heat and light through combustion, including coal, charcoal, and biomass [10]. According to Annenberg, more than 3 billion people rely on solid fuels such as biomass (wood, charcoal, agricultural residues, and animal dung) and coal as the primary source of household energy [11]. The share of the population relying on solid fuels for energy needs ranges from less than 25% in some developing countries to 95% in many Sub-Saharan African countries. It is nearly 100% in many rural areas [12].

1. Performance:
   Solid fuels like wood, coal, and biomass generally have lower energy efficiency than liquid and gaseous fuels. The higher moisture content and incomplete combustion of solid fuels result in lower energy conversion efficiency [13]. Solid fuels' higher heating value (HHV) is typically lower than liquid and gaseous fuels. For example, the HHV of wood is around 9.6 MJ/kg, while the HHV of natural gas is around 50 MJ/kg [13].

2. Availability:
   Solid Fuels are standard in many regions, especially in low-income countries. Women and children, however, get burdened with time-consuming and physically demanding fuel collection that prevents them from attending school or working and puts them at risk of violence in some conflict areas [11].

3. Environmental Impact:
   Household solid fuel combustion is associated with 3.5 million and 0.5 million premature deaths annually due to exposure to indoor and outdoor air pollution [11]. Inefficient burning of solid fuels for energy also contributes to climate change, and when wood fuel is 3 unsustainably harvested, deforestation, forest degradation, and loss of habitat and biodiversity can result.

B. Kerosene

Kerosine is a complex combination of hydrocarbons produced by distilling crude oil. It consists of hydrocarbons predominantly in the range of 10 to 16 carbon atoms [14]. It is a colorless, thin, volatile liquid with a distinctive odor. It has lower flammability and higher flash point than 4gasoline, making it safer. The specific energy content of kerosine is around 43.1 MJ/kg [14].

1. Performance:
   Kerosene provides a reliable energy source but emits harmful pollutants when burned. A study comparing the performance of composite sawdust briquettes (solid fuels) with kerosene for cooking indicated that kerosene had a similar cooking time to the briquettes for beans. However, considering availability and cost, the study suggested composite sawdust briquettes might be preferred over kerosene for cooking beans. [14], Thus, in terms of performance and efficiency, Kerosene performs like solid fuels.

2. Availability:
   Kerosene is widely used across Africa, particularly in rural areas without access to electricity grids, as it is an accessible lighting and cooking fuel option. [15][16]. The availability of kerosene in rural areas can be limited compared to urban centers, as the distribution and supply chains may need to reach remote locations more effectively [15][16]. A study found that kerosene retail prices in rural areas are significantly higher than in urban centers [15][16]. On average, rural households in the five African countries studied paid 35% more for kerosene than their urban counterparts [16]. The high kerosene costs in rural areas pose a significant financial burden on households, as they may need to allocate less money for other essential needs or reduce the hours of lighting provided by kerosene lamps [16].

3. Environmental Impact:
   Kerosene has significant environmental impacts, particularly in terms of emissions and contributions to global warming. Kerosene combustion releases greenhouse gases and pollutants, contributing to climate change. The incomplete combustion of kerosene leads to the release of soot or Black Carbon, a potent climate warmer. One kerosene lamp emits about 200 lbs. of CO_2 annually, but the Black Carbon emitted is equivalent to about 4,000 lbs. of CO_2. This highlights the substantial environmental impact of kerosene combustion [17]. The incomplete combustion of kerosene also leads to poor indoor air quality. Fine particles of Black Carbon emitted by kerosene lamps can also quickly become lodged in the bronchial system, leading to chronic diseases and health issues. This indoor air pollution poses significant health risks, particularly in regions where kerosene is widely combusted [17].

C. Gaseous Fuels

1. Performance:
Gas cookers are known for their efficiency and speed in cooking. They provide faster cooking times and more precise temperature control than kerosene stoves. Gas cookers are more efficient in cooking performance [18][19]

2. Availability:
Cooking with gas is generally considered cheaper than using kerosene. While there may be initial costs associated with acquiring a gas cooker and cylinder, the ongoing cost of using gas for cooking is often more economical in the long run. Gas cookers are perceived to be more cost-effective compared to kerosene stoves [19][20].

3. Environmental Impact:
Gaseous fuels, such as liquefied petroleum gas (LPG), have a more favorable environmental impact in cooking than other fuels like kerosene. LPG is considered a cleaner burning fuel than kerosene, emitting negligible amounts of black carbon and other pollutants contributing to global warming. The use of LPG has been shown to reduce indoor air pollution and greenhouse gas emissions, offering environmental benefits over kerosene [21].
Also, cooking with LPG reduces exposure to harmful pollutants like delicate particulate matter (PM2.5) and carbon monoxide (CO), which are associated with adverse health effects. LPG emits lower contaminants than kerosene. However, LPG is still a derivative of 4 fossil fuels, and emissions and negative environmental impact still stand [21].

D. Electricity

1. Performance:
Electric stoves are known for their efficiency in cooking, providing precise temperature control and even heat distribution. This can result in faster cooking times and more consistent results than traditional stoves using kerosene or wood [22]. Electric stoves are convenient to use, requiring minimal setup and maintenance compared to conventional stoves that rely on fuels like kerosene or wood. They are also easy to operate and do not involve the handling of flammable fuels [23].

2. Availability:
While the initial cost of purchasing and installing electric stoves may be higher than traditional stoves, the long-term operating costs can be more economical. Electric stoves are energy-efficient, and the cost of electricity can be competitive or even lower than the ongoing expenses of purchasing fuels like kerosene or wood [24]. However, the availability of electricity for cooking in Africa varies across the continent, with significant disparities in access and adoption of electric cooking solutions. While progress has been made in expanding electricity access, particularly in urban areas, many regions still face challenges accessing reliable and affordable electricity for cooking purposes. While 160 million Africans gained access to electricity over 2010-19, more than 40% of Africans are still deprived of service [25]. Cooking appliances influence the availability of electricity for cooking in Africa.

3. Environmental Impact:
Cooking with electricity, as opposed to traditional biomass or kerosene stoves, eliminates the release of harmful pollutants like particulate matter and carbon monoxide indoors. This leads to improved indoor air quality and reduced health risks associated with household air pollution [26][27]. Electric cooking appliances can significantly reduce greenhouse gas emissions compared to cooking with biomass or fossil fuel-based stoves when powered by renewable or clean energy sources. This contributes to climate change mitigation efforts [26][27]. The availability of electric cooking solutions provides an opportunity to integrate renewable energy sources, such as solar or hydropower, into the cooking energy mix. This can further enhance the environmental sustainability of electric cooking [26][27].

III. A New Revolution of Hydrogen as a Cooking Fuel

A. Hydrogen

Hydrogen is a clean and sustainable alternative to traditional cooking fuels like firewood and charcoal and fossil fuels like natural gas or LPG [28].

1. Performance:
Hydrogen has a higher energy content by weight than other standard fuels like gasoline, natural gas, and propane [28]. This means that hydrogen can produce more energy for the same weight. The combustion characteristics of hydrogen, such as its high flame speed and wide flammability range, allow for increased engine efficiency, especially at part-load conditions [29]. The high energy content and combustion properties of hydrogen make it a more cost-effective energy carrier compared to synthetic fossil fuels like gasoline or diesel [30]. Overall, hydrogen has the potential for higher efficiency as a fuel compared to conventional fossil fuels, especially at part-load conditions where the efficiency gains can be substantial. The efficiency advantage of hydrogen is primarily due to its unique combustion characteristics that allow for lean, high-efficiency operation.

2. Availability:
Hydrogen is the most abundant element in the universe, and it exists in compounds such as water (hydrogen and oxygen) and fossil fuels (hydrogen and carbon) [31]. However, the current global hydrogen production capacity is about 120 million

tons [31]. About 80% of this capacity is through steam methane reforming and coal gasification without carbon capture [32]. This production capacity represents about 65% pure hydrogen, and about 33% is a mixture with other gases [31]. The main challenge currently with hydrogen is the high capital cost of the required infrastructure, such as the electrolysis equipment and hydrogen storage/distribution systems [33]. As 5 hydrogen technologies mature, costs are expected to decrease over time [33].

3. Environmental Impact:
   When used for cooking, hydrogen has several key advantages:
   I. *Zero Carbon Emissions:* Burning hydrogen only produces water vapor as a byproduct, with no carbon dioxide or other greenhouse gas emissions [33]. This makes it a much more environmentally friendly option compared to fossil fuels.

   II. *Reduced Indoor Air Pollution:* The combustion of traditional solid fuels like wood and charcoal can release harmful particulates and pollutants indoors, posing health risks. Hydrogen combustion is clean, reducing indoor air pollution [33].

   III. *Renewable Production Potential:* Hydrogen can be produced through renewable methods like solar powered water electrolysis rather than relying on finite fossil fuel sources [33]. This allows for a sustainable hydrogen cooking fuel supply.

B. Key Production Methods of Hydrogen

Hydrogen production methods vary widely in terms of efficiency, cost, and environmental impact. Below are the main production methods that encapsulate the most currently used approaches.

1. Steam Methane Reforming (SMR):
   This is the most common hydrogen production technique, producing most hydrogen. It involves reacting methane (CH4) with steam (H2O) at high temperatures (800-1000°C) and pressures (1.5-3MPa) in the presence of a catalyst (usually nickel), which gives out Carbon Dioxide and Hydrogen [34]. The primary advantage of SMR is its high efficiency and relatively low cost. Still, it produces carbon dioxide (CO2) as a byproduct, contributing to greenhouse gas emissions unless carbon capture and storage (CCS) technologies are employed [34]. Additionally, the high temperatures required to convert methane require expensive construction materials for the reformer to withstand the thermal stress, and coke formation could be considered a drawback [35]
2. Electrolysis:
   Electrolysis involves converting electric power into chemical energy, resulting in hydrogen and oxygen as byproducts [34]. The process occurs at two electrodes: the anode and the cathode. At the anode, water molecules split into oxygen gas (O_2) [36]. At the cathode, hydrogen gas (H_2) is produced. Overall, this process generates hydrogen and oxygen.

   Main types of Water Electrolysis Technologies:
   I. Alkaline Water Electrolysis:
   This type uses concentrated lye (potassium hydroxide) as an electrolyte. Employs non-noble metal-based electrodes (e.g., nickel) [37]. A gas separator is required to prevent the mixing of gas products. Operating temperature: 50–80 °C. Operating pressures: Up to 30 bars.
   II. Proton-Exchange Membrane (PEM) Electrolysis:
   Utilizes humidified polymer membranes as electrolytes. Employs noble metals (e.g., platinum or iridium oxide) as electrocatalysts [38]. Similar operating temperature and pressure ranges as alkaline electrolysis.
   III. Solid Oxide Electrolysis:
   Operates at high temperatures (700–900 °C). Converts water into hydrogen and oxygen [34]. Higher thermal demand due to elevated temperatures. Less common for large-scale implementation. Electrolysis can be powered by renewable energy sources such as solar or wind, offering a pathway to "green hydrogen" production with zero greenhouse gas emissions, and it generally achieves high hydrogen purity (99.9%) with zero CO_2 emissions and enables on-site hydrogen production without transportation [38]. However, despite its environmental benefits, hydrogen produced by electrolysis remains more expensive than fossil fuel-based hydrogen [34]. However, ongoing research and technological advancements may further improve the efficiency and cost-effectiveness of electrolysis for hydrogen production.

3. Gasification:
   Gasification involves a thermochemical reaction between organic matter and a gasifier (like oxygen, steam, air, or carbon dioxide) to produce synthetic gas (syngas) at high temperatures, typically 700–1200 °C. 6 It can utilize both renewable (e.g., agricultural waste) and non-renewable (e.g., coal) sources, with biomass gasification being a prominent example. This reaction occurs at high temperatures dictated by a partial oxidation process to release hydrogen, carbon monoxide, methane, and other trace gases [40]. While it reduces

reliance on non-renewable sources and improves waste management, challenges include biomass availability and control/optimization complexities, with potential carbon emissions from incomplete combustion [39].

4. Photo and Thermochemical Processes:
   Photochemical water splitting harnesses sunlight and semiconductors within specialized cells to initiate a reaction that breaks down water into hydrogen and oxygen [39][41]. It directly utilizes renewable solar energy but faces low efficiency and material stability challenges. On the other hand, thermochemical water splitting relies on heat to decompose water molecules, typically through specific chemical cycles involving sulfur trioxide and iodine catalysts, which react at high temperatures [39]. This method is known for its potential environmental benefits, such as reduced CO2 emissions, but requires high energy input and complex reaction kinetics.

5. Biological Production:
   Biological hydrogen production involves two main processes: dark fermentative and photo fermentative [34]. In dark fermentative processes, anaerobic bacteria act on carbohydrate-rich substrates without light, yielding hydrogen, organic acids, and CO2 [41]. This process occurs at any time, utilizing enzymes at ambient conditions, but maximum hydrogen yield is limited due to metabolic pathways [42]. On the other hand, photo fermentation uses photosynthetic bacteria under anaerobic conditions, harnessing sunlight to assimilate organic molecules and produce hydrogen and CO2 [43]. While offering a high theoretical yield and efficient chemical oxygen demand removal, its economic viability is hindered by nitrogenase metabolism and light intensity. Dark fermentative processes have lower yields than photo fermentation under sunlight [44]. Both dark fermentative and photo fermentative methods encounter challenges in maximizing hydrogen yield, controlling environmental conditions, ensuring substrate availability, stabilizing processes for scalability, and achieving economic viability [34].

   Each of these methods has its advantages and challenges, and the choice of hydrogen production method depends on factors such as cost, environmental impact, availability of feedstocks, and desired scale of production. Despite the commercial advantages of using fossils for hydrogen production, which currently make up the bulk of hydrogen production, the environmental implications call for a decrease in their use, which calls for research and development of more affordable "Green Hydrogen" [34].

   'Green' hydrogen is primarily produced by the electrolysis of water using renewable energy sources like solar and wind power, ensuring that the production process is sustainable and environmentally friendly [45][46]. Natural gas accounts for most of the world's total hydrogen production [47]. When H2 is produced from natural gas with no CCS via SMR, the direct emissions are approximately 9 kg of CO2 eq per kg of hydrogen. Global temperatures are expected to rise to 5.4 degrees Celsius by 2100, and these rising global temperatures due to increased atmospheric carbon dioxide concentrations are driving the need for sustainable energy solutions. "Green Hydrogen" offers a promising pathway to mitigate this temperature rise [39].

IV. ELECTROLYSIS

Electrolysis is a process that splits water into its constituent elements using an electric current [48]. This process is essential because it is crucial in producing green hydrogen, which emits non-toxic gases to the environment as a by-product.

A. Types of Electolysis

1. Proton Exchange Membrane Electrolyzer (PEM):
   Proton Exchange Membrane (PEM) is a type of electrolysis that produces hydrogen through water splitting, where a gas-tight and proton-conducting polymer membrane separates the electrodes [49].

   Working Principle
   The anode, the cathode, and the membrane group of a Proton Exchange Membrane Electrolyzer form a membrane electrode assembly [51]. Common materials for its cathodes and anodes are platinum, iridium, ruthenium, and platinum on carbon [50]. Around the anode, water is catalytically oxidized by the catalyst on the membrane to generate oxygen, electrons, and protons, and the protons generated at the anode are circulated to the cathode end through the membrane and reduced to create hydrogen. PEM technology as seen in figure 3 uses a perfluorosulfonic acid proton exchange membrane as an electrolytic membrane [50].

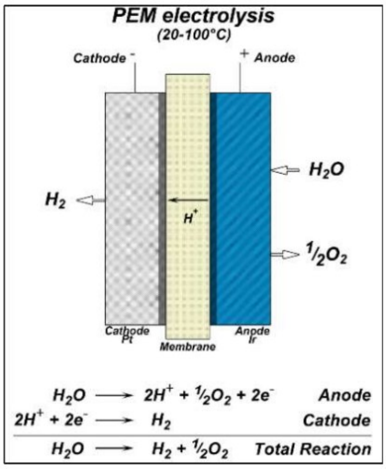

Figure 3: PEM Electrolysis

Advantages and Disadvantages of PEM
The significant advantages of PEM are that it can perfectly deal with load fluctuations due to its rapid response, and it can also produce hydrogen with about 99.99% purity [52]. Furthermore, compared with traditional membranes, PEM membranes have the advantages of stable chemical properties, high proton conductivity, nonporous gas isolation, and others. PEM can be integrated with electrodes to reduce the extra resistance and power loss caused by the distance between the two electrodes [53]. Therefore, this technology can improve the purity of hydrogen production and, at the same time, obtain sizeable current density, which is suitable for renewable energy power generation systems with large fluctuations [53]. However, its main disadvantage is its high cost due to the noble materials used inside the electrolyzer, such as platinum/iridium. Another shortcoming of this technology is its availability. The technology is mainly imported from developed countries such as Europe and America, making it very challenging for small household use on developing continents such as Africa [53].

2. Alkaline Water Electrolyzer (AWE):
Alkaline water electrolyzers are the most reliable among other types, with a relatively high efficiency, from 42% to 78% [53]. Working Principle AWE is composed of two electrodes submerged in a liquid electrolyte water solution, usually 20–40% sodium hydroxide (NaOH) or potassium hydroxide (KOH) [54]. A diaphragm separates these electrodes in the solution, allowing water molecules and hydroxide ions to pass through. The diaphragm also separates H2 and O2 for safety and purity. The diaphragm is mainly made of porous materials, such as asbestos, ceramics, and nylon [53]. When the electrolysis temperature is 20~90 degrees Celsius, water is reduced to produce hydrogen in the cathode, and OH- passes through the diaphragm to reach the anode oxidation to produce oxygen.

Advantages and Disadvantages Alkaline Water Electrolysis technology has made progress in two aspects since the beginning of its usage: first, the efficiency of the electrode has improved, and the operating cost related to electricity consumption has been significantly reduced; second, the operating current density has increased, and the investment cost has decreased [55]. Although Alkaline Water Electrolysis technology as seen in figure 4 has the characteristics of low cost, long service life, mature technology, and stable operation, there are still many shortcomings in its engineering application, such as low current density, poor dynamic response, diaphragm gas leakage, alkali corrosion, and others [51].

To solve these problems, researchers have developed an Anion Exchange Membrane technology (AEM), which is expected to become an improved scheme of traditional alkaline electrolysis technology and play a technical and cost advantage in large-scale hydrogen production [56].

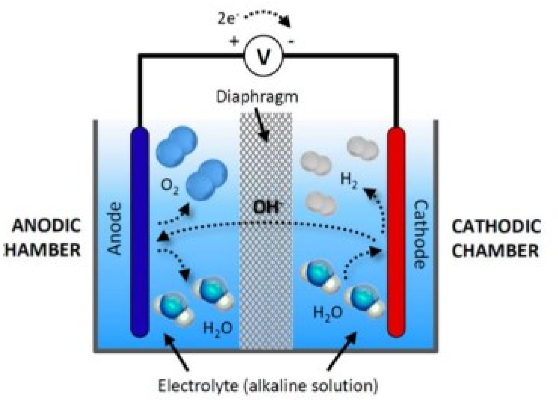

Figure 4: Alkaline Water Electrolysis

3. Anion Exchange Membrane (AEM):
AWE and PEM are combined in AEM to address some drawbacks of these first two electrolyzers [50]. This is seen in figure 5.

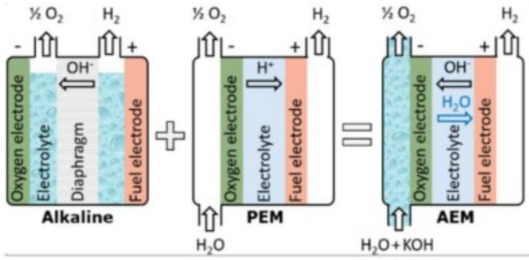

Figure 5: Anion Exchange Membrane

Working Principle
AEM combines a low-concentration alkaline solution as opposed to a 20–40% KOH or NaOH aqueous solution with a solid electrolyte (polymeric) membrane (e.g., Mg-Al LDH) [57]. Furthermore, the anode in an AEM is manufactured from Ni-based (e.g., Ni foams) or titanium materials, and the cathode comprises Ni, Ni-Fe, and NiFe2O4 [58][59][60].

Advantages and disadvantages
AEM technology's main challenges are the need for such a device with high conductivity and alkaline corrosion resistance and the increased cost of using precious metal catalysts. Also, CO2 entering the contact film reduces the membrane and electrode resistance, thus reducing the electrolytic performance [51].

4. Solid Oxide Water Electrolysis:
Solid oxide electrolysis is where solid oxide electrolysis cells produce hydrogen and oxygen (by product), through water splitting using

electrolysis [61]. Solid oxide ceramic is an electrolyte in Solid Oxide Electric Water technology [51]. Its working temperatures are between 500 to 1000 degrees Celsius. Although SOE operates at a high temperature, the electricity required to drive its electrolysis process at such a high temperature is significantly reduced compared to low-temperature electrolysis [50], thus improving the system's efficiency through affordable thermal energy.

Operating Principles
In Solid Oxide Electrolyzers as seen in figure 6, water is converted into water vapor at high temperatures, and the current electrolyzes the water molecules adsorbed on the cathode catalytic layer into H+ and O2-; the free electrons of H+ transmitted through the external circuit are then reduced to H2 and the O2- passes through the solid electrolyte layer to reach the anode catalytic layer [51]. At the same time, the lost electrons are converted into oxygen, and the free electrons enter the external circuit [62]. It is required that the electrolyte has a high oxygen ion conductivity so that O2- can pass through the electrolyte layer, and its electronic conductivity is very low to prevent short circuits [51]. The anode and the cathode are porous structures beneficial for gas diffusion and constructing the interfaces of the 3-phase catalytic.

Advantages and Disadvantages
SOE has high energy conversion efficiency, which can effectively reduce the energy consumption required in the electrolytic processes [63]. The anode is composed of perovskite ceramic composite, and the cathode is made of nickel-based composite; thus, a precious metal catalyst is not needed, and the preparation costs of the catalyst are low [64]. However, the high working temperatures of the system create problems such as difficulty in sealing and higher requirements for the chemical and mechanical stability of electrodes and catalytic materials in high temperature and high humidity environments, which limits the development of SOE technologies [51]. Moreover, the gas produced at the cathode is not pure hydrogen; it consists of both hydrogen and water vapor, and this needs to be further separated and purified, increasing costs compared to conventional liquid electrolysis. Thus, due to all these 9 problems, the short life of the battery stack, and the need for auxiliary components in the process, the SOE technology cannot be commercialized [65].

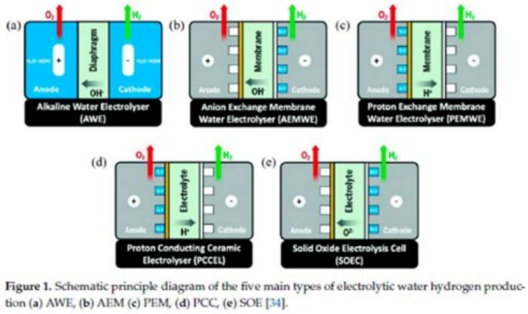

Figure 6: Solid Water Oxide Electrolysis

V. CONCLUSION

Overall, hydrogen presents a unique opportunity to address the cooking energy crisis in Sub-Saharan Africa, primarily due to its significantly higher heating value compared to other conventional fuels and hydrocarbons. Its standout feature is its ability to combust without emitting toxic gases. However, there are still barriers to sustainable hydrogen production, which must be economical and affordable while minimizing negative social impacts and greenhouse gas (GHG) emissions.

The biggest challenge lies in affordability, which involves a tradeoff between efficiency and environmental impacts. An analysis of hydrogen production methods, including steam reforming and biomass gasification, indicates that only green hydrogen production—via water electrolysis powered by renewable energy sources like wind and solar—effectively tackles this challenge. This method, however, presents challenges, such as the need for a substantial water supply and a consistent renewable energy source. Fortunately, Sub-Saharan Africa hosts two of the largest deserts on the continent, namely the Kalahari and Namib deserts. Sub-Saharan Africa's strategic location between the Indian and Atlantic oceans offers numerous opportunities for hydrogen production, leveraging abundant access to essential resources like water and sunlight.

The Namibia Desert as seen in figure 7, is an ideal site for a hydrogen production plant because of its adjacency to the Atlantic Ocean, providing access to abundant sunlight and extensive water resources. This setup would involve establishing a pipeline to transport water from the ocean. The produced hydrogen could then be transported to neighboring communities, such as Botswana and Zimbabwe, by road, train, or pipeline.

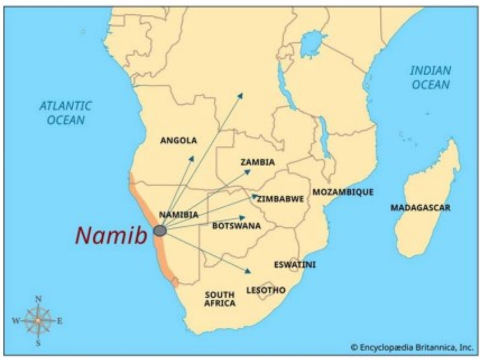

Figure 7: Potential beneficiaries of mass hydrogen

Alternatively, instantaneous hydrogen production for cooking could eliminate storage and transportation costs and mitigate associated risks. However, this approach necessitates determining the most suitable electrolysis process. Despite being affordable, Anion Exchange Membrane (AEM) electrolysis is less efficient and may not be ideal for instantaneous production. Solid Oxide Electrolysis (SOE) is highly efficient but costly due to the use of transitional elements, making it unaffordable. Proton Exchange Membrane (PEM) electrolysis balances cost and efficiency, presenting a high potential for use. Nevertheless, further research is needed to evaluate its feasibility on a case-by-case basis. For AEM, there is a need to experimentally determine the maximum production rate from the best possible cell to assess whether it can feasibly meet consumer needs for instantaneous hydrogen production.

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