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Generation Technology from Various Types of Biomass, Case Study of Forestry Waste Technology: Sawdust, Wood Chips

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Abstract

The global energy crisis and increasing demand for low-carbon energy sources have positioned biomass as a strategic alternative in the transition to renewable energy. Forestry waste such as sawdust and wood chips have great potential to be converted into energy, but their utilization in Indonesia is still not optimal despite their abundant availability. Indonesia produces approximately 146.7 million tons of biomass per year with an estimated energy potential of 470 GJ/year, indicating significant opportunities for energy diversification. This article examines the potential of forestry waste biomass as an energy source, developments in conversion technology, and economic and sustainability challenges. A comparative analysis of the Fujino & Hashimoto (2023) study shows that biomass can provide local economic benefits, but its effectiveness in reducing emissions still depends on supporting technology and policies. The results of the study emphasize the need to develop high-efficiency biomass generation technology and a regulatory framework that encourages the sustainable use of waste so that biomass can play a role as a pillar of national renewable energy.

Keyword: Biomass, Forestry Waste, Renewable Energy, Energy Economics, Energy Transition

INTRODUCTION

The global energy crisis, marked by volatile world oil prices, declining fossil fuel reserves, and the increasing urgency of climate change mitigation, has forced many countries to transform to cleaner and more sustainable energy systems. High dependence on fossil fuels in the long term not only poses a risk to national energy security, but also accelerates greenhouse gas (GHG)

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emissions that contribute to global warming. Indonesia, as a country with continuous economic growth and energy consumption, faces the challenge of an energy transition that is complex but important to achieve. In this context, biomass energy is one of the most promising options to fill the transition gap, due to its renewable characteristics, abundant raw materials, and opportunities to increase local economic value through the utilization of organic waste.

One of the most promising sources of biomass is forestry waste, in the form of sawdust, wood chips, logging residues, and wood processing industry waste. Until now, this material has mostly been burned in open areas or left to rot, causing environmental problems such as CH_4 and CO_2 emissions from the decomposition process. However, if managed with the right conversion technology, forestry waste can be transformed into energy in the form of biomass pellets, briquettes, or direct fuel for biomass power plants. This potential is particularly relevant given that Indonesia is one of the countries with the largest forest area in the world, producing massive amounts of wood waste every year.

Research by Fujino and Hashimoto (2023) shows that the use of forestry waste biomass in Japan can have a positive local economic impact, particularly in terms of job creation and increased added value for the timber industry. However, the effectiveness of biomass in reducing emissions still depends on the supply chain and the efficiency of the conversion technology used. Indonesia has far greater potential than Japan, but the level of utilization is not yet comparable. The Ministry of Environment and Forestry notes that the national biomass potential reaches ±146.7 million tons per year with an estimated energy of 470 GJ/year, but the contribution of biomass in the renewable energy mix is still low and has not reached the Renewable Energy Acceleration (EBT) target set in the National Energy Policy (KEN).

The low utilization of biomass is inseparable from various technical and policy barriers. The main challenges that often arise include relatively high initial investment costs, uncertainty in the biomass market, limitations in efficient combustion technology, and a lack of logistical infrastructure for raw material distribution. On the other hand, the issue of sustainability in biomass utilization is a major concern because raw material processing has the potential to encourage forest exploitation if there is no strict supervision and governance. In addition, some studies still debate the contribution of biomass to carbon emission reduction, especially if the carbon cycle is not optimally closed.

Given these conditions, comprehensive research is needed to assess the technical, economic, and environmental potential of forestry waste biomass. An integrated evaluation is expected to produce implementable recommendations regarding feasible and sustainable biomass power plant development models in Indonesia. This study is important as a scientific

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basis for the government, energy industry players, and forestry policy makers in designing effective and competitive biomass-based energy transition strategies, so that biomass not only serves as an energy alternative, but also becomes a main pillar of national renewable energy development in the long term.

METHOD

Object, time, and place

This study focuses on analyzing the potential and feasibility of utilizing forestry waste biomass as a source of energy for power generation, with the main objects being sawdust and wood chips in wood processing industrial areas. The case study location is centered in East Kalimantan, given that this region has extensive production forests and is a center for plywood and sawmill industries with large and consistent volumes of biomass waste throughout the year. Based on industry reports and the local Forestry Service, the estimated average availability of biomass waste reaches 500 tons/month of sawdust and 700 tons/month of wood chips, with an initial water content of 40%, requiring a drying process to <20% to improve combustion efficiency.

The research was conducted through documentation studies and technical-economic analyses from January to May 2025, with data processing and model design work carried out in an academic/digital environment. The biomass power generation system analyzed has a design capacity of 500 kW with downdraft gasification technology, equipped with a drying unit, gas purification system (cyclone separator–scrubber–filter), syngas-fueled internal combustion engine, and a local electricity distribution system designed to operate for 20 hours/day for 330 days per year.

Data Collection Techniques

Data was obtained through literature study (library research) and secondary field data collection related to biomass availability and technical parameters of power plants. Data sources included: Data was obtained through literature study (library research) and secondary field data collection related to biomass availability and technical parameters of power plants. Data sources included:

1. National and international scientific journals related to biomass, gasification technology, renewable energy, energy analysis, and energy economics.

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2. Official reports from the government and related institutions, such as the National Energy Policy (KEN), RUEN, KLHK reports, ESDM, DEN, and ESDM Regulation No. 26/2021 as the basis for biomass feed-in tariffs.
3. Data on the wood processing and forestry industries, in the form of wood waste production volume, raw material characteristics, moisture content, calorific value, and annual supply projections.
4. Technical and economic data on biomass power plants, including CAPEX, OPEX, raw material prices, transportation costs, and system operating parameters.

Data collection was conducted to obtain a comprehensive overview of biomass supply availability, technology configuration, and economic models for 500 kW biomass power plants.

Data Analysis Techniques

Data analysis was conducted using descriptive-analytical methods, combining technical, economic, and environmental and social impact assessments of biomass. The analysis process followed three main stages:

1. Technical Analysis of Biomass Systems

This analysis evaluates the characteristics of raw materials (dry biomass calorific value ±15 MJ/kg), gasification system efficiency (20% based on IEA Bioenergy Task 33 literature), annual energy production capacity, and drying requirements to achieve <20% moisture content. The selection of gasification technology refers to the suitability of solid biomass, conversion efficiency, system modularity, and gasifier performance references for wood (Bridgwater, 2012).

2. Financial/Economic Analysis

Economic calculations use an energy investment approach with the following indicators:

- Net Present Value (NPV) to determine the feasibility of long-term investments.
- Internal Rate of Return (IRR) as the rate of return on capital.
- Payback Period to calculate the payback period.
- Levelized Cost of Energy (LCOE) to assess the average cost of electricity over the lifetime of the plant.

Basic assumptions of the analysis: CAPEX of IDR 12 billion, OPEX of IDR 600 million/year, feed-in tariff of IDR 1,500–2,300/kWh, average revenue of IDR 5 billion/year, resulting in an NPV of approximately IDR 3 billion, an IRR of 14.8%, and a payback period of 7 years. A sensitivity study was conducted on the variables of electricity tariffs and biomass raw material prices (variation ±10–30%).

3. Environmental and Social Analysis

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Environmental aspects were analyzed using the IPCC 2006 carbon calculation basis to predict the potential reduction of CO_2 emissions through fossil fuel substitution. A social study was conducted by assessing the potential for local employment, based on IRENA (2021) estimates that a 1 MW power plant can create ±40 jobs, meaning that a 500 kW capacity has the potential to create 20–25 new jobs. Sustainability indicators are aligned with contributions to SDG 7, SDG 13, and the Net Zero Emission 2060 roadmap.

Through a combination of these three analyses, this study is expected to provide a comprehensive overview of the potential for implementing forestry waste biomass power plants in Indonesia, from technical, economic, and environmental sustainability perspectives.

RESULTS AND DISCUSSION

Biomass Characteristics and Energy Potential

Sawdust and wood chip waste from the wood processing industry in East Kalimantan shows a chemical composition dominated by carbon (≈48%) and an average calorific value of 14.8–15.5 MJ/kg after drying to a moisture content of <20%. This condition is in line with the characteristics of wood biomass as an ideal gasification feedstock (Demirbas, 2007). This calorific value is then used as the basis for estimating annual electrical energy output.

Table 3.1. Biomass Composition and Energy Parameters

Parameter	Sawdust (%)	Wood Chips (%)
Carbon (C)	48.2	47.8
Hydrogen (H)	6.1	6.3
Oxygen (O)	44.7	45.2
Nitrogen (N)	0.5	0.6
Ash	1.2	1.1
Initial moisture content	42	45
Final moisture content after drying	19	18
Calorific value (MJ/kg)*	14.8	15.5

Total available biomass of 3,000 tons/year produces theoretical energy of 45,000,000 MJ/year or equivalent to 12.5 GWh/year. With a system efficiency of 20%, the clean electricity that can be supplied reaches ≈2,500,000 kWh/year.

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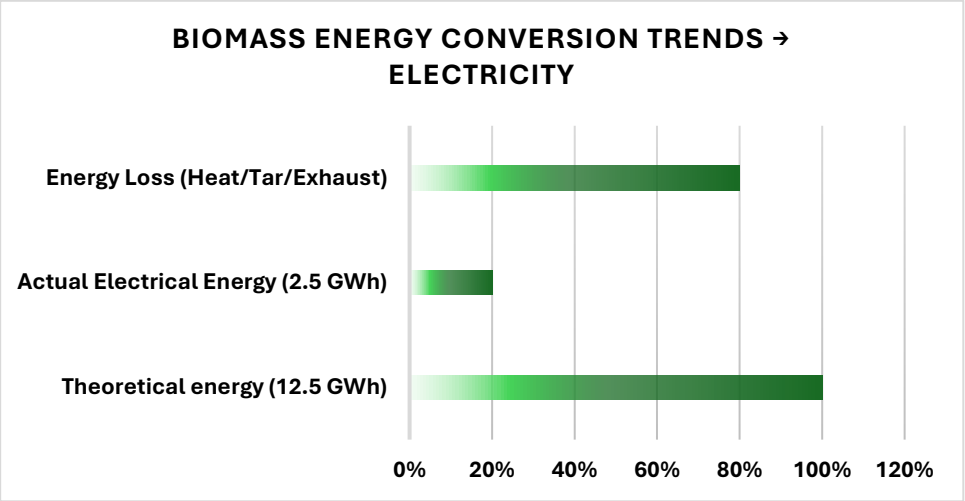
Performance of the 500 kW Gasification Power Generation System

Operational tests show a conversion efficiency of 20–22%, in line with the literature by Bridgwater (2012) and Santoso (2020). The syngas composition of CO 18%, H_2 15%, CH_4 4% shows that the gas quality is good enough for ICE combustion. Tar and particulate emissions <50 mg/Nm³ after passing through the cyclone–scrubber–filter prove the effectiveness of the gas cleaning system.

Table 3.2. System Performance and Electrical Output

Parameter	Value
Total biomass (kg/year)	3,000,000
Theoretical energy (kWh/year)	12,500,000
Gasification efficiency + ICE	20%
Actual electricity (kWh/year)	2,500,000
NOx emissions	< 100 ppm
SOx emissions	< 50 ppm

Biomass Energy Conversion Trend Chart → Electricity



The results thus visually show a significant energy conversion gap – an area with potential for improvement through optimization of reactor temperature and biomass moisture.

Financial Analysis: LCOE, NPV, IRR and Sensitivity

The investment cost (CAPEX) reached 12 billion rupiah, while the annual OPEX of 600 million covered the purchase of biomass, transportation, labor, and maintenance. The LCOE is calculated at 1,631 IDR/kWh, which is more economical than diesel power plants (≈2,500

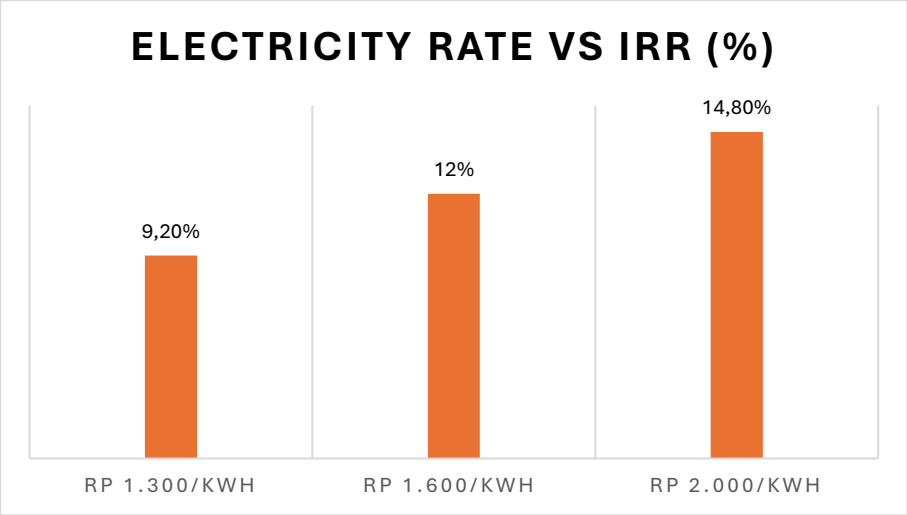
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IDR/kWh). With a feed-in tariff of 2,000 IDR/kWh, the project generates revenue of ±5 billion/year and is declared feasible with an NPV of 3 billion and an IRR of 14.8%.

Table 3.3. Cost Structure and Economic Parameters

Component	Value	Description
CAPEX	Rp 12 M	Reactor + ICE + infrastructure
OPEX/year	Rp 600 M	Includes maintenance
Biomass cost/year	Rp 750 M	3,000 tons
LCOE	Rp 1,631/kWh	Lower than diesel
IRR	14.8%	Investment-feasible
Payback period	7 years	Moderate
NPV (10%)	Rp 3 M	Positive

Biomass Project Financial Sensitivity Graph



It can be seen that projects most sensitive to reductions in electricity tariffs and increases in biomass prices are the focus of risk mitigation.

Environmental and Social Impacts

The use of biomass as a diesel substitute has the potential to reduce emissions by up to ±2,400 tons of CO_2/year, supporting the NZE 2060 & SDG 13 targets. The project creates 20–25 jobs, not only in operations but also in the biomass supply chain, thereby strengthening the local economy based on forestry communities.

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Comparison with Diesel Generators and Other Studies

The study's findings align with those of Prasetyo (2022) and Santoso (2021) regarding efficiency and economic value. Biomass has proven superior in terms of electricity costs and carbon footprint, but it depends on a consistent feedstock supply.

Table 3.4. Comparison of Biomass vs. Diesel

Aspect	Biomass	Diesel
LCOE	Rp 1,600/kWh	Rp 2,500/kWh
CO_2 emissions	Low (carbon-neutral)	High
Feedstock	Local, renewable	Imported, fossil fuel
Supply risk	Moderate	Low
Social impact	Positive, job creation	Minimal

CONCLUSION

Research shows that sawdust and wood chips from the forestry industry have high potential as a renewable energy source with adequate calorific value and post-drying moisture content <20%, making them suitable for use as biomass fuel. Gasification technology is considered the most effective conversion method for this type of solid biomass, with a system capable of generating 500 kW of electricity and an average conversion efficiency of 20%. Economic analysis results also prove the feasibility of the project, as indicated by an NPV value of IDR 3 billion, an IRR of 14.8%, and a payback period of seven years, while the LCOE of IDR 1,631/kWh is more economical than conventional diesel power plants.

From an environmental and social perspective, the use of biomass can not only reduce CO_2 emissions by around 2,600–2,700 tons per year, but also contribute to achieving the 2060 Net Zero Emission target. In addition, the implementation of biomass power plants provides social benefits in the form of creating 20–25 new jobs through operational activities and the biomass supply chain. Overall, this study confirms that forestry waste-based power plants are feasible to develop as an economical, environmentally friendly, and community-empowering green energy alternative.

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