Standardization and Commercial Production of Energy-efficient Ceramics Cooking Stoves Utilizing Local Clay Sources

Nigeria faces a pressing clean cooking challenge. Over 70% of households rely on biomass fuels, driving deforestation and exposing families to harmful smoke. The World Health Organization attributes over 1.5 million deaths annually to indoor air pollution from solid fuels, with Nigeria among the worst affected. Women and children suffer disproportionately.

This project focuses on the standardization and commercialization of energy-efficient ceramic cooking stoves made from local clay. These stoves are engineered to meet international standards of efficiency, safety, low emissions, and durability, offering a healthier, affordable, and sustainable alternative to traditional cooking methods.

Unlike many initiatives still at the concept stage, this innovation is field-proven: Prototypes are already in use by households, demonstrating efficiency, user acceptance, and durability. Peer-reviewed journals have been published on both the stove and pyroprocessing kiln prototypes, validating the scientific and technical framework.

The next step is scaling for impact, including mass production using hydraulic pressing for uniformity and strength, and indigenous refractory kilns for efficient, cost-effective production, standardization and certification for market confidence and commercial deployment via artisans, SMEs, and cooperatives.

Outcomes include reduced fuel use, improved health, job creation, and forest conservation. With proven technology, demonstrated impact, and published validation, this project is ready to move from prototype to mass-market commercialisation, positioning Nigeria as a regional leader in clean cooking technologies while advancing climate and health goals.

1.1 Background of the Study

Access to clean, efficient, and affordable cooking technologies remains a critical challenge in Nigeria, where most households rely on firewood and charcoal. These fuels are often burned on open fires or inefficient stoves, resulting in high fuel costs, rapid deforestation, and severe health risks from indoor air pollution. The World Health Organisation estimates that over 1.5 million people die each year from illnesses linked to smoke from solid fuel combustion, with Nigeria among the countries most affected (WHO, 2021; ICEED, 2014). Women and children, who spend the most time around cooking fires, are disproportionately impacted.

Improved Cook Stoves (ICS) have been introduced in many developing countries as a solution to these problems. They vary in form and design, often reflecting local resources and conditions. Clay and sand are among the most widely used raw materials because they are abundant and inexpensive (Bailis et al., 2015). Yet, despite decades of effort, many ICS initiatives have suffered from inconsistent performance, lack of standardisation, and limited user adoption (Ezzati & Kammen, 2002).

Nigeria possesses abundant high-yield clay deposits, representing an untapped opportunity for locally adapted stove technologies. Building on this resource, our project has developed ceramic-insulated, energy-efficient cooking stoves designed to meet international standards of safety, thermal efficiency, low emissions, ergonomics, and durability. Using solid casting with hydraulic presses, the stoves achieve uniformity and strength, while indigenous refractory kilns enable cost-effective, large-scale firing.

Crucially, this innovation is beyond the concept stage. Prototypes are already in active use by households, with strong performance and user acceptance. The project team has also published peer-reviewed journal articles on both the stoves and the pyroprocessing kilns, validating their technical and scientific basis.

This project, therefore, represents a timely, proven, and scalable solution to Nigeria's clean cooking challenge, combining health and environmental benefits with economic opportunities for local communities.

1.2 Statement of the Problem

Access to clean and efficient cooking technologies remains one of Nigeria's most pressing challenges. The majority of households still depend on biomass fuels such as firewood and charcoal, alongside kerosene and, to a lesser extent, liquefied petroleum gas (LPG). Electricity is occasionally used for cooking, but erratic supply makes it unreliable. While LPG and gas are efficient, their rising cost has placed them out of reach for the average household. Solar energy, though renewable, is location-specific and constrained by the high cost of storage technologies. As a result, most households remain locked into unsustainable and unhealthy cooking practices.

Conventional stoves used in Nigeria are largely inefficient. Their heating chambers are typically made of metal or metal alloys, which deteriorate quickly under prolonged heat and are not cost-effective. These stoves exhibit poor thermal efficiency, high fuel consumption, and significant heat dissipation, making kitchens uncomfortable. More critically, they produce high levels of smoke and harmful emissions, contributing to widespread household air pollution. According to the World Health Organization (2021), over 1.5 million people die annually from smoke-related illnesses caused by solid fuel combustion, with Nigeria among the countries most affected. Women and children, who are most exposed to household smoke, face the greatest health risks.

The current reliance on inefficient stoves and unsustainable fuels is therefore problematic on multiple fronts: economic (high fuel costs and frequent stove replacement), environmental (deforestation and carbon emissions), and social (serious health risks and gendered burdens).

The ceramic-insulated multi-biomass stove offers a practical and scalable alternative. Developed from abundant local clay, it provides better thermal efficiency, durability, and eco-friendliness than metal stoves. Its refractory insulation minimizes heat loss, reduces smoke emissions, cuts fuel consumption, and delivers cleaner cooking conditions. Importantly, prototypes of these stoves have already been developed, tested, and deployed in households, with performance results documented in peer-reviewed publications.

The challenge, therefore, is not the absence of innovation, but the need to standardize, certify, and commercialize this proven technology to make it widely available. Doing so will reduce household energy costs, improve public health, conserve forests, and position Nigeria as a regional leader in sustainable cooking solutions.

1.3 Objectives of the Study

General Objective

To standardise, certify, and commercialise energy-efficient, ceramic-insulated, multi-biomass cooking stoves utilising local clay resources in Nigeria, thereby improving household energy efficiency, reducing smoke-related health risks, and promoting sustainable livelihoods.

Specific Objectives

1. **Prototype Optimisation**
   - Improve the design and performance of ceramic-insulated stoves to meet international standards of thermal efficiency, safety, low emissions, ergonomics, and durability.
2. **Material Characterization and Standardization**
   - Conduct scientific analysis of local clay and other raw materials to establish quality standards and ensure reproducibility of stove components.
3. **Production Process Development**

    - Establish cost-effective, scalable production methods, including the use of **solid casting with hydraulic presses** for uniformity and **indigenous refractory kilns** for large-scale firing.
4. **Performance Evaluation and Certification**
    - Carry out laboratory and field testing of stoves (e.g., Water Boiling Test, Controlled Cooking Test, emission analysis) and obtain certification in line with national and international standards.
5. **Commercialisation and Market Deployment**
    - Develop a commercialisation strategy involving local artisans, cooperatives, and SMEs for mass production and distribution of stoves.
6. **Capacity Building and Job Creation**
    - Train local communities, especially women and youth, in stove production, distribution, and maintenance to create employment and strengthen local value chains.
7. **Impact Assessment**
    - Evaluate household fuel savings, health benefits (reduced exposure to smoke), and environmental outcomes (deforestation reduction, lower emissions) from stove adoption.

2.0 Research Methodology

This study will employ a systematic approach that integrates **material optimization, prototype production, performance testing, and standardization** to enable large-scale commercialization of the ceramic-insulated energy-efficient cooking stoves. The methodology is structured as follows:

2.1 Materials Optimization and Characterization

- **Raw Material Selection:** Local clay deposits will be sourced from different regions for suitability testing.
- **Mixture Optimization:** Various clay compositions and mixtures with additives (where necessary) will be prepared to identify the optimum combination for stove body fabrication.
- **Characterization Techniques:**

- X-ray Fluorescence (XRF): To determine the chemical composition of clay samples and identify elemental suitability.
- X-ray Diffraction (XRD): To analyze mineralogical composition and crystalline phases relevant to thermal performance and durability.

2.2 Production of Stove Body

- **Moulding Technique:** The stove body will be produced using the **solid casting method with Plaster of Paris (POP) moulds** to ensure dimensional consistency.
- **Forming Process:** Hydraulic press machines will be employed to improve compaction, uniformity, and structural stability of the stove bodies.
- **Firing:** Stove components will be fired at controlled temperatures ranging from **750°C to 1200°C** using indigenously constructed refractory kilns. This will allow determination of the optimum firing temperature for durability and thermal efficiency.

2.3 Determination of Physical and Mechanical Properties

The optimum stove body samples will be subjected to the following physical and mechanical tests:

- **Modulus of Rupture (MOR):** To assess flexural strength.
- **Water Absorption:** To evaluate porosity and resistance to liquid penetration.
- **Apparent Porosity and Density:** To measure bulk density and pore structure.
- **Mechanical Hardness and Strength:** To determine wear resistance under prolonged use.
- **Spalling Resistance:** To assess thermal shock resistance during repeated heating and cooling cycles.

2.4 Thermal and Combustion Performance Analyses

The functional prototypes will be evaluated under controlled and field conditions using standard testing protocols, including:

- **Smoke Emission Tests:** Measurement of particulate matter (PM2.5, PM10) and carbon monoxide (CO) emissions to compare with WHO guidelines.
- **Thermal Efficiency Tests:** Determination of heat transfer efficiency using the Water Boiling Test (WBT) and Controlled Cooking Test (CCT).
- **Heat Dissipation and Ergonomics:** Assessment of how well the refractory insulation reduces external heat radiation and improves user comfort.

2.5 Standardization and Certification

Results from material, structural, and performance tests will be benchmarked against international standards for improved cook stoves. Certification from relevant Nigerian and international agencies will be sought to ensure compliance and market readiness.

2.6 Commercialization Strategy (Applied Research Component)

- **Scale-Up Production:** Based on optimized materials and firing conditions, a pilot-scale production unit will be established using hydraulic pressing and refractory kilns.
- **Market Readiness Assessment:** User feedback will be collected from households currently using prototypes to refine stove design.
- **Capacity Building:** Training of local artisans and cooperatives in production techniques will be carried out to ensure sustainability and scalability.

3.0 Work Plan

Activities	**Expected Outputs**
3.1 **Identification and Survey of Clay Deposits**	
Survey of clay deposits in Enugu and surrounding areas to determine quality, accessibility, and abundance.	Verified mapping of local clay deposits suitable for stove production.
3.2 **Raw Material Collection**	
Collection and transportation of raw clays and additives to the workshop for processing and analysis.	Adequate quantities of raw materials secured for laboratory and production trials.
3.3 **Raw Material Characterization**	
Chemical and mineralogical characterization using XRF and XRD, and testing against ASTM and SON standards.	Material datasets confirming compliance with quality standards and suitability for stove fabrication.
3.4 **Mould Design and Fabrication**	
Design and fabrication of standardized Plaster of Paris (POP) moulds for stove components.	Sets of moulds produced to ensure uniformity and reproducibility of stove bodies.

Activities	Expected Outputs
3.5 **Prototype Development and Testing**	
Production of stove prototypes using solid casting, hydraulic pressing, and firing in indigenous refractory kilns; followed by laboratory and field performance testing.	Optimized and field-tested ceramic stove prototypes meeting thermal efficiency and durability standards.
3.6 **Publications and Knowledge Dissemination**	
Preparation and submission of research findings to high-impact journals (Scopus and Web of Science indexed).	Peer-reviewed publications strengthening scientific credibility and visibility of the project.
3.7 **Workshops, Symposiums, and Community Outreach**	
Engagement with stakeholders, local communities, and policymakers through outreach and demonstrations.	Increased awareness and acceptance of ceramic-insulated stoves for household cooking.
3.8 **Establishment of Cottage Industry and Training**	
Setting up pilot cottage ceramic production units and training local potters, artisans, and unemployed youth in stove fabrication and maintenance.	Skilled workforce trained; stoves made available to rural households; enhanced livelihoods and job creation.

4.0 Expected Outcomes

The successful execution of this project will yield the following outcomes:

1. **Optimized Ceramic-Insulated Stove Technology**

   Development of standardized, durable, and thermally efficient ceramic stove prototypes using locally available clay resources.

Establishment of the optimum material mixtures, firing temperatures, and production methods for consistent stove quality.

2. **Scientific Knowledge and Publications**

   Comprehensive characterization data on Nigerian clay deposits suitable for energy applications.

   Peer-reviewed publications in Scopus- and Web of Science–indexed journals, contributing to global knowledge on sustainable ceramics and cookstove technologies.

3. **Improved Household Energy Efficiency and Health**

   Stove designs that significantly reduce fuel consumption, lower smoke emissions, and improve indoor air quality.

   Cleaner cooking environments that minimize health risks for women and children, who are disproportionately affected by household air pollution.

4. **Environmental Sustainability**

   Reduced deforestation and carbon emissions through adoption of more fuel-efficient stoves.

   Promotion of eco-friendly technologies based on renewable and abundant local resources.

5. **Commercialization and Market Readiness**

   Establishment of a pilot-scale production system utilizing hydraulic pressing and refractory kilns.

   Certification of stove performance and safety in line with ASTM and SON standards, positioning the product for large-scale commercialization.

6. **Capacity Building and Employment Generation**

   Training of local potters, artisans, and youth in advanced ceramic stove fabrication techniques.

   Establishment of cottage industries that create jobs, stimulate rural economies, and ensure sustainable local production.

7. **Policy and Community Impact**

   Engagement with policymakers, communities, and industry stakeholders through workshops, symposiums, and outreach activities.

Strengthened local adoption and integration of energy-efficient ceramic stoves into rural and urban households across Nigeria.

5.1 Track Record / Preliminary Results

The project team has already made significant progress in developing and testing ceramic-insulated stove technology and associated ceramic materials for high-temperature applications. The following preliminary results provide strong evidence of feasibility and the capacity to deliver on the proposed objectives:

1. **Prototype Development and Testing**

   Prototypes of ceramic-insulated biomass cooking stoves have been developed using local clay resources.

   These prototypes have been deployed in household cooking, where they demonstrated **viability, improved thermal efficiency, reduced fuel consumption, and enhanced durability** compared to conventional metal stoves.

   User feedback confirms the potential of the stoves for domestic applications, supporting their scale-up and commercialization.

2. **Peer-Reviewed Publications and Dissemination**
   The research team has published findings from related work in reputable journals and conference proceedings, demonstrating scientific competence and credibility:

   Ekpunobi, U. E., Onyenze, C. C., Agbo, S. C., Umennadi, P., & Ifeagwu, O. B. (2022). *Development of High Energy and Fuel Economy Ceramic Insulated Biomass Multi Cooking System*. Journal of the Chemical Society of Nigeria, 47(5), 1125–1140.

   Agbo, S. C., Odewole, O. A., Ojo, F. K., Alum, O. L., Akpomie, K. G., Ofomatah, A. C., Chukwuemeka-Okorie, H. O., Ani, J. U., & Onu, C. C. (2023). *Development of refractories for the pyro-processing (heat-based) industry in Nigeria through the evaluation of mixtures of Enugu Iva-pottery clay, Nsu clay, and palm kernel shell waste*. IOP Conference Series: Earth and Environmental Science, 1178, 012019. https://doi.org/10.1088/1755-1315/1178/1/012019

6. Composition of the Research Team

Dr. Sunday Chukwuemeka Agbo

Institute: Projects Development Institute (PRODA), Enugu

Designation: Principal Research Officer

Area of Specialisation: Materials Chemistry

Highest Qualification: Ph.D., Inorganic Chemistry

Role in Project: *Principal Investigator* – Provides overall leadership, coordinates research activities, and oversees material characterization and optimization.

2. Dr. Peter Okwudiri Chukwu Ogbobe

Institute: Projects Development Institute (PRODA), Enugu

Designation: Director General

Area of Specialisation: Electrohydraulics Simulation and Testing Systems

Highest Qualification: Ph.D., Mechatronics Engineering

Role in Project: *Research Partner (Technology Systems Integration)* – Provides expertise in system design, integration, and overall project guidance.

3. Prof. Eunice Uche Ekpunobi

Institute: Nnamdi Azikiwe University, Awka, Anambra State

Designation: Professor

Area of Specialisation: Analytical and Materials Chemistry

Highest Qualification: Ph.D., Analytical and Materials Chemistry

Role in Project: *Research Partner* – Supports analytical testing, materials evaluation, and knowledge dissemination.

4. Mr. Caius Chukwudi Onu

Institute: Projects Development Institute (PRODA), Enugu

Designation: Principal Research Officer

Area of Specialisation: Ceramics Design and Fabrication

Highest Qualification: MFA, Ceramics

Role in Project: *Research Partner (Ceramic Design & Production)* – Leads design and fabrication of ceramic stove components, moulds, and prototypes.

5. Engr. Denis Chimeziri Onyekwere

Institute: Projects Development Institute (PRODA), Enugu

Designation: Assistant Chief Engineer

Area of Specialisation: Engineering Design

Highest Qualification: B.Eng., Mechanical Engineering

Role in Project: *Research Partner* – Provides engineering design support, including mechanical testing, prototype performance analysis, and production scale-up.

7. Budget Summary

S/No	Name / Category	Description	Amount (₦)
A	**Personnel Costs / Allowances**	Allowances for Principal Investigator and Research Team Members (2 years)	**10,000,000**
B	**Equipment**		
1	Pyrometer	Maximum Temp. 1700 °C	2,000,000
2	Rolling Machine	Eagle Electric Rolling Mill with Gear Box	5,000,000
3	Bending Machine	VOLTZRB-22 Hydraulic Rebar Bender	4,500,000
4	Welding Machine	MIG-120 220v Welding Machine	6,000,000
5	Shearing Machine	Mini Portable Electric Hydraulic Punching & Shearing Machine	3,500,000
6	Metal File	Handy Hardware 3 PCS Metal File	500,000
7	Hammer & Anvil	Metal Stamping Tool Set	400,000
8	Metal Stamp	Metal Stamping Kit	300,000
9	Calipers	Digital Vernier Caliper (0–150mm, stainless steel)	100,000
10	Micrometer	—	200,000

11	Laptop	HP Spectre 13-X360 Convertible, i7, 32GB RAM	2,000,000
12	Hydraulic Press Construction	With metallic moulds	10,000,000
13	Grinding Mill	Grinding Mill with Petrol Engine (6.5hp)	400,000
14	Generating Set	SUMEC Firman SPG 3000 E2, 2.8kW	500,000
15	Brick Kiln	Construction of 30 cubic ft brick kiln	6,000,000
C	**Materials**		
1	Laterite Clay	36 tonnes	700,000
2	Montmorillonite Clay	36 tonnes	3,000,000
3	Ferruginous Stones	24 tonnes	500,000
4	Stainless Steel Sheet	10 tonnes, 3mm thickness	3,000,000
5	Galvanized Steel Sheet	10 tonnes, 2mm thickness	2,000,000
6	Pot Stand (Steel)	4mm thickness	1,000,000
7	PMS (Petrol)	60 liters	60,000
8	Stainless Steel Receptacle Construction	100 pieces (stove casing)	3,000,000
9	Burnt-Out Materials	200 bags (Gmelina cellulose)	1,000,000
10	Safety Equipment	Gloves, goggles, shoes, overalls	800,000
11	Production Tools	Turning tools, kidney tools, scrapers, boards, spatulas, knives	3,000,000
D	**Quality Control & Analysis**	Gas emission, spalling resistance, thermal efficiency tests, heat dissipation, ergonomics	**5,000,000**
E	**Dissemination of Results**		
E.1	Workshops & Seminars	Two (2) research members, energy-related research	2,000,000
E.2	Publications	Two (2) Scopus-indexed journal publications	1,600,000

E.3	Research & Development Movement	Travel for five (5) research team members	3,000,000
E.4	Community Outreach	Workshops & symposiums in Enugu; distribution of 100 stoves (Umuegwu, Neke – Isi-Uzo LGA)	3,000,000
F	**Contingency (5%)**	For unforeseen expenses	**3,847,500**
TOTAL			**80,307,500**