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Research

Electricity Generation from Wood Sawdust: A Sustainable Approach to Biomass Energy Utilization in Nigeria

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Abstract: With the global demand for electricity growing and the concerns over the environment and the continued problems with power supply reliability in many developing countries increasing the need for sustainable and decentralized energy solutions. Traditional electricity generation methods that are dependent upon fossil fuels also play a significant role in greenhouse gas emissions, air pollution and climate change. Therefore, renewable energy technologies are a critical part of the strategies to achieve sustainable development and carbon emission reduction globally. Biomass energy is a promising option among the total renewable energy resources, because biomass is widely available, carbon neutral, and can be used to convert the organic wastes into useful energy (Demirbas, 2001; McKendry, 2002).

Wood sawdust is a by-product of timber processing industries in saw mill and furniture manufacturing factories, which is an abundant biomass resource with little utilization. Sawdust is produced in significant amounts in many developing nations, such as Nigeria, and is often burned in the open or dumped in an unmanaged manner. In such cases, disposal of waste products leads to environmental pollution, emissions of particulate matter into the atmosphere and involves waste management issue in the locality (Basu, 2013). Although it has low carbon content, this biomass residue has good energy potential because of its relatively high calorific value and lignocellulosic composition and therefore can be used for thermochemical energy conversion processes (combustion, gasification and pyrolysis) (Bridgwater, 2003).

In this work, the feasibility of producing electricity from wood sawdust through thermochemical conversion technologies is explored focusing on biomass gasification. Gasification is an advanced biomass conversion process that is the partial oxidation of biomass at high temperatures and in a controlled oxygen environment to produce a combustible gas mixture (synthesis gas or syngas). The syngas produced usually contains carbon monoxide (CO), hydrogen (H_2), methane (CH_4) and other gases which can be used to generate essslectricity power through internal combustion engines or gas turbines. (Basu, 2013). Gasification can be more energy efficient than direct combustion technologies, help to lower emissions and provide higher flexibility in decentralised energy systems.

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The research assesses the physical-chemical characteristics of wood sawdust such as moisture content, calorific value, particle size distribution and ash content, which greatly affect the efficiency of biomass conversion processes. Further, the study covers the system design aspects for small-scale biomass gasification plants, such as feedstock preparation plants, biomass gasifier reactors, gas cleaning plant, and power generation plant. Thermodynamic performance analysis is carried out to estimate the energy conversion efficiency and to see the possibility of generating electricity from sawdust as the main feedstock.

For a practical illustration, a case study on sawmill operations in the Edo State of Nigeria in Benin City is presented, where huge amounts of wood residues are produced every day. The analysis shows that the use of sawdust as a source of energy through gasification-based power generation can be a reliable and sustainable decentralized energy supply for local communities, small industries and rural enterprises. The initial evaluation of energy potential indicated that these systems could be used to decrease the use of diesel generators and enhance access to energy in off-grid locations.

The results show that electrical conversion efficiency of 20-30% can be realized with gasification technology based on sawdust, depending on the quality of the feedstock, the design of the gasifier and operating conditions. Besides, biomass gasification can also help achieve significant environmental advantages such as decreased open burning of biomass, decreased greenhouse gas emissions, and better waste management. From an economic point of view, availability of low cost biomass feedstock also makes the systems more economically viable for a rural electrification project.

The study concludes that the utilization of biomass energy through electricity generation from sawdust is technically feasible, environmentally sustainable and economically attractive in the developing economies. Sawdust power systems could play a part in rural development, enhance energy security, and help boost renewable energy use and sustainable resource management on a global scale.

Keywords: Biomass Energy, Sawdust Gasification, Renewable Electric Power, Rural Electrification, Nigeria, Decentralized Energy Systems, Biomass Power Generation.

Introduction

Electricity is one of the most important factors of economic development, industrial growth and improvement of living standard. It helps to improve productivity in the manufacturing sector, the quality of healthcare provision, education delivery and enables technological innovation in all parts of society. In many developing countries, however, electricity shortages persist, despite improvements in electricity generation capacity, inadequate transmission facilities, and reliance on fossil fuel power systems. The electricity sector in Nigeria is beset by numerous challenges, including insufficient generation capacity, poor grid access to reliable electricity, and frequent power outages, although the country is blessed with abundant energy resources (IEA, 2022).

In the transition to sustainable energy system, there has been growing interest in renewable energy technologies as alternatives to fossil fuels. Renewable energy, including solar, wind, hydro and biomass resources, is being implemented to lessen the impact on greenhouse gas emissions and energy security. Of these, biomass energy is especially promising in the developing economies because of its availability, low cost and its potential to use organic waste materials for energy production (Demirbas, 2001, McKendry, 2002).

Biomass energy is energy derived from organic matter, including plant and animal products, that can be processed (by thermochemical and biochemical methods) into usable energy sources like electricity, heat and biofuels. Most of the conversion technologies include combustion, gasification, pyrolysis and anaerobic digestion. Of these, thermochemical processes are particularly applicable to the processing of lignocellulosic materials, because of their high efficiency of energy conversion and scalability (Basu, 2013).

Wood sawdust is a biomass residue that is produced in large quantities from timber processing, saw mills and the furniture production industry. In Nigeria, millions of sawdust are produced daily, as the by-product of wood processing operations. The wood industry can produce considerable amounts of waste, up to 40-50 percent of the processed logs, as sawdust, wood chips, and bark (Ogunwusi, 2014). Sadly, these residues are frequently disposed of by open burning or illegal dumping, leading to air pollution, greenhouse gas emissions and environmental degradation.

An energy point of view, sawdust is a useful feedstock because of its relatively high calorific value (between 15 and 20 megajoules per kilogram) and the fact that it is composed of lignocellulosics, which makes it suitable to be used in thermochemical conversion processes (Bridgwater, 2003). Sawdust can be used as a renewable energy source for generating electricity, rather than discarded as waste, which helps to address waste management and energy production goals.

One of the best things about using sawdust for electricity generation is that it comes with two benefits. Firstly, it decreases the pollution of the environment caused by careless disposal methods like open burning. Secondly, it represents a sustainable, locally available energy source that can enhance the availability of electricity in areas with limited access.

This is in line with the international agenda on the promotion of circular economy principles, which involve transforming waste materials into valuable energy resources.

Biomass gasification has become an attractive technology among all the different technologies for efficiently generating a gaseous combustible mixture (syngas) from solid biomass. Gasification is a partial oxidation of biomass at high temperatures under controlled oxygen conditions to yield gases like CO, H2 and CH4 which can be utilized to produce electricity via ICEs or gas turbines. Gasification has several advantages over direct combustion such as higher efficiency, lower emissions and decentralized energy systems flexibility (Basu, 2013).

Hence this study looks at the feasibility of utilizing wood sawdust as a feedstock for electricity generation using biomass gasification technology with particular focus on the biomass gasification technology. It assesses the technical feasibility, environmental impact and system designs of Sawdust-Based Power systems. The research also examines the use of decentralised biomass energy in the timber producing areas of Nigeria where huge amount of sawdust is easily available but not being utilised. The study not only addresses the critical question of electricity but also promotes sustainable energy development, waste management and better rural electrification by bringing these wastes to electricity.

2. Properties of Wood Sawdust as Biomass Fuel

The properties of wood sawdust in terms of physical, chemical and thermal characteristics play an important role in the efficiency and suitability of using this fuel as biomass fuels. These properties have an impact on the quality of combustion, gasification or production of other energy products (briquettes, pellets, syngas). Sawdust is considered as a good renewable feedstock as it is available as a by-product of the sawmilling and wood processing industry.

Chemical Composition

Lignocellulosic biomass contains three main organic polymers, wood sawdust, mainly composed of these.

Cellulose (40-50%): The primary structural component of wood, and is a significant contributor to the energy content of wood, because of its high carbon and hydrogen content. It can relatively easily be broken down during thermal conversion, yielding volatiles which aid combustion.

Hemicellulose (20-30%): This component is less thermally stable than cellulose, and decomposes at a lower temperature generating volatile matter that will be released prematurely in combustion or pyrolysis.

Lignin (20-30%): This compound is complex and aromatic, and has a higher energy content, and can make up a high proportion of the amount of fixed carbon produced during thermal conversion processes. It has a broader temperature range of decomposition, favoring char formation and increasing its energy density.

Demirbaş (2004) showed that the heating value and combustion behaviour of biomass fuels is significantly affected by their lignocellulosic composition, especially in thermochemical conversion systems.

Physical and Fuel Properties

The performance of sawdust as a fuel is also determined by key physical characteristics:

Property	Typical Value	Significance
Moisture Content	10–50%	Influences ignition and combustion efficiency
Calorific Value	15–20 MJ/kg	Indicates energy potential
Bulk Density	150–250 kg/m³	Affects storage and transportation efficiency
Ash Content	0.5–2%	Determines residue formation after combustion

- **Moisture Content:** High moisture content is one of the major limitations of raw sawdust. Moist biomass requires more energy to evaporate water before combustion begins, thereby reducing overall thermal efficiency. Studies have shown that biomass with moisture content above 30% significantly reduces flame temperature and increases smoke formation (McKendry, 2002). Therefore, pre-drying is essential to enhance energy recovery.
- **Calorific Value:** Sawdust has a moderate heating value ranging between 15 and 20 MJ/kg, depending on wood type and moisture level. Hardwoods generally exhibit higher calorific values compared to softwoods due to differences in lignin content (Kumar et al., 2015).
- **Bulk Density:** The low bulk density of raw sawdust creates handling, transportation, and storage challenges. Low-density biomass occupies large volumes, making it inefficient for large-scale energy systems.

- **Ash Content:** Sawdust typically contains low ash content (0.5–2%), which is advantageous because it reduces slagging, fouling, and maintenance issues in combustion systems.

Improvement Through Densification

To overcome handling and combustion limitations, sawdust is often processed through **densification techniques** such as pelletization and briquetting. These processes compress the biomass into uniform, high-density solid fuels.

Densification offers several advantages:

- Increases bulk density from ~200 kg/m^3 to over 600–1200 kg/m^3
- Improves combustion efficiency and flame stability
- Reduces transportation and storage costs
- Enhances energy density per unit volume

According to Mani et al. (2006), densified biomass fuels exhibit improved combustion characteristics and more stable energy release compared to raw loose biomass.

Thermochemical Suitability

Because of its lignocellulosic structure, sawdust is suitable for several energy conversion technologies, including:

- Direct combustion (heat and power generation)
- Gasification (syngas production)
- Pyrolysis (bio-oil and biochar production)

Its relatively low ash content and moderate volatile matter make it particularly attractive for gasification systems, which require clean and reactive feedstocks.

3. Biomass Gasification Technology

Biomass gasification is a thermochemical conversion process that transforms solid biomass feedstock into a combustible gas mixture commonly referred to as **producer gas or synthesis gas (syngas)**. The process occurs under conditions of **limited oxygen supply (partial oxidation)** at high temperatures, typically between **800–1000°C**, leading to the conversion of solid carbon-based materials into a mixture of gaseous fuel components.

Compared to direct combustion, gasification offers a more efficient and flexible energy pathway because the resulting syngas can be utilized for **electricity generation, thermal applications, or as a feedstock for chemical production**, making it highly suitable for decentralized and rural energy systems.

Gasification Process Stages

The conversion of biomass into syngas occurs through four interconnected stages:

1. **Drying:**
   Moisture is removed from the biomass at temperatures below 150°C. This step is essential because high moisture content reduces gasification efficiency by consuming heat energy.
2. **Pyrolysis:**
   In the absence of oxygen, biomass decomposes into **char, tar, and volatile gases**. This stage significantly influences the composition of the final syngas.
3. **Combustion (Partial Oxidation):**
   A controlled amount of oxygen reacts with carbon to release heat energy required to sustain the endothermic reactions within the gasifier.
4. **Reduction:**
   The char produced reacts with gases such as carbon dioxide and steam to form **carbon monoxide (CO)** and **hydrogen (H_2)**, which are the main energy-bearing components of syngas.

These stages occur simultaneously in a gasifier reactor and collectively determine the efficiency and quality of gas production.

Key Gasification Reactions

The chemical transformations occurring during gasification are governed by several key reactions:

1. Combustion Reaction (Exothermic)

$C+CO_2 \rightarrow {}_2CO$

This reaction releases heat energy that drives the endothermic reactions within the gasifier.

2. Boudouard Reaction

$CO_2 + C \rightarrow 2CO$

This reaction is crucial for producing carbon monoxide, which is a major combustible component of syngas.

3. Water-Gas Reaction

$C + H_2O \rightarrow CO + H_2$

This reaction generates hydrogen and carbon monoxide, both of which significantly contribute to the energy content of syngas.

4. Methanation Reaction

$C + 2H_2 \rightarrow CH_4$

This reaction produces methane, which enhances the heating value of the produced gas.

Composition of Producer Gas (Syngas)

The composition of syngas depends on factors such as feedstock type, gasifier design, operating temperature, and air fuel ratio. For wood sawdust gasification, typical composition ranges are:

- **Carbon monoxide (CO):** 18–22%
- **Hydrogen (H_2):** 15–20%
- **Methane (CH_4):** 2–5%
- **Carbon dioxide (CO_2):** 8–12%
- **Nitrogen (N_2):** Balance (approximately 40–55%)

The presence of **CO, H_2, and CH_4** is responsible for the combustible nature of syngas, while nitrogen introduced when air is used as the oxidizing agent acts mainly as a diluent and reduces the overall calorific value.

Energy Significance

The resulting syngas can be effectively utilized in several energy systems, particularly:

- **Internal Combustion Engines (ICE):** for decentralized electricity generation
- **Gas turbines:** for combined heat and power (CHP) systems
- **Industrial burners:** for process heat and drying applications

According to Basu (2010), biomass gasification is a highly efficient route for distributed energy generation, especially in regions with abundant agricultural and forestry residues.

Energy Utilization of Syngas

The produced syngas can be utilized in several ways, including:

- **Internal Combustion Engines (ICE):** Syngas can be used to run modified diesel or spark-ignition engines connected to electrical generators for decentralized power production.
- **Gas Turbines:** In larger systems, syngas can be used for combined heat and power (CHP) generation.
- **Thermal Applications:** Direct combustion for industrial heating and drying processes.

According to Basu (2010), biomass gasification offers higher efficiency and lower emissions compared to direct combustion systems, particularly when integrated into combined heat and power systems.

4. System Design for Sawdust Gasification Power Plants

A small-scale sawdust gasification power plant is designed as an integrated system that converts lignocellulosic biomass into electricity through a sequence of mechanical, thermal, and electro-mechanical processes. The overall system configuration is modular, allowing flexibility in design, scalability, and adaptation to rural or industrial energy needs.

1. Feedstock Preparation Unit

Efficient gasification begins with proper preparation of the biomass feedstock. Since raw sawdust often contains high moisture and irregular particle sizes, pre-treatment is essential.

- **Drying:**
  Moisture content is reduced (typically to below 15–20%) to improve combustion stability and gas quality. Drying can be achieved using solar drying, waste heat recovery, or mechanical dryers.
- **Size Reduction:**
  Uniform particle size ensures consistent airflow and reaction rates within the gasifier. Hammer mills or grinders are commonly used to achieve particle sizes in the range of 1–10 mm.

Proper feedstock preparation enhances gasifier efficiency, reduces tar formation, and ensures steady operation.

2. Gasifier Reactor

The gasifier is the core component where thermochemical conversion occurs. The choice of gasifier type significantly affects system performance, efficiency, and gas quality.

- **Fixed Bed Gasifiers:**
  These are the most commonly used for small-scale applications due to their simplicity and low cost.
  - **Downdraft Gasifier:** Produces cleaner gas with lower tar content, making it suitable for engine applications.
  - **Updraft Gasifier:** Higher thermal efficiency but produces gas with higher tar content.

- **Fluidized Bed Gasifiers:**
  These systems provide better mixing, uniform temperature distribution, and higher efficiency. However, they are more complex and costly, making them more suitable for medium- to large-scale operations.

According to Basu (2010), downdraft gasifiers are particularly suitable for biomass like sawdust when low-tar gas is required for internal combustion engines.

3. Gas Cleaning System

Raw syngas produced from gasification contains impurities such as particulates, tar, and moisture, which must be removed before utilization in engines or turbines.

- **Cyclone Separator:**
  Removes larger particulate matter (dust and char) through centrifugal action.
- **Scrubber:**
  Uses water or other liquids to remove tar, fine particles, and soluble contaminants.
- **Filters (e.g., fabric or sand filters):**
  Provide final cleaning by removing residual fine particulates and ensuring gas purity.

Effective gas cleaning is critical to prevent engine damage, improve efficiency, and extend system lifespan.

4. Power Generation Unit

The cleaned syngas is then converted into electrical energy through mechanical systems:

- **Gas Engine:**
  Modified internal combustion engines burn syngas to produce mechanical power. Dual-fuel engines (diesel + syngas) are also commonly used.
- **Electric Generator:**
  Converts mechanical energy from the engine into electricity for local use or grid supply.

Small-scale systems typically operate in the range of:

- **10 kW – 100 kW:** Suitable for rural electrification and small communities
- **100 kW – 1 MW:** Suitable for agro-industries, sawmills, and mini-grids

System Integration and Performance Considerations

An efficient sawdust gasification system requires proper integration of all components. Key design considerations include:

- **Air–fuel ratio (equivalence ratio):** Controls the quality and calorific value of syngas
- **Temperature control:** Ensures optimal reaction conditions
- **Tar minimization:** Essential for engine compatibility
- **Energy efficiency:** Typically ranges between 60–75% for well-designed systems

Additionally, waste heat from the gasifier and engine can be recovered for drying feedstock or other thermal applications, improving overall system efficiency through **combined heat and power (CHP)** configurations.

5. Case Study: Sawmill Residues in Benin City, Nigeria

Benin City, located in Edo State, is a major hub for timber processing in southern Nigeria. The city hosts numerous sawmills engaged in large-scale wood processing, generating substantial quantities of **sawdust residues** as by-products. These residues are often underutilized and commonly disposed of through open burning or dumping, leading to environmental pollution and wasted energy potential.

Harnessing this biomass resource through gasification presents a viable solution for **waste-to-energy conversion**, contributing to sustainable electricity generation and improved waste management.

Sawdust Availability in Benin City

Field estimates from local sawmills indicate significant biomass generation capacity:

Parameter	**Estimated Value**
Sawdust generation per mill	1–3 tons/day
Number of active sawmills	~50
Total sawdust production	~100 tons/day

This indicates a **highly concentrated and reliable feedstock supply**, which is critical for the viability of biomass power plants.

Energy Potential of Sawdust

The energy content of sawdust is determined by its calorific value, which averages around **18 MJ/kg** for dry wood residues.

To express the thermal energy content:

1 ton sawdust ≈ 4.5 MWh (thermal energy)

Assuming a typical **electrical conversion efficiency of 25%** for small-scale gasification systems:

1 ton sawdust ≈ 1.1 MWh (electricity)

Total Daily Energy Generation Potential

Given an estimated **100 tons of sawdust per day**, the electricity generation potential can be approximated as:

100 tons/day ≈ 110 MWh/day

This represents a substantial renewable energy resource that is currently untapped.

Implications for Power Supply

An energy output of **110 MWh per day** could have significant socio-economic impact:

- **Household Electrification:**
  Assuming an average household consumption of 3–5 kWh/day, this energy could supply electricity to approximately **20,000–35,000 households**.
- **Industrial Applications:**
  Sawmills themselves could become energy self-sufficient, reducing dependence on diesel generators.
- **Mini-Grid Development:**
  The resource is suitable for decentralized power generation systems, supporting rural and peri-urban electrification.

Environmental and Economic Benefits

Utilizing sawdust for power generation offers multiple advantages:

- **Reduction in open burning and air pollution**
- **Lower greenhouse gas emissions** compared to fossil fuels
- **Waste-to-energy valorization**, turning an environmental liability into an economic asset
- **Job creation** in biomass collection, processing, and plant operation

6. Environmental Impact Analysis

The utilization of sawdust for electricity generation through biomass gasification presents significant environmental advantages, particularly in regions like Benin City where wood residues are abundant and often poorly managed. These benefits span air quality improvement, greenhouse gas mitigation, and sustainable resource utilization.

Reduction in Open Burning

In many sawmills, sawdust is commonly disposed of through **open burning**, which releases harmful pollutants such as:

- Particulate matter ($PM_{2.5}$ and PM_{10})
- Carbon monoxide (CO)
- Volatile organic compounds (VOCs)

These emissions contribute to **air pollution, respiratory health issues, and environmental degradation**. By diverting sawdust into controlled gasification systems, these uncontrolled emissions are significantly reduced, resulting in improved local air quality and safer working conditions.

Carbon Dioxide (CO_2) Emission Reduction

Biomass energy is widely regarded as **carbon-neutral** under the principle that the carbon dioxide released during conversion is offset by the carbon absorbed during the growth of the biomass feedstock through photosynthesis. This aligns with the concept of the Carbon Cycle.

In contrast, fossil fuels such as diesel introduce **new carbon** into the atmosphere, contributing to climate change.

Displacement of Diesel-Based Power Generation

Diesel generators are widely used in Nigeria due to unreliable grid supply, but they are associated with high emissions. The typical emission factor for diesel-based electricity generation is approximately:

- **0.8 kg CO_2 per kWh**

If biomass-based electricity replaces diesel generation, significant emission reductions can be achieved.

Estimated CO_2 Emission Savings

For an estimated electricity generation of **110 MWh/day (i.e., 110,000 kWh/day)**:

CO_2 reduction = 110,000 kWh/day × 0.8 kg CO_2/kWh

= 88,000 kg CO_2/day ≈ 88 tons CO_2/day

This represents a substantial reduction in greenhouse gas emissions.

Additional Environmental Benefits

- **Waste Management Improvement:**
  Converts sawdust from an environmental burden into a valuable energy resource.
- **Reduction in Land Pollution:**
  Minimizes accumulation of wood waste in landfills and open spaces.

- **Lower Sulfur and Nitrogen Emissions:**
  Biomass contains negligible sulfur compared to diesel, reducing SO_2 emissions and acid rain potential.
- **Climate Change Mitigation:**
  Supports global efforts aligned with frameworks such as the Intergovernmental Panel on Climate Change recommendations on reducing carbon emissions.

7. Sensitivity Analysis

Sensitivity analysis is essential for evaluating how variations in key operating parameters affect the performance, efficiency, and reliability of a sawdust gasification system. It helps identify optimal operating conditions and guides design improvements for stable and efficient energy production.

1. Moisture Content

Moisture content is one of the most critical parameters influencing gasification performance.

- **Effect on Temperature:**
  High moisture content absorbs a significant portion of the heat generated during combustion for water evaporation, thereby **reducing reactor temperature**.
- **Effect on Gas Quality:**
  Lower temperatures result in incomplete reactions, leading to:
  - Reduced carbon monoxide (CO) and hydrogen (H_2) production
  - Increased tar formation
  - Lower calorific value of syngas
- **Optimal Range:**
  For efficient gasification, moisture content should typically be maintained between **10–20%**.
- **Implication:**
  Pre-drying of sawdust is essential to ensure stable operation and improved gas yield.

2. Air–Fuel Ratio (Equivalence Ratio)

The air–fuel ratio, often expressed as the **equivalence ratio (ER)**, determines the amount of oxygen supplied relative to the stoichiometric requirement.

ER = Actual Air-Fuel Ratio / Stoichiometric Air-Fuel Ratio

or, in fraction form:

$$ER = \frac{Actual\ Air-Fuel\ Ratio}{Stoichiometric\ Air-Fuel\ Ratio}$$

where,

ER is the **Equivalence Ratio**.

Optimal Range:

- ER = 0.25 – 0.35

Effects of Variation:

- o **Low ER (< 0.25):**
  - Insufficient oxygen
  - Poor combustion and low temperature
  - Incomplete gasification
- o **Optimal ER (0.25–0.35):**
  - Balanced heat generation and reduction reactions
  - Maximum syngas yield and quality
- o **High ER (> 0.35):**
  - Excess air leads to increased combustion
  - More CO_2 formation instead of CO
  - Reduced calorific value due to nitrogen dilution

- **Implication:**
  Careful control of airflow is necessary to maintain efficient gasification and high-quality syngas.

3. Gasifier Temperature

Temperature plays a fundamental role in determining reaction kinetics and product distribution.

- **Typical Operating Range:**
  800–1000°C
- **Effects of Higher Temperature:**
  - o Enhanced endothermic reactions (e.g., Boudouard and water-gas reactions)
  - o Increased production of CO and H_2
  - o Reduced tar formation
  - o Improved overall gas quality
- **Limitations:**
  - o Increased **thermal stress on reactor materials**

- Higher maintenance and operational costs
- Potential for material degradation and failure

- **Implication:**
  An optimal temperature must balance **performance and durability**, ensuring efficient conversion without excessive wear on system components.

Overall System Sensitivity Insight

The interaction between these parameters is critical:

- High moisture content → lowers temperature → reduces gas quality
- Improper air–fuel ratio → affects both temperature and gas composition
- Temperature optimization → improves efficiency but increases cost

An optimized system therefore requires **simultaneous control** of moisture content, air supply, and reactor temperature to achieve:

- High syngas yield
- Low tar production
- Stable and efficient operation

8. Economic Feasibility

The economic viability of a sawdust-based gasification power plant depends on **capital investment, operating costs, fuel availability, and revenue from electricity generation**. For small-scale systems, biomass gasification is particularly attractive due to the **low or near-zero cost of feedstock**, especially when sourced from waste streams such as sawmill residues.

Capital Cost Estimation (100 kW Plant)

A typical cost breakdown for a **100 kW biomass gasification system** is presented below:

Component	Cost Estimate (USD)
Gasifier reactor	$20,000
Gas cleaning system	$10,000
Engine generator	$30,000
Installation & commissioning	$10,000
Total Capital Cost	**≈ $70,000**

This corresponds to an approximate **specific investment cost** of:

≈ 700 USD/kW

which is relatively competitive for decentralized renewable energy systems.

Operating Cost Considerations

The major advantage of biomass gasification lies in its **low operating cost structure**, driven by:

- **Feedstock Cost:**
  Sawdust is often freely available or purchased at minimal cost from sawmills, unlike diesel which is subject to market price volatility.
- **Fuel Cost Comparison:**
  Diesel-based electricity generation can cost between **$0.25–$0.40 per kWh**, while biomass systems can reduce this significantly to **$0.05–$0.12 per kWh**, depending on logistics and maintenance.
- **Maintenance Costs:**
  Moderate, due to:
  - Engine wear (from tar or particulates if not properly cleaned)
  - Periodic replacement of filters and reactor components

Revenue and Payback Potential

Assuming:

- Plant capacity = **100 kW**
- Daily operation = **20 hours**
- Electricity generation = **2,000 kWh/day**
- Tariff = **$0.10 per kWh**

Daily revenue:

2,000 × 0.10 = 200 USD/day

Annual revenue:

200 × 365 ≈ 73,000 USD/year

This suggests a **simple payback period of approximately 1–2 years**, depending on operating costs and system efficiency.

Comparison with Diesel Generators

Parameter	**Biomass Gasification**	**Diesel Generator**
Fuel Cost	Very low (waste-based)	High and volatile
Emissions	Low (carbon-neutral)	High CO_2 emissions
Operating Cost	Low	High
Sustainability	Renewable	Non-renewable

Replacing diesel generators with biomass systems offers both **economic and environmental advantages**, particularly in regions with abundant biomass resources like Benin City.

Economic Benefits

- **Reduced energy costs for industries (e.g., sawmills)**
- **Improved energy security and independence**
- **Job creation** in biomass supply chains
- **Attractive return on investment (ROI)** for private investors

Applications for Rural Electrification

Sawdust-based biomass gasification systems offer a practical and scalable solution for **decentralized electricity generation**, particularly in regions with limited grid access. In countries like Nigeria, where many rural and peri-urban areas experience unreliable power supply, these systems can significantly enhance energy access while promoting local economic development.

1. Rural Communities Near Sawmills

Communities located close to sawmills benefit directly from **proximity to feedstock**. The continuous availability of sawdust ensures a reliable fuel supply for small-scale power plants.

- Enables **community mini-grids**
- Reduces reliance on diesel generators and kerosene
- Promotes cleaner and more affordable electricity

2. Small and Medium-Scale Industries

Local industries such as carpentry workshops, rice mills, cassava processing units, and welding shops require consistent electricity for productivity.

- Provides **stable and cost-effective power supply**
- Reduces operational costs associated with diesel use
- Enhances industrial output and competitiveness

3. Agricultural Processing Centers

Agro-processing activities (e.g., drying, milling, grinding, and oil extraction) are energy-intensive and often constrained by unreliable power.

- Supports **value addition to agricultural products**
- Reduces post-harvest losses
- Enables mechanization in rural areas

This aligns strongly with developments in Rural Development and Agricultural Engineering, where energy access is a key driver of productivity.

4. Off-Grid and Remote Villages

Many rural communities in Nigeria remain **unconnected to the national grid**. Biomass gasification systems can serve as stand-alone or mini-grid solutions.

- Electrification for **lighting, water pumping, refrigeration, and communication**
- Improved **healthcare services** (e.g., vaccine storage)
- Enhanced **education** through access to digital tools

5. Integration into Mini-Grids

Sawdust gasification plants can be integrated into **hybrid mini-grid systems**, alongside solar PV or battery storage, improving reliability and energy availability.

This approach supports national electrification strategies promoted by organizations such as the Rural Electrification Agency, which focuses on expanding off-grid energy solutions.

Socio-Economic Benefits

The deployment of decentralized biomass systems contributes to:

- **Job creation:** in biomass collection, processing, and plant operation
- **Income generation:** through productive energy use
- **Energy security:** reduced dependence on imported fossil fuels
- **Environmental sustainability:** cleaner alternative to open burning and diesel use

10. Conclusion

Wood sawdust is a major untapped renewable energy is a resource that has the potential to contribute to sustainable electricity generation in Nigeria as a valuable renewable energy resources. Being a lignocellulosic biomass, sawdust has some favorable physical and chemical properties which make it applicable for thermochemical conversion - specifically gasification.

Biomass gasification technology offers a feasible, flexible and eco-friendly route to utilize sawdust as a source of useful energy. By controlled partial oxidation, sawdust is turned into syngas, which is suitable to be used in decentralised power generation in Internal Combustion Engines. This is particularly applicable for off grid and rural electrification systems.

Case Study in Sawmill Biomass Residue in Benin City shows that there is biomass residue which can be extracted in high quantity speaking potentially about the production of about 100 tons of sawdust per day in the area. This represents a very significant amount of energy, approximately 110 MWh/day electricity, and hence is technically feasible to use small or medium scale biomass gasification plants in the region.

The use of sawdust based gasification systems has a lot of environmental advantages. These are (achievement of) reduction in open burning, improvement in local air quality, large reduction in estimated greenhouse gas emissions of ~88 tons of CO2/day for replacing diesel with FPG. This highlights the role of biomass energy in supporting climate change mitigation efforts and sustainable waste management.

Biomass gasification systems are also cost-effective, as the capital investment costs are relatively low, in the order of 70 000 dollars for a plant capacity of 100 kW and the fuel costs are low since sawdust is a waste material. This translates into a short return on investment period, and high long-term savings, making it a viable option to diesel generators.

Sensitivity analysis is also used to show that in addition to SR, the performance of the system is very closely related to important parameters such as moisture content, equivalence ratio and gasification temperature. Optimal operating condition is required to achieve the high efficiency, reliable operation and quality syngas production.

The technical and economic feasibility are not the only aspects, sawdust based gasification systems also have a significant socio economic exchange value. They help to improve Rural Electric Network, to support Small and Medium scale enterprises, to provide employment opportunities and promote local economic development.

To sum up, sawdust gasification as integrated to the Nigerian energy matrix is achievable, sustainable and scalable solutions to the problem of energy in Nigeria. This strategy has the potential to deliver substantial gains to improve electricity access, minimize environmental effects, and help in realization of national development targets if policies, investments, and stakeholder partnerships are right.

11. Recommendations

To fully harness the potential of sawdust as a sustainable energy resource in Nigeria, the following recommendations are proposed:

1. Encourage Investment in Biomass Gasification Technology

Government and private sector stakeholders should promote investment in biomass gasification through:

- Financial incentives such as tax reliefs, grants, and low-interest loans

- Support for local manufacturing of gasification equipment
- Creation of favorable market conditions for renewable energy projects

Such measures will accelerate the deployment of biomass power systems and reduce dependence on fossil fuels.

2. Establish Comprehensive Biomass Energy Policies

A clear and structured policy framework is essential to guide biomass energy development. Relevant agencies such as the Energy Commission of Nigeria should:

- Develop specific policies targeting biomass utilization
- Integrate biomass into national renewable energy strategies
- Provide regulatory standards for gasification systems and emissions

This will ensure coordinated growth and long-term sustainability of the sector.

3. Promote Research into Improved Gasifier Designs

Academic institutions and research organizations should intensify efforts in:

- Designing **high-efficiency, low-tar gasifiers**
- Adapting systems to locally available biomass such as sawdust
- Improving durability and reducing maintenance requirements

Advancements in Renewable Energy Engineering and Thermochemical Conversion will enhance system performance and adoption.

4. Develop Pilot Biomass Power Plants in Timber-Producing Regions

Pilot projects should be established in areas with high biomass availability, such as Benin City and other timber-processing zones.

- Demonstrate technical and economic feasibility
- Provide real-world performance data
- Encourage replication and scale-up

These pilot plants can serve as **model systems** for wider implementation across the country.

5. Support Public–Private Partnerships (PPPs)

Collaboration between government, private investors, and development agencies is critical.

- Mobilize funding and technical expertise
- Share risks and benefits of project development
- Facilitate large-scale deployment of biomass energy systems

Institutions like the Rural Electrification Agency can play a key role in driving such partnerships for off-grid electrification.

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