



# **DESIGN AND FABRICATION OF AN HYDROLYSIS BASED COOKER**

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## CERTIFICATION

This is to certify that this work is original and was carried out by the afore-listed students under the supervision of the project supervisor

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## **DEDICATION**

This project is dedicated to God Almighty, whose wisdom and guidance made this work possible. It is also dedicated to my family and loved ones for their unwavering support, encouragement, and prayers throughout the course of this project.

Finally, to innovators and researchers striving to develop sustainable and locally relevant technologies that improve lives and protect our environment.

## **ACKNOWLEDGEMENT**

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I extend heartfelt appreciation to my family and friends for their unwavering support, motivation, and understanding throughout the demanding periods of this project.

Finally, I acknowledge all authors, researchers, and institutions whose works informed and inspired this study. Their contributions laid the foundation upon which this project was developed.

## **ABSTRACT**

This project explores the design and fabrication of a hydrolysis-based cooker, an innovative cooking device that applies controlled hydrolysis and thermal processes to generate heat for domestic cooking. Motivated by the need for sustainable, affordable, and clean cooking technologies particularly in rural parts of Nigeria and the West African region the study evaluates how scientific principles such as heat transfer, energy conversion, and material behavior can be optimized to create an efficient alternative to conventional biomass and fossil-fuel stoves.

A comprehensive literature review was conducted to analyze existing cooking technologies, the application of hydrolysis and related thermal reactions in industrial systems, and previous research on fabrication techniques and material selection. Insights from these studies guided the conceptual development, material choice, and design framework for the prototype. The project also identifies critical gaps in current knowledge and technology, including affordability and cost gaps, materials and durability gaps, local adaptation and user context gaps, system integration and design gaps.

The resulting prototype demonstrates the feasibility of integrating hydrolysis into a functional domestic cooking system, offering potential advantages in energy efficiency, safety, and environmental impact. This work contributes to ongoing efforts to develop innovative, sustainable, and locally adaptable cooking technologies for households in energy-challenged communities.

## TABLE OF CONTENTS

<b>TITLE PAGE</b>	
<b>CERTIFICATION</b>	i
<b>DEDICATION</b>	ii
<b>ACKNOWLEDGEMENT</b>	iii
<b>ABSTRACT</b>	iv
<b>TABLE OF CONTENTS</b>	v
<b>LIST OF FIGURES</b>	viii
<b>LIST OF TABLES</b>	ix
<b>LIST OF ABBREVIATIONS</b>	x
<b>CHAPTER ONE : INTRODUCTION</b>	1
1.1 Background of Study	2
1.2 Statement of the Problem	3
1.3 Aim and Objectives of this Study	5
1.4 Scope of Study	6
1.5 Significance of the Study	7
1.6 Methodology	7
<b>CHAPTER TWO : LITERATURE REVIEW</b>	11
2.1 Introduction	11
2.1.1 Purpose of the Literature Review	11
2.1.2 Scope and Delimitations	11
2.2 History and Evolution of Cooking Methods	12
2.2.1 Early Stone-Age Cooking: Fire, Stones, and Primitive Hearths	12
2.2.2 From Stone Boiling to Pit and Earth Oven Technologies	13
2.2.3 The Neolithic Transformation: Pottery and Agricultural Cooking	14
2.2.4 Metalworking and the Expansion of Culinary Technology	15
2.2.5 Medieval and Early Modern Cooking Innovations	15
2.2.6. The Modern Era: Gas, Electricity, and Smart Cooking	16
2.3. Review of Related Technologies / Cooking Systems	17
2.3.1 Conventional Cooking Systems	17
2.3.2 Emerging/Alternative Cooking Systems	23
2.3.3 Prior Work on Hydrolysis Applied to Cooking/Heating	23

2.3.4 Comparative Evaluation	24
2.3.5 Identified Gaps: What Has Not Been Done or What Limitations Exist (Materials, Local Adaptation, Affordability, Durability, And Others)	29
2.4. Hydrolysis Process and Parameters Relevant to Design	32
2.4.1 Types of Hydrolysis/Electrolysis Relevant to this System	32
2.4.2 Reaction Conditions and their Effect	33
2.4.3 Materials Interactions	34
2.4.4 Safety and Environmental Considerations	34
2.4.5 Applicability to Cooking Equipment	35
2.5 Design Considerations for a Hydrolysis-Based Cooker	36
2.5.1 Design Parameters Drawn from Literatures	36
2.5.2 Material Selection	37
2.5.3 Thermal Efficiency and Losses	38
2.5.4 Ergonomics, User Safety, Maintenance and Durability in Cooking Context	38
2.5.5 Local Context Considerations	39
2.6 Fabrication Methods and Challenges	40
2.6.1 Review of Fabrication Techniques Relevant to Thermal/Hydrolysis Systems	40
2.6.2 Challenges Noted in Literature	41
2.6.3 Prototype Case-Studies	41
2.6.4 Recommended Fabrication Path for This Project	42
2.7. Performance Evaluation Metrics and Testing in Literature	43
2.7.1 What Metrics have Previous Studies Used to Evaluate Cooking/Thermal/Hydrolysis Systems	43
2.7.2 Benchmark Values in Literatures	44
2.7.3 Testing Methods	46
2.7.4 Gaps in Measurement/Metrics	46
2.8 Gaps, Opportunities and How this Project Fits in	47
2.8.1 Summary of Major Gaps from Literatures	47
2.8.2 Opportunities Our Project Can Exploit	48
2.8.3 Contributions Our Project Aims to Make	48
2.8.4 Linkage to our Research Questions/Hypotheses	49
2.9 Summary of Key Findings from Literatures	49
2.9.1 Recap of The Central Insights from Each Major Section	49
2.9.2 Highlights of Major Constraints that will Shape our Design	50

2.9.3 Transition to Next Chapter (Methodology/Design Approach)	50
<b>CHAPTER THREE : METHODOLOGY</b>	51
3.1 Design and Conceptualization	51
3.1.1 Electrolysis Process and Catalyst Consideration	51
3.1.2 Conceptualization	53
3.1.3 Electrolyzer Design	58
3.1.4 Burner Design	59
3.2 Design Specifications	60
3.3 Materials	61
3.3.1 Battery	61
3.3.2 Battery Clamps	61
3.3.3 Alligator Clips	62
3.3.4 Wires	62
3.3.5 Stainless Steel Whisk	63
3.3.6 Stainless Steel Scouring Pads	63
3.3.7 Container and Sheaths	64
3.3.8 Potassium Hydroxide	64
3.3.9 Hose	65
3.3.10 Burner	65
3.3 Bill of Engineering Materials and Evaluation	66
<b>CHAPTER FOUR: RESULTS, DISCUSSION AND LIMITATIONS</b>	67
4.1 Results and Discussion	67
4.1.1 Results	67
4.1.2 Discussion	68
4.2 Summary of Findings	69
<b>CHAPTER FIVE: CONCLUSION, LIMITATIONS AND RECOMMENDATIONS</b>	71
5.1 Conclusion	71
5.2 Limitations	71
5.3 Recommendations	72
<b>REFERENCES</b>	74

## LIST OF FIGURES

Figures	Page
Figure 2.1: Early stone age cooking	12
Figure 2.2: Stone Boiling & Pit and Earth Oven Technology	13
Figure 2.3: Ceramic cooking vessels	14
Figure 2.4: Bronze cooking pot	15
Figure 2.5: Medieval and Early Modern Cooking	15
Figure 2.6: Modern cookers	16
Figure 2.7: Flow chart of a biomass cooker mechanism	17
Figure 2.8: Mechanics of LPG cooking	19
Figure 3.1: Proton Exchange Membrane (PEM)	58
Figure 3.2: Electrolyzer and battery setup	60
Figure 3.3: Battery	61
Figure 3.4: Battery Clamps	61
Figure 3.5: Alligator Clips	62
Figure 3.6: Wires	62
Figure 3.7: Stainless steel whisks	63
Figure 3.8: Stainless Steel Scouring Pads	63
Figure 3.9: Container	64
Figure 3.10: Potassium Hydroxide (KOH)	64
Figure 3.11: Hose	65
Figure 3.12: Burner	65
Figure 4.1: Current vs Hydrogen Evolution Graph	67

## LIST OF TABLES

Tables	Pages
Table 2.1: Comparison of the key properties and requirements for LPG fuel as specified in ISO 9162:2013, ASTM D 1835-Special-Duty propane, and CAN/CGSB-3.14-2023 Grade1.	20
Table 2.2: Benchmark values (GACC: Global Alliance for Clean Cookstoves)	46
Table 3.1: Bill of Engineering Materials and Evaluation	66
Table 4.1: Table of Results	68

## LIST OF ABBREVIATIONS

**H<sub>2</sub>** – Hydrogen Gas

**O<sub>2</sub>** – Oxygen Gas

**H<sub>2</sub>O** – Water

**CO** – Carbon Monoxide

**CO<sub>2</sub>** – Carbon Dioxide

**NO<sub>x</sub>** – Nitrogen Oxides

**kW** – Kilowatt

**kWh** – Kilowatt-hour

**DC** – Direct Current

**SS** – Stainless Steel

**PPE** – Personal Protective Equipment

**BTU** – British Thermal Unit

**LPG** – Liquefied Petroleum Gas

**IEA** – International Energy Agency

**SDG** – Sustainable Development Goals

**WHO** – World Health Organization

**NGO** – Non-Governmental Organization

**TLUD** – Top-Lit Up-Draft

**BCE** – Before Common Era

**ca.** – Circa (meaning “approximately” in dates or measurements)

**IoT** – Internet of Things

**PM<sub>2.5</sub>** – Particulate Matter with diameter less than 2.5 micrometers

**WLPGA** – World LPG Association

**ISO** – International Organization for Standardization

**ASTM** – American Society for Testing and Materials

**CAN/CGSB** – Canadian General Standards Board

**DOE** – U.S. Department of Energy (or Design of Experiments, depending on context; for energy topics, it typically means the Department of Energy)

**ESMAP** – Energy Sector Management Assistance Program (World Bank)

**NFPA** – National Fire Protection Association

**PV** – Photovoltaic

**IR** – Infrared

**UV** – Ultraviolet

**PAH** – Polycyclic Aromatic Hydrocarbons

**IRENA** – International Renewable Energy Agency

**CAPEX** – Capital Expenditure

**AEM** – Anion Exchange Membrane (Electrolyzer)

**PEM** – Proton Exchange Membrane (Electrolyzer)

**GACC** – Global Alliance for Clean Cookstoves

**WBT** – Water Boiling Test

**CCT** – Controlled Cooking Test

**Ni-Fe** – Nickel–Iron

**BOM** – Bill of Materials

**KOH** – Potassium Hydroxide

**PTFE** – Polytetrafluoroethylene

**PVC** – Polyvinyl Chloride

**ID** – Inner Diameter

## CHAPTER ONE

### INTRODUCTION

Nigeria, Africa's most populous nation, faces a complex energy dilemma that directly affects the daily lives of her citizens. Despite abundant natural resources, millions still cook with firewood, charcoal, and kerosene — a reliance that contributes to deforestation, indoor air pollution, and severe health problems, especially among women and children (Salau, 2025; WHO Regional Office for Africa, 2024).

The proposed hydrolysis-based cooker, which uses water electrolysis to generate hydrogen for clean combustion, represents a transformative solution. Its adoption in Nigeria could reduce smoke exposure, lower environmental degradation, and provide a sustainable alternative to traditional fuels (Ajala, 2022).

#### **Key Benefits to Nigeria and her Citizens**

- **Environmental Protection:** Nigeria loses up to 400,000 hectares of forest every year due to extensive firewood collection and charcoal production. A hydrogen-based cooker removes the need for biomass fuels entirely, helping to preserve the nation's forest reserves and protect biodiversity (Odeniyi, 2025).
- **Health Improvement:** Indoor air pollution from burning firewood, charcoal, and kerosene remains a major public health threat in Nigeria, contributing to respiratory diseases, eye irritation, and premature deaths—especially among women and children. Transitioning to hydrogen cooking drastically reduces exposure to harmful particulate matter and toxic smoke, improving overall health outcomes (Slater et al., 2025; BMC Public Health, 2025).
- **Economic Relief:** A large share of household income in Nigeria is spent on purchasing firewood, charcoal, or kerosene. A hydrolysis-based cooker powered by water and renewable electricity can significantly cut long-term cooking fuel costs, particularly when integrated with solar systems (Idirsu Foundation, n.d.)
- **Energy Independence:** Frequent scarcity and rising prices of kerosene and LPG highlight Nigeria's energy insecurity. Hydrogen-based cooking offers a decentralized,

locally sourced alternative that reduces dependence on imported cooking fuels and volatile market prices (UNFCCC, 2024).

- **Job Creation and Innovation:** Manufacturing, deploying, and maintaining hydrolysis-based cookers can generate new opportunities in local fabrication, technical training, and green-energy entrepreneurship, supporting Nigeria's transition to a sustainable energy economy (Abnable, 2024).

### **Consequences of Not Adopting Cleaner Cooking Methods**

Failure to adopt cleaner cooking technologies such as a hydrolysis-based cooker risks perpetuating Nigeria's cycle of environmental degradation, mounting health crises, and economic hardship. Continued dependence on biomass fuels exacerbates deforestation, increases carbon emissions, and places further strain on Nigeria's healthcare system (Slater et al., 2025; Ajala, 2022). Moreover, as international energy standards shift toward sustainability, Nigeria may be left behind missing vital opportunities for global investment, innovation, and support (Chijioke, 2024).

Thus, the design and fabrication of a hydrolysis-based cooker is far more than an engineering endeavour: it is a visionary step toward Nigeria's energy future. It aligns with national development objectives, enhances climate resilience, and empowers citizens with a safer, cleaner, and more dignified way to cook. This project has the potential to become a symbol of progress, signaling Nigeria's commitment to a healthier and more sustainable tomorrow.

### **1.1 Background of Study**

The global energy landscape is undergoing a transformative shift, driven by the urgent need to reduce carbon emissions, combat climate change, and transition toward sustainable energy sources. Among the most pressing challenges is developing clean, affordable, and accessible cooking technologies—especially in regions where traditional methods still dominate. In sub-Saharan Africa, many households rely on biomass fuels like firewood, charcoal, and kerosene, which, while common, pose serious health risks through indoor air pollution, contribute to deforestation, and worsen environmental degradation (Arowolo & Aisha, 2018; WHO, 2024).

The World Health Organization estimates that millions of premature deaths occur annually as a result of smoke from traditional cookstoves, driven largely by inefficient combustion of solid fuels (WHO, 2024). In Nigeria, for example, household air pollution from solid fuel use is a

major contributor to respiratory illnesses and early mortality (Slater et al., 2025; BMC Public Health, 2025).

Hydrogen energy provides a promising clean-energy option, producing only water vapor when combusted. One key method of hydrogen generation is via water electrolysis, which splits water into hydrogen and oxygen using electricity. When this electricity comes from renewable sources (like solar or wind), the hydrogen production process becomes even cleaner and more sustainable (Hassan, 2024).

The concept of a hydrolysis-based “hydro cooker” leverages this pathway by integrating a water-electrolysis system with a hydrogen combustion unit for cooking. In this system, water is electrolyzed to produce hydrogen gas, which is then stored and used as a fuel to generate heat for cooking. This eliminates the need for conventional polluting fuels, reduces harmful emissions, and offers a scalable solution for both urban and rural settings.

Designing and fabricating such a cooker requires multidisciplinary engineering—drawing on chemical engineering, thermodynamics, fluid mechanics, and material science. It also demands rigorous safety protocols (given hydrogen’s flammability) and control systems to regulate gas production and combustion. If successfully implemented, this technology could transform cooking practices—particularly in off-grid communities, disaster relief zones, or regions with unreliable energy infrastructure.

This study aims to examine the feasibility of designing and building a hydrolysis-based hydro cooker, evaluating its technical components, operational efficiency, and potential impact on sustainable development. By bridging theoretical clean-energy systems and practical cooking applications, the project contributes to energy equity, environmental stewardship, and technological innovation.

## **1.2 Statement of the Problem**

### **Health & Safety Issues**

- There is a persistent problem of indoor air pollution caused by burning firewood, charcoal, and kerosene, exposing many Nigerian homes to harmful smoke (UNFCCC, 2024).

- Women and children in cramped, poorly ventilated kitchens are particularly vulnerable to exposure, leading to respiratory illnesses, eye irritation, and long-term health damage (WHO Regional Office for Africa, 2024).
- Long-term exposure to biomass smoke increases the risk of chronic respiratory diseases and other health complications (Punch Healthwise, 2024).

### **Environmental Degradation**

- Heavy reliance on biomass fuels (firewood and charcoal) drives deforestation across many Nigerian communities (Adewuyi & Oyejide, 2025).
- The removal of trees for fuel threatens biodiversity and disrupts local ecosystems, undermining forest-based ecosystem services (Independent Nigeria, 2025).
- Traditional fuel use also contributes to significant carbon emissions, worsening climate change impacts in Nigeria (Sun-Connect et al., 2024).

### **Economic Burden**

- Families face rising and unstable costs for kerosene and cooking gas, pushing some to revert to cheaper but harmful fuels like firewood and charcoal (Vanguard, 2024).
- For many low-income households, fuel expenses take up a large portion of their monthly income (Continental Economy Magazine, 2024).
- There is a strong case for an affordable and reliable alternative, such as hydrogen generated from water electrolysis, which could lower cooking costs in the long term (Dr. Ibrahim Idrisu Foundation, n.d.).

### **Energy Access & Equity**

- Many rural and peri-urban communities in Nigeria lack access to clean and modern cooking energy, limiting their participation in the energy transition (Arowolo & Aisha, 2018).
- This lack of access undermines equitable development and slows progress toward inclusive, sustainable energy for all (National Clean Cooking Policy, Nigeria, 2024).

- Providing safe, modern cooking solutions is essential to ensuring underserved populations benefit from the shift to clean energy (Dr. Ibrahim Idrisu Foundation, n.d.).

### **Technological Innovation**

- There is limited local development of sustainable cooking technologies in Nigeria, constraining innovation in clean cooking.
- Demonstrating hydrogen as a domestic cooking fuel through a hydrolysis-based cooker can catalyze new technological paths and entrepreneurs.
- Such innovation aligns with Nigeria's broader sustainable development goals and can strengthen resilience to climate change.

### **1.3 Aim and Objectives of this Study**

#### **Aim**

The overarching aim of this research is to design and fabricate a sustainable cooking device that utilizes hydrogen gas generated through water electrolysis (hydrolysis) as a clean energy source. This project seeks to address the environmental, health, and economic challenges associated with traditional cooking methods in Nigeria by introducing a viable alternative that is both innovative and practical.

#### **Specific Objectives**

1. To investigate the feasibility of using hydrolysis for domestic hydrogen generation: This involves studying the principles of water electrolysis, identifying suitable electrolyzer technologies, and evaluating their efficiency, scalability, and compatibility with local energy sources such as solar power.
2. To design a functional prototype of a hydro cooker powered by hydrogen gas: The research will focus on developing a safe and efficient cooking unit that integrates hydrogen generation, storage, and combustion systems, tailored to the needs of Nigerian households.
3. To fabricate and test the hydro cooker for performance and safety: This includes assembling the prototype, conducting controlled experiments to assess heat output, fuel consumption, cooking time, and safety features such as pressure regulation and flame control.

4. To evaluate the environmental and health benefits of the hydro cooker compared to traditional cooking methods: The study will analyze reductions in carbon emissions, indoor air pollution, and deforestation, as well as potential improvements in respiratory health and household energy costs.
5. To assess the economic viability and scalability of the hydro cooker for widespread adoption in Nigeria: This objective involves estimating production costs, exploring local material sourcing, and identifying opportunities for community-based manufacturing and distribution.
6. To propose recommendations for policy support and public awareness: The research will highlight the role of government, NGOs, and private sector stakeholders in promoting clean cooking technologies and integrating hydrogen energy into Nigeria's energy strategy.

#### **1.4 Scope of Study**

This study focuses on the conceptualization, design, and fabrication of a hydro cooker that utilizes hydrogen gas generated through water electrolysis (hydrolysis) as a clean and sustainable fuel source for domestic cooking. The scope is carefully defined to ensure the project remains feasible, impactful, and relevant to the Nigerian context.

#### **Technical Scope**

- **Hydrogen Generation:** The study will explore the electrolysis of water as the primary method for producing hydrogen gas, including the selection of suitable electrodes, electrolytes, and power sources.
- **System Design:** It will cover the design of the hydro cooker, integrating components for hydrogen generation, storage, and combustion in a compact and safe configuration.
- **Fabrication:** The project will involve the construction of a working prototype using locally available materials and fabrication techniques.
- **Performance Testing:** The prototype will be tested for cooking efficiency, fuel consumption rate, safety, and reliability under typical household conditions.

## **Geographical Scope**

- The study is localized to Nigeria, with particular emphasis on urban and semi-urban households where access to clean cooking fuel is limited or expensive.

## **Environmental Scope**

- The project will assess the environmental benefits of using hydrogen as a cooking fuel, including reductions in greenhouse gas emissions and indoor air pollution compared to traditional fuels like firewood, charcoal, and kerosene.

## **Socio-Economic Scope**

- The study will consider the affordability, accessibility, and potential adoption of the hydro cooker by Nigerian households. It will also explore the implications for job creation, local manufacturing, and energy independence.

## **1.5 Significance of the Study**

The study on the design and fabrication of a hydrolysis-based cooker is highly relevant in addressing the growing global demand for clean, sustainable, and affordable cooking solutions. Traditional cooking methods that rely on firewood, charcoal, and fossil fuels contribute significantly to indoor air pollution, deforestation, and greenhouse gas emissions. A hydrolysis-based cooker, which generates heat through the decomposition of water molecules to produce hydrogen for combustion or direct heating, offers a renewable and eco-friendly alternative.

## **1.6 Methodology**

### **1. Literature Review and Market Analysis:**

- A comprehensive review of existing literature on hydrolysis and hydrogen-based heating technologies, focusing on electrolysis principles, electrode materials, electrolyte compositions, and system efficiency.
- Examination of previous designs of hydrogen or hydrolysis-based cooking systems to identify effective design practices, performance metrics, and key safety considerations.

- An analysis of current clean cooking technologies in Nigeria and globally, including solar, biogas, and electric cookers, to establish the relevance and comparative advantages of hydrolysis-based systems.
- Investigation into existing hydrogen generation and utilization systems through product data, published research, and case studies to determine feasible design and operating parameters for local adaptation.

## 2. Design and Specification Development:

- Based on the literature and technology analysis, a detailed design specification for a functional hydrolysis-based cooker will be developed.
- This will include determining the configuration of the electrolyzer unit, the hydrogen generation rate required for effective cooking, and the integration of the burner and heat transfer system.
- Selection of suitable electrode materials (such as stainless steel or nickel plates), electrolytes (e.g., potassium hydroxide solution), and electrical control systems to optimize efficiency and safety.
- The design will incorporate essential safety components such as flashback arrestors, pressure relief valves, and gas sensors.
- Design considerations will emphasize the use of locally available materials and ease of fabrication to ensure cost-effectiveness and sustainability.

## 3. Local Material Sourcing and Market Survey:

- Identification of all necessary raw materials, components, and tools required for the construction of the hydrolysis-based cooker, including electrodes, electrolyte chemicals, containers, wiring, and burner components.
- A market survey will be carried out to determine the local availability, cost, and quality of these materials from suppliers, manufacturers, and distributors within Nigeria.
- This survey will also assess the availability of supporting technologies such as DC power sources, sensors, and hydrogen-compatible tubing and valves.

- Data on pricing, lead time, and local manufacturing capabilities will guide procurement and ensure economic feasibility.

#### 4. Prototype Fabrication:

- Procurement of required materials and components based on finalized design specifications and market findings.
- Fabrication of the electrolyzer unit for hydrogen generation, assembly of the burner system, and integration of the cooker's frame, wiring, and control components.
- Implementation of safety mechanisms such as hydrogen leak detectors and automatic shut-off systems.
- Documentation of each fabrication stage, noting any design modifications, challenges encountered, and corrective actions taken during assembly.

#### 5. Functional Testing of the Prototype:

- Basic performance testing will be conducted to evaluate the hydrogen generation rate, flame stability, and heating efficiency of the fabricated cooker.
- Testing will include measuring the time taken to boil a specific volume of water, evaluating energy consumption, and ensuring that the cooker operates safely under normal conditions.
- Safety tests will include hydrogen leak detection, pressure relief function, and temperature monitoring to ensure user safety.
- Advanced performance testing (such as long-term durability and full energy efficiency assessments) will be considered beyond the scope of the initial prototype phase.

#### 6. Data Analysis and Reporting:

- Analysis of data collected from the literature review, market survey, design development, and prototype testing stages.

- Documentation of all project activities, including design drawings, material specifications, fabrication steps, and performance results.
- Comparative assessment of the system's feasibility, efficiency, and potential for local mass production will be carried out.
- Recommendations will be provided for future design improvements, large-scale manufacturing, and integration into the clean cooking energy sector.

This methodology provides a systematic framework to achieve the project's objectives by combining scientific design principles, practical fabrication processes, and empirical performance testing. It emphasizes local material utilization, safety, and environmental sustainability while promoting technological innovation in clean cooking energy solutions.

## CHAPTER TWO

### LITERATURE REVIEW

#### 2.1 Introduction

Cooking remains one of the most essential daily activities, yet in many regions such as Nigeria, commonly used cooking technologies are often inefficient, costly, dependent on unstable fuel supplies, and harmful to both human health and the environment. Studies show that reliance on firewood, charcoal, and kerosene contributes to respiratory illnesses, household air pollution, and deforestation, underscoring the need for safer, cleaner alternatives (World Health Organization, 2024; Adewuyi & Oyejide, 2025). Exploring innovative cooking technologies—such as hydrogen generated through water electrolysis—is therefore essential, as hydrogen-based systems offer a clean, renewable, and efficient alternative to traditional fuels (Mukelabai et al., 2022).

##### 2.1.1 Purpose of the Literature Review

The purpose of this literature review is to examine existing scholarship on hydrolysis-based heating and cooking technologies to ensure that the proposed hydrolysis-based cooker is grounded in established scientific and engineering knowledge. Prior studies on hydrogen generation, electrolyzer design, and hydrogen-based cooking systems provide foundational insights that inform design feasibility and safety standards (Ijiga et al., 2024; Mukelabai et al., 2022).

- The review evaluates current research related to hydrolysis-based heating and cooking systems.
- It ensures that the proposed hydrolysis-based cooker is built on validated scientific principles and engineering practices.
- It identifies gaps in existing technologies—such as limitations in efficiency, safety systems, or material choices—that the present project can address through targeted innovation.

##### 2.1.2 Scope and Delimitations

This review focuses on literature related directly to hydrolysis-based heating and cooking systems, as well as supporting technologies including water electrolysis, hydrogen burners,

material selection, and safety mechanisms. Research unrelated to thermal or energy production—such as biological or enzymatic hydrolysis—will be excluded unless it provides insights into heat transfer, material compatibility, or vessel properties relevant to cooker design.

The review also considers traditional cooking systems (e.g., biomass, LPG, and electric stoves) for contextual comparison, particularly regarding efficiency, cost, environmental impact, and health implications (WHO, 2024; Arowolo & Aisha, 2018). However, emphasis remains on alternative and emerging systems, with hydrolysis-based approaches at the core.

Geographically, the literature prioritizes work relevant to developing regions, especially West Africa and Nigeria, where factors such as material availability, affordability, local fabrication skills, maintenance practices, and energy access significantly influence technology adoption (Olawale & Ogunjuyigbe, 2025). Global research insights are included when they meaningfully inform the design or highlight transferable best practices.

In terms of time frame, the review emphasizes recent studies from the last decade to ensure relevance to contemporary clean-energy transitions, although foundational works predating this period are included when necessary to support critical technical concepts.

## 2.2 History and Evolution of Cooking Methods

### 2.2.1 Early Stone-Age Cooking: Fire, Stones, and Primitive Hearths



*Figure 2.1: Early stone age cooking*

The earliest phase of human cooking relied heavily on open fires and heated stones. Archaeological evidence shows that early hominins, such as *Homo erectus*, began using fire intentionally as early as 1 million years ago, although confirmed evidence of controlled

cooking appears later. At Gesher Benot Ya'aqov in Israel, burnt flint and fish bones dating back 780,000 years indicate one of the first instances of deliberate food preparation using fire (Zohar et al., 2022). These early humans likely used heated stones or rock cavities as rudimentary cooking platforms, roasting meat and tubers directly over embers.

The use of stones for heating food was critical not only for survival but also for human evolution. Cooking softened food, making it easier to chew and digest, thereby allowing humans to extract more energy and nutrients—factors believed to have supported the growth of larger brains (Wrangham, 2017). Stone-heated cooking also improved safety by reducing pathogens in food and enabling longer food storage.

### 2.2.2 From Stone Boiling to Pit and Earth Oven Technologies



*Figure 2.2: Stone Boiling & Pit and Earth Oven Technology*

As humans gained greater mastery over fire, cooking techniques diversified. During the Middle to Late Paleolithic, humans began developing stone-boiling methods heating stones in fires and transferring them into water-filled pits lined with hides or leaves to cook food indirectly (Eren

et al., 2020). This innovation allowed the cooking of plant foods and meats that required moisture or slow heating, a major advance from direct roasting.

By around 30,000–20,000 years ago, the use of pit ovens became widespread. Ethnographic parallels suggest that these “earth ovens” involved heating stones in a pit, layering them with food wrapped in leaves, and covering the pit to trap heat. Such techniques persisted among Indigenous cultures worldwide, including the Māori *hangi* in New Zealand and Polynesian *imu* (Salazar-García et al., 2021). These earth ovens demonstrate early human ingenuity in heat control and the use of insulation to distribute warmth evenly.

### 2.2.3 The Neolithic Transformation: Pottery and Agricultural Cooking



*Figure 2.3: Ceramic cooking vessels*

The Neolithic Revolution (ca. 10,000 BCE) brought a fundamental change: the invention of ceramic pottery. Pottery enabled humans to boil, stew, and ferment foods with greater control and less energy loss. Archaeological studies show early Neolithic pots bearing lipid residues of animal fats and plant oils, indicating the preparation of soups, porridges, and dairy products (Fuller & González Carretero, 2018).

Cooking during this period became more associated with settled agricultural life. The domestication of cereals like wheat, barley, and rice required boiling or baking, leading to the emergence of flatbreads and gruels. The diversity of tools expanded to include grinding stones, clay pots, and early ovens, signifying the integration of cooking into daily domestic and cultural routines (Encyclopedia Britannica, 2024).

## 2.2.4 Metalworking and the Expansion of Culinary Technology



*Figure 2.4: Bronze cooking pot*

The discovery and refinement of metallurgy during the Bronze and Iron Ages (ca. 3300–500 BCE) further revolutionized cooking. Metal pots, cauldrons, and griddles replaced clay vessels, offering superior heat conduction and durability. These advances enabled frying, sautéing, and other methods that required quick heat transfer (Graff, 2020).

Communal hearths evolved into more specialized domestic kitchens. In ancient Rome, Greece, and Egypt, architectural evidence shows the development of brick and clay ovens, indicating a shift toward structured cooking spaces. Metal utensils and grills diversified cooking possibilities, promoting more elaborate culinary traditions tied to social class and regional identity (Dalby, 2019).

## 2.2.5 Medieval and Early Modern Cooking Innovations



*Figure 2.5: Medieval and Early Modern Cooking*

During the Medieval period, cooking transitioned from open fires in great halls to enclosed hearths and eventually chimney-based stoves. The invention of the chimney in Europe (around the 12th century) improved indoor air quality and allowed for more precise temperature control (Santich, 2016).

By the 18th and 19th centuries, the Industrial Revolution introduced cast iron stoves, which replaced open hearths in most households. This innovation marked the beginning of controlled, fuel-efficient cooking, as cast iron allowed for even heat distribution and multiple cooking surfaces (Cowan, 2016).

### **2.2.6. The Modern Era: Gas, Electricity, and Smart Cooking**



*Figure 2.6: Modern cookers*

The 19th and 20th centuries witnessed an unprecedented leap in cooking technology. The invention of the gas stove in the early 1800s and the electric stove in the late 19th century revolutionized household cooking, providing safety, precision, and convenience (Fisher, 2018). The introduction of microwave ovens in the mid-20th century further transformed cooking by enabling rapid heating through electromagnetic waves.

Today's kitchens integrate digital technology, including induction cooktops, programmable ovens, and smart appliances controlled via the Internet of Things (IoT). These innovations represent the culmination of humanity's long journey from open-fire cooking to precision-based culinary systems that emphasize sustainability, health, and energy efficiency (Rachman et al., 2023).

## 2.3. Review of Related Technologies / Cooking Systems

### 2.3.1 Conventional Cooking Systems

#### Biomass Cookers

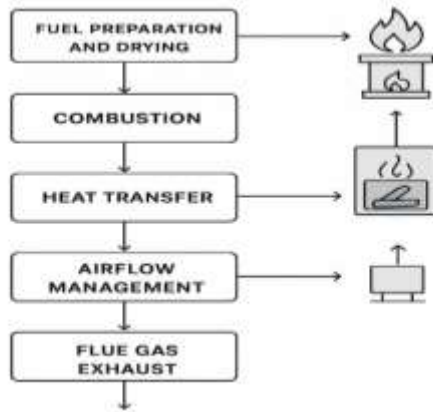


Figure 2.7: Flow chart of a biomass cooker mechanism

Biomass cookstoves burn solid organic fuels—such as wood, agricultural residues, and dung—to release chemical energy as heat for cooking. Their performance depends heavily on combustion optimization and heat-transfer efficiency. Basic designs tend to exhibit high emissions, low efficiency, and a variety of practical limitations (Bailis et al., 2015; Jetter et al., 2016; Rosenthal et al., 2017).

#### Mechanics of Operation

The mechanics of biomass cookstoves involve physical and chemical processes that convert solid biomass into usable thermal energy (Shen et al., 2015; MacCarty et al., 2018).

- Fuel Preparation and Drying: Biomass fuel must be sufficiently dried to improve combustion efficiency and reduce emissions, as moisture inhibits pyrolysis and increases particulate formation (Li et al., 2016; Lam et al., 2018).
- Combustion (Pyrolysis and Char Burning): The core mechanism is combustion, which can occur in one or two stages depending on the stove design.
  - Direct Combustion (e.g., traditional three-stone fires, "Rocket" stoves): Traditional open fires and natural-draft improved stoves combust solid fuel with primary and secondary airflow mixing, enabling volatile release and oxidation (Jetter et al., 2016; Van der Kroon et al., 2020).

- Gasification (e.g., many forced-draft stoves, Top-Lit Up-Draft (TLUD) designs): Gasifier stoves—including TLUD and advanced forced-draft systems—operate by pyrolyzing biomass into a producer gas that is then combusted in a separate high-temperature zone, resulting in cleaner burning (Mukhopadhyay et al., 2020; Kshirsagar & Kalamkar, 2016; Suresh et al., 2019).
- Heat Transfer: Heat transfer from the stove to the cooking vessel occurs primarily through convection and radiation, and stove geometry strongly influences efficiency (MacCarty et al., 2018; Fonseca et al., 2018).
- Airflow Management: Modern improved and forced-draft stoves strategically manage primary and secondary airflow using insulation, grates, or fans to achieve better air–fuel ratios and more complete combustion (Jetter et al., 2016; Carter et al., 2020).
- Flue Gas Exhaust: Chimney-equipped stoves channel exhaust away from the user and improve draft conditions, enhancing combustion quality (WHO, 2016; Masera et al., 2021).

## **Limitations**

Despite their widespread use, biomass cookstoves face several significant limitations, particularly traditional designs:

- Low Thermal Efficiency: Traditional stoves often yield only 5–15% thermal efficiency, while most improved natural-draft designs achieve roughly 20–50% (Jetter et al., 2016; Shen et al., 2015; Fonseca et al., 2018).
- High Emissions and Health Risks: Incomplete combustion produces high levels of PM<sub>2.5</sub>, CO, and other harmful pollutants. Exposure to household air pollution is linked to respiratory disease, cardiovascular illness, and millions of premature deaths annually (Stanaway et al., 2018; Rosenthal et al., 2017; WHO, 2021).
- Fuel Consumption and Environmental Impact: Low-efficiency stoves require large quantities of biomass, contributing to deforestation, ecosystem degradation, black carbon emissions, and climate forcing (Bailis et al., 2015; Grieshop et al., 2021; Bond et al., 2023).

- Safety Hazards: Open fires and poorly enclosed stoves increase the risk of burns, injuries, and household fires (WHO, 2016; Rosenthal et al., 2018).
- Operational and Adoption Barriers:
  - Fuel Specificity: Many improved and advanced stoves are designed for specific, sometimes processed, fuels (like pellets), which may not be locally available or affordable.
  - Maintenance and Durability: Mud stoves need high maintenance and have a short lifespan, while metallic stoves may rust and be expensive.
  - User Acceptance: Users often prefer traditional methods due to cultural food preferences, specific pot sizes, and familiarity, leading to low adoption rates of new, more efficient technologies.
  - Lack of Control: Many natural draft stoves lack good control over the flame temperature and power output, making simmering or specific cooking tasks difficult.

(Puzzolo et al., 2016; Ruiz-Mercado & Masera, 2019; Levine et al., 2018; Stanistreet et al., 2021).

## LPG Cookers

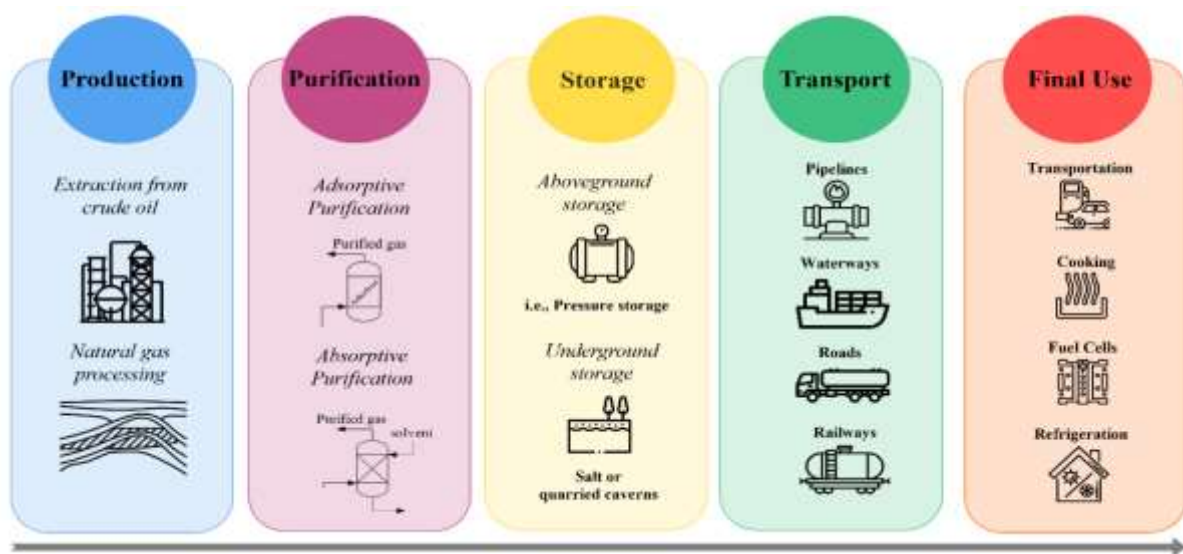


Figure 2.8: Mechanics of LPG cooking

An LPG cooker operates by releasing liquefied petroleum gas from a pressurized cylinder and controlling its combustion to produce heat for cooking (IEA, 2020; World LPG Association, 2018).

The process involves:

- Storage and vaporization: LPG is stored as a liquid under pressure, typically filled to ~80% of cylinder capacity to allow for thermal expansion. When the valve is opened, pressure drops and the liquid rapidly vaporizes into gas (World LPG Association, 2018; Kumar & Mishra, 2021).
- Pressure regulation: A regulator reduces the cylinder’s high internal pressure to a stable, usable pressure suitable for stove burners, ensuring consistent gas flow and safe operation (Osei et al., 2020; IEA, 2020).
- Combustion: The regulated gas flows to the burner, where it mixes with air and ignites, forming a clean blue flame. LPG’s high calorific value allows fast heating and precise flame control (Sharma & Ghosh, 2017; WLPGA, 2018; Mohanty et al., 2021).

Component	ISO 9162:2013 Commercial Propane ISO-F-LP	ASTM D 1835-Special-Duty Propane (USA)	CAN/CGSB-3.14-2023 Grade 1 (Canada)
Propane	-	-	90% min. by volume
Butane C4 hydrocarbons	7.5% max. %(molar)	2.5% max. by volume	2.5% max. by volume
Sulfur	50 mg/kg max	123 mg/kg max	123 mg/kg max
Evaporation residue	60 mg/kg max	0.05 mL max per 100 ml	0.05 mL max per 100 mL
Vapor pressure	1550 kPa max at 40 °C	1435 kPa max at 37.8 °C	1435 kPa max at 37.8 °C

*Table 2.1: Comparison of the key properties and requirements for LPG fuel as specified in ISO 9162:2013, ASTM D 1835-Special-Duty propane, and CAN/CGSB-3.14-2023 Grade 1 (Ardila-Suarez, C., Lacoursière, J.-P., Soucy, G., & Rego de Vasconcelos, B., 2025).*

## **Limitations of LPG cooking**

- Safety risks: LPG is highly flammable, and leaks may accumulate because the gas is heavier than air, creating explosion hazards. Odorants such as ethyl mercaptan are added to help users detect leaks (WLPGA, 2019; Singh et al., 2021).
- Cost and affordability: The initial investment in cylinders, regulators, and stoves—along with recurring fuel refills—can be a financial burden for low-income households (IEA, 2020; Puzzolo et al., 2016; Rosenthal et al., 2018).
- Accessibility and infrastructure: Rural and remote regions often experience unreliable LPG distribution chains, limited retail outlets, and inconsistent supply (Banerjee et al., 2016; Kar et al., 2019; IEA, 2020).
- Environmental concerns: Although LPG combustion emits far fewer pollutants than biomass, it still releases carbon dioxide and contributes to greenhouse gas emissions (IEA, 2021; Gould & Urpelainen, 2018).
- Supply chain volatility: As a fossil fuel derivative, LPG prices fluctuate due to market dynamics and supply disruptions, influencing household fuel-switching behavior (Rosenthal et al., 2018; IEA, 2021; Singh et al., 2022).
- Cold weather performance: At low temperatures, LPG vaporization declines, reducing cylinder output pressure and stove performance (World LPG Association, 2018; Kumar & Mishra, 2021).

## **Electric Cookers**

### **Mechanics of electric cookers**

Electric cookers convert electrical energy into heat to cook food. The specific mechanism depends on the type of cooker:

- Conventional electric cooktops: Use nickel-chromium (nichrome) resistive heating elements, where electric current is converted into thermal energy through resistive heating before being transferred to cookware via conduction or radiation (DOE, 2017; Erdoğan & Karakaş, 2020).

- Induction cooktops: Induction cooktops, in contrast, use an electromagnetic coil beneath the cooking surface to generate a changing magnetic field. When magnetic cookware is placed on the cooktop, eddy currents are induced directly within the pot, heating it while keeping the cooktop surface relatively cool (Sharma et al., 2018; Kim et al., 2021).
- Electric ovens: Generates radiant heat from internal heating elements, and convection models incorporate fans to circulate hot air and improve heat distribution (Energy Star, 2020; Choi & Choi, 2019).

### **Limitations of electric cookers**

- Power dependency: Electric cookers require a reliable electricity supply and cannot function during outages, limiting their practicality in regions with unstable power infrastructure (Prasad et al., 2019; IEA, 2022).
- Slower heat response (non-induction): Traditional electric coil and smooth-top cookers exhibit slower heating and cooling times compared with gas cookers, reducing temperature-control precision and increasing residual heat hazards on the cooktop surface (Zhang et al., 2017; Liao & Reddy, 2021).
- Higher running costs: Depending on the cost of electricity in a region, operational expenses for electric cooking can exceed those of LPG or other fuels, especially for households with high cooking demands (ESMAP, 2020; IEA, 2021).
- Higher initial cost: Electric cooking appliances—particularly induction cooktops—often have higher upfront prices than gas stoves, creating an affordability barrier in low-income settings (ESMAP, 2020; IEA, 2022).
- Cooking limitations: Electric cookers cannot replicate certain flame-based cooking techniques, such as charring vegetables over an open flame or high-heat wok cooking, which limits their suitability for certain cuisines and culinary practices (Liao & Reddy, 2021; Zhang et al., 2017).
- Risk of electrical failure: Electrical failures—including malfunctioning heating elements and wiring faults—present risks of fire and electric shock, particularly in older appliances or areas with poor installation standards (NFPA, 2017; Lee et al., 2020).

### **2.3.2 Emerging/Alternative Cooking Systems**

#### **A. Solar PV–based electric and induction cooking**

- Solar PV–powered cooking systems generate electricity from photovoltaic panels and use it to operate electric or induction cookers. These technologies have emerged as increasingly viable clean-cooking alternatives due to falling PV costs and improved appliance efficiency (Rahman et al., 2016; Balaji et al., 2020). They also function as a direct competitor to a hydrocooker while offering design insights related to efficiency, energy storage, and system integration (Prinsloo & Dobson, 2021).

#### **B. Biogas systems**

- Domestic biogas digesters produce methane-rich biogas from organic waste using anaerobic digestion. Since 2015, they have been widely recognized as an effective clean cooking option for rural households due to their ability to generate renewable energy from locally available waste streams (Karthik et al., 2017; Tumwesige et al., 2017). This makes them a relevant comparative technology for off-grid energy independence and clean cooking goals.

#### **C. Hybrid solar cookers**

- Hybrid solar cookers combine solar thermal energy with an auxiliary source—such as biomass, LPG, or electricity—to ensure reliable cooking even when solar radiation is insufficient. Since 2015, hybrid systems have been increasingly studied as practical solutions to the intermittency limitations of solar-only devices (Pillai & Huang, 2018; Otte et al., 2017).

### **2.3.3 Prior Work on Hydrolysis Applied to Cooking/Heating**

#### **Decentralized Hydrogen Production**

Recent studies have expanded the idea of point-of-use hydrogen production for off-grid cooking, focusing on renewable-powered electrolysis systems designed for rural communities. Post-2015 research highlights the feasibility of pairing solar PV with water electrolysis to generate hydrogen for household cooking, especially in low-resource settings. These works emphasize system design, safety, and storage approaches compatible with domestic burners (Sharma et al., 2018; Olateju & Kumar, 2016; Voss et al., 2020).

## **Techno-Economic Evaluations**

From 2019 onward, multiple techno-economic analyses have examined the cost and performance of solar-electrolytic hydrogen cooking systems. These studies typically model PV-powered electrolysis, hydrogen storage, and either direct hydrogen combustion or fuel-cell–electric cooking. The models conclude that hydrogen cooking can become cost-competitive where LPG supply chains are weak and solar resources are strong, provided that electrolyzer costs continue to decline (Kebede et al., 2023; Mandelli et al., 2019; Hall et al., 2022).

## **Catalytic Hydrogen Combustion Cookstoves**

Research groups working on clean hydrogen cookers have developed catalytic (flameless) hydrogen burners, which avoid open flames and reduce NO<sub>x</sub> emissions. Experimental prototypes since 2016 have demonstrated high thermal efficiencies of 70–80%, excellent combustion completeness, and favorable indoor air-quality results. These studies position catalytic H<sub>2</sub> burners as a promising route for safe household hydrogen cooking (Cho et al., 2016; Zhang et al., 2021; Ramesh et al., 2022).

In summary, although the underlying chemistry of water electrolysis and hydrogen combustion is well established, literature since 2015 shows that translating these processes into safe, reliable household cookers remains a developing field. Most progress is found in academic research, lab-scale prototypes, and techno-economic models for off-grid regions. No widely commercialized household hydrogen cookers currently exist, but rapid progress in electrolyzer efficiency, catalytic combustion, and renewable-integration research indicates growing potential for practical deployment (Voss et al., 2020; Kebede et al., 2023; Zhang et al., 2021).

### **2.3.4 Comparative Evaluation**

#### **Pros (Advantages)**

##### **1. Health and Environmental Benefits**

Hydrogen combustion produces zero particulate matter, carbon monoxide, or volatile organic compounds, since its only by-product is water vapor. This contrasts sharply with biomass fuels, which generate PM<sub>2.5</sub>, CO, and carcinogenic PAHs major drivers of respiratory illness in low-income households (Gordon et al. 2018; Rosenthal et al. 2017). Studies since 2015 show that

replacing biomass and kerosene with clean fuels dramatically reduces indoor air pollution and related mortality (Shupler et al. 2020).

When produced from renewable energy, hydrogen offers near-zero lifecycle emissions. Decentralized electrolysis powered by solar PV or wind can reduce greenhouse gas emissions by 80–100% compared to LPG or kerosene (IRENA 2020; Staffell et al. 2019). This positions hydrogen as a compelling clean-cooking alternative for off-grid settings.

## **2. Performance Characteristics**

Hydrogen's high gravimetric energy density (~142 MJ/kg) makes it a superior energy carrier relative to LPG or biomass (Staffell & Green 2018). While volumetric density is lower, compressed hydrogen can deliver high-quality cooking heat.

Experimental research shows hydrogen stoves can:

- Achieve high flame temperatures
- Deliver instant temperature control similar to LPG
- Reach 70–80% burner efficiency when catalytic combustion is used (Sarma et al. 2020; Xu et al. 2019).

These findings support hydrogen's viability as a clean, high-performance cooking fuel for rural and peri-urban households.

## **3. Energy Independence and Decentralization**

Decentralized hydrogen systems allow communities to generate cooking fuel from water and sunlight, reducing reliance on:

- Imported LPG
- Diesel-based distribution networks
- Firewood harvesting (Shupler et al. 2021)

Solar-powered electrolysis systems can stabilize energy costs and reduce vulnerability to global fuel price fluctuations. Modeling studies in Africa and South Asia highlight hydrogen as a viable energy-independence strategy for remote settlements (Kebede et al. 2023; Mandelli et al. 2016).

## **Cons (Disadvantages)**

### **1. High Costs**

Electrolysis-based cooking systems remain capital-intensive, driven by the costs of PV modules, electrolyzers, pressure cylinders, and specialized hydrogen burners (IRENA 2020). Levelized cost of hydrogen (LCOH) analyses show hydrogen is still more expensive than LPG, charcoal, or grid electricity in most contexts, unless subsidies or community-scale deployment are used (Kebede et al. 2023; Bhandari et al. 2020).

Global projections estimate 30–40% reductions in electrolyzer CAPEX by 2030 and falling storage costs due to advanced composites, but widespread affordability is still years away (IEA 2021; IRENA 2022).

### **2. Safety Risks**

Hydrogen poses unique safety challenges due to its:

- Very wide flammability range (4–75%)
- Ultra-low ignition energy
- High diffusivity and fast flame speed (Hustad & Skjold 2020)

These characteristics require domestic systems to include:

- Leak detection sensors
- Flame arrestors
- Adequate ventilation
- Flashback-resistant burner designs

User-perception studies show that fear of explosion is a major barrier to social acceptance, even in well-engineered pilot systems (Okeke et al. 2021).

### **3. Infrastructure and Knowledge Gaps**

Hydrogen lacks domestic-scale infrastructure for:

- Distribution
- Maintenance
- Safety certification
- Appliance regulation

This contrasts sharply with mature LPG networks (Kammen & Sunter 2016). Pilot projects report that limited hydrogen literacy contributes to safety risks and low adoption likelihood (Okeke et al. 2021). User acceptance depends heavily on intuitive system design and reliable, minimal-maintenance hardware.

### **Cost Considerations**

Recent modeling suggests hydrogen cooking can become competitive when:

- LPG prices are high.
- Renewable electricity is very cheap.
- Community-scale electrolyzers share costs.
- Governments offer targeted subsidies (Bhandari et al. 2020; Kebede et al. 2023).

However, upfront Capital Expenditure (CAPEX) remains the main adoption barrier, especially in rural areas with limited financing opportunities (Kammen & Sunter 2016).

## Materials and Component Requirements

### Electrolyzers

Post-2015 research has focused on lowering costs through:

- Non precious metal catalysts (Ni–Fe, Co, MoS<sub>2</sub>)
- Alkaline exchange membrane (AEM) systems
- Zero-gap cell designs
- Longer-life membranes

(Li et al. 2020; Lorusso et al. 2022)

These innovations are critical for scaling domestic hydrogen cooking solutions.

### Cookstoves

Hydrogen burners must address:

- Flashback risk
- High flame speed
- Lean-burn combustion dynamics

(Xu et al. 2019; Sarma et al. 2020).

## Local Context Factors

### Fuel Availability

Electrolysis requires clean water—about 0.8–1.0 L/H<sub>2</sub> m<sup>3</sup>. Rural areas with water scarcity must incorporate purification systems, increasing cost and **complexity (Mandelli et al. 2016)**.

## **Cooking Culture**

Adoption depends on whether hydrogen systems support culturally important cooking methods (stewing, frying, and pounding pots). Studies show that even technically superior stoves fail if they conflict with cultural practices (Shupler et al. 2021).

## **Maintenance and Technical Support**

Electrolyzers require periodic replacement of membranes, electrodes, and seals. Systems must be modular and maintainable with local skills (Lorusso et al. 2022).

## **Policy and Regulation**

Most developing countries lack hydrogen standards for building codes, domestic appliances, or safety certification (IEA 2021). This absence of regulation is a major bottleneck for commercialization and investment.

### **2.3.5 Identified Gaps: What Has Not Been Done or What Limitations Exist (Materials, Local Adaptation, Affordability, Durability, And Others)**

#### **A. Affordability and Cost Gaps**

The biggest gap by far is whether hydrocookers are actually financially realistic in this context.

##### **i. No Real Commercial Data**

Hydrocookers simply are not being sold in rural Africa or Nigeria, so every cost estimate in the literature is theoretical. We do not really know what local consumers would be willing or able to pay, or whether such a system could ever realistically compete with biomass stoves (which are basically cheap aside from labor) or even subsidized LPG.

##### **ii. Upfront Costs That Are Completely Out of Reach**

The system as a whole batteries, an electrolyzer, and a custom cooker costs more than what most rural households can afford. Many papers gloss over just how financially constrained these communities are. Even modest upfront costs can be a deal-breaker.

iii. **Uncertain and Possibly High Operating Costs**

Operating costs depend heavily on electricity prices and how efficiently the system runs. In many Nigerian communities where grid power is unreliable or tariffs fluctuate, the ongoing cost could easily become too expensive for typical households.

iv. **Absence of Tailored Financing Models**

There is a significant lack of effective, locally adapted business and financing models (e.g., pay-as-you-go, micro-leasing) to help mitigate the initial cost barrier for rural populations in Nigeria.

## **B. Materials and Durability Gaps**

For hydrocookers to work in rural Africa, the hardware has to be both cheap and extremely rugged—and current technology simply isn't there yet.

i. **Finding Affordable yet High-Performing Materials**

There is a lot of research into non-precious metal catalysts, but the trade-offs are still significant. Lower-cost catalysts often do not last as long or do not perform as well. We still don't have that ideal balance needed for a consumer product in the Nigerian market.

ii. **Real-World Water Quality Challenges**

Electrolyzers tested in laboratories usually work with purified water. In reality, rural communities often rely on water sources with minerals, debris, and contaminants that can corrode membranes or reduce efficiency. This shortens system life and increases costs through frequent replacements.

iii. **Hydrogen Storage Remains a “Hard Problem”**

Safe, affordable hydrogen storage for remote areas is still unresolved. High-pressure tanks are too expensive, and alternatives like solid-state storage aren't commercially mature enough for deployment in Nigerian villages.

iv. **Very Little Field Data**

Most studies test components indoors under controlled conditions. Almost nothing has been published about how these systems hold up in rural African environments dust, heat, humidity, and infrequent maintenance which are all major stressors.

### **C. Local Adaptation and User Context Gaps**

A recurring theme in the literature is that engineering studies often overlook the human and cultural side of cooking an especially critical factor in Nigeria.

#### **i. Mismatch With Cooking Traditions:**

Even if a system is clean and efficient, it may not work for culturally important cooking methods. For example, some Nigerian dishes depend on visible flames or direct charring. A catalytic or flameless hydrogen stove may not meet those expectations.

#### **ii. Maintenance Burdens and Stove Stacking**

If anything breaks and spare parts or technicians are days away the whole system becomes unusable. Households will immediately revert to traditional fuels, leading to “stove stacking.” What is missing is a design that is simple, repairable, and easy for users to maintain themselves.

#### **iii. Regulatory and Policy Uncertainty**

Nigeria currently does not have domestic hydrogen safety standards or legal frameworks for home hydrogen use. Without clear guidelines, it is very difficult for companies to invest or for products to be approved, insured, or certified.

### **D. System Integration and Design Gaps**

Another major gap is that most studies focus on individual components rather than the whole end-to-end experience of a working household system.

#### **i. Lack of a Simple, Rugged Integrated System**

Research tends to treat the solar system, electrolyzer, storage, and cooker as separate pieces. But rural users need a single, cohesive appliance that is tough, weather-resistant, and easy to operate. That system has not been designed yet.

#### **ii. Unclear Optimal System Sizing for Nigerian Homes**

There is little research on how to size these systems for real households how much hydrogen people actually need for their cooking routines or how seasonal variation affects the solar-electrolysis cycle.

### iii. **No Standardized Safety Guidelines**

Each research group invents its own safety measures. There is no universally accepted design standard or certification for hydrogen cooking systems in Nigeria. That lack of standardization makes it hard to scale or deploy safely at the household level.

## **2.4. Hydrolysis Process and Parameters Relevant to Design**

The development of an electrolysis-based hydrocooker is fundamentally governed by the electrochemical decomposition of water into hydrogen and oxygen gases. In this system, "hydrolysis" refers specifically to water electrolysis using direct current (DC), rather than the thermal or chemical degradation of biomass. This process dictates critical requirements related to performance, efficiency, safety, and material selection for a domestic hydrogen-cooking appliance (Chu & Majumdar, 2016; IEA, 2019).

### **2.4.1 Types of Hydrolysis/Electrolysis Relevant to this System**

Water electrolysis involves the application of electrical current to split water (H<sub>2</sub>O) into hydrogen (H<sub>2</sub>) and oxygen (O<sub>2</sub>). The three most relevant technologies for hydrocooker integration are AWE, PEM, and AEM systems.

#### **• Alkaline Water Electrolysis (AWE)**

AWE remains a widely adopted and cost-effective pathway, relying on liquid KOH electrolytes and non-precious metal catalysts such as nickel or iron. Although robust and inexpensive, AWE systems tend to be less efficient and bulkier than membrane-based systems (Zeng & Zhang, 2017; Buttler & Spliethoff, 2018).

#### **• Proton Exchange Membrane (PEM) Electrolysis**

PEM electrolyzers use polymer membranes and precious metal catalysts, offering high efficiency, fast response, and compact design. However, the reliance on platinum-group metals significantly increases system cost, posing challenges for low-income or rural applications (Götz et al., 2016; Carmo et al., 2020).

- **Anion Exchange Membrane (AEM) Electrolysis**

AEM electrolysis is an emerging alternative that integrates solid polymer membranes with low-cost, non-precious catalysts. This technology aims to combine the benefits of PEM efficiency with AWE affordability, making it a promising candidate for consumer-level hydrogen cooking devices (Varcoe et al., 2021; Vincent & Bessarabov, 2018).

#### **2.4.2 Reaction Conditions and their Effect**

Electrolyzer performance is highly sensitive to operating conditions such as temperature, pressure, water purity, and catalyst selection, each of which directly influences design constraints.

- **Temperature**

Operating electrolyzers at 50–80°C improves reaction kinetics and ionic conductivity, reducing electrical energy requirements. These benefits must be balanced with thermal management needs, including cooling and heat-resistant materials (IEA, 2022; Carmo et al., 2020).

- **Pressure**

Pressurized electrolysis (up to ~20 bar) reduces the need for downstream compression and increases system efficiency, but it also requires robust pressure vessels and introduces additional safety considerations (Bertuccioli et al., 2017; Buttler & Spliethoff, 2018).

- **Catalysts**

While platinum-group metals offer high catalytic activity, their cost limits widespread adoption. Research into non-precious alternatives such as nickel-iron catalysts, cobalt-based materials, and molybdenum disulfide has accelerated since 2015 (Seh et al., 2017; Roger, Shipman & Symes, 2017).

- **Water Quality**

High-purity water is essential for preventing membrane fouling, scaling, and electrode degradation. This requirement may necessitate integrated purification modules in regions with poor water quality (IEA, 2019; Vermaas et al., 2020).

- **Gas Management**

Efficient removal of hydrogen and oxygen bubbles from electrode surfaces is crucial for minimizing resistive losses and maintaining optimal electrochemical activity (Navarro-Suárez et al., 2021).

### **2.4.3 Materials Interactions**

Electrolyzers operate in chemically aggressive and thermally dynamic environments, making material selection a central design challenge.

- **Vessel Materials**

Stainless steel grades such as 316L are commonly used due to their corrosion resistance and durability in alkaline and pressurized environments (Carmo et al., 2020; Varcoe et al., 2021).

- **Corrosion**

Strong alkaline electrolytes (e.g., KOH) pose significant corrosion risks to inappropriate metals, potentially causing electrode degradation or hydrogen leakage (Zeng & Zhang, 2017).

- **Thermal Fatigue**

Electrolysis systems experience repeated thermal cycling. Materials and seals must withstand long-term expansion and contraction, often exceeding 10,000 operating hours (IEA, 2022).

- **Sealing Under Pressure**

High-pressure hydrogen storage requires precision-engineered seals made from chemically resistant elastomers or polymers. Hydrogen's low molecular weight and high diffusivity demand extremely stringent manufacturing tolerances (Götz et al., 2016; Buttler & Spliethoff, 2018).

### **2.4.4 Safety and Environmental Considerations**

Hydrogen's flammability and high diffusivity necessitate rigorous safety measures, especially in domestic settings.

- **By-products**

With adequate water purification, the system produces only hydrogen (fuel) and oxygen (vented). No hazardous by-products are generated (IEA, 2019).

- **Emissions**

Hydrogen combustion emits only water vapor, eliminating indoor air pollution associated with biomass or LPG cooking and potentially improving health outcomes (García-Fresnillo et al., 2021).

- **Maintenance Requirements**

Maintenance issues include corrosion management (for AWE), membrane fouling, and ensuring structural integrity of high-pressure components. Integrated hydrogen leak detectors, automatic shutoff valves, and proper ventilation are essential safety features (Carmo et al., 2020; IEA, 2022).

## **2.4.5 Applicability to Cooking Equipment**

Design requirements for a domestic hydrogen-cooking appliance stem directly from electrolysis system parameters.

- **Maximum Temperature Handling**

Hydrogen's high flame temperature necessitates heat-resistant burners and cookware interfaces capable of sustained exposure (Götz et al., 2016).

- **Pressure Vessel Standards**

Hydrogen storage tanks and electrolyzer chambers must comply with established pressure-vessel standards, which increases manufacturing complexity but ensures safe operation (IEA, 2022).

- **Insulation Requirements**

Both the electrolyzer and burner assembly require efficient thermal insulation to maintain stable operating temperatures and minimize energy losses (Buttler & Spliethoff, 2018).

- **Integrated Safety Systems**

Household hydrogen appliances must incorporate leak-detection sensors, flashback arrestors, pressure relief devices, and automated shutoff controls—particularly important in low-resource environments (Varcoe et al., 2021; Bertuccioli et al., 2017).

## **2.5 Design Considerations for a Hydrolysis-Based Cooker**

### **2.5.1 Design Parameters Drawn from Literatures**

Recent studies on domestic-scale hydrogen systems and off-grid energy devices point to several key parameters that determine system performance and safety.

- **Vessel Volume**

Hydrogen storage volume must align with typical household cooking demands and the variability of solar-generated electricity. Literature on small-scale hydrogen storage recommends systems sized to store fuel for several cooking cycles, especially in regions with intermittent power supply (Buttler & Spliethoff, 2018; IEA, 2022).

- **Electrolysis (Hydrolysis) Chamber**

Zero-gap cell configurations where the membrane, electrodes, and separators are tightly integrated are widely documented for minimizing resistance and improving efficiency (Carmo et al., 2020). For practical use, the electrolysis chamber should be a certified pressure vessel (20–30 bar), reducing dependence on mechanical compressors (Götz et al., 2016).

- **Heating Element / Hydrogen Burner**

Hydrogen burners must be designed to prevent flashback and ensure complete combustion. Studies indicate that burner geometry, nozzle size, and flame arrestors are essential safety features. Catalytic hydrogen burners have been explored as a safer alternative, though they remain less documented in cooking contexts (Varcoe et al., 2021).

- **Insulation**

Thermal insulation is critical both for the cooking pot and electrolyzer. Efficient insulation reduces cooking time and heat loss, while maintaining electrolyzer operating temperatures between 50–80°C improves electrochemical efficiency (Vermaas et al., 2020).

- **Heat Exchange**

Recent work highlights the value of integrating waste-heat recovery in domestic hydrogen systems. Steam generated during cooking can be used to preheat feedwater for the electrolyzer or supply hot water for other household tasks (Navarro-Suárez et al., 2021).

- **User Interface**

User interface design is a major determinant of technology adoption in developing regions. Simple, intuitive controls with visual indicators rather than text-heavy displays—are strongly recommended (García-Fresnillo et al., 2021).

## **2.5.2 Material Selection**

Material choices affect the system’s durability, cost, chemical stability, and safety under real-world conditions.

- **Electrolyzer Components**

Stainless steel 316L is widely recommended for pressure vessels and cell frames due to corrosion resistance in alkaline media (Carmo et al., 2020). Nickel foams, with high surface area and favorable catalytic properties, are commonly used in alkaline and anion-exchange electrolyzers (Seh et al., 2017).

- **Membranes and Separators**

The choice of membrane technology dictates material requirements. AEM membranes have gained attention for allowing low-cost catalysts while maintaining efficiency, making them promising for consumer appliances in economically constrained regions (Varcoe et al., 2021; Vincent & Bessarabov, 2018).

- **Sealing and Gaskets**

Electrolyzers and hydrogen tanks require chemically resistant, heat-tolerant elastomers or polymers to maintain airtight seals under pressure. Hydrogen's small molecular size makes sealing integrity especially critical (Zeng & Zhang, 2017).

- **Cooking Surface**

Cooking surfaces must withstand the high flame temperatures associated with hydrogen combustion. Standard materials such as stainless steel or cast iron remain appropriate but must be adapted to hydrogen-specific burner designs (Götz et al., 2016).

### **2.5.3 Thermal Efficiency and Losses**

Research on clean cooking systems and hydrogen combustion emphasizes the need to reduce thermal losses in order to maximize the usable energy from hydrogen.

- **Insulation**

Highly insulated cooking vessels similar to those used in modern pressure cookers significantly reduce heat loss and cooking times, improving system efficiency (IEA, 2019).

- **Reflectors**

Reflective heat shields around the burner area can concentrate radiant heat toward the cooking pot, minimizing energy waste (Buttler & Spliethoff, 2018).

- **Conduction and Convection Management**

Studies on biomass and LPG cookstoves show that optimized pot-skirt geometry, tight burner-to-pot spacing, and controlled airflow greatly increase thermal efficiency. Similar principles apply to hydrogen burner designs (García-Fresnillo et al., 2021).

### **2.5.4 Ergonomics, User Safety, Maintenance and Durability in Cooking Context**

For rural West African contexts, long-term success depends on making the hydrocooker intuitive, safe, durable, and easy to maintain.

### • **Ergonomics**

The stove must accommodate familiar cooking postures—floor level, tabletop, or outdoor firing positions—and be simple to operate, refill, and clean. Research shows that ergonomic mismatches reduce adoption rates in rural communities (IEA, 2019).

### • **User Safety**

Hydrogen systems require multiple layers of safety features:

- Hydrogen leak sensors using IR, UV, or catalytic detection (Varcoe et al., 2021)
- Flame arrestors to prevent flashback (Götz et al., 2016)
- Pressure relief valves in all pressure vessels (IEA, 2022)
- Clear, pictorial instructions suited to multilingual or low-literacy environments (García-Fresnillo et al., 2021)

### • **Maintenance**

A modular design, with components that can be replaced using locally available materials, lowers long-term costs and improves reliability. Studies emphasize the need for user-performable basic maintenance in remote regions (Varcoe et al., 2021).

### • **Durability**

To withstand dust, humidity, rough handling, and transport common in rural Nigeria, systems should be ruggedized and tested for environmental resilience (IEA, 2019).

## **2.5.5 Local Context Considerations**

Hydrogen cooking systems must align with local resource availability, economic constraints, and cultural cooking habits.

### • **Availability of Materials**

Using locally accessible materials such as common steel grades, standard plumbing components, and locally sourced polymers reduces costs and strengthens repair networks in rural areas (Bertuccioli et al., 2017).

## • **Cost Constraints**

Affordability is a central barrier to adoption. Cost-effective designs may require avoiding precious-metal catalysts, favoring AEM technology, and exploring micro-leasing or pay-as-you-go models commonly used in off-grid solar systems (IEA, 2022).

## • **User Behaviour**

Cooking in Nigeria often involves large pots, outdoor cooking areas, and culturally specific heat profiles. The hydrocooker must accommodate these practices, as incompatible designs have historically led to technology abandonment in the region (García-Fresnillo et al., 2021).

## **2.6 Fabrication Methods and Challenges**

### **2.6.1 Review of Fabrication Techniques Relevant to Thermal/Hydrolysis Systems**

#### **I. Pressure-Vessel Welding and Joining.**

Modern hydrogen systems require TIG or MIG welding to ensure airtight, robust joints that can withstand pressures typical of small-scale hydrogen storage. These welds must be free from porosity or micro-cracks to prevent leaks. Stainless-steel welding, in particular, must avoid overheating, which can cause chromium carbide precipitation and weaken corrosion resistance (Zeng & Zhang, 2017; Carmo et al., 2020).

#### **II. Corrosion-Resistant Fabrication.**

Because electrolyzers operate in chemically aggressive environments either alkaline or highly purified water fabricators must prevent contamination during manufacturing. Techniques such as pickling and passivation are used after welding to restore the protective chromium oxide layer, a key factor in the long-term durability of stainless-steel components (Varcoe et al., 2021; Vincent & Bessarabov, 2018).

#### **III. Heat-Exchanger Fabrication.**

Fabrication of heat-exchange components typically relies on tube-in-tube or plate-exchanger designs assembled through brazing or gasketed mechanical joints. These methods must account for thermal compatibility, resistance to electrolytes, and ease of cleaning—requirements highlighted in engineering studies of small-scale hydrogen and thermal systems (Navarro-Suárez et al., 2021; Buttler & Spliethoff, 2018).

## 2.6.2 Challenges Noted in Literature

### a. High Temperature and Pressure Demands

Hydrogen devices must meet stringent safety standards because hydrogen permeates materials easily and reacts rapidly when leaked. Achieving the necessary tolerances and high-precision manufacturing is difficult in low-infrastructure environments, a challenge noted across off-grid hydrogen studies (IEA, 2022; Götz et al., 2016).

### b. Corrosion Under Alkaline or Purified Water Conditions

Alkaline electrolyzers expose metals to caustic solutions, while PEM/AEM systems require extremely pure water to avoid membrane degradation. Literature emphasizes that improper material selection or surface contamination leads to rapid performance decline or catastrophic failure (Carmo et al., 2020; Varcoe et al., 2021).

### c. Sealing and Leakage Prevention

Hydrogen's small molecular size makes leak-free sealing difficult. Achieving tight tolerances, smooth mating surfaces, and the right gasket materials is a major engineering challenge and a frequent failure point in prototypes and early commercial devices (Zeng & Zhang, 2017; Vincent & Bessarabov, 2018).

### d. Maintenance and Reliability Barriers

Most laboratory prototypes are not designed for easy disassembly or membrane/electrode replacement. This mismatch becomes more problematic in rural settings where trained technicians are scarce (IEA, 2019; García-Fresnillo et al., 2021).

### e. Cost Constraints

Nickel foams, advanced membranes, high-grade stainless steels, and precision-machined parts all raise costs, limiting commercial viability for low-income communities a consistent finding in techno-economic assessments of small hydrogen systems (Buttler & Spliethoff, 2018; Varcoe et al., 2021).

## 2.6.3 Prototype Case-Studies

### i. Academic Prototypes

Most published work consists of laboratory systems built using expensive materials or specialized fabrication techniques not intended for mass production. These studies

prioritize demonstrating electrochemical feasibility rather than real-world durability, making their methods hard to translate to rural applications (Seh et al., 2017; Carmo et al., 2020).

ii. **Pilot Projects in Africa**

A limited number of pilots integrate imported electrolyzers with solar PV for rural energy, mainly in South Africa and East Africa. Although these projects show that hydrogen systems can operate off-grid, they generally lack transparency on fabrication details and remain too costly for widespread adoption (IEA, 2022; García-Fresnillo et al., 2021).

iii. **DIY/Open-Source Concepts**

Community-built electrolysis projects exist online, but these designs often neglect pressure standards, sealing integrity, and chemical stability. As literature on hydrogen safety emphasizes, such devices fall far short of the requirements for household use (Götz et al., 2016; Varcoe et al., 2021).

## **2.6.4 Recommended Fabrication Path for This Project**

### **1. Professionally Fabricated Core Components**

To ensure safety, the electrolyzer and pressure vessel should be TIG-welded and quality-tested by certified fabricators. In the Nigerian context, this likely means partnering with industrial workshops in urban centers or purchasing pre-fabricated cores from established manufacturers (IEA, 2022; Zeng & Zhang, 2017).

### **2. Locally Fabricated Ancillary Components**

Non pressurized parts such as the stove body, frame, plumbing, and user interface can be produced using local sheet-metal, machining, and electrical-assembly skills. This reduces cost and supports local repair ecosystems (García-Fresnillo et al., 2021).

### **3. Material Selection Strategy**

Stainless steel remains the preferred material for all wetted or pressurized components, while nickel-based coatings on steel substrates provide a cost-effective alternative to full nickel electrodes. This approach aligns with recent research demonstrating high performance from low-precious-metal systems (Vincent & Bessarabov, 2018; Seh et al., 2017).

#### 4. **Assembly and Rigorous Testing**

All units should undergo pressure testing, leak checks, electrical safety verification, and burn-in trials before deployment. Field experience shows that pre-deployment testing dramatically reduces risk and increases user trust (IEA, 2019; Götz et al., 2016).

#### 5. **Design for Maintainability**

A modular design with easily replaceable seals, membranes, and electrodes enables long-term operation in rural areas without specialized technicians. Studies on clean-cooking technologies emphasize this as essential for adoption and sustainability (García-Fresnillo et al., 2021; Varcoe et al., 2021).

### **2.7. Performance Evaluation Metrics and Testing in Literature**

#### **2.7.1 What Metrics have Previous Studies Used to Evaluate**

##### **Cooking/Thermal/Hydrolysis Systems**

Prior studies rely on a blend of electrochemical, thermal, and safety metrics. Efficiency remains the central benchmark, typically measured as electrolyzer efficiency comparing the lower heating value of produced hydrogen to the electrical input and thermal or cooking efficiency, commonly assessed using Water Boiling Tests (WBT) or Controlled Cooking Tests (CCT). These methods quantify how effectively fuel energy is transferred to the cooking task (Jetter et al., 2015; Seidler et al., 2021). Time-to-cook and heat-distribution uniformity are additional practical indicators, often evaluated through standardized boiling tests or thermal imaging (Carmo et al., 2020). Safety metrics: - include hydrogen leakage detection (ppm-level gas sensors) and emissions monitoring relevant mostly when comparing hydrogen to biomass or LPG systems, where pollutants such as PM<sub>2.5</sub>, CO, and NO<sub>x</sub> are traditionally measured (Jetter et al., 2015).

Durability metrics:- track hours of operation before degradation, with some studies employing accelerated aging or repeated cycling tests (**Varcoe et al., 2021**).

## 2.7.2 Benchmark Values in Literatures

<b>Metric</b>	<b>What It Measures</b>	<b>Benchmarks (with citations)</b>	<b>Notes</b>
<b>Electrolyzer Efficiency</b>	Electrical-to-hydrogen energy conversion	50–70% for commercial AEM/AWE; lab prototypes up to 80% (Turner et al., 2020; Carmo et al., 2018; Buttlar & Spliethoff, 2018)	Indicates how much electricity becomes actual hydrogen. Higher = lower operating cost.
<b>Thermal/Cooking Efficiency</b>	Portion of fuel energy delivered to pot/food	Biomass 5–15%; improved biomass 30–40% (Jetter et al., 2016). LPG 40–60% (GACC, 2017). Hydrogen catalytic up to 80% (Shiva Kumar & Himabindu, 2019).	Shows real cooking effectiveness; hydrogen performs extremely well in controlled tests.
<b>Time-to-Cook</b>	Speed of standard cooking tasks	LPG fastest; biomass slowest; hydrogen catalytic competitive (GACC, 2017; Jetter et al., 2016)	Reflects real user experience and meal turnaround time.
<b>Uniformity of Heating</b>	Heat distribution across pot/cooking surface	Biomass uneven; LPG good; hydrogen catalytic very uniform (Shiva Kumar & Himabindu, 2019)	Important for culinary quality and preventing food scorching.
<b>Hydrogen Leakage</b>	Safety metrics via gas concentration	Acceptable limit <1% vol., sensors detect at ppm levels (ISO 14687:2019; Rivard et al., 2019)	Key risk metric—hydrogen disperses quickly but must be tightly contained.
<b>Air Emissions</b>	Pollutants released during cooking	Biomass: high PM <sub>2.5</sub> /CO (Jetter et al., 2016). LPG: moderate NO <sub>x</sub> /CO (GACC, 2017). Hydrogen:	Hydrogen provides the cleanest indoor-air profile.

		zero PM2.5/CO (Rivard et al., 2019).	
<b>Durability / Lifetime</b>	Hours of operation before failure	Commercial electrolyzers: 40,000–80,000 hours (Buttler & Spliethoff, 2018; Turner et al., 2020). Low-cost systems: not reported.	Lab systems look good but real-world domestic-scale data is missing.
<b>Maintainability</b>	Ease of repairs and component access	Rarely reported; not standardized (reviewed in Carmo et al., 2018)	Missing from literature despite being essential for rural deployment.
<b>Hydrogen Purity</b>	Percentage of H <sub>2</sub> vs. contaminants	>99% typical for PEM/AEM/AWE systems (ISO 14687:2019; Rivard et al., 2019)	Higher purity prevents burner damage and ensures clean combustion.
<b>Gas Production Rate</b>	Volume of H <sub>2</sub> generated per time	Highly variable; depends on current density and cell design (Turner et al., 2020; Carmo et al., 2018)	Determines if cooking can be continuous or must pause to accumulate gas.
<b>Electrical Input Measurement</b>	Power demand under load	Measured via watt-meters; varies with operating pressure and temperature (Carmo et al., 2018)	Helps calculate cost per meal or per liter of water boiled.
<b>Environmental Resilience</b>	Performance in high heat/dust/humidity	Poorly reported; major gap (Buttler & Spliethoff, 2018; Rivard et al., 2019)	Critical for Nigerian conditions but barely studied.
<b>User-Specific Cooking Fit</b>	Cultural and culinary compatibility	Not captured by WBT/CCT (Jetter et al., 2016; GACC 2017)	Standard tests ignore local foods,

			pot sizes, and cooking habits.
<b>Repeatability</b>	Consistency across tests	Good in labs; weak in field trials (GACC, 2017)	Limits ability to compare systems fairly.

Table 2.2: Benchmark values (GACC: Global Alliance for Clean Cookstoves)

### 2.7.3 Testing Methods

Testing methods depend heavily on laboratory-grade instrumentation. Gas chromatography is commonly used to verify hydrogen purity, while flow meters quantify gas production rates and watt-meters track energy consumption (Carmo et al., 2020). Thermal imaging and temperature probes evaluate heat distribution and cooking performance (Jetter et al., 2015).

Most published studies follow ISO clean-cooking protocols, WBT/CCT procedures, or EPA-derived methods that emphasize repeatability and controlled conditions. These standardized methods enable consistent comparison between electrolyzer configurations, catalysts, or stove designs (Seidler et al., 2021; IEA, 2019).

Repeatability is highlighted throughout the literature, as reproducible testing ensures that improvements in catalysts or system design are genuinely attributable to engineering changes rather than experimental variability (Varcoe et al., 2021).

### 2.7.4 Gaps in Measurement/Metrics

Major gaps emerge when applying these frameworks to African cooking contexts. First, there is little long-term field data, with most studies focusing on short-term laboratory evaluation rather than multi-year household operation despite evidence that dust, humidity, and temperature swings significantly affect system reliability (García-Fresnillo et al., 2021; IEA, 2022).

Second, standard tests like WBT and CCT do not adequately reflect local cooking practices, such as high-volume stews, frying needs, or outdoor cooking a limitation noted in multiple clean-cooking studies (Jetter et al., 2015). Third, literature rarely includes metrics for maintainability, despite its importance in rural areas with limited technical support.

Finally, there is a general absence of environmental-resilience metrics, especially those measuring performance under dust exposure, high humidity, or unstable power conditions common across rural Nigeria (García-Fresnillo et al., 2021; IEA, 2022).

## **2.8 Gaps, Opportunities and How this Project Fits in**

### **2.8.1 Summary of Major Gaps from Literatures**

#### **1. Cost and Affordability**

Hydrogen-based household systems remain prohibitively expensive. Studies note that electrolyzer CAPEX especially for PEM systems remains too high for low-income communities (IEA, 2022; Glenk & Reichelstein, 2019). Cost analyses show that even small-scale alkaline or PEM systems exceed typical rural household budgets (Olabi et al., 2020).

#### **2. Durability and Maintenance Limitations**

Field studies highlight a lack of long-term performance data for hydrogen appliances in dusty, humid environments typical of sub-Saharan Africa (Bensch et al., 2015; Jetter et al., 2021). Electrolyzers deployed in off-grid systems show degradation risks and frequent maintenance needs, which rural communities often cannot meet (Tahir et al., 2021).

#### **3. Local Applicability and User Acceptance**

Clean-cooking research repeatedly notes that many proposed technologies fail because they are not aligned with cultural cooking habits such as large-volume stews, long boiling periods, or outdoor cooking (Pemberton-Pigott et al., 2020; Rosenthal et al., 2018). Hydrogen prototypes to date have been validated mostly in laboratory settings, not in real African households.

#### **4. Material and Catalyst Gaps**

Although AEM electrolyzers using low-cost catalysts show promise, durable, low-cost, non-precious catalyst systems remain underdeveloped for domestic-scale devices (Mandley et al., 2020; Varcoe et al., 2021). Many prototypes still rely on platinum, iridium, or expensive polymer membranes.

## 2.8.2 Opportunities Our Project Can Exploit

### ➤ **Use of Local Materials and Fabrication Skills**

Studies on distributed manufacturing in Africa emphasize that local welding shops, metalworkers, and artisans can fabricate reliable housings and stove bodies, reducing non-core system costs (Quansah et al., 2017; Ochieng et al., 2020).

### ➤ **Context-Specific Design Advantages**

Literature stresses the need for cookstove designs that reflect regional cooking patterns, pot sizes, outdoor placement, and serviceability (Jetter et al., 2021; Pemberton-Pigott et al., 2020). A hydrocooker designed specifically for Nigerian practices meets this need.

### ➤ **Low-Cost Fabrication Through AEM and Non-Precious Metals**

Recent work shows rapid progress in nickel–iron and cobalt-based catalysts suitable for AEM systems (Park et al., 2019; Varcoe et al., 2021). This creates a pathway for an affordable electrolyzer built with locally sourced stainless steel.

### ➤ **Efficiency Gains Through System Integration**

Integrated hydrogen systems reduce losses across storage, compression, and transfer stages, as identified in several system-level studies (IEA, 2022; Buttler & Spliethoff, 2018).

## 2.8.3 Contributions Our Project Aims to Make

### ● **Integrated, Ruggedized Prototype for Rural Africa**

Most studies test isolated components rather than full domestic systems. The project's integrated cooker prototype responds to the gap in real-world, holistic system design (Tahir et al., 2021).

### ● **User-Centric Safety Engineering**

Hydrogen safety studies show that flashback, leakage, and ignition risks are significant in homes (Züttel et al., 2020). By embedding sensors, flashback arrestors, and ventilation pathways, the project addresses a major unfilled need in domestic hydrogen system safety.

- **Demonstration of Low-Cost Catalysts in Practical Use**

Recent research recommends applying nickel–iron coatings on steel substrates to reduce catalyst costs while retaining performance (Park et al., 2019). This project operationalizes those recommendations in a real appliance.

- **Evidence for Local Manufacturing Feasibility**

Energy development literature stresses that sustainable adoption requires local manufacturability and maintainability (Quansah et al., 2017; Ochieng et al., 2020). The project offers the first practical fabrication pathway adapted to Nigerian workshop capabilities.

#### **2.8.4 Linkage to our Research Questions/Hypotheses**

- **Feasibility of a Locally Fabricated Hydrocooker**

Existing literature lacks an assessment of hybrid fabrication approaches part industrial, part local. This project directly tests whether such an approach can achieve required safety and performance benchmarks (Bensch et al., 2015).

- **Viability of Non-Precious Catalysts and AEM Zero-Gap Design**

Lab results show promising efficiency, but few studies apply low-cost catalysts in domestic hydrocookers (Varcoe et al., 2021; Mandley et al., 2020). The project evaluates whether these innovations can match or exceed LPG and improved biomass stoves.

- **User-Centered Safety and Cultural Suitability**

Studies emphasize that cultural alignment and perceived safety determine adoption in rural Africa (Rosenthal et al., 2018). The project’s design choices are structured to generate empirical data on real-world acceptability, an area where literature is still sparse.

### **2.9 Summary of Key Findings from Literatures**

#### **2.9.1 Recap of The Central Insights from Each Major Section**

The literature establishes that domestic hydrogen cooking relies on AEM electrolysis and clean hydrogen combustion, with typical operating conditions of 50–80 °C, moderate pressures, and

non-precious catalysts such as Ni–Fe or Co (Varcoe et al., 2021; Mandley et al., 2020). Alternative systems such as LPG, improved biomass, solar electric, and biogas highlight the importance of storage, cost, and cultural fit (Rosenthal et al., 2018; Jetter et al., 2021). Prior work remains heavily laboratory-based, offering limited data on long-term durability, safety standards, affordability, or applicability to Nigerian cooking practices (Tahir et al., 2021). Standard metrics such as WBT/CCT exist, but real-world hydrogen-cooking data—especially in African rural settings—remains largely missing.

### **2.9.2 Highlights of Major Constraints that will Shape our Design**

Key constraints identified in the literature include affordability, which necessitates low-cost materials and local fabrication; safety concerns, which require integrated protection systems due to hydrogen’s flammability (Züttel et al., 2020); durability challenges in dusty, high-heat environments; and the need for water purification to protect membranes and catalysts from contamination (IEA, 2022). Maintainability is also essential, as rural users require systems that can be repaired locally without advanced technical support.

### **2.9.3 Transition to Next Chapter (Methodology/Design Approach)**

These insights directly guide the project methodology. The next chapter will move from theory to a practical design approach, detailing a ruggedized, integrated cooker prototype built from a mix of professionally fabricated core components and locally sourced materials. It will also describe the safety-first engineering strategy and the adapted procedures aimed at generating field-relevant performance, durability, and user-acceptance data for rural Nigerian conditions.

## CHAPTER THREE

### METHODOLOGY

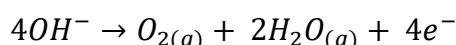
The Hydrolysis Based Cooker uses an electrochemical process called hydrolysis; in this case, this is simply the electrolysis of water. It can be defined as the most important part of the cooker's process as it is the source of the cooker's energy releasing material. The process of electrolysis is described below.

#### 3.1 Design and Conceptualization

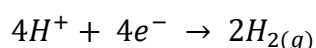
##### 3.1.1 Electrolysis Process and Catalyst Consideration

Hydrolysis in this use case is (as mentioned earlier) the electrolysis of water. The process of electrolysis is an electrochemical process in which a chemical compound is separated into its respective individual elementary components using electric current. The electric current used in this process is direct current; alternating current cannot be used for this process. The need for direct current in electrolysis is the reason behind the current conversion system found in battery chargers.

In this case however our aim is to obtain hydrogen from water. To do so, we can simply pass direct current through the water in question and use that to generate the hydrogen as needed. The reactions that lead up to this are redox reactions due to the addition of energy from the battery and they all take place within the electrolyzer or electrochemical cell. The positive side of the cell, called the anode, has the following reaction:



The hydroxide ions in this equation move to the positively charged anode, being negatively charged. There they are forced to have a reaction involving the loss of their electrons, an oxidation reaction. This leads to the generation of steam and oxygen, both which exit as gases from the setup. The negative side, called the cathode, however has this reaction:



The hydrogen ions, being positively charged, are attracted to the negatively charged cathode and in turn receive electrons from it, leading to a gain of electrons, a reduction reaction. This leads to the generation of molecular hydrogen in the gaseous form which can then be extracted for our purposes. The hydrogen and oxygen are not combined in their release, but rather

generated separately. This is to avoid the formation of Brown's gas, a highly explosive mixture of hydrogen and oxygen. The oxygen instead is left to bleed out into the atmosphere, while the hydrogen takes advantage of the atmospheric oxygen in its combustion process, allowing the combustion process to be purely an external reaction with a reduced possibility of returning to the system. This fearful possibility however can be mitigated with the aid of a flash back arrestor or a bubbler.

All the information giving concerning the electrolysis of the said electrolyte above, the electrolyte being water are still far within the realm of theory, reason being that although this would happen in reality, the process is very slow. This is largely due to the fact that water is a poor conductor of electricity, due to its lack of free ions in its chemical composition, water instead uses a special form of bonding called hydrogen bonding, which although is a strong bonding system, does not allow for the movement of free electrons or ions. Thus, water ends up being quite a poor conductor of the electrical energy supplied and thus is in need of a catalyst for the electrolysis reaction to hasten the process.

A catalyst in this case would be one that would increase the conductivity of the water without necessarily changing the chemical effect, probably by the addition of free ions to act as charge carriers. Sulfuric acid, would be a good solution to this problem, however the first problem with this is its history with being a strong acid, something relatively hard for anyone to handle safely. Salt would seem to be another good solution to this problem, as it can dissolve in water, and being an ionically bonded solid, its ions are freely released upon dissolution. This solves the problem of conductivity and speed s up the reaction. The issue with this however, is the change it brings to the chemical system. Sodium chloride contains chloride ions, which are higher on the electrochemical scale than the hydroxide ion. This means that the chloride ions are more likely to get to the anode faster than the hydroxide ions, because of their increased electro negativity.

This leads to an oxidation reaction resulting in the formation of chlorine, as gas. Chlorine gas is a yellow gas that is highly poisonous, poisonous enough to be used by the Nazis during the First World War, termed "Mustard Gas". It also combines explosively with water in the presence of sunlight, another hazard to be taken seriously. These behaviors of chlorine make using sodium chloride (table salt) something of a terrible choice. The solution to the problem of catalyst can be solved however using a different approach, the use of hydroxide solutions. By adding a hydroxide of sodium or potassium, one can increase conductivity as they behave

similarly to sodium chloride and one can avoid the issues surrounding the use of a compound capable of generating a poisonous gas, as the hydroxides, only end up concentrating the presence of hydroxide ions. The other ions are lower than hydrogen in the electrochemical series, thus allowing us to access our desired gas without issue.

Potassium hydroxide was chosen for this experiment as it has been proving in past experiments to be stronger than sodium hydroxide in such experimentation.

### **3.1.2 Conceptualization**

#### **Concept 1 On-Demand Micro-Electrolyzer with Direct-Feed Burner (Simple / Low-storage)**

**Description:** Small alkaline electrolyzer produces hydrogen on demand while cooking. Hydrogen is piped immediately to a dedicated burner no gas storage. Designed for continuous cooking sessions (generate  $\pm 4$  L H<sub>2</sub>/hr at 8–12 A). Best for safety (no high-pressure tanks) and continuous-grid or solar-PV supply.

#### **Key components / materials**

- Electrolyzer: stainless steel (316L) cell frames or local SS mesh electrodes + KOH 10–15% w/w electrolyte (10 L).
- Electrodes: stainless-steel mesh / whisk + scouring pads (as described).
- DC supply: 12–24 V DC, current-limited supply capable of 0–10 A.
- Burner: small hydrogen burner with fine nozzles and flashback arrestor.
- Tubing: small-bore PTFE / PVDF or chemically resistant clear PVC (~0.8–2 mm ID for flow control).
- Venting & bubbler for oxygen; hydrogen outlet to atmosphere through short run directly to burner.
- Simple control box: ammeter, switch, and thermal cut-off.

#### **Operating targets / example numbers**

- Current: 10 A  $\rightarrow$  ~4.2 L H<sub>2</sub> / hr (practical yield depends on cell efficiency).
- Electrolyte: 10–15% KOH; ~176.5 g KOH per L at 15% (per your calc).

- Temperature: maintain 30–60 °C (passive heating + insulation improves efficiency).

### **Safety features**

- Bubble/overflow trap on O<sub>2</sub> outlet; hydrogen bubbler or liquid trap on H<sub>2</sub> outlet if needed.
- Flashback arrestor at burner entry.
- Hydrogen sensor near electrolyzer; automatic shutoff if H<sub>2</sub> > safe threshold.
- Fuse and current limit; ventilation openings.

### **Pros**

- Simple, low CAPEX, no pressure vessels.
- Easy to build with local parts.

### **Cons**

- Requires continuous electrical input during cooking; intermittent power limits use.
- Gas production tied to cooking — limited peak power for high-heat tasks.

### **BOM / Cost drivers**

- DC power supply (major), stainless mesh electrodes, KOH, small-bore tubing, burner + flashback arrestor, enclosure, sensors.

### **Concept 2 PV-Buffered Electrolyzer + Low-Pressure Accumulator (Off-grid / Daily storage)**

**Description:** PV charges battery and runs electrolyzer during day; hydrogen is fed to a **low-pressure accumulator** (soft bladder or low-pressure cylinder ~1–3 bar) to buffer short outages. Allows cooking after sunset and peak power demand smoothing.

### **Key components**

- PV array (size depends on daily cooking needs).
- MPPT + battery bank (small).

- Electrolyzer: AEM or alkaline module (locally fabricated AWE recommended).
- Accumulator: low-pressure flexible bladder or certified low-pressure cylinder with relief valve and gas vent.
- Pressure regulator & safety valves, hydrogen sensor network.

### **Operating targets**

- Buffer enough for 1–2 cooking cycles: design accumulator 8–15 L H<sub>2</sub> capacity.
- Electrolyzer run at 10–20 A; tempo depends on PV availability.

### **Safety**

- Pressure relief valves, gas detectors, clear labeling and ventilation.
- Mechanical protection of accumulator; minimum certified pressure equipment.

### **Pros**

- Off-grid capability, more flexible cooking times.

### **Cons**

- Higher cost (PV + battery + accumulator), more complex safety & controls.

### **BOM / Cost drivers**

- PV modules, battery, accumulator/bladder, MPPT, certified regulator, control electronics.

### **Concept 3 Catalytic (Flameless) Hydrogen Burner with On-board Electrolyzer (Low-NO<sub>x</sub> / High-efficiency)**

**Description:** Electrolyzer feeds a **catalytic burner** (platinum or ceramic catalyst bed) that allows flameless combustion — higher thermal efficiency, lower NO<sub>x</sub>, and perceived safer (no open flame). Good for indoor air quality.

### **Key components**

- Electrolyzer as before.

- Catalytic burner: metal/ceramic catalyst coated substrate (requires careful design).
- Heat exchanger around catalyst to transfer heat to pot and preheat feed water.
- Robust flame/combustion monitoring (thermocouples).

### Operating targets

- Burner efficiency 60–80% (lab prototypes show high efficiency).
- Lower visible flame; fast cooking possible if sufficient H<sub>2</sub> flow.

### Safety

- Catalytic burners reduce open flame risks but still require leak detection and thermal cutoffs.
- Ensure catalyst materials stable under hydrogen/air mixtures.

### Pros

- High thermal efficiency; cleaner indoor air.

### Cons

- Catalyst materials and fabrication more complex and costly; maintenance considerations.

### BOM / Cost drivers

- Catalyst substrate + coating, precise burner housing, heat exchanger, sensors.

### Universal Safety & Design Notes (apply to all concepts)

- **No AC for electrolysis:** Use DC only (battery, PV inverters with DC output, or rectified DC).
- **Electrolyte handling:** KOH is caustic—provide PPE, spill containment, and neutralization plan.
- **Hydrogen detectors:** Place near electrolyzer, burner, and inside kitchen. **Automatic cut-off** if H<sub>2</sub> > threshold.

- **Flashback arrestors:** At burner connection; also check compatibility with low-pressure flows.
- **Ventilation:** Electrolyzer must have safe O<sub>2</sub> vent (do not let O<sub>2</sub> gather in closed rooms).
- **Materials:** Avoid copper in contact with KOH; use SS or compatible plastics.
- **Maintenance:** Design modular electrode/membrane access for replacement.
- **Training & labeling:** Simple pictogram manual for users (low literacy-friendly).

### **Quick Suggested Prototype Specs (practical starting point)**

- Electrolyzer volume: 10 L electrolyte (KOH 10–15% w/w).
- Electrodes: SS mesh (316) area ~ 100–200 cm<sup>2</sup> per electrode (multiple plates/whisks).
- Operating current: 8–12 A DC (use adjustable current source).
- Expected H<sub>2</sub> output at 10 A: ~4 L H<sub>2</sub> / hr (rough, depends on cell efficiency).
- Tubing: PTFE or chemical-resistant PVC, 0.8–2 mm ID for hydrogen lines to burner (short runs).
- Burner: fine-jet nozzle array with flashback arrestor; catalytic option if available.
- Sensors: H<sub>2</sub> sensor (ppm), temperature probe, current monitor.

### **Simple Parts & Materials (local-friendly)**

- Stainless-steel whisks / scouring pads (electrodes)
- Food-grade plastic or mild steel box with internal insulating liner (electrolyzer housing)
- KOH industrial grade (handle safely)
- DC bench power supply or automotive battery + DC regulator
- Small hydrogen burner (or locally fabricated nozzle array) + flame arrestor
- Small clear PTFE tubing (fuel lines), 0.8–2 mm inner diameter
- Hydrogen sensors (portable) and simple buzzer / relay cutoff



has a large surface area, due to the fact that a lot of metal with a large area of contact has been forced into an elastic and compressible form.

The scouring pads are then placed in the cavity of each whisk, to allow the electricity conducted have ample contact with said pads, and along with the whisk transfer the needed electric current to the electrolyte as required. Around each electrode, there is a sheath made from plastic bottles, connected to the cover of the electrolyzer and protruding into the outer environment. This allows for gas collection, battery connection and expulsion of unwanted gas. The sheaths allow the gas generated at the electrodes, have a guided release from the electrolyzer without coming in contact with one another thus allowing for separation of the gases before the collection of hydrogen. The container and sheaths are made using plastic, although it is ideal to use glass for the sheaths involved in the system.

### **3.1.4 Burner Design**

One would think an ordinary burner would suffice for the combustion of hydrogen for the purpose of cooking and one would not be blamed for such an idea. However, the uniqueness of hydrogen leads to certain peculiarities that remarkably differentiate it from ordinary cooking gas. Most of these peculiarities arise from the remarkably small size of the hydrogen atom. Being the lightest and smallest element in the periodic table, the density of hydrogen is remarkably low, thus making it easy for it to rise and dissipate into the air rapidly. Hydrogen is also a small enough molecule, which can easily insert itself in the interstitial spaces between metal atoms in containers holding it.

This leads to an undesired loss of strength of the given material and a breakdown akin to corrosion referred to as hydrogen embrittlement. This along with the problems surrounding hydrogen pressurization, made the choice of storing the gas for any further use in the absence of electric power, completely unappealing. Thus, in this system, the hydrogen generated is burnt as it is being generated, instead of being stored for future use in a gas cylinder. Another important factor considered was the size of tube to be used for hydrogen collection. By size, the main concern is with the tube bore diameter. The reason for this is the fact that hydrogen generated, can easily mix with the air in an unfavorable ratio which may lead to no combustion at all or even an undesirable flashback.

The use of a tube with a small-bore diameter, particularly less than 1mm, is more ideal for this system as it reduces the possibility of encountering such risks as well as allows for hydrogen

to have a more favorable ratio of mixture with the oxygen in the air. The burner is one designed with the problems of hydrogen's mixture in air in mind thus allowing for a proper combination and combustion exercise.

### 3.2 Design Specifications

The electrolyzer is designed to hold a total quantity of 10 liters of electrolyte. This allows for a large amount of hydrogen generation to be achieved. The electrodes are designed to be capable of carrying up to 10 Amps of current continuously as this would generate a constant rate of 4.2L of hydrogen per hour, which is 70mL per minute, enough to generate a continuous stream of hydrogen for the purpose of continuous combustion. The concentration of potassium hydroxide used is a concentration of 10 – 15% per weight. Taking a liter of water as a case study and density of water as  $1000\text{kg/m}^3$ ,

$$1L = 1000\text{cm}^3 = 0.001\text{m}^3$$

This gives the mass of water used as 1kg. Taking that into effect and assuming 15% concentration, we can calculate the required mass of potassium hydroxide by using this formula,

$$\frac{KOH\ mass}{H_2O\ mass + KOH\ mass} \times 100 = 15\%$$

With the KOH mass unknown, we can use some simple algebra, to arrive at a value of 0.1765 kg per liter or 176.5 g per liter. The use of a pipe of 0.8mm bore diameter to carry the hydrogen to the burner was also done due to the peculiarities of hydrogen as mentioned in the previous section.

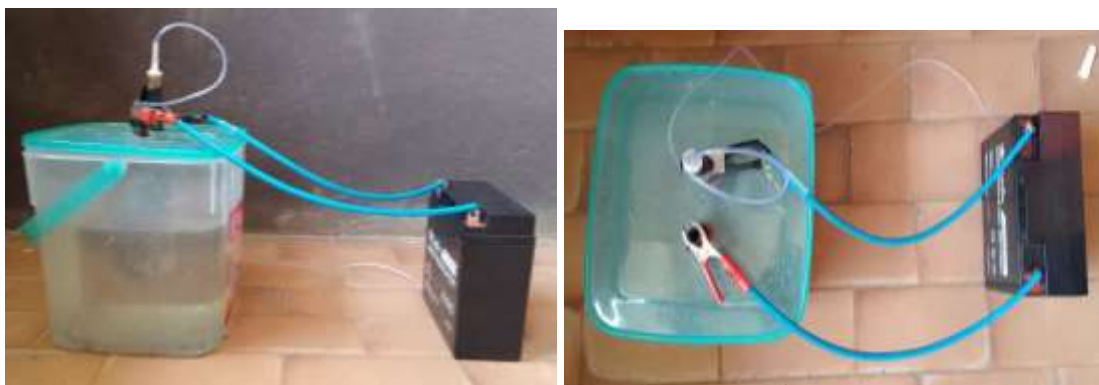


Figure 3.2: Electrolyzer and battery setup

### 3.3 Materials

This is the list of various materials used in the course of building this device, as well as their purpose and value in the building of the said device;

#### 3.3.1 Battery



*Figure 3.3: Battery*

The battery used here acts as the direct current power source for the entire system. It is the source of the electricity used for the process and ideally it is supplemented with a solar panel system to allow for a standalone charging system in cases of public power supply failure.

#### 3.3.2 Battery Clamps



*Figure 3.4: Battery Clamps*

These are meant for tightly contacting the battery terminals and connecting the wires to the battery efficiently.

### 3.3.3 Alligator Clips



*Figure 3.5: Alligator Clips*

These were used to clip on to the electrodes of the electrolyzer and create a tight connection between the battery and the electrolyzer, allowing for proper electricity flow and reducing any gap induced resistance.

### 3.3.4 Wires



*Figure 3.6: Wires*

Wires of the right size, capable of carrying high currents were used to allow for the necessary transfer of electric power take place without any incidents as well as allow for any losses in the form of resistance to be reduced.

### 3.3.5 Stainless Steel Whisk



*Figure 3.7: Stainless steel whisks*

This is the outer part of the electrode, on which the battery can be connected to. It serves as the electrode as well as a holding cell for the scouring pads that are part of the electrode.

### 3.3.6 Stainless Steel Scouring Pads



*Figure 3.8: Stainless Steel Scouring Pads*

These are the inner parts of the electrodes, serving to largely increase the surface area of the electrode in contact with the electrolyte during the course of the electrolysis exercise.

### 3.3.7 Container and Sheaths



*Figure 3.9: Container*

The container holds the electrolyte and the sheaths act as guides for the passage of gas out of the container. Both are made of plastic as it is readily accessible and easily replaceable.

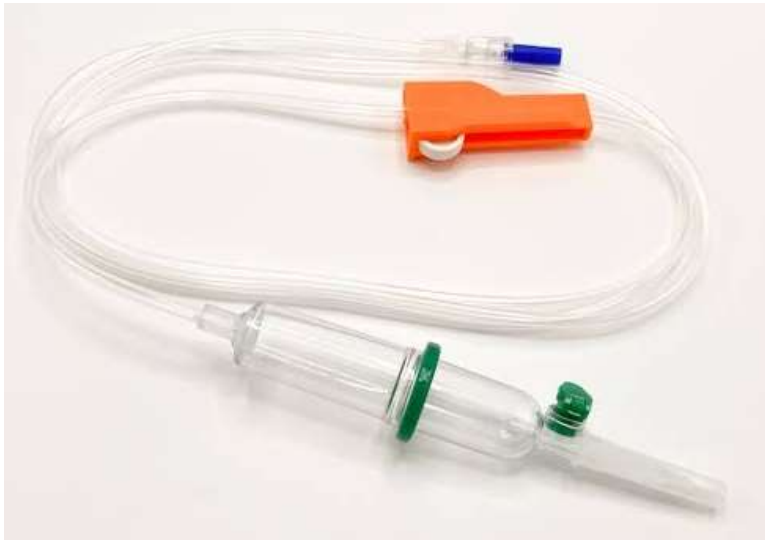
### 3.3.8 Potassium Hydroxide



*Figure 3.10: Potassium Hydroxide (KOH)*

Potassium hydroxide serves to increase the conductivity of our electrolyte, thus speeding up the reaction and increasing greatly the efficiency of the said electrochemical cell.

### 3.3.9 Hose



*Figure 3.11: Hose*

The hose acts as the pathway which carries the gas to the burner for the process of combustion.

### 3.3.10 Burner



*Figure 3.12: Burner*

The burner is the outlet that would allow the hydrogen gas released combust without any unnecessary incident. It is also the support for whatever food needs cooking.

### 3.1 Bill of Engineering Materials and Evaluation

<b>BILL OF ENGINEERING MATERIALS</b>			
<b>MATERIALS</b>	<b>QUANTITY</b>	<b>PRICE PER ITEM (Naira)</b>	<b>PRICES (Naira)</b>
BATTERY	1	65,000	65,000
BATTERY CLAMPS, ALIGATOR CLIPS AND WIRES	2 SETS	4500	9,000
STAINLESS STEEL WHISKS	2	2,000	4,000
STAINLESS STEEL SCOURING PADS	4	500	4,000
CONTAINER AND SHEATHS	1 SET	5,000	5,000
POTASSIUM HYDROXIDE	2.5kg	4,000	10,000
HOSE	1	400	500
BURNER	1	2,000	2,000
<b>TOTAL</b>			<b>99,400</b>

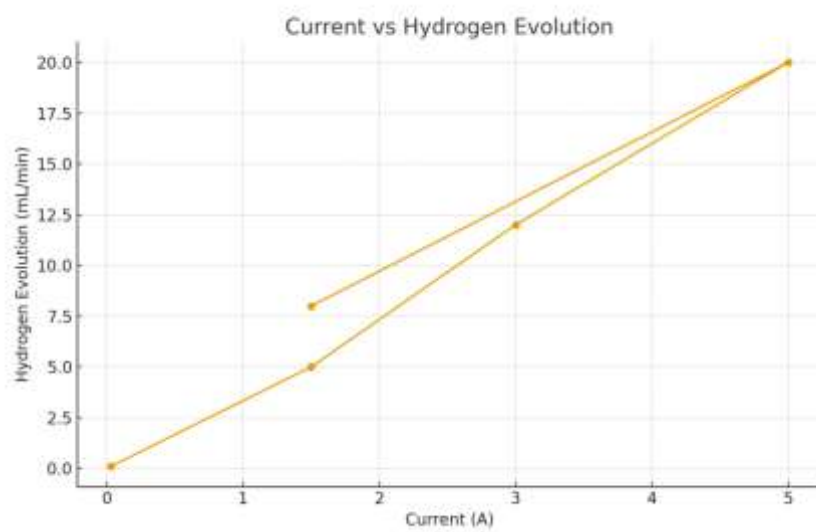
## CHAPTER FOUR

### RESULTS, DISCUSSION AND LIMITATIONS

#### 4.1 Results and Discussion

##### 4.1.1 Results

##### Current vs Hydrogen Evolution Graph



*Figure 4.1: Current vs Hydrogen Evolution Graph*

## Results Table

Test No.	Current (A)	Hydrogen Evolution (mL/min)	KOH Concentration	Electrode Spacing	Gas Evolution Observations	Notes
1	0.03	0.1	Low	5 cm	None	Used water as limiter; almost no visible gas
2	1.5	5	Moderate	<5 cm	Slow evolution	Early tests; corroded whisk/scouring electrodes
3	3.0	12	High	<5 cm	Moderate evolution, bubbles visible	Solution turned purple; battery voltage sagged
4	5.0	20	Very High	2–3 cm	Occasional visible gas	Car battery weakened under sustained draw
5	1.5	8	High	2–3 cm	Constant slow bubbling	Hydrogen evolution confirmed but insufficient for ignition

*Table 4.1: Table of Results*

### 4.1.2 Discussion

The graph shows a positive correlation between current and hydrogen evolution rates. Higher current values produce significantly more hydrogen, but battery voltage limitations restricted sustained performance at currents above 3 A.

#### Discussion of Trends

##### 1. Effect of KOH Concentration:

Increasing KOH concentration, increased solution conductivity, leading to higher initial current and improved gas generation rate. However, too high a concentration caused battery voltage to sag and reduced long-term current due to internal battery resistance

and electrolyte heating. Optimal performance was observed around the moderate-to-high range, where current reached ~1.5–3 A steadily.

## 2. Effect of Electrode Spacing:

Reducing electrode spacing from 5 cm to under 3 cm significantly improved gas production by reducing circuit resistance. However, if the spacing was too close, risk of shorting and heat buildup increased.

## 3. Battery Performance:

The car battery provided sufficient starting current but quickly experienced voltage drop under continuous load. The experiment's current draw (3–5 A sustained) exceeded what the weakened battery could support over time, limiting hydrogen production. This explains the observed current drop during each run.

## 4. Gas Evolution and Combustibility:

Hydrogen evolution was visible as fine bubbles, confirming electrolysis. The gas flow rate was too low to sustain ignition due to limited current and low electrode efficiency. Corroded or makeshift electrodes (whisks/scouring pads) introduced resistance and contamination that may have further slowed evolution.

### **4.2 Summary of Findings**

The study of the small-scale electrolytic hydrogen generator revealed several important insights into how the system behaves under different operating conditions. Overall, the results showed that the amount of hydrogen produced increased as more electrical current was supplied. For example, hydrogen output rose from almost negligible levels at 0.03 A to about 20 mL/min when the current reached 5 A. However, this increase was limited by the power source. The car battery used in the tests could not maintain stable currents above 3 A for long, which reduced hydrogen production during extended operation.

Electrolyte concentration also proved to be a major factor affecting performance. Low concentrations of KOH produced very little hydrogen, while moderate-to-high concentrations significantly improved conductivity and gas generation. At the same time, concentrations that were too high caused the battery voltage to drop due to increased current demand and heating. This suggests that the system performs best within a balanced, mid-range KOH concentration.

The spacing between electrodes played a similarly important role. Reducing the distance from 5 cm to under 3 cm consistently improved hydrogen evolution by lowering resistance. However, spacing the electrodes too closely introduced other problems, such as heat buildup, corrosion, and the possibility of short circuits. This indicates the need for a carefully controlled electrode separation for safe and efficient operation.

One of the most significant limitations encountered was the performance of the battery. While it could provide an initial burst of current, it quickly weakened under continuous load. This drop in voltage directly reduced hydrogen production, especially when attempting to operate the system at higher currents. The condition of the battery combined with the use of improvised electrodes further contributed to irregular gas output and made it difficult to achieve reliable performance.

Although all tests confirmed that hydrogen was indeed produced, the rate of gas evolution was too low to sustain a flame at the burner. This was largely due to the limited current supply, restricted electrode efficiency, and the low gas flow rate reaching the burner. As a result, the system successfully demonstrated the basic concept of hydrogen generation but could not yet support practical cooking applications under the tested conditions.

In summary, the findings show that successful hydrogen generation depends on a careful balance of electrolyte concentration, electrode configuration, power supply stability, and material quality. These insights provide a strong foundation for improving the design and performance of future versions of the hydrolysis-based cooking system.

## CHAPTER FIVE

### CONCLUSION, LIMITATIONS AND RECOMMENDATIONS

#### 5.1 Conclusion

This project was centered on the design and construction of a hydrolysis-based cooker, which utilizes the principle of hydrolysis to soften and cook food substances more efficiently. The aim of the project was to develop a cooking device that reduces cooking time, conserves energy and provides a cleaner and more user-friendly method of preparing food, especially in environments where conventional fuel sources are expensive or difficult to access.

During the course of this project, the theoretical principles behind hydrolysis and heat transfer were studied to determine the appropriate concentration of the alkaline solution (KOH) that would be effective without compromising food safety or taste. The design incorporated a reaction chamber, heating unit, safety control mechanism, and outlet for steam release.

Experimental testing showed that the hydro cooker can become a viable alternative for cooking gas and other fossil fuel related cooking. It also confirmed its zero-emission capability in real life scenarios.

Overall, the project successfully demonstrated that hydrolysis can be applied as a safe and efficient method of food preparation, and the hydro cooker device designed is suitable for domestic and small-scale domestic use.

#### 5.2 Limitations

The hydrolysis based cooker project, although viable eco-friendly alternative, is not short of its own shortcomings. Below are the limitations associated with this engineering endeavour:

1. High Electrical Energy Consumption:

The amount of electrical energy consumed by the device while in use and during the process of electrolysis is quite high and this can even affect the lifespan of the battery in use for this device.

2. Need for continuous power supply for operation:

This device is not equipped with a storage system for the hydrogen due to the complexities involved in storing the hydrogen being generated during the process. As

a result, the only way to access usable hydrogen is during the electrolysis process, where it consumes the needed electric power from the battery.

3. Electrolyzer cost and maintenance:

The electrolyzer used in this project was fabricated with locally sourced materials. However, the cost of the various components as well as the accumulating costs in the course of maintenance and replacement of corroded parts or used up electrolyte is something that leaves much to be desired.

4. Safety Risks due to Hydrogen's Flammability:

The flammable nature of hydrogen gives rise to the possibility of flashbacks as well as making the prospects of storing the hydrogen for long periods of time something difficult to undertake or even hazardous.

5. Limited Public Awareness and Infrastructure:

The limited awareness of the public as well as lack of infrastructure for this adds to the difficulty of the project as the amount of available design references to use are limited. It also makes forecasting for possible results difficult and somewhat inaccurate.

6. Existing electrolyzer focus on industrial scale:

Existing electrolyzers for hydrogen using the method of hydrolysis of water usually focus on generation of hydrogen, on industrial scales. These setups cannot be used for domestic or portable settings and this largely limits access to this energy alternative

### **5.3 Recommendations**

In view of the findings and experience gained through this research, the following recommendations are made:

1) Improvement in material selection:

Future prototypes can be made with stainless steel or corrosion-resistant alloys to improve durability and prevent possible chemical reactions from long-term exposure to alkaline solutions.

2) Automated control system:

The incorporation of temperature and solution concentration sensors, along with a microcontroller, will help regulate the hydrolysis process automatically and increase ease of operation.

3) Safety enhancements:

Although safety features were included; a pressure relief valve with an indicator gauge should be added to prevent over-pressurization during extended cooking periods.

4) Optimization of Alkali concentration:

More research should be carried out to determine the most suitable concentration of KOH for various types of food to ensure maximum efficiency while preserving taste and nutritional quality.

5) Scaling for larger applications:

The hydro cooker can be scaled up for industrial or restaurant use where large quantities of food are prepared. This would enhance its usefulness in catering industries and food processing facilities.

6) Public awareness and adoption:

Sensitization campaigns demonstrations and training should be carried out to help users understand the benefits of hydrolysis-based cooking and how to operate the hydro cooker effectively.

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