# PYROLYSIS TECHNOLOGY FOR THE PRODUCTION OF FUELS FROM PLASTIC WASTE IN NIGERIA: PILOT SCALE-UP

**A PROPOSAL SUBMITTED TO**

**THE NATIONAL AGENCY FOR SCIENCE AND ENGINEERING INFRASTRUCTURE (NASENI)**

**FOR THE**

**NASENI RESEARCH COMMERCIALIZATION GRANTS PROGRAMME (NRCGP)**

**SEPTEMBER, 2025**

**Thematic Area: Renewable Energy and Sustainability**

**Project Title: "Pyrolysis Technology for The Production of Fuels from Plastic Waste in Nigeria: Pilot Scale-Up"**

## Executive Summary

The rapid accumulation of plastic waste represents a pressing environmental challenge due to its persistence and resistance to degradation. Conventional recycling strategies, including mechanical and chemical routes, are limited in their ability to handle heterogeneous and contaminated plastic waste streams. Catalytic pyrolysis has emerged as a promising thermochemical approach capable of converting plastics into high-value liquid fuels, gaseous products, and char while mitigating waste disposal problems. This proposal outlines the design, fabrication, and commissioning of a catalytic pyrolysis pilot plant capable of processing mixed waste plastics. The project will focus on reactor design, catalyst performance, product separation, and regeneration strategies, with a strong emphasis on optimizing fuel quality and ensuring economic feasibility. The total budget of the proposed project is One Billion Four Hundred and Sixty-Eight Million Five Hundred Thousand Naira. (₦1,468,500,000). The outcomes will contribute to advancing sustainable waste management practices while providing an alternative pathway for energy production.

## 1.0 Introductory Background and Statement of Need

Global plastic waste is an issue of great concern, with over 450 million tons of plastic waste generated annually (Ritchie & Roser, 2022). Alarmingly, less than 10% of this waste get recycled and most end up in the environment contributing to marine pollution, carbon footprint and toxic emissions from open burning (Glaser *et al.,* 2022). Nigeria ranks ninth globally among countries with the highest contributions to plastic pollution, produces 2.5 million tons of plastic waste annually with over 88% not been recycled (Nnebue & Abubakar, 2023). Currently the country's energy sector is facing significant challenges due to fuel shortage and high dependence on fuel importation.

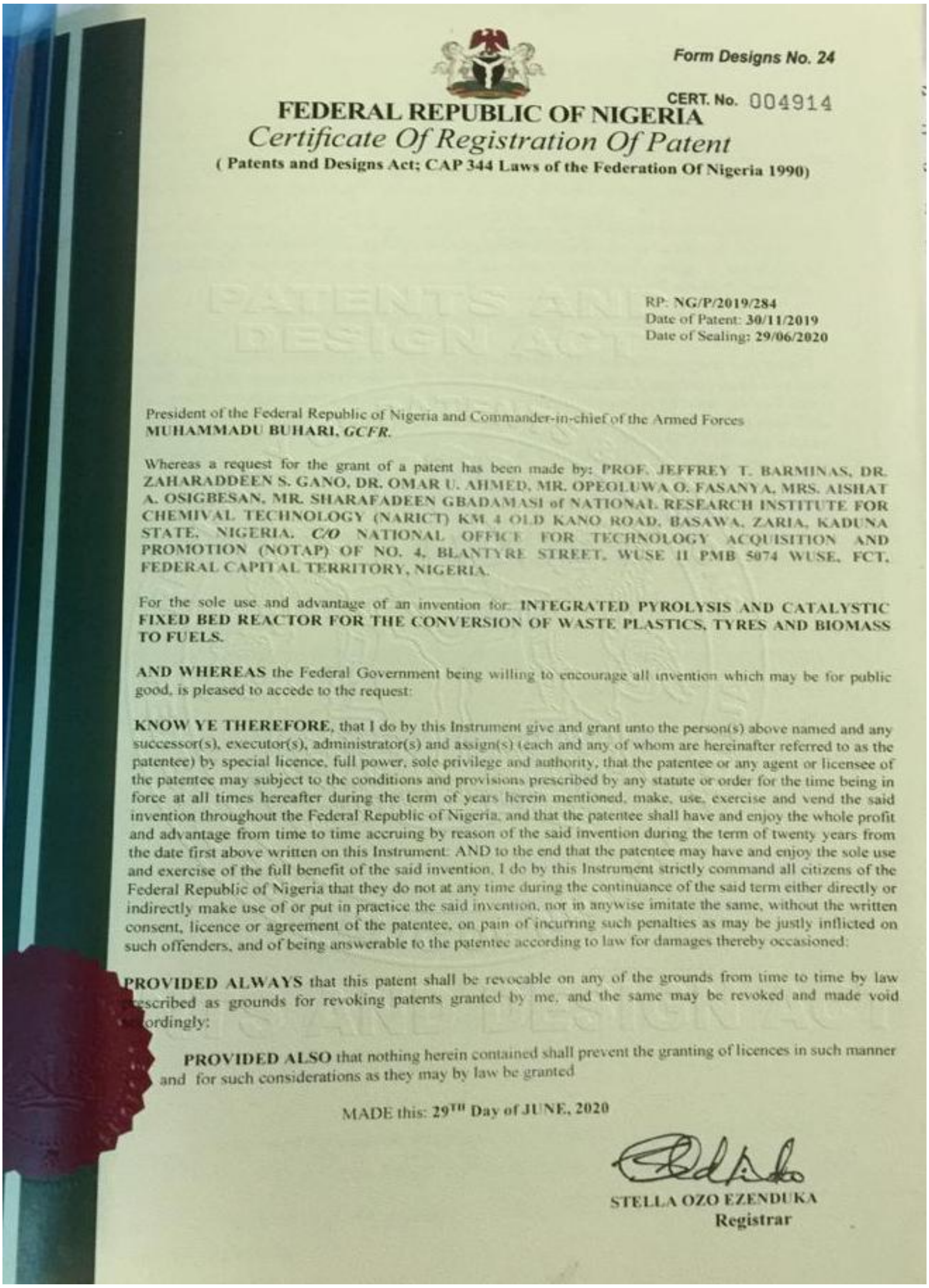
To address these issue, pyrolysis technology (thermochemical decomposition of plastics in the absence of oxygen) offers a promising solution converting plastic waste into valuable fuels such as pyrolysis oil, diesel, kerosene-like fractions and gasoline (Yang *et al.,* 2022). The products of pyrolysis can augment fuel supply in Nigeria, reduce plastic pollution and create industries in the waste to wealth value chain. Around the world, countries like USA, Japan, India, China and Netherlands are advancing pyrolysis technology for the production of fuels from waste. However, Nigeria lags behind despite the growing plastic waste pollution which serve as abundant feedstock. Local adaptation and pilot scale up are key to harness the potential of pyrolysis technology in the country.

Non catalytic pyrolysis often yields a broad spectrum of hydrocarbons ($C_1$ – $C_{60}$) and heavy tars with limited selectivity (Ratnasari *et al.,* 2017). Catalytic pyrolysis addresses this by converting plastic polymers into selective liquid fuels and value-added chemicals under moderate conditions (Aisien *et al.,* 2021). Zeolite-based catalysts have shown promise in improving product quality due to their acidity and shape-selective properties. However, their microporous nature and high acid site density make them highly susceptible to coke formation under the harsh conditions (Xu *et al.,* 2020).

Several pilot-scale catalytic pyrolysis systems have been demonstrated worldwide. For example, Wu and Williams (2010) showed that fluidized-bed reactors using ZSM-5 could produce high yields of gasoline-range hydrocarbons from polyethylene and polypropylene. However, challenges such as inconsistent feedstock, reactor fouling, and limited catalyst longevity remain. More recent studies emphasize the integration of catalytic pyrolysis with separation and upgrading technologies to produce fuels that meet commercial specifications (Huang *et al.,* 2022). Despite these advances, there remains a gap in pilot-scale data for mixed municipal plastic waste streams, particularly regarding catalyst regeneration strategies and process economics.

This proposal responds directly to NASENI's call for research commercialization grant under the Renewed Hope Agenda for Renewable Energy and Sustainability. It builds on our existing pyrolysis technology at the National Research Institute for Chemical Technology (NARICT), Zaria, where a functional pyrolysis reactor has been designed, fabricated, tested and catalytic feasibility has been demonstrated reaching Technology Readiness Level four (TRL 4). The NARICT pyrolysis team has made remarkable progress in obtaining a patent for the multifunctional integrated pyrolysis/fixed bed reactor system and has published the research on catalyst characterization (Gano *et al.* 2024) and the application of local catalysts for plastic pyrolysis (Audu *et al.* 2024). We intend to scale up the technology to pilot level in preparation to its commercialization.

Figure 1. Multifunctional pyrolysis and Fixed Bed Reactor system at NARICT Zaria



Form Designs No. 24

CERT. No. 004914

**FEDERAL REPUBLIC OF NIGERIA**

*Certificate Of Registration Of Patent*

**( Patents and Designs Act; CAP 344 Laws of the Federation Of Nigeria 1990)**

RP: **NG/P/2019/284**
Date of Patent: **30/11/2019**
Date of Sealing: **29/06/2020**

President of the Federal Republic of Nigeria and Commander-in-chief of the Armed Forces
**MUHAMMADU BUHARI,** ***GCFR.***

Whereas a request for the grant of a patent has been made by: **PROF. JEFFREY T. BARMINAS, DR. ZAHARADDEEN S. GANO, DR. OMAR U. AHMED, MR. OPEOLUWA O. FASANYA, MRS. AISHAT A. OSIGBESAN, MR. SHARAFADEEN GBADAMASI of NATIONAL RESEARCH INSTITUTE FOR CHEMIVAL TECHNOLOGY (NARICT) KM 4 OLD KANO ROAD, BASAWA, ZARIA, KADUNA STATE, NIGERIA. *C/O* NATIONAL OFFICE FOR TECHNOLOGY ACQUISITION AND PROMOTION (NOTAP) OF NO. 4, BLANTYRE STREET, WUSE II PMB 5074 WUSE, FCT, FEDERAL CAPITAL TERRITORY, NIGERIA.**

For the sole use and advantage of an invention for: **INTEGRATED PYROLYSIS AND CATALYSTIC FIXED BED REACTOR FOR THE CONVERSION OF WASTE PLASTICS, TYRES AND BIOMASS TO FUELS.**

**AND WHEREAS** the Federal Government being willing to encourage all invention which may be for public good, is pleased to accede to the request:

**KNOW YE THEREFORE,** that I do by this Instrument give and grant unto the person(s) above named and any successor(s), executor(s), administrator(s) and assign(s) (each and any of whom are hereinafter referred to as the patentee) by special licence, full power, sole privilege and authority, that the patentee or any agent or licensee of the patentee may subject to the conditions and provisions prescribed by any statute or order for the time being in force at all times hereafter during the term of years herein mentioned, make, use, exercise and vend the said invention throughout the Federal Republic of Nigeria, and that the patentee shall have and enjoy the whole profit and advantage from time to time accruing by reason of the said invention during the term of twenty years from the date first above written on this Instrument: AND to the end that the patentee may have and enjoy the sole use and exercise of the full benefit of the said invention, I do by this Instrument strictly command all citizens of the Federal Republic of Nigeria that they do not at any time during the continuance of the said term either directly or indirectly make use of or put in practice the said invention, nor in anywise imitate the same, without the written consent, licence or agreement of the patentee, on pain of incurring such penalties as may be justly inflicted on such offenders, and of being answerable to the patentee according to law for damages thereby occasioned:

**PROVIDED ALWAYS** that this patent shall be revocable on any of the grounds from time to time by law escribed as grounds for revoking patents granted by me, and the same may be revoked and made void ordingly:

**PROVIDED ALSO** that nothing herein contained shall prevent the granting of licences in such manner and for such considerations as they may by law be granted

MADE this: **29TH Day of JUNE, 2020**

**STELLA OZO EZENDUKA**
**Registrar**

Figure 2. Patent certificate of the NARICT Multifunctional pyrolysis and Fixed Bed Reactor system

## 1.1 Innovation of the research

The innovation of the project relates to the scaling up of catalytic pyrolysis technology to include pre-treatment, pyrolyzer and product separation systems in converting mixed plastic wastes including HDPE, LDPE, PP, PS and PET to fuels. This will serve as a basis for commercialisation of the technology.

## 1.2 Research Justification

This project is crucial as it offers innovative solutions to address the global challenge of plastic waste pollution, especially in African regions where there are limited proper plastic management systems. Existing methods used in plastic management have been majorly incineration and dumping in landfills which generates toxic pollutants (Huang *et al.,* 2022).

In another perspective, even with the increasing energy demand in the country, Nigerians are still grappling with the effect of increase in fuel prices. This situation justifies quest for the provision of fuels from alternative sources like plastic pyrolysis technology, thus contributing to energy security, and long-term sustainability.

Another justification for this project is to build on and consolidate existing research efforts in the development of local catalytic pyrolysis technology from its current TRL of 4. With this, scale up, the TRL is expected to reach 5, thus bridging the gap between academic research and the industry, creating the platform for commercialization. The outcomes of this project will support the advancement of efficient, clean technologies for plastic valorisation, in line with Sustainable Development Goals 7 (Affordable and Clean Energy) and 12 (Responsible Consumption and Production).

## 1.3 Research Objectives

i. Design, fabricate and commission a pilot plant that convert waste plastics to various categories of fuels.
ii. Validate the operational stability and reliability of the pilot plant.
iii. Quantify and characterize the yield and quality of the products.
iv. Generate operational and design data to inform commercialization.

## 1.4 Conceptual/Theoretical Framework

The core concept of this work involves the thermochemical conversion of waste plastic (long chain hydrocarbons) under control conditions into fuel range shorter chain hydrocarbons. Heat is used to crack the waste plastics where carbon-carbon bond is broken in to smaller components as gas, liquid and char.

Plastic + Heat (without Oxygen) $\longrightarrow$ Hydrocarbon Vapours (condensables) + Wax + Char + Non-Condensable Gases

The incorporation of catalysts systems into the reaction lowers the activation energy of bond breaking and promotes specific reaction pathways, thereby increasing selectivity toward high-value fuels while suppressing unwanted heavy products.

## 2.0 Technology Readiness Level (TRL)

Currently our technology is at TRL 4, we have conducted concept design of product and process and validated experimental process of the lab scale pyrolysis reactor (see Figure 1). We are aiming to take the project to TRL 5 scale up to pilot plant, run the process in larger capacity and conduct techno-economic assessment of the plant.

## 3.0 Methodology

This project will be accomplished by integrating scientific research knowledge and collaborative efforts with other researchers with an interdisciplinary research team.

### Phase I: Design, Fabrication, and Commissioning of the Pilot Pyrolysis Reactor

To achieve this objective, the feedstock (plastic waste) will be collected, sorted out, shredded and dried. Feedstock will be characterized using proximate analysis (moisture, ash, volatile content), ultimate analysis (CHNS/O), calorific value and FTIR spectroscopy.

### Reactor Design

A fixed-bed catalytic reactor will be design to operate at 450 – 550 °C under an inert nitrogen atmosphere.

Hot vapours exiting the reactor will pass through a condensation system comprising water-cooled condensers and knock-out drums liquid oil, non-condensable gases.

The recovered pyrolysis oil will be subjected to fractional distillation to separate gasoline, kerosene, and diesel fractions. Properties such as calorific value, viscosity, and density will be evaluated against commercial fuel standards.

### Process Flow Diagram

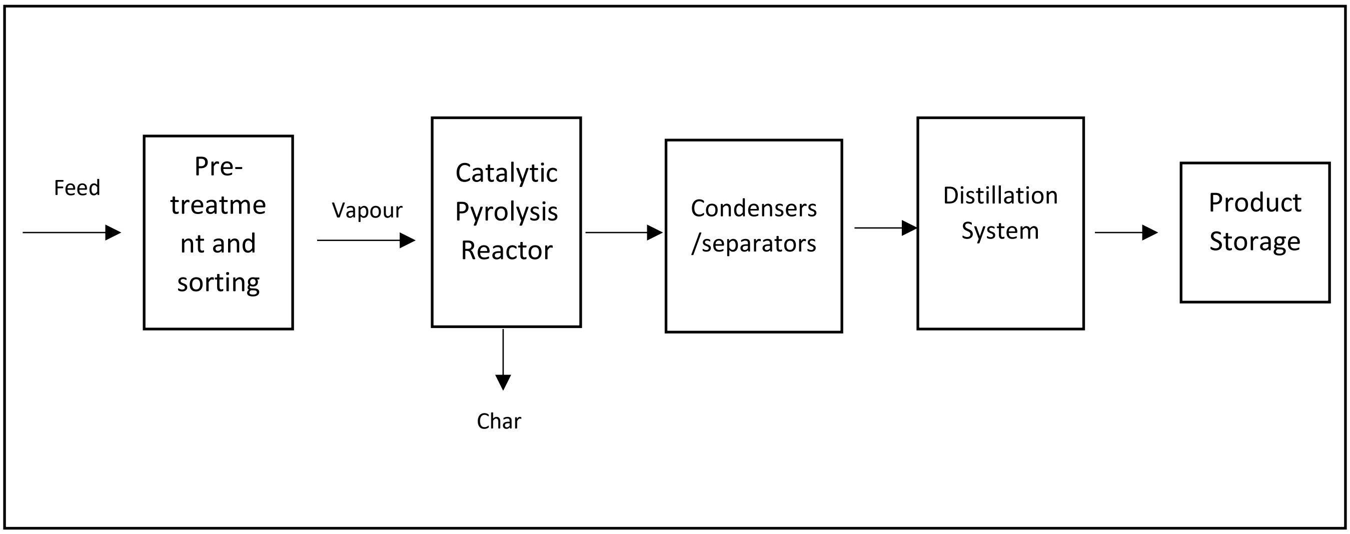



Figure 3. Block Flow Diagram (BFD) of the technology

**Pilot Plant Fabrication**

The pilot plant will be fabricated locally, Basic components of the plant such as structural steel, piping, motors will be sourced locally while specialized components (high-temperature alloys, advanced sensors) will be imported. The plant will be designed for a capacity of 20 – 30 kg/hr of plastic feedstock. Safety systems (pressure relief valves, gas monitoring) will be integrated.

There after the plant will undergo commissioning to assess and validate operation and safety.

**Phase II: Operational Stability and Reliability Testing**

To meet objective (ii), the fabricated reactor will be tested using feedstock sourced withing Nigeria. Batch test runs will be conducted using different operating condition.

**Phase III: Product Yield, Characterization and Quality Validation**

To meet objective (iii), the pyrolysis oil obtained at different operating conditions will be collected and subjected to both quantitative and qualitative analysis. Pyrolysis yield will be calculated for each run while physicochemical analysis including density, viscosity, flash point, calorific value, sulfur content will be carried out using ASTM methods of analysis. Fourier Transform Infrared Spectroscopy (FTIR) and Gas Chromatography-Mass Spectrometry (GC-MS)/ Gas Chromatography will be conducted for identification and confirmation of hydrocarbon range present.

The synthesized catalyst will be characterized using FTIR (functional groups), SEM (morphology), XRD (for crystallinity and metal dispersion), XRF (elemental composition), zeta potential (surface charge behaviour) and XPS (binding mechanism), BET (surface area and pore structure) and $NH_3$-TPD (surface acidity).

## 4.0 Expected Outputs and Method of Dissemination

i. A developed scaled up pilot plant for converting waste plastics to fuels
ii. High quality fuels for diverse application such as transportation and energy generation
iii. One patent, two peer-reviewed publications in scientific journals where other researchers elsewhere can access.
iv. Presentation of results at various national and international conferences.
v. Stake holder engagement to create awareness for policy adoption.
vi. Scalable pilot plant design data for industrial application.

## 5.0 Expected Impact

i. Promotion of circular economy and reduction of plastic waste in landfills and the environment
ii. Support Nigeria’s economy by producing a low-cost fuel, revenue generation and job creation
iii. Diversify the Nigeria's fuel sector, reducing reliance on traditional fuels.
iv. Improve public health by reducing plastic waste and pollution

v. Enhance energy security through local production of alternative fuels

**6.0 Project Team Members and Specialization**

1. Engr. Dr. Kabiru Muazu is the DG/CEO, NARICT with discipline in Chemical Engineer, he will provide technical support to ensure project success overall project. With over 40 publications in peer reviewed journals and conferences, his expertise in reactor design and process scale up is critical for this project. He. His role will ensure the pilot plant's design aligns with thermodynamic principles and engineering best practices.

2. Engr. Dr. Zaharaddeen Sani Gano, a Chemical & process engineer and Director of Research at NARICT with over 40 publications in peer reviewed journals and conferences, brings indispensable skills in process synthesis, integration, and scaling from laboratory to pilot scale. He will serve as the Principal Investigator, providing overall project leadership, strategic direction, and technical oversight. His role will also include designing the process flow diagrams (PFDs), specifying major equipment, and developing the plant's operational protocols to ensure a safe, scalable, and economically viable system.

3. Dr. Omar Ahmed Umar, an Associate Professor of Chemical and Process Engineering with over 50 publications, offers academic rigor and specialized knowledge in thermochemical conversion processes like pyrolysis. He will serve as an external collaborator, providing advanced expertise in process modelling and validation of reactor performance. His expertise will be pivotal in optimizing the pyrolysis reaction parameters and developing/selecting catalysts to enhance the quality and selectivity of the produced fuels.

4. Ephraim Akuaden Audu, an Assistant Chief Research Officer specializing in Analytical Chemistry, Catalysis, and Chemical Reactions, provides the critical link between engineering and chemistry. With 20 publications in peer reviewed journals and conferences, his skills are vital for analysing reaction mechanisms and products. He will be the Lead for Product Analysis and Catalyst Testing, responsible for characterizing the produced oil, gas, and char using advanced analytical techniques (GC-MS, FTIR) to ensure fuel quality meets standards.

5. Aisha Osigbesan, an Assistant Chief Research Officer and Chemical Engineer with over 20 publications, offers strong foundational knowledge in unit operations and material and energy balances. She will support process design, data collection, and optimization of reactor performance at the pilot scale.

6. Femi Adebola Ade-Ajayi, a Chief Laboratory Technologist with over 20 publications, He will be the Pilot Plant Operations and Safety Lead, directly responsible for the day-to-day running of the laboratory activities, maintenance, troubleshooting, and enforcing strict health, safety, and environmental (HSE) protocols throughout the project's duration.

7. Tajudeen Fatiu Adebayo, an Assistant Chief Accounting Officer with a background in accounting and computing, provides expertise in techno-economic evaluation and financial modeling of industrial projects. He will play a critical role in integrating economic analysis with technical outcomes to guide decision-making and commercialization strategies for the project.

8. Prof. Jeffrey T. Barminas, a Professor of Chemistry with over 60 publications will serve as external collaborator. With his vast research experience and expertise in chemical reaction and kinetics, he will provide technical support to aid the success of the project.

### 6.1 Track Record and Demonstration of Expertise

NARICT is an institute of great repute which is well rooted in research and development, converting indigenous raw materials into valuable chemicals and petrochemicals to solve real world problems. The institute has state of the art laboratories and equipment to ensure reliable research outcomes. The institute has developed technologies such as a multifunctional pyrolysis reactor, precipitated calcium carbonate (PCC) plant, Essential oil extraction plant, indigenous fertilizer production plant, adhesive production plant and others. NARICT is supported by adequate human resource composing of Research officers, Laboratory technologist and administrative staff from different disciplines.

The Principal Investigator (PI) is a Chemical and process engineer with specialty in process engineering. He has over a decade of research experience in the area of pyrolysis of plastics to fuels and optimization of reaction conditions. This project brings together a transdisciplinary and interdisciplinary team composed of chemical engineering, process engineering, chemistry, mechanical engineering, environmental science, and economic. This will ensure that the project is carried out effectively. Relevant outputs include:

i. Two peer-reviewed journal publications demonstrating catalyst synthesis from locally sourced materials and reactor performance evaluation in plastic pyrolysis:
   a. Audu, E. A., Ade-Ajayi, A. F., Osigbesan, A. A., Gano, Z. S., & Barminas, J. T. (2024). FeO–alumina catalyst for reforming waste polyethylene terephthalate (PET) pyrolyzed products: synthesis, characterization, and performance evaluation Comptes Rendus. Chimie, 27(S3), 117-128.
   b. Gano, Z. S., Audu, E. A., Osigbesan, A. A., Ade-Ajayi, A. F., & Barminas, J. T. (2024). Novel mesoporous iron oxide synthesized from naturally occurring magnetic sand: A potential and promising catalyst for chemical processes. Inorganic Chemistry Communications, 159, 111854

ii. One granted patent (see Figure 2).

iii. Operational pyrolysis pilot plant at NARICT (see Figure 1)

## 7.0 Sustainability & Commercialization Plan

To ensure the sustainability and commercialization of this project, we will focus on two key approaches:

Firstly, we will prioritize community engagement by actively involving local stakeholder to take part in implementing pyrolysis to fuel technology as alternative and for waste management.

To ensure financial sustainability, the project will apply for new grants from donors from government, international environmental and public health organizations and foundations.

We will also go into partnerships with plastic waste collectors will ensure steady supply of feedstock. This will ensure that pyrolysis becomes part of the community's everyday practices, encouraging waste plastic collection and recovery.

The project will ensure commercialization by:

Showcasing in demonstration hub and seminars to attract private sector investors and small industries.

Provide detailed market analysis from the pyrolysis data obtained from the research project and conduct financial projection.

## 8.0. Timeline

We expect to begin this project by 2026 and anticipate for all studies outlined in this proposal to be completed within 2 years, by the end of 2027

| Phase | Activities | Timeline (Months) |
|---|---|---|
| **Phase 1: Conceptual Design** | Literature review, catalyst selection, process flow design, safety assessment | 1–3 |
| **Phase 2: Engineering Design & Procurement** | PFDs, P&IDs, equipment specification, procurement of major units | 4–7 |
| **Phase 3: Fabrication & Installation** | Reactor construction, assembly of units, piping, instrumentation, safety systems | 8–13 |
| **Phase 4: Commissioning & Testing** | Plant commissioning, pilot runs, data collection, catalyst evaluation | 14–20 |

| Phase | Activities | Timeline (Months) |
|---|---|---|
| **Phase 5: Data Analysis & Reporting** | Data processing, optimization, techno-economic analysis, final reporting | 21–24 |

**9.0 Monitoring and Evaluation**

The project team will conduct regular progress assessments, identify potential challenges, and develop contingency plans, backup suppliers for materials. Evaluation will be conducted by assessing Key Performance Indicators (KPIs)

9.1 KPI.

i. Functional commissioned pilot plant.
ii. High fuel production yield ≥ 80%.
iii. Two peer reviewed journal publication and 1 patent.
iv. $CO_2$-equivalent emissions per fuel unit and compliance with emission limit

9.2 Risk management plan.

Technical risks such as plant malfunctioning will be mitigated by conducting thorough testing of each component and repair or replacement of faulty parts. Reactor fouling, feed variability, and catalyst coking will be mitigated through staged feed preparation, and scheduled regeneration. Alternative synthesis method will be explored or a different catalyst will be investigated for low selective catalyst. While financial risks will be mitigated by phase disbursement of funds, external audits and sourcing for other grants.

**10.0 Project Budget and Justification**

| Category | Description | Estimated Cost (₦) |
|---|---|---|
| Equipment | Reactor system, condensers, distillation columns, gas scrubbers | 330,000,000 |
| Catalyst & Regeneration | Initial catalyst charge (ZSM-5, silica–alumina, Ni-based), regeneration unit | 120,000,000 |
| Separation Systems | Gas–liquid separators, oil/water separators, filtration units | 90,000,000 |
| Feedstock Preparation | Shredders, dryers, feed conveyors | 600,000,00 |
| Instrumentation & Control | Sensors, flow meters, temperature/pressure controllers, data acquisition | 120,000,000 |
| Utilities & Installation | Piping, insulation, electrical wiring, civil works | 165,000,000 |
| Safety & Environmental considerations | Gas cleaning, flare system, emission control, PPE | 75,000,000 |

| Category | Description | Estimated Cost (₦) |
|---|---|---|
| Laboratory & Testing | Fuel analysis equipment (GC–MS, calorimeters, sulfur analyzer) | 105,000,000 |
| Personnel & Training | Salaries for engineers, operators, technicians; training programs | 165,000,000 |
| Consumables & Operating Costs (1 year) | Feedstock supply, utilities (electricity, nitrogen), maintenance | 105,000,000 |
| Dissemination and Capacity Building | Travels, publications, allowance, workshops and conferences. | 90,000,000 |
| Contingency (10%) | | 136,500,000 |
| **Total Estimated Budget** | | **1,501,500,000** |

### 10.1 Budget Justification

Equipment

The reactor system is the most critical cost component, representing the heart of the pyrolysis process. It requires durable construction materials to withstand high temperatures and corrosive environments. Associated units such as condensers and distillation columns are necessary for product recovery and fuel upgrading.

Catalyst and Regeneration

Catalysts such as ZSM-5 and silica–alumina are selected for their proven performance in enhancing cracking selectivity. Catalyst regeneration facilities are included to restore activity after coking, which is essential for continuous operation.

Separation Systems

Gas–liquid separation and oil purification units ensure efficient recovery of pyrolysis products. These systems are required to achieve fuel-grade specifications and minimize losses.

Feedstock Preparation

Pre-treatment units including shredders and dryers are necessary to provide uniform feedstock to the reactor. Proper preparation reduces energy consumption and improves process stability.

Instrumentation and Control

Advanced monitoring systems are required to track temperature, pressure, and flow rates in real time. This ensures safe operation and generates high-quality experimental data for analysis.

Utilities and Installation

Includes piping, electrical connections, and insulation, which are essential for plant integration. Civil works such as foundations and housing structures are budgeted to ensure plant safety and durability.

Safety and Environmental Systems

Gas cleaning units and flare systems are essential for emission control, while personal protective equipment ensures operator safety. Compliance with environmental regulations is prioritized.

Laboratory and Testing Facilities

Analytical equipment such as GC–MS and calorimeters are needed to characterize fuel properties, verify compliance with standards, and monitor catalyst performance.

Personnel and Training

Skilled engineers, technicians, and operators are required for design, fabrication, and plant operation. Training programs are budgeted to ensure personnel are well-prepared to handle pilot-scale challenges.

Consumables and Operating Costs

Covers recurring expenses including feedstock procurement, utilities (electricity and nitrogen gas), and routine maintenance.

Dissemination and Capacity Building

Funds for Dissemination and Capacity Building will support conference participation, publications, workshops, and training, ensuring effective communication of project outcomes and capacity development for stakeholders

Contingency

A 10% allocation covers unexpected costs during fabrication, installation, or operation, reflecting best practices in pilot plant budgeting.

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