**Project Title:** Automated Hot-Air Cabinet Dryer powered by a Top-Lit-Up-Draft (TLUD) Biomass Gasifier

# 1. INNOVATION DESCRIPTION

The proposed innovation is an Automated Hot-Air Cabinet Dryer powered by a Top-Lit-Up-Draft (TLUD) Biomass Gasifier, developed to address Nigeria's pressing challenges of food wastage, high post-harvest losses, and dependence on costly fossil fuels for agro-processing. This dryer combines renewable energy, smart control systems, and locally available biomass residues to deliver a sustainable, affordable, and efficient drying solution tailored for Nigerian farmers and agro-industrial stakeholders.

## 1.1 Core Components

The main components of the drying system are:

1. TLUD Biomass Gasifier
    i. Converts low-cost agricultural residues such as palm kernel shells (PKS), coconut shells (CCS), and wood shavings (WDS) into clean combustible gas.
    ii. Operates on the top-lit-updraft principle, ensuring higher combustion efficiency (up to 88.8%) and low particulate emissions.
    iii. Produces a clean flame reaching 875°C, later moderated to safe drying levels.
2. Heat Exchanger Unit
    i. Receives hot gases from the gasifier and tempers them to 50–120°C via heat conduction and controlled mixing of ambient air.
    ii. Designed with a 91% heat exchange efficiency, minimizing energy losses.
3. Cabinet Dryer Unit
    i. Stainless steel chamber with stacked trays that allows uniform drying of fruits, vegetables, tubers, and grains.
    ii. Drying time reduced to 133 minutes, compared to over 200–360 minutes in solar or open-air drying.
4. Automated Control & Monitoring Unit

i. Powered by Arduino Mega 2560 microcontroller, running on solar energy with a 150W PV panel and 30Ah battery backup.
ii. Integrated with temperature sensors, moisture probes, humidity monitors, and SD card data logging.
iii. Enables real-time feedback and adaptive control of airflow, fan speed, and heating rates to ensure consistent product quality.

### 1.2 Distinguishing Features

The following are the Distinguishing Features of the drying system:

a) Energy Autonomy: Operates off-grid, combining biomass and solar power.
b) Sustainability: Utilizes agricultural waste as fuel, reducing environmental impact and energy costs.
c) Smart Drying Technology: Automated controls prevent over-drying or under-drying, ensuring consistent moisture content <9%.
d) Scalability: Modular design allows for adaptation to different drying capacities (smallholder farms, cooperatives, or industrial processors).
e) Multi-Crop Application: Suitable for plantain, yam chips, cassava, tomatoes, pepper, maize, and other perishable crops.

This innovation is not just a dryer, but a renewable-energy-powered agro-processing solution, designed to transform Nigeria's post-harvest processing landscape by reducing waste, cutting costs, and improving rural livelihoods.

## 2. PROBLEM STATEMENT

### 2.1 Post-Harvest Food Loss in Nigeria

Nigeria faces one of the highest rates of post-harvest food losses in Sub-Saharan Africa, with up to 40% of perishable produce lost annually due to inadequate preservation and drying techniques. For crops like plantain, yam chips, cassava, pepper, and tomatoes, traditional sun-drying is still the dominant method. However, this method is slow, unhygienic, and weather-dependent, resulting in microbial contamination, uneven drying, and unsafe moisture levels that encourage mold growth (e.g., aflatoxins). This exacerbates food insecurity, drives up prices, and undermines national food security objectives.

## 2.2 Energy Insecurity in Agro-Processing

Most smallholder and medium-scale processors rely on diesel or LPG-powered dryers. These fuels are expensive, volatile in price, and heavily impacted by global energy crises. Rural areas often lack access to reliable grid electricity, making mechanical and solar dryers impractical for continuous operations. Consequently, agro-processing activities are energy-constrained, limiting productivity and profitability.

## 2.3 Economic Impact on Farmers

The combination of high spoilage rates and high energy costs reduces farmers' income by an estimated 20–30% annually. Farmers are often forced to sell fresh produce at low prices during peak harvest seasons due to lack of preservation options. This market glut effect reduces profitability, discourages farming, and perpetuates rural poverty.

## 2.4 Environmental Impact of Existing Drying Methods

- **I.** Open sun drying: Exposes food to contamination, animals, and environmental hazards.
- **II.** Diesel/LPG dryers: Contribute to carbon emissions, air pollution, and environmental degradation.
- **III.** Inefficient dryers: Waste significant amounts of energy due to poor thermal efficiency, sometimes <50%.

The need for eco-friendly, affordable, and reliable drying systems is therefore urgent, especially under Nigeria's climate change mitigation commitments.

## 2.5 Gap in Innovation and Commercialization

Although several biomass drying technologies have been researched in Nigeria, very few have been commercialized at scale due to lack of funding, weak industry linkages, and limited policy support. Most prototypes remain at laboratory or pilot stages. This creates a critical gap between research outputs and market-ready technologies, which NASENI's commercialization grant aims to bridge.

### 2.6 Direct Relevance to NASENI's Thematic Priorities

This problem directly falls within NASENI's focus on:

- **a)** Renewable Energy & Sustainability – replacing fossil fuels with biomass residues.
- **b)** Agriculture & Food Manufacturing – reducing post-harvest losses and improving agro-processing.
- **c)** Health & Biotechnology – ensuring food safety by preventing contamination and mold growth.

## 3. OBJECTIVES & ALIGNMENT WITH RENEWED HOPE AGENDA

### 3.1 General Objective

To develop, optimize, and commercialize an automated hot-air cabinet dryer powered by a TLUD biomass gasifier as a sustainable, affordable, and efficient post-harvest processing technology for Nigerian agriculture.

### 3.2 Specific Objectives

1. To reduce post-harvest food losses
   - **i.** Deploy the dryer to rural farming communities to lower crop spoilage rates by at least 30–40% compared to traditional sun-drying.
   - **ii.** Enable year-round preservation of perishable products (plantain, cassava, tomatoes, vegetables).
2. To promote renewable and clean energy use in agro-processing
   - **i.** Replace reliance on grid electricity, diesel and liquified petroleum gas (LPG) powered dryers with biomass residues and solar power, reducing greenhouse gas emissions.
   - **ii.** Demonstrate environmental sustainability by achieving >80% reduction in $CO_2$ emissions compared to fossil-fuel-based drying.

3. To enhance energy security and autonomy in rural agro-processing.
   i. Provide an off-grid solution powered by agricultural residues and solar energy.
   ii. Ensure continuous operation even in areas with weak or no electricity infrastructure.
4. To increase farmers' income and strengthen rural economies
   i. Improve the marketability of dried products through hygienic, uniform drying.
   ii. Extend product shelf life, reducing forced sales at low harvest prices and enabling value addition.
   iii. Target 20–30% increase in farmer profit margins by reducing energy costs and spoilage.
5. To demonstrate scalability and commercial viability
   i. Pilot commercial deployment in at least five rural communities.
   ii. Establish a local manufacturing and distribution model for wider adoption.
   iii. Build a maintenance and service framework to ensure long-term sustainability.

### 3.3 Alignment with Renewed Hope Agenda

This project directly contributes to key pillars of the Renewed Hope Agenda of the Federal Government of Nigeria:

a) **Food Security and Poverty Eradication:** By cutting post-harvest losses, extending shelf life, and enabling food processing, the dryer strengthens food supply chains and ensures affordability of staple foods.

b) **Job Creation and Industrialization:** Local manufacturing of the dryer, coupled with training of artisans for maintenance, creates new green jobs and promotes small-scale industrial clusters in rural areas.

c) **Energy Sustainability:** By shifting from fossil fuels to biomass and solar, the innovation reduces energy import dependence and supports Nigeria's energy transition roadmap.

d) **Climate Change Mitigation:** Using biomass residues instead of LPG or diesel lowers carbon emissions, while simultaneously reducing waste burning in farms, which is a major contributor to rural air pollution.

e) **Innovation and Technology Transfer:** The dryer serves as a model for research-to-market commercialization, addressing NASENI's mandate of bridging the gap between R&D and industrial application.

## 3.4 Contribution to NASENI Mandate

This project embodies NASENI's core vision of *"fueling Nigeria's innovation for a sustainable future"*

by:

- **A.** Commercializing a proven research output.
- **B.** Building indigenous engineering capacity.
- **C.** Providing a scalable renewable-energy-based solution with measurable socio-economic impact.

# 4. INNOVATIVENESS AND NOVELTY

The Automated Hot-Air Cabinet Dryer powered by a TLUD Biomass Gasifier represents a breakthrough in Nigeria's renewable energy–driven agro-processing sector. Its novelty lies not only in the technical design but also in its commercialization potential as a sustainable alternative to fossil-fuel dryers.

## 4.1 Technical Innovation

**1.** Hybrid Energy Autonomy

- **i.** The system uniquely combines biomass residues with solar PV backup to guarantee off-grid operation.
- **ii.** Unlike conventional dryers that rely on unstable electricity or expensive LPG/diesel, this dryer runs entirely on locally available fuels, ensuring independence from energy supply crises.

**2.** Advanced Gasification Process

- **i.** Uses the Top-Lit Updraft (TLUD) gasification principle, which achieves cleaner combustion, lower tar emissions, and higher flame stability compared to traditional downdraft gasifiers.

ii. Achieves thermal efficiency of 86% and combustion efficiency of 88.8%, outperforming conventional dryers that average 40–60%.

**3.** Automated Smart Control

i. Incorporates an Arduino Mega 2560 microcontroller that regulates temperature, airflow, and moisture removal in real time.

ii. Equipped with moisture sensors, thermocouples, humidity probes, and SD-card data logging, ensuring precision drying and eliminating guesswork common in manual drying processes.

**4.** Optimized Design via Simulation & Modelling

i. The dryer was simulated using ANSYS-CFD Fluent 24.1, producing temperature contour maps that validated uniform hot-air distribution.

ii. Response Surface Methodology (RSM) was applied to determine optimum drying parameters, ensuring maximum product quality and efficiency.

## 4.2 Product Novelty

**i.** Uniform Drying Efficiency: Optimized airflow ensures consistent drying across trays, unlike open-sun or solar dryers that suffer from uneven drying.

**ii.** Crop Versatility: Works for multiple Nigerian crops – plantain, cassava, yam, maize, vegetables, and grains – giving it broad commercialization appeal.

**iii.** Eco-Friendly: Produces emissions (CO, PM2.5, TVOC) well below USEPA standards, making it safer for both users and the environment.

**iv.** Scalable & Modular: The system can be scaled from 20 kg batch models for cooperatives to 200 kg+ industrial-scale models, creating flexibility for different user categories.

## 4.3 Commercial & Market Innovation

**A.** Cost Advantage:

i. Operates on agricultural residues that are otherwise discarded or burned.

ii. Cuts operational costs by 70–80% compared to diesel/LPG dryers.

**B.** Inclusive Design:

i. Designed for low-income rural farmers, yet scalable to meet SME and industrial needs.
ii. Provides an affordable entry point for smallholder cooperatives.

**C.** Innovation to Commercialization Pathway:

i. Unlike existing academic prototypes, this dryer is market-ready with proven pilot tests, technical optimization, and commercialization roadmap (manufacturing partnerships, farmer cooperatives, service centers).

### 4.4 Differentiation from Existing Solutions

| **Feature** | **Sun Drying** | **Solar Dryers** | **LPG/Diesel Dryers** | **Proposed TLUD Dryer** |
|---|---|---|---|---|
| Drying Time | >360 min | >200 min | 150–180 min | 133 min |
| Energy Source | Sunlight (unreliable) | Sunlight (weather-dependent) | LPG/Diesel (costly, polluting) | Biomass residues + solar (cheap, renewable) |
| Cost Efficiency | Low | Medium | High | Very Low |
| Food Safety | Poor (contamination risk) | Medium | High | Very High |
| Emissions | Zero (but unhygienic) | Zero | High $CO_2$, NOx | Minimal, below USEPA limits |
| Grid Independence | Yes | Yes | No | Yes |

## 5. Commercial Viability

Commercial viability is the cornerstone of NASENI's Research Commercialization Grants Programme

This proposal has been carefully structured to demonstrate that the Automated Hot-Air Cabinet Dryer powered by a TLUD Biomass Gasifier is not only technically sound but also financially sustainable, market-ready, and scalable.

## 5.1 Target Market Segments

The dryer is positioned to serve multiple tiers of Nigeria's agro-processing ecosystem:

1. Smallholder Farmers and Cooperatives.
    - i. Batch dryers of 200 – 500 kg capacity for on-farm and village-level use.
    - ii. Directly addresses food wastage at the farm gate.
2. Agro-SMEs (Small and Medium Enterprises).
    - i. Units of 500 – 1,000 kg capacity for SMEs engaged in processing plantain chips, cassava flakes, vegetables, and fruits.
    - ii. Enhances value-added processing and enables participation in urban retail chains.
3. Industrial Agro-Processors.
    - i. Large modular systems integrated into food processing factories.
    - ii. Positioned as a low-cost alternative to LPG/diesel dryers, cutting operational expenses by up to 70%.

## 5.2 Competitive Advantages

Compared to alternatives, the TLUD dryer offers:

- i. Lower Operating Costs: Biomass residues (PKS, CCS, WDS) are often free or very cheap (< ₦30/kg), unlike diesel (> ₦1,200/litre) or LPG (> ₦1,100/kg). Estimated savings: ₦2,000,000 – ₦3,000,000 per year per unit for SMEs.
- ii. High Reliability: It operates off-grid with solar backup, avoiding losses during power outages.
- iii. Regulatory Fit: It meets food safety standards by eliminating contamination risks common in sun-drying. It also aligns with Nigeria's Energy Transition Plan (ETP) by reducing reliance on fossil fuels.
- iv. Eco-Friendly Credentials: It produced very minimal emissions (CO, PM2.5, TVOCs) which are below USEPA standards, ensuring safe indoor/outdoor usage and environmental compliance.

### 5.3 Business Model & Revenue Streams

1. Direct Sales of Dryers:
   i. Manufactured in Nigeria with local materials to reduce costs.
   ii. Entry-level unit: ₦5,000,000 – ₦10,000,000 depending on capacity.
2. Leasing Model for Cooperatives:
   i. Farmers' groups can lease units at affordable rates per drying cycle, lowering upfront costs.
3. Maintenance & Servicing Contracts:
   i. Annual service packages for calibration, parts replacement, and efficiency optimization.
4. Local Manufacturing Partnerships:
   i. Collaboration with Nigerian fabricators ensures job creation and technology transfer.

### 5.4 Scalability and Replication

a) The design is modular, meaning units can be scaled up or down to meet market demand.
b) Pilot deployment in 5–10 communities will serve as proof of concept before nationwide scale-up.
c) Replicable beyond Nigeria in West Africa, where post-harvest losses are equally high (estimated 30–40% of total production).

### 5.5 Financial Sustainability

a) Payback Period: 1.5–2 years for SME operators due to energy savings and reduced spoilage.
b) Return on Investment (ROI): Projected at 30–35% annually.
c) Market Size: With over 20 million smallholder farmers in Nigeria, even a 5% adoption rate represents over 1 million potential units.

### 5.6 Risk Mitigation

a) **Technology Risk:** Already piloted with successful results; validated through CFD simulations.
b) **Market Risk:** High demand for dryers due to persistent post-harvest losses; backed by government focus on food security.
c) **Operational Risk:** Service and maintenance contracts ensure long-term reliability.
d) Financial Risk: Leasing options reduce barriers to entry for smallholders.

## 6. PROTOTYPE DEVELOPMENT STAGE

The Automated Hot-Air Cabinet Dryer powered by a TLUD Biomass Gasifier has progressed beyond conceptual design to a functional prototype, which has undergone laboratory development, field trials, simulation studies, and optimization. This maturity strengthens its case for commercialization.

### 6.1 Development Phases

1. Laboratory Design and Fabrication:
    i. Fabricated a TLUD reactor with dimensions 28 cm (diameter) × 90 cm (height) for efficient gasification.
    ii. Constructed a stainless-steel cabinet dryer chamber with stacked trays (20 kg batch capacity).
    iii. Integrated heat exchanger designed to reduce flame temperatures (700–900°C) to drying-safe levels (50–120°C).
    iv. Incorporated Arduino Mega 2560 microcontroller, moisture probes, thermocouples, and SD card logging for automation.
2. Pilot Field Trials:
    i. Conducted tests in local farming communities using plantain and other perishable crops.
    ii. Results showed drying time reduced to ~133 minutes, compared to over 200 minutes in solar dryers and >360 minutes in open sun drying.

iii. Dried products achieved safe moisture content (<9%), uniform texture, and improved storage stability.

3. Simulation and Modelling (CFD)
   i. Used ANSYS-CFD Fluent 24.1 to model airflow, heat transfer, and moisture removal inside the dryer.
   ii. Temperature contour plots demonstrated uniform hot-air distribution across trays, preventing uneven drying.
   iii. Simulation also optimized tray placement, confirming the second tray level achieved the best balance of air velocity and heat distribution.
4. Optimization via Response Surface Methodology (RSM)
   i. Employed Box-Behnken and Central Composite Designs (CCD) to optimize drying conditions.
   ii. Optimal conditions identified:
      a) Air Temperature: 80°C
      b) Slice Thickness: 5 mm
      c) Slice Orientation: 90°
      d) Pre-treatment: Neem extract soaking
   iii These conditions produced maximum drying efficiency, product quality, and energy savings.

## 6.2 Prototype Performance Validation

i. Moisture Reduction: Initial MC = 61%, reduced to final MC = 8% in 133 min.
ii. Thermal Efficiency: Gasifier = 86.02%; Heat Exchanger = 91.11%
iii. Fuel Use: Consumes ~14 kg/hour of PKS to generate 260 MJ/h.
iv. Environmental Compliance: Emissions (CO, PM2.5, TVOC) below USEPA thresholds.
v. Product Quality: Dried plantain contained 75.56% carbohydrates, 6.78% protein, and safe iron levels (2.61 mg/100 g).

## 6.3 Current State of Readiness

i. Prototype Status: Fully functional and pilot-tested.

ii. Technology Readiness Level (TRL): TRL 6–7 (prototype demonstrated in relevant environment, nearing full operational validation).

iii. Commercialization Potential: Ready for scale-up, mass production, and deployment in farming communities.

## 7. Societal & Economic Benefits

The commercialization of the Automated Hot-Air Cabinet Dryer powered by a TLUD Biomass Gasifier goes far beyond technical innovation—it delivers tangible societal, economic, and environmental benefits aligned with Nigeria's national development goals and NASENI's commercialization mandate.

### 7.1 Societal Benefits

1. Food Security Enhancement
   i. Post-harvest losses for perishable crops in Nigeria currently exceed 40% annually, with vegetables, plantain, yam, and cassava being among the most affected.
   ii. By providing affordable drying technology, this innovation directly extends shelf life, reduces wastage, and stabilizes food supply.
   iii. Impact: If adopted by just 5% of Nigeria's farmers (~1 million), potential savings could exceed 5 million tonnes of food annually.
2. Improved Nutrition and Food Safety
   i. Open sun-drying exposes food to contamination from dust, pests, and microbes, leading to health hazards.
   ii. The dryer ensures hygienic drying under controlled heat, reducing risks of aflatoxins and foodborne illnesses.
   iii. Consistent moisture control ensures that products are safe for long-term storage and human consumption.
3. Community Empowerment
   i. Rural cooperatives and women-led farming groups will particularly benefit, as they are the primary handlers of post-harvest processing.

ii. Access to drying technology enables them to engage in value-added processing (e.g., plantain chips, dried vegetables), improving livelihood opportunities.

**4.** Education and Technology Transfer

i. Deployment of this innovation will be coupled with training programs for local technicians, fabricators, and farmers.

ii. Builds technical capacity in rural areas, enhancing knowledge of renewable energy and agro-processing technologies.

## 7.2 Economic Benefits

1. Increased Farmer Income

   i. Farmers are often forced to sell fresh produce at low prices during harvest gluts due to lack of preservation options.

   ii. By enabling drying, farmers can store and sell later at higher off-season prices, increasing income by an estimated 20–30%.

   iii. Example: A plantain farmer drying 1 tonne of produce could save ₦150,000–₦200,000 per season by avoiding spoilage losses.

2. Cost Savings on Energy

   i. LPG/diesel dryers cost up to ₦40,000–₦60,000 per month in fuel, whereas the TLUD dryer uses cheap or free agricultural residues (PKS, CCS, WDS).

   ii. This translates to annual savings of ₦500,000–₦700,000 per SME processor.

3. Market Expansion for Agro-SMEs

   i. SMEs using this dryer can supply high-quality dried foods to supermarkets, export markets, and industrial processors.

   ii. Strengthens Nigeria's position in regional trade under AfCFTA (African Continental Free Trade Area).

4. Job Creation

   i. Commercial production of the dryers will create jobs in fabrication, assembly, distribution, and servicing.

   ii. Estimated potential: 1,500–2,000 direct jobs and 5,000+ indirect jobs if scaled nationwide.

5. Industrialization Drive

  i. Local fabrication ensures that value chains remain within Nigeria.
  ii. Supports NASENI's mandate of building indigenous engineering capacity and reducing dependence on imported agro-machinery.

7.3 Environmental Benefits

1. Emission Reduction
   - **i.** Diesel/LPG dryers emit significant $CO_2$, NOx, and $SO_2$ pollutants.
   - **ii.** The TLUD dryer records CO = 1.33 ppm and PM2.5 = 24.66 µg/m$^3$, which are well below USEPA standards.
2. Waste-to-Energy Utilization
   - **i.** Agricultural residues (PKS, CCS, WDS) that are usually discarded or openly burned are converted into productive fuel.
   - **ii.** Reduces environmental degradation from indiscriminate waste disposal and slash-and-burn practices.
3. Climate Change Mitigation
   - **i.** By displacing fossil fuels, the dryer contributes to Nigeria's Energy Transition Plan (ETP) and Nationally Determined Contributions (NDCs) under the Paris Agreement.

## 7.4 Long-Term National Impact

If scaled across Nigeria, it will have the following impacts:

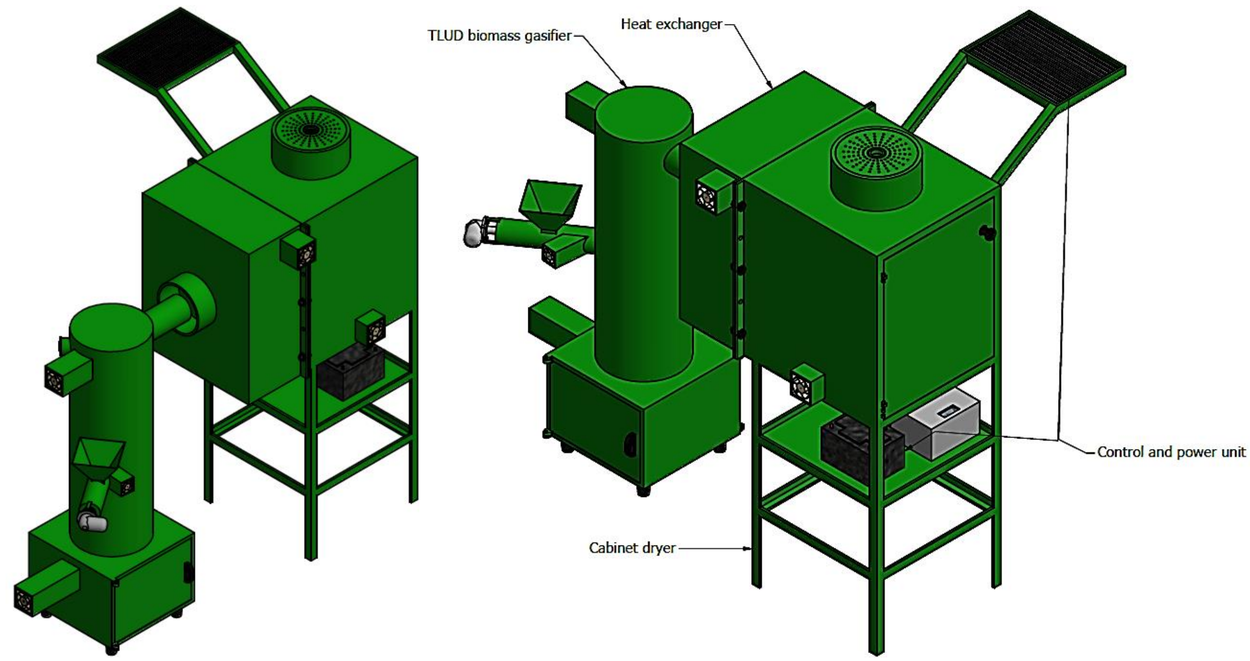
**a)** Food Security: Reduce national food loss by at least 15–20% within 5 years.
**b)** Energy Security: Replace thousands of fossil-fuel dryers with renewable alternatives.
**c)** Economic Impact: Save billions of naira annually in reduced spoilage and energy costs.
**d)** Global Recognition: Position Nigeria as a leader in renewable-powered agro-processing innovation in Africa.

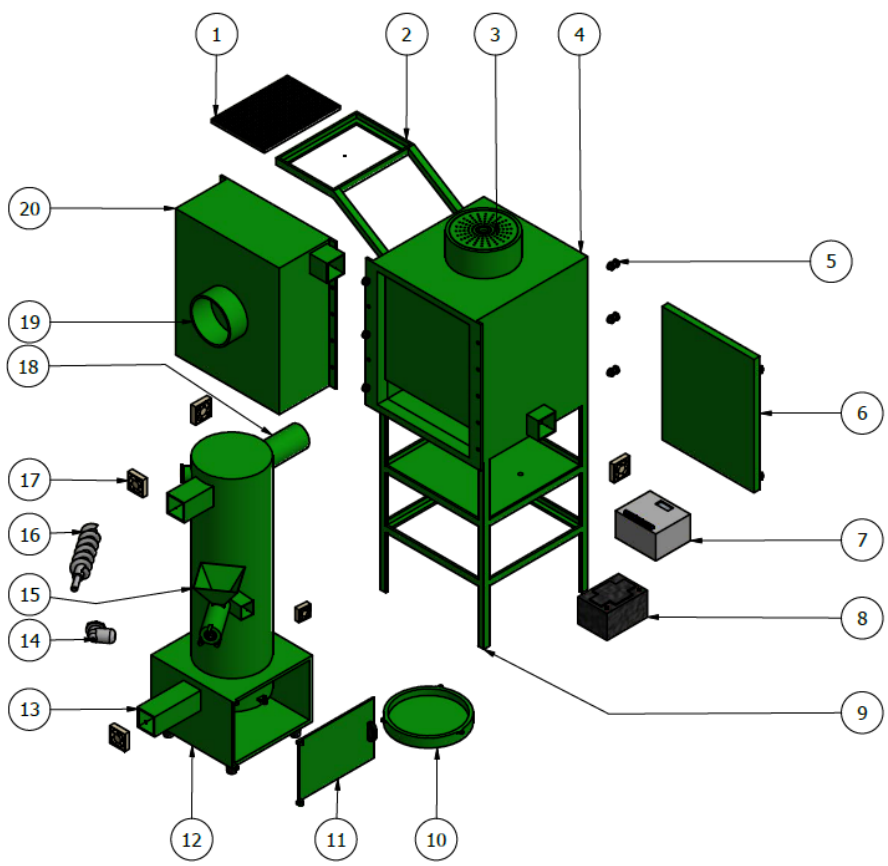
# 8. ENGINEERING DESCRIPTION & SPECIFICATIONS

The basic engineering theories, engineering calculations, engineering drawings, and modelling are presented in this session.

## 8.1 Description of the Drying System

The drying system, Figure 1, comprises of four distinct units. The first unit is the top-lit-up-draft (TLUD) biomass gasifier which consists of a reactor, outer chamber, residue chamber, DC fans, primary and secondary air inlets, hopper, feed auger, DC motor, ignition unit, stand, and flame outlet tube. The second unit is the heat exchanger unit, which comprises of the heat exchanger shell, the heat exchanger plate, the baffle, the hot-flame inlet pipe, the ambient air inlet tube, and the controlled hot-air outlet holes. The third unit is the cabinet dryer unit which comprises majorly of the hot air inlet chute, plenum chamber, ambient air inlet pipe, trays, cabinet chamber, door, and chimney. The fourth unit is the system control and power unit comprise majorly of the control box, Arduino Mega microcontroller, LCD display, temperature sensor, thermocouples, speed sensors, DC axial fans, moisture probes, DC battery, and solar panel.



| PARTS LIST | | |
|---|---|---|
| ITEM | QTY | PART NAME |
| 1 | 1 | solar panel |
| 2 | 1 | panel stad |
| 3 | 1 | chimney |
| 4 | 1 | cabinet |
| 5 | 7 | bolt&nut |
| 6 | 1 | cabinet door |
| 7 | 1 | Arduino Mega |
| 8 | 1 | Battery |
| 9 | 1 | stand |
| 10 | 1 | residue discharge cover |
| 11 | 1 | chamber cover |
| 12 | 1 | residue discharge chamber |
| 13 | 5 | air inlet pipe |
| 14 | 1 | DC motor |
| 15 | 1 | biomass hopper |
| 16 | 1 | biomass auger |
| 17 | 1 | DC axial fan |
| 18 | 1 | flame outlet pipe |
| 19 | 1 | flame inlet pipe |
| 20 | 1 | heat exchanger shell |

**Figure 1:** The automated drying system

## 8.2 Principle of Operation

The biomass gasifier utilizes the principle of top-lit-updraft process to thermo-convert biomass into producer gas (mainly carbon monoxide, hydrogen and methane gases) for clean flame needed for drying. Biomass is loaded into the reactor, lit with starter fuel, and combustion begins after eighty seconds. The air from the DC fans, through primary and secondary air inlets, supports the combustion and gasification process. The biomass, initially heated to over 300°C, undergoes pyrolysis and combustion, producing gases like CO, $H_2$, and $CH_4$, along with non-combustible gases such as $CO_2$ and $H_2O$. These gases are further combusted in the secondary zone, producing a clean, luminous blue flame. The combustion zone moves down the reactor, with combustion zone velocity (CZV) increasing as fan speed increases, Figure 2. The biomass is continuously gasified and combusted, with the gasifier enabled for continuous recharge through the gasifier hopper and its auger system, needed for continuous energy production. Residues (mainly char, ash, and slag) are discharged off the gasifier through residue discharge chamber after complete gasification. The clean heat generated by the gasifier is transferred into the heat exchanger unit, where heat conduction occurs through the exchanger plate, transferring heat to the hot-air baffle at the opposite end. A DC fan draws ambient air into the heat exchanger Figure 3, and as the air moves through the baffle, it gains heat, exiting through the hot-air holes into the plenum chamber of the cabinet dryer, reaching temperatures of about 120°C. To further regulate the temperature, the cabinet DC axial fan introduces additional ambient air mixing with the heated air in a controlled volume, as governed by the control system. The controlled hot air introduced into the cabinet moves moisture through the product to be dried placed on the cabinet trays, Figure 4, through the first tray, second tray and finally the third tray, and the moist-air in the cabinet chamber exit the dryer continuously through the chimney, leaving the products on the trays dried. The entire drying system is powered by the control and power unit, which uses an Arduino Mega microcontroller to manage the DC fans and record data from sensors (moisture, temperature, relative humidity, and fan speed sensors), storing the information on an attached SD card. The control unit is powered by a DC source through a 30Ah backup battery, which is charged by a 150W solar panel. This setup ensures a continuous supply of DC energy to the drying system, allowing for uninterrupted drying operation. Products to be dried are placed on the cabinet trays, with all drying parameters continuously monitored and controlled.

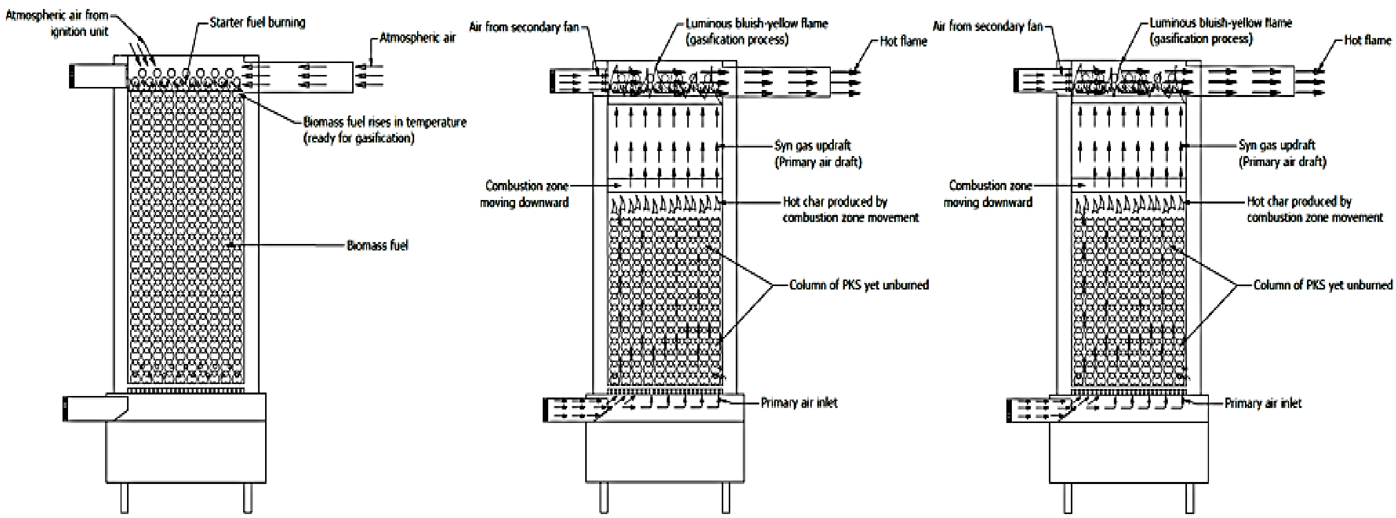



**Figure 2:** Principle of operation of the TLUD biomass gasifier reactor

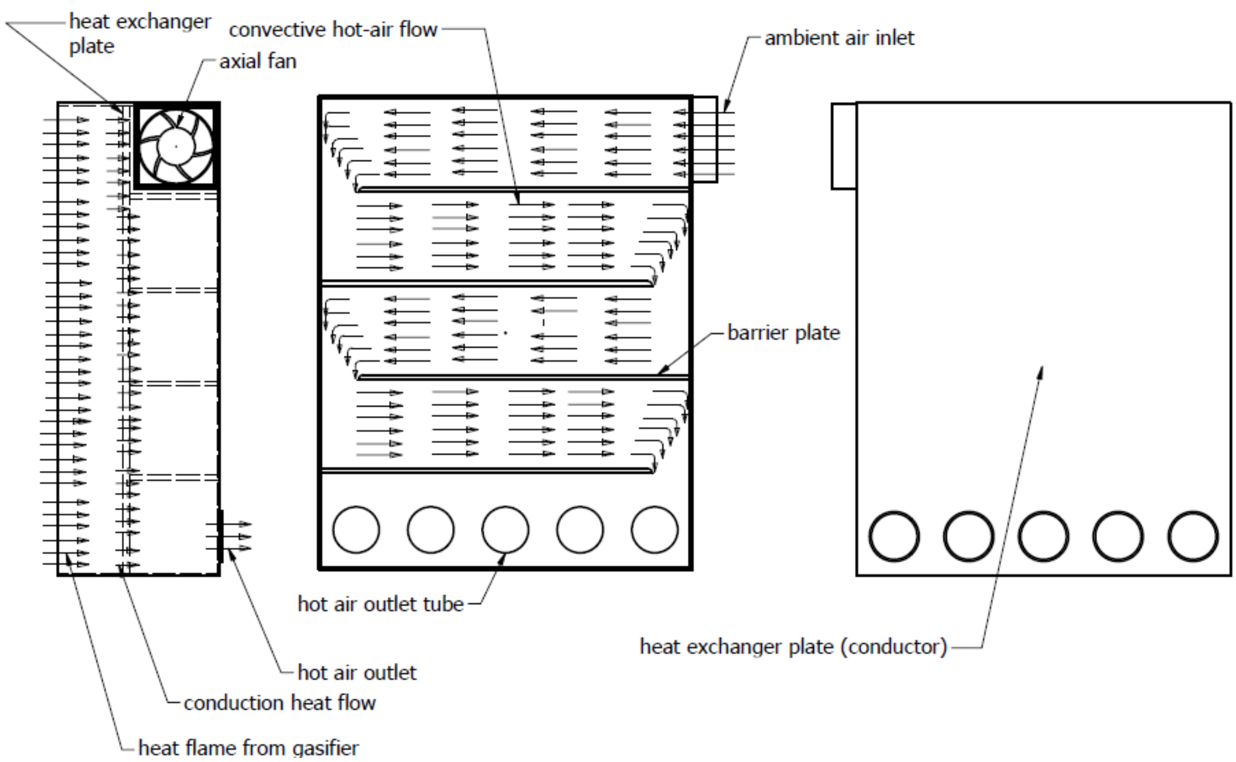



**Figure 3:** The heat exchanger's mechanism

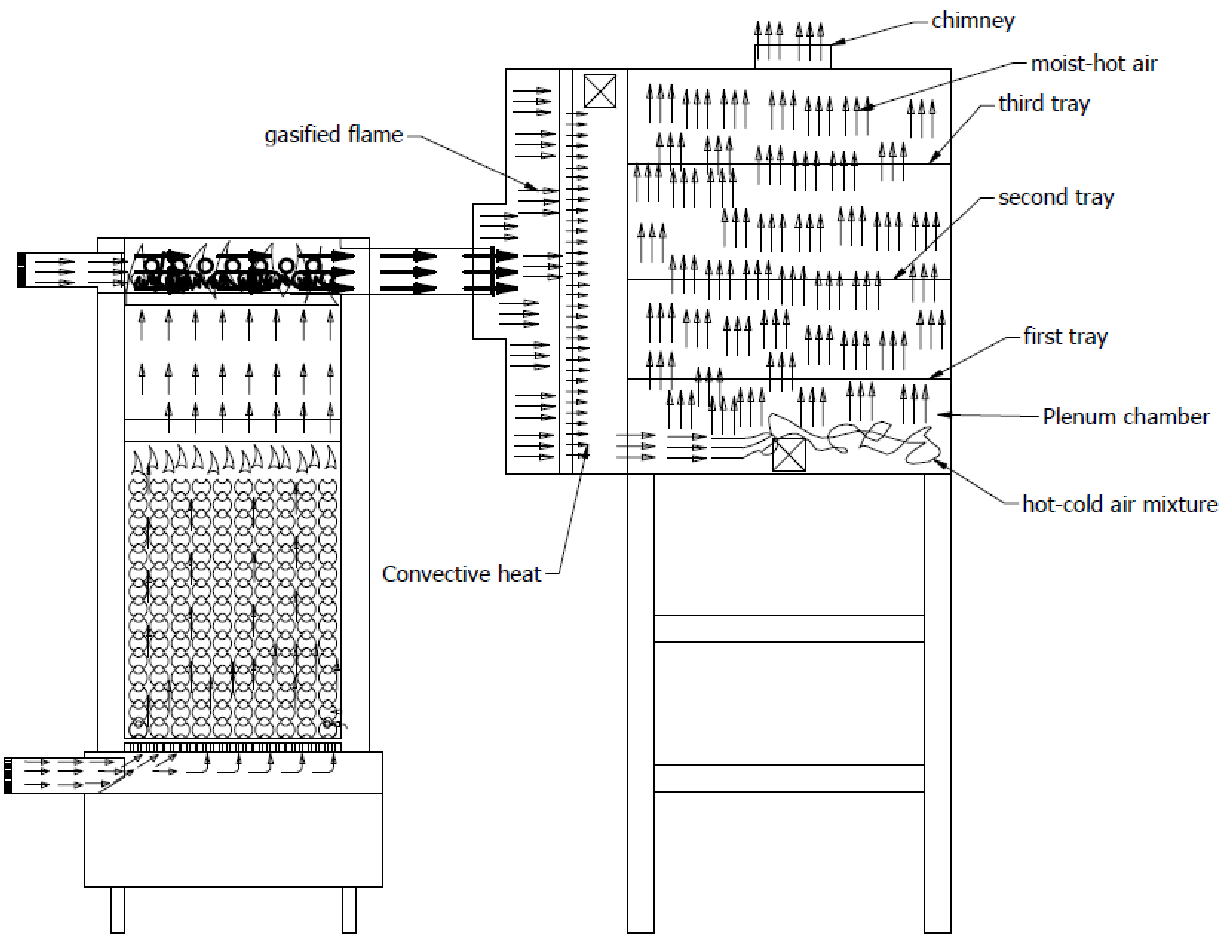


**Figure 4:** Operational principle of heat and mass transfer system of the dryer.

### 8.3 System Design

The design of the drying system considered the material to be dried, the TLUD biomass gasifier, the heat exchanger and the cabinet dryer. Some of the design components are discussed below.

#### 8.3.1 Moisture to be removed in material

For experimental purpose, plantain slices were selected as a sample product that was tested with the drying system. It is imperative to mention that other agricultural materials, such as vegetables, tubber crop slices, fruits slices, etc., can be dried with the drying system adopting appropriate design configuration.

The moisture removed from the plantain dried ($M_w$), according to Muritala *et al.* (2022), was calculated using the expression:

$$M_w = M_p \frac{(M_i - M_f)}{(100 - M_f)} \tag{1}$$

Where $M_p$ is the initial mass of plantain slices to be dried which for this design was 20kg, $M_i$ and $M_f$ are the initial and final moisture content of the plantain slices gotten as 61% and 8 % respectively.

$$M_w = 20\frac{(61-8)}{(100-8)} = 11.52$$

The amount of moisture evaporated from the plantain slices per batch of drying was 11.52kg.

### 8.3.2 Quantity of heat needed to evaporate moisture from the material

According to Muritala *et al.* (2022), the amount of heat energy ($Q_n$) needed to evaporate the moisture from the plantain slice was determined using equation (2.2).

$$Q_n = M_w \times h_{fg} \qquad (2)$$

Where $h_{fg}$ is the latent heat of water (given as 2264.705kJ/kg).

$$Q_n = 11.52 \times 2264.705 = 26{,}093.34$$

The heat energy used to evaporate the moisture from the plantain slices was 26,093.34kJ.

### 8.3.3 Energy required from the gasifier

The heat energy required from gasifier ($Q_r$) needed to achieve optimum removal of moisture from the plantain slices, according to Adeyi *et al.* (2023), was determined with equation (2.3).

$$Q_r = \frac{Q_n}{1000 \times D_t}\varphi \qquad (3)$$

Where $D_t$ is the drying time (h). The average drying time of plantain, reported by Famurewa and Adejumo (2015), Muritala *et al.* (2022), Ekeke *et al.* (2019), and Ajala *et al.* (2021), was 4 hours. $\varphi$ is the energy conversion coefficient, according to Adeyi *et al.* (2023), was selected as 40.

$$Q_r = \frac{26{,}093.34 \times 40}{1000 \times 4} = 260$$

The gasifier supplied 260MJ/h energy for drying the plantain slices.

### 8.3.4 Energy input into the gasifier

The amount of biomass fuel (PKS, CCS, and WDS) needed to be fed into the gasifier to supply the required energy (FCR), fuel consumption rate, according to Ojolo *et al.* (2012), was determined with equation (2.4).

$$FCR = \frac{Q_r}{C_f \times \epsilon_s} \qquad (4)$$

Where $C_f$ is the calorific value of biomass material (kJ/kg), and $\in_s$ is the theoretical gasifier efficiency. The maximum of the calorific values of selected biomass (PKS, CCS, and WDS), according to Onochie *et al.* (2015), was 23604.71kJ/kg for PKS. $\in_s$ of 80% was selected, hence:

$$FCR = \frac{260000}{23604.71 \times 0.2} = 13.7684$$

$$FCR \approx 14kg/h$$

To achieve FCR of 14kg/h, the gasifier reactor diameter and height were determined as 28cm and 90cm respectively to achieve fuel consumption time of 2.34h, stoichiometry air requirement and gasification air flow rate of 6.22kg of air/ kg of fuel and 82.1m$^3$/h respectively.

### 8.3.5 Conduction and convention heat flow of the heat exchanger

These, according to Famurewa *et al.* (2017), were determined with equations (2.5) and (2.6).

$$Q_c = \frac{kA\Delta T}{x_p} \qquad (5)$$

$$Q_v = hA(T_s - T_\delta) \qquad (6)$$

Where $Q_c$ is the conduction heat flow (W), $k$ is the thermal conductivity of heat exchanger plate (steel = 54 W m-$^1$ K$^{-1}$), $A$ is the surface area of the heat exchanger plate (m$^2$), $\Delta T$ is the heat exchanger plate temperature difference at time interval t. (°C), $x_p$ is the thickness of the heat exchanger plate. $Q_v$ is the convection heat flow (W), $h$ is convection heat transfer coefficient (W m-$^2$ K$^{-1}$), $A$ is surface area of the heat exchanger plate (m$^2$), $T_s$ is the surface temperature of the heat exchanger plate (°C), and $T_\delta$ is the surface temperature of the surrounding fluid (ambient air °C). $Q_c$ and $Q_v$ are the same and were determined as 252,564kJ, and $x_p$ was determined as 5mm.

### 8.3.6 Performance response models of the drying system

The various drying system responses were determined, following standard models, as briefed below.

1. **Thermal efficiency of the gasifier ($TE_g$):** The effectiveness of the gasifier in converting the energy available in the biomass fuel to usable heat energy was determined, according to Verma *et al.* (2024), using equation (2.7).

$$TE_{\boldsymbol{g}} = \left( \frac{f_m \times LHV}{\dot{m}_F \times C_{pf} \times \Delta T \times t} \right) \times 100 \qquad (7)$$

Where $f_m$ is the mass of biomass loaded into the gasifier (kg), $LHV$ is the lower heating value of the biomass (MJ/kg), $\dot{m}_F$ is the mass flow rate of the exhaust flame (kg/s), $C_{pf}$ is the specific heat capacity of the exhaust flame (kJ/kg·K), $\Delta T$ is the temperature increase of the exhaust flame from ambient to exit temperature (K), and $t$ is the time duration of gasification (s).

2. **Combustion efficiency of the gasifier:** The amount of biomass fuel gasified with respect to the fuel loaded, according to Chatchai and Pakamon, 2022, was determined with equation (2.8)

$$CE = \frac{f_{mg}}{f_m} \times 100 \qquad (8)$$

Where $f_m$ is the initial mass of biomass loaded into the gasifier (kg), and $f_{mg}$ is the amount of biomass gasified in the gasifier till complete gasification (kg).

3. **Heat exchanger efficiency:** The ability of the heat exchanger to reduce the heat conducted and convent into the heat baffle zone to minimum required level, as controlled by the system with the ambient air mixture strategy, was determined with equation (2.9).

$$HE_R = \frac{T_f - T_b}{T_f} \times 100 \qquad (9)$$

Where $HE_R$ is the heat exchanger efficiency (%), $T_f$ is the gasifier flame temperature (C), and $T_b$ is the exit hot-air temperature of the heat exchanger into the cabinet dryer.

4. **Thermal efficiency of the dryer:** These, according to Khan and Ahamad (2016), was determined using the expression in equation (2.10).

$$TE_{\boldsymbol{d}} = \frac{LA_d h_{fg}\left(M_i - M_f\right)}{Ft\left(100 - M_f\right)} \qquad (10)$$

Where L is the weight density of the plantain slices per unit area (kg/m²), $A_d$ is the total product area (m²), $h_{fg}$ is the latent heat of vaporization (kJ/kg), $M_i$ is the initial moisture content (% w.b), $M_f$ is the final moisture content (% w.b.), F is the power of the heat source (kW), and t is the operation time of the heat source (h).

5. **Drying efficiency ($\eta_{\boldsymbol{d}}$):** The efficiency of the dryer in reducing the moisture content of the product to safe moisture content was determined, according to Muritala *et al.* (2022), using equation (2.11).

$$\eta_d = \frac{\left(M_i - M_f\right)}{M_i} \times 100 \tag{11}$$

6. **Drying rate:** Agricultural products behave differently from materials like textiles or sand during drying. They retain residual moisture due to their hygroscopic nature, whereas non-hygroscopic materials can have their moisture content reduced to zero. The moisture flow rate is primarily influenced by the vapor pressure difference between the material and its surroundings, but resistance to moisture flow also plays a role. Drying of agricultural products typically occurs in two stages: a constant drying rate period and a falling drying rate period. According to Chen *et al.*, 2023, drying rate of the plantain was determined using equation (2.12).

$$DR = \frac{M_{t+dt} - M_t}{dt} \tag{12}$$

Where DR is the drying rate in (%/min), $M_{t+dt}$ is the moisture content of the sample at time (t + dt), $M_t$ is the moisture content of the sample at time t, and dt represents the time difference between the two measurements.

7. **Moisture ratio (MR):** The moisture ratio of the plantain slices during drying, an essential component of drying kinetics of any product, was determined, according to Famurewa and Adejumo (2015), using equation (2.13).

$$MR = \frac{(M_t - M_e)}{(M_i - M_e)} \tag{13}$$

Where $M_t$ is moisture content at any time, $M_o$ is initial moisture content, and $M_e$ is equilibrium moisture content.

8. **Moisture diffusivity:** Fick's second law of diffusion was applied to determine the effective moisture diffusivity, assuming constant moisture diffusivity, an infinite cylindrical geometry, and a uniform initial moisture distribution. According to Ajala *et al.* (2021), the fick's law is expressed with equation (2.14).

$$MR = \frac{6}{\pi^2} exp\left(-\frac{\pi^2 Deff^t}{r^2}\right) \tag{14}$$

Where MR is moisture ratio (dimensionless), Deff is the effective diffusivity ($m^2/s$), and r is the radius of slice of the sample (m). from equation (2.13) and (2.14), the effective moisture diffusivity of the plantain slice during drying was determined using equation (2.15).

$$Deff = \left(\frac{\Delta \ln(MR)}{\Delta t}\right) \times \left(\frac{r^2}{\pi^2}\right) \quad (15)$$

9. **Activation energy:** The activation energy ($E_a$) of the drying kinetics if the plantain was determined using the Arrhenius equation, which relates the diffusivity to drying temperature. According to Chen *et al.*, 2023, the activation energy of the drying process was determined using equation (2.16).

$$Deff = D_0 exp\left(-\frac{E_a}{RT}\right) \quad (16)$$

Where $D_0$ is the pre-exponential factor (dimensionless), $E_a$ is the activation energy (J/mol), R is the gas constant (8.314 J/mol·K), and T is the absolute temperature (K).

$$E_a = -\frac{\Delta \ln(Deff)}{\Delta(1/T)} \times R \quad (17)$$

### 8.6 Optimization Results

**a)** Best drying conditions identified (via RSM):

**i.** Air temperature = 80°C.

**ii.** Slice thickness = 5 mm.

**iii.** Slice orientation = 90°.

**iv.** Pre-treatment = Neem extract soaking.

### 8.4 Experimental Procedure

The experimental procedure involved setting up a drying system by coupling the biomass gasifier, with all its accessories, into a heat exchanger and subsequently coupling it with a thin-layer cabinet dryer. A control system was implemented to monitor, control, and data-log all experimental data. The evaluation of the system was conducted in three stages. In Stage 1, the TLUD biomass gasifier was evaluated, using the selected biomass materials (PKS, CCS, and WDS), along with devices like a weighing balance, thermocouple, DC motor, and DC axial fan. Biomass fuel was prepared to have moisture content below 15% using the oven drying method and was fed into the gasifier using the DC motor and auger. Temperature readings inside the gasifier reactor and the outlet chute were taken using thermocouples to calculate the heat energy generated. After loading the biomass fuel, 2 ml of kerosene was added as a starter fuel, and the gasifier was ignited. The fan speed was measured with fan sensors, and all parameters were logged every 5 minutes. The gasifier operation was conducted following safety practices according to the United States Environmental Protection Agency (USEPA, 2021) guidelines. Stage 2 involved the heat exchanger, where the heat from the gasifier was directed into the exchanger, and a fan controlled the air flow for temperature reduction. Thermocouples monitored the temperatures at the baffle column and outlet chute, with fan speed, ambient, and outlet temperatures being logged every 5 minutes of operation. Stage 3 focused on the drying unit, where the cabinet dryer was set up with moisture metering devices, temperature measuring devices, and fan speed sensors. The cabinet dryer had an air inlet fan that was fully automated to work in response to the preset drying temperature. The inlet hot air temperature from the heat exchanger, plenum temperature, and various plantain slice temperatures and moisture contents were measured and logged every 5 minutes by the control system. The plantain slices, sliced to a thickness of 5mm and 10mm**,** were prepared using a precise cutter. The slices were grouped into three sets. The first group was subjected to blanching at 70°C for 60 seconds**,** while the second group was treated with 10g of neem plant extract in 250ml of fermented water from gruel "Omi Ogi" and soaked for 4 hours at 40°C. These prepared samples were arranged into different orientations (0°, 45°, 90°) in a 3x3 factorial design to ensure uniform heat distribution during drying. Moisture content was monitored, and once it reached safe moisture level (<9% MC), the dried product was removed and tested for proximate analysis and iron content, for product quality assessment. The logged data was collected from the control system via an SD card, categorized by stage, and stored in Excel format. The data was checked for consistency, missing values were addressed through reruns, and equipment calibration was performed using standard devices such as an oven drying method for the moisture meters, following Association of Official Analytical Chemists (AOAC) standard, and a digital tachometer for fan speed sensors.

## 8.5 System Control

The Arduino Mega 2560 microcontroller manages the entire system, Figure 5, regulating parameters such as temperature, fan speed, and moisture content, while also adjusting the fan speed and monitoring real-time moisture data for consistent drying. Key components include the Arduino Mega 2560 for system control, DHT11 temperature and humidity sensors for environmental humidity monitoring, 12 moisture sensors for tracking moisture content in the plantain slices, MAX6675 thermocouple for measuring heat from the biomass gasifier, heat exchanger and cabinet dryer, relays for controlling high-power devices, motors and PWM controllers to regulate airflow, a graphic display for real-time feedback, a micro SD card for data storage and analysis, and a boost converter to ensure stable voltage. The system adjusts fan speeds and heating elements to maintain a target temperature of 50°C to 100°C, uses real-time moisture data to prevent over-drying, logs data for future analysis, and optimizes drying conditions using Response Surface Methodology (RSM) to accommodate varying plantain varieties, slice thicknesses, and slice orientation.

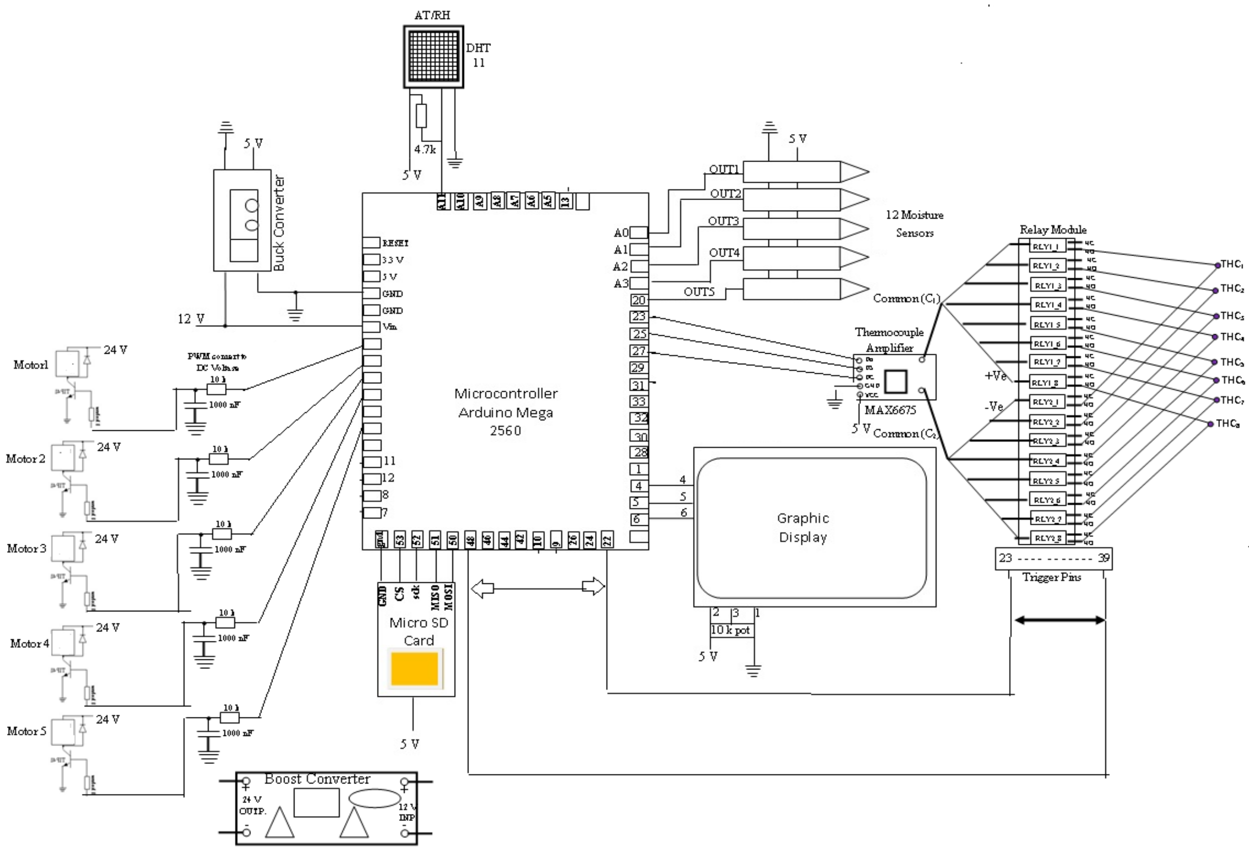



**Figure 5:** The circuit diagram of the control unit

## 8.6 System Simulation

The airflow, temperature, radiative heat flux, and other parameters within the automated hot-air cabinet drying system were simulated using ANSYS-CFD Fluent 24.1 software. A 3D model was developed to study heat transfer inside the system, specifically for drying plantain slices. The heat exchanger and the cabinet dryer model, created in Autodesk Inventor 2019**,** included different configurations to study the fluid flow in the two systems. The simulation setup considered various conditions of the models which include the material properties, the cell zone conditions, the boundary conditions, and reference values, The model for the heat exchanger contained 2,001,341 cells, 447,620 faces, 418696 nodes, and 2,387,211 cells, 784,670 faces, 2,745,201 nodes, for the heat exchanger and the cabinet dryer respectively. The mesh was refined near the walls using the inflated boundary conditions of ANSYS-CFD Fluent 24.1**.** The simulation focused on determining air velocity, temperature, heat transfer coefficient, radiative heat flux, pressure, and other drying parameters, and various simulation results were obtained. The obtained result justified the placement of the dryer tray at the second tray level of the cabinet, Figure 6, to obtained uniform hot air flow in the dryer for uniform drying of the plantain slices.

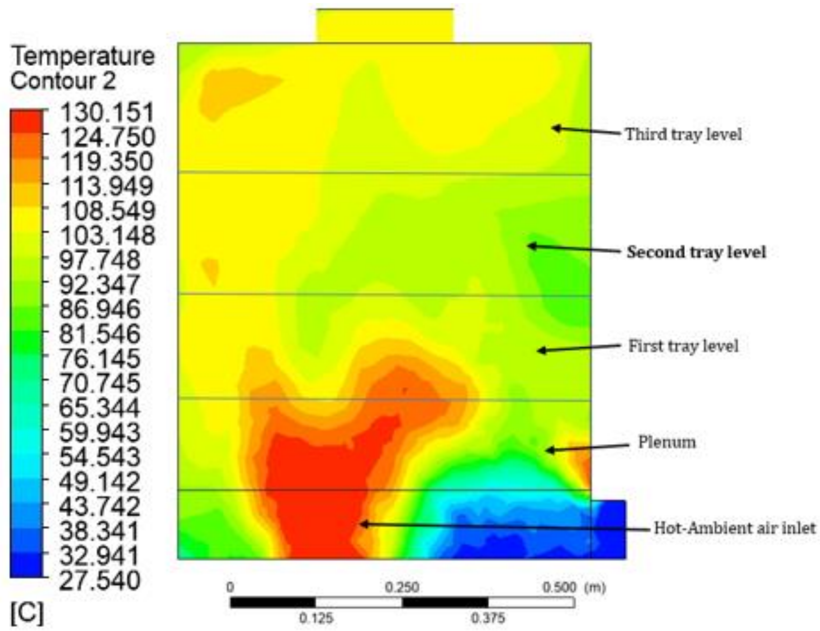



**Figure 6:** Temperature contour image of the hot-air distribution in the cabinet dryer

### 8.7 System Optimization

The optimum conditions for the TLUD biomass gasifier, the hot-air cabinet dryer and the dried plantain slices were determined using a Box-Behnken design and central composite design (CCD) respectively, under Response Surface Methodology (RSM)**.** The optimization process studied three variables, which include the fuel loading, the fan speed, and the fuel type, to determine the optimal responses of the gasifier (the thermal responses and flame emission quality). Likewise, four variables, which include air temperature and velocity, plantain slice thickness, slice orientation, and pretreatment, where studied to determine the optimal responses of the hot-air cabinet dryer and the dried plantain (this includes the thermal and performance responses of the dryer, and the drying kinetics and product quality of the dried plantain slices. Each variable was tested at different levels, with slice thickness varied twice, fan speed, fuel type, slice orientation, and pretreatment varied thrice, the fuel type varied at four levels, the drying mechanism and pre-treatment varied at four levels, while the drying temperature and velocity were varied at five levels. The lowest level was designated as "-1" and the higher level as "+1". A factorial design was used to analyze experimental data, and Design Expert version 13.0 software was employed to analyze the effects of the factors on the system and product quality.

### 8.8 System Modelling

To determine the best model for describing the drying characteristics of the plantain slices, drying curves were fitted with thin layer drying models**.** Fifteen of the existing thin layer model were selected. These models included semi-theoretical and empirical models derived from theoretical equations like Fick's second law, with empirical coefficients for improved fitting. Non-linear regression using moisture ratio (MR) was performed in Microsoft Excel v21(Solver analysis). The model selection was based on statistical parameters such as the coefficient of determination ($R^2$), chi-square ($\chi^2$), root mean square error **(**RMSE), mean bias error (MBE)**,** standard error or estimate (SEE), and sum of squared errors (SSE). The best model was selected using the highest value for the coefficient of determination ($R^2$) and the lowest value for the reduced chi-square ($\chi^2$) as the primary criterion for selecting the best model. The standard error (SEE) and SSE were used for model validation. The equations of statistical parameters, according to Ajala *et al.* (2021) are provided in equations 2.18 to 2.21.

$$R^2 = \frac{\sum_{i=1}^{n}(MR_e - MR_p)\sum_{i=1}^{n}(MR_e - MR_p)}{\sqrt{\sum_{i=1}^{n}(MR_e - MR_p)\sqrt{\sum_{i=1}^{n}(MR_e - MR_p)}}} \tag{18}$$

$$\chi^2 = \frac{\sum_{i=1}^{n}(MR_e - MR_p)^2}{N - n} \tag{19}$$

$$MBE = \frac{1}{N}\sum_{i=1}^{n}(MR_e - MR_p) \tag{20}$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{n}(MR_e - MR_p)^2\right]^{\frac{1}{2}} \tag{21}$$

Where $R^2$ is the coefficient of determination, $\chi^2$ is Chi-Square, RMSE is Root Mean Square Error, $MR_p$ is predicted moisture ratio, $MR_e$ is experimented moisture ratio, i is the ith data point, n is the number of observations, and N is the number of constants. These were fitted into fifteen models shown on Table 1.

**Table 1:** Thin layer models

| S/N | Model Name | Model Equation | Reference |
|---|---|---|---|
| 1 | Lewis | $MR = \exp(-kt)$ | Famurewa et al (2017) |
| 2 | Page | $MR = \exp\ (-kt^n)$ | Ajala et al. (2024) |
| 3 | Modified Page | $MR = \exp\ [-(kt)^n]$ | Ajala et al. (2024) |
| 4 | Henderson And Pabis | $MR = aexp(-kt)$ | Aduewa et al., (2019) |
| 5 | Logarithmic | $MR = aexp(-kt) + c$ | Oforkansi and Oduola (2016) |
| 6 | Two Term | $MR = aexp(-k_1t) + bexp(-k_2t)$ | Famurewa et al (2017) |
| 7 | Two Term Exponential | $MR = aexp(-kt) + (1-a)\exp\ (-kat)$ | Ajala et al. (2024) |
| 8 | Wangh and Singh | $MR = 1 + at + bt^2$ | Oforkansi and Oduola (2016) |
| 9 | Approximation Of Diffusion | $MR = aexp(-kt) + (1-a)\exp\ (-kbt)$ | Famurewa and Adejumo (2015) |
| 10 | Verma et al | $MR = aexp(-kt) + (1-a)\exp\ (-gt)$ | Aduewa et al., (2019) |
| 11 | Modified Henderson & Pabis | $MR = aexp(-kt) + bexp(-gt) + cexp(-ht)$ | Oforkansi and Oduola (2016) |
| 12 | Simplified Flick's Diffusion | $MR = aexp[-c\left(\frac{t}{L^2}\right)]$ | Adeyi et al. (2023) |
| 13 | Modified Page II | $MR = \exp\ [-k(\frac{t}{L^2})^n]$ | Ajala et al. (2024) |
| 14 | Midilli & Kucuk | $MR = aexp(-ktn) + bt$ | Aduewa et al., (2019) |
| 15 | Hill et al. | $MR = aexp(-kt^n) + bexp(-gt^n)$ | Aduewa et al., (2019) |

## 8.9 Performance Response Summary of the Drying System

The performance responses of the drying system are summarized in the Table 2 below.

**Table 2:** Performance response summary of the drying system

| Parameter | Response |
|---|---|
| Gasifier Performance | PKS biomass as fuel, 6000 rpm fan speed, 20 kg fuel loading, 86.02% thermal efficiency, 88.8% combustion efficiency, 42.61kW fire power, maximum flame temperature of 875°C, and emissions of 1.33ppm CO, 24.66 μg/m³ $PM_{2.5}$, 36 μg/m³ $PM_{10}$, 0.0083mg/m³ HCHO, and 0.0138mg/m³ TVOC, indicating emission threshold below USEPA, 2021 standard**.** |
| Heat Exchanger Efficiency | 91.11% heat exchanging efficiency, demonstrating effective heat transfer for drying. |
| Dryer Performance Factors | Evaluated with slice thickness (5mm & 10mm), slice orientation ($0^0$, $45^0$, & $90^0$), and pre-treatment (control, blanching, & neem bark extract). |
| Air Velocity for Efficiency | Higher air velocities (19 m/s to 24 m/s) significantly improved drying efficiency and moisture diffusivity. |
| Input Biomass Calorific Value | 23,604.71 kJ/kg |
| Energy Input | 318.66MJ/h |
| Heat Energy Output | 349.96MJ/h |
| Energy Efficiency | 91% |
| Energy Balance | Achieved through optimal operation at 5000 rpm fan speed and PKS fuel |
| Moisture Diffusivity | Ranged from $2.89 \times 10^{-7}$ to $9.06 \times 10^{-7}$ m²/s. |
| Activation Energy | Ranged from 9.18 kJ/mol to 19.19 kJ/mol. |
| Drying Time | Average of 132.93min |
| System Optimized Parameters | Gasifier: 20 kg fuel loading, 5000 rpm fan speed, PKS as biomass fuel.<br>Dryer: 80°C drying air temperature, 90° slice orientation, Neem extract pre-treatment, and 5 mm slice thickness. |

| | |
|---|---|
| Drying Model | Modified Page II model best described the drying behavior, validated by $R^2$, RMSE, $\chi^2$, and MBE of 0.999878, 0.00329, 1.20E-05, and -0.000894 respectively at pretreatment of Blanching, 5mm slice thickness, and 80°C air temperature, |
| Product Quality: Proximate and Mineral Analysis | Moisture content (8.2%), ash content (2.97%), fat content (1.09%), fiber content (3.67%), protein content (6.78%), carbohydrate content (75.56%), energy value (332.55Kcal/g), potassium level (585.37mg/100g), magnesium level (59.54 mg/100g), and iron content (2.61 mg/100g). |

## 9. COMPARISONS AND RECOMMENDATIONS

The drying system was compared with conventional dryers as summarized in Table 3 below.

**Table 3:** Drying system comparison with conventional dryers

| Feature | Sun Drying | Solar Dryer | LPG Dryer | TLUD Dryer (Developed) |
|---|---|---|---|---|
| Drying Time (min) | > 360 | > 200 | 150–180 | 133 |
| Cost Efficiency | Low | Moderate–High | Moderate–High | Very Low |
| Energy Source | Sunlight | Solar Energy | LPG/Diesel | Biomass (free/cheap) |
| Environmental Impact | High | Medium | Medium–High | Low (renewable energy) |
| Grid Independence | No | No | No | Yes |

## 10. RECOMMENDED INVESTORS

1) Federal Ministry of Agriculture and Food Security (FMAFS)
2) Nigerian Stored Products Research Institute (NSPRI)
3) National Centre for Agricultural Mechanization (NCAM)

## 11. LINK TO VIDEO DOCUMENTATION

Demonstration videos of the automated hot-air cabinet dryer powered by a TLUD biomass gasifier, during operation, is available at the video link below:

[https://drive.google.com/file/d/1_X6e1XNmmR_wb8xcc4BzNS6l7YRAkJxB/view?usp=sharing]

## 12 PROJECT BUDGETING

**Total Budget:** ₦50,000,000

### 1. Research & Development (₦6,000,000 – 12%)

- Design refinement (drawings, CFD simulations, material tests) – ₦2,000,000
- Prototype iterations (different capacity units) – ₦3,000,000
- Laboratory testing (nutritional analysis, emissions, performance) – ₦1,000,000

### 2. Fabrication & Materials (₦10,000,000 – 20%)

- Stainless steel sheets, insulation materials – ₦3,500,000
- Biomass gasifier components – ₦3,000,000
- Electronics (Arduino, sensors, solar units) – ₦2,000,000
- Machining, welding, finishing – ₦1,500,000

### 3. Commercialization & Deployment (₦20,000,000 – 40%)

- Fabrication of **20 commercial pilot units** – ₦15,000,000
- Deployment logistics (5 agro-ecological zones) – ₦3,000,000
- Installation & community workshops – ₦2,000,000

### 4. Capacity Building & Training (₦5,000,000 – 10%)

- Training local technicians & artisans – ₦2,000,000
- Farmer cooperative training – ₦1,500,000
- Manuals, multimedia, and guides – ₦1,500,000

### 5. Monitoring, Evaluation & Optimization (₦3,500,000 – 7%)

- Data collection & performance tracking – ₦1,500,000

- Optimization based on feedback – ₦1,000,000
- Certification (SON, NSPRI, NCAM) – ₦1,000,000

**6. Project Management & Administration (₦3,500,000 – 7%)**

- Salaries & stipends for PI, co-PIs, and assistants – ₦2,000,000
- Logistics, office, utilities – ₦1,500,000

**7. Dissemination & Outreach (₦2,000,000 – 4%)**

- Academic publications, briefs, conference papers – ₦1,000,000
- Stakeholder engagement & publicity – ₦1,000,000

### 12.1 Budget Summary Table

| Category | Amount (₦) | % of Total |
|---|---|---|
| Research & Development | 6,000,000 | 12% |
| Fabrication & Materials | 10,000,000 | 20% |
| Commercialization & Deployment | 20,000,000 | 40% |
| Capacity Building & Training | 5,000,000 | 10% |
| Monitoring & Evaluation | 3,500,000 | 7% |
| Project Management & Admin | 3,500,000 | 7% |
| Dissemination & Outreach | 2,000,000 | 4% |
| **Total** | **50,000,000** | **100%** |

## 13. PROFILES OF KEY INNOVATORS

The innovation is led by a multidisciplinary team of agricultural engineers, renewable energy specialists, and applied researchers with extensive expertise in post-harvest technology, biomass energy, and smart control systems.

### 13.1 Lead Innovator

**Prof. A. P. Olalusi**

- **Designation:** Professor, Department of Agricultural and Environmental Engineering, Federal University of Technology, Akure (FUTA).
- **Expertise:** Post-harvest technology, agricultural mechanization, renewable energy systems.
- **Experience:** Over 25 years in agricultural engineering research, with multiple peer-reviewed publications on food drying systems, biomass energy utilization, and agricultural machinery design.
- **Relevance to Project:** Provides leadership in system design, optimization, and integration with agricultural value chains.

## 13.2 Co-Innovators

### I. Prof. K. F. Jaiyeoba

- **Designation:** Professor, Agricultural and Environmental Engineering, FUTA.
- **Expertise:** Farm power and machinery, energy efficiency, and engineering materials for agro-processing.
- **Experience:** Led several R&D projects in renewable energy-powered processing systems, including gasifier-based heating and solar-assisted technologies.
- **Relevance to Project:** Provides oversight on mechanical design, durability, and field adaptation of the dryer.

### II. Dr. J. Isa

- **Designation:** Associate Professor, Agricultural and Environmental Engineering, FUTA.
- **Expertise:** Agricultural Processing Machineries and Food Engineer.
- **Experience:** Published widely on food engineering models, drying simulations, and energy technologies.
- **Relevance to Project:** Responsible for modelling, simulation, and thermal optimization of the dryer system.

### III. Engr. Dr. S. A. Olaleye

- **Designation:** Lecturer, Department of Agricultural & Bio-Environmental Engineering Technology, Federal College of Agriculture, Akure (FECA).
- **Expertise:** Renewable energy applications, smart sensor integration, automation of agricultural systems.
- **Experience:** Involved in multiple innovation projects on IoT-enabled smart farming devices, biomass energy systems, and farm machinery prototyping.
- **Relevance to Project:** Leads automation, instrumentation, and control systems, ensuring precision monitoring and operation of the dryer.

## 13.3 Supporting Team

- **Technologists & Fabricators:** Experienced local artisans and engineers from FUTA and FECA workshops who participated in the fabrication and pilot testing.
- **Graduate Students:** Provided assistance with simulation modelling, data collection, and optimization trials.
- **Community Farmers:** Served as field trial partners, validating the dryer's performance under real agricultural conditions.

## 13.4 Team Strengths

- **Proven Track Record:** Team members have successfully led projects funded by local and international agencies in renewable energy and agricultural technology.
- **Balanced Skill Set:** Expertise spans mechanical engineering, energy systems, computational modelling, and smart automation.
- **Industry and Policy Linkages:** Team members are active in professional bodies such as NSE (Nigerian Society of Engineers) and NSEABE (Nigerian Society of Agricultural Engineers), enabling strong connections for scaling and policy influence.
- **Capacity to Deliver:** With the support of NASENI, the team has the competence, facilities, and industry partnerships to take the dryer from prototype to commercial product.

# 14. CONCLUSION AND RECOMMENDATIONS

## 14.1 Conclusion

The Automated Hot-Air Cabinet Dryer powered by a TLUD Biomass Gasifier is a proven, sustainable, and scalable solution to one of Nigeria's most pressing challenges – post-harvest food loss.

The innovation has:

I. **Technical Strength:** Successfully designed, fabricated, and pilot-tested with validated results (drying time reduced by 40–60%, thermal efficiency >85%, emissions below USEPA limits).

II. **Economic Value:** Demonstrated strong commercial viability with reduced operating costs (70–80% cheaper than LPG/diesel dryers), short payback periods (1.5–2 years), and high ROI (30–35%).

III. **Societal Impact:** Shown potential to reduce national food wastage by 15–20% within five years, improve farmer incomes by 20–30%, and create thousands of jobs in fabrication, operation, and servicing.

IV. **Environmental Benefit:** Reduced carbon emissions, promoted waste-to-energy conversion, and aligned with Nigeria's Energy Transition Plan and climate commitments.

V. **Strategic Alignment:** Directly contributes to NASENI's priority areas — Renewable Energy, Agriculture & Food Manufacturing, and Health & Biotechnology — while indirectly supporting Sustainable Transportation, Smart Cities, and Defense Logistics.

The project is at Technology Readiness Level (TRL) 6–7, meaning it is beyond theory and pilot testing and is ready for scaling into commercial production with NASENI's support.

## 14.2 Recommendations

1. Commercialization Support from NASENI: NASENI should fund the scale-up of this innovation to move from prototype to mass production, targeting SMEs, cooperatives, and rural farmers as the primary beneficiaries.

2. Manufacturing Partnerships: Establish Partnerships between the research team, local fabricators, and NASENI's engineering hubs to ensure indigenous mass production of the dryers, reducing dependence on imports.
3. Pilot Deployment at Scale: Deploy pilot commercial units across at least five states representing different agro-ecological zones (Southwest, Southeast, Northcentral, Northwest, and Niger Delta) to validate large-scale adoption.
4. Capacity Building & Training: Train local technicians, artisans, and farmer cooperatives on the operation, servicing, and maintenance of the dryers. This ensures sustainability and creates jobs.
5. Partnership with Relevant Agencies: Collaborate with:
    a) Federal Ministry of Agriculture and Food Security (FMAFS) for farmer adoption.
    b) Nigerian Stored Products Research Institute (NSPRI) for food quality validation.
    c) National Centre for Agricultural Mechanization (NCAM) for large-scale mechanization.
    d) Standard Organization of Nigeria (SON) for certification and regulatory compliance.

6. Inclusion in National Food Security Programs: Integrate the dryer into government-led food preservation programs to strengthen Nigeria's food storage and processing systems.
7. Regional Export Potential: Position the innovation for West African markets where post-harvest losses are equally high (30–40% of total produce), thereby making Nigeria a regional hub for renewable-powered agro-processing technologies.

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