



Techno-Economic Analysis of Electricity Generation from Rice Husk Based on Demand for Electric Vehicle: A Case Study in Surabaya City, Indonesia

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Article History

Received: 17 January 2024; Received in Revision: 6 August 2024; Accepted: 2 February 2025

Abstract

On August 5, 2019, the President of the Republic of Indonesia issued a Presidential Regulation (Perpres) concerning the acceleration of the battery-based electric motorized vehicle program for road transportation, which targets as many as 20% of electric vehicle users by 2025. The vehicle data projection was made until 2025, which is equivalent to 773,617 cars and 3,418,490 motorcycles. However, fossil energy sources such as coal, oil and natural gas used in conventional power plants are increasingly limited, so alternative energy that is more sustainable and environmentally friendly is needed. One source of sustainable electrical energy is biomass wastes such as rice husks, which are processed into electrical energy and have a potential CO₂ emission reduction of 142,610.51 tCO₂/year. The method used for technical analysis is simulating the process of processing biomass waste into electrical energy using the gasification process with Aspen Plus software as a tool to obtain optimum operating conditions. Biomass with flow 32,906.9 kg/h is fed into the gasification process area and then produces 1,538 kmol/h of syngas which reacted with airflow 9,779 kmol/h. The parameters used to analyze economic feasibility are Capex and Opex costs. The selling target for electric products is to supply the electricity needs of electric vehicle users in Surabaya. This research is possible to do with the consideration that East Java is the province with the largest rice production in Indonesia, Surabaya is a metropolitan city and is the economic center of the province of East Java so it is possible to developments related to the infrastructure of electric vehicles and the electric vehicle itself. Based on the economic feasibility analysis, the biomass power plant has an NPV of Rp.163 million, an IRR is 15.01%, WACC 7.34%, LCOE 4.063 Rupiah/kWh and a payback period of 6 years.

Keywords: Technical analysis, economic analysis, electricity, rice husk, gasification, electric vehicles

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1. Introduction

The increase in the electricity demand is in line with population growth and industrial development. However, fossil energy sources such as coal, oil, and natural gas used in conventional power plants have become gradually depleted; therefore, it is necessary to utilize renewable energy resources that are more environmentally friendly. One promising energy source for electricity generation is biomass, such as crop residues and other organic wastes. Here are three methods of converting biomass into electrical energy, which are gasification, combustion, and

pyrolysis (Bridgwater, 2012). Among the others, gasification technology offers several advantages, i.e., having a relatively small levelized cost of electricity, which is 14% lower than the pyrolysis method, and having a relatively high energy conversion efficiency that is 5% higher than the combustion process (IRENA, 2012).

Gasification is a thermochemical process that involves the conversion of carbonaceous feedstock into synthetic gas (Curcio, A. et al., 2025; De and Assadi, 2009). The gasification process involves heating a feedstock in an environment with a gasifying agent such as

water vapor or limited oxygen/air to produce a gaseous mixture of hydrogen (H_2), carbonmonoxide (CO), methane (CH_4), and carbon dioxide (CO_2). Syngas produced from the gasification process can be used as a fuel to produce electrical energy through power generation engines or gas turbines (Basu, 2010).

Gasification technology uses a reactor commonly called a gasifier to perform various types of combustion. Biomass in the gasifier reacts with air that is entered through two types of injection flow. In general, there are three categories of biomass contact in gasifiers based on the medium of gasification, i.e., fixed/moving bed, fluidized bed, and entrained bed (Akudo, 2008; Basu, 2010). Furthermore, according to its working principle, the gasification system can be divided into three classifications, i.e., updraft gasifier, downdraft gasifier, and crossdraft gasifier (Narega et al., 2022). One factor affecting the syngas compositions is the gasifying agent. A gasifying agent, also known as a gasification medium, is a reactant that interacts and reacts with the carbonaceous solid feedstock to produce syngas (Khan et al, 2009). Steam is a gasifying agent that is considered to be the most effective in the gasification process to produce syngas with combustible gas compositions such as H_2 , CO, and CH_4 with a lower heating value of 43% greater than syngas produced involving pure O_2 and air as gasifying agents (Watson, 2018).

Some previous studies investigated the conversion of biomass into electrical energy through a gasification process. Cardoso et al. (2017) evaluated biomass gasification using a biomass source in the form of a forestry biomass blend, the power plant can produce 11 MW of electricity with an NPV value of 2,367 M€ and an IRR of 8.66% and a payback period of 23.1 years. In Greece, Damartzis et al. (2012) evaluated the technical aspects of the biomass gasification process integrated with an internal combustion engine (ICE) by using the Aspen Plus simulation software. They concluded the potential of converting 1kg/h of biomass into 5 kW of electrical energy. Salisu et al. (2021), evaluated both technical and economic aspects of biomass gasification to produce electrical energy on a small scale, to supply electricity for a rice milling process. With their final result of 215 kW of electrical energy production, they suggested a net present value of \$1.68 million for a 15-year plant lifetime, with a payback period of 6 years and an internal rate of return of 24%.

In other research, large-scale electrical energy production has been carried out, Park et al. (2020) evaluated biomass gasification with the final product being syngas from rice husks with a capacity of 20 tons per day using air as a gasifying agent, producing a gas product with a composition of H_2 of 2.7%, CO of 19%, CH_4 of 6.85% and CO_2 of 16.1% with an LHV value of 1236.6 kcal/Nm³, then it will be used to operate a gas engine with a capacity of 400 kWe (Zhai et al., 2015).

You et al. (2017) evaluated medium-scale electrical energy production from Oil Palm Frond (OPF), Palm Kernel Shell (PKS), and Empty Fruit Bunch (EFB) to supply electrical energy to 300 – 500 homes with the final result being able to meet electrical energy needs of 1.8 kWh per house. Muhyiddin (2014), conducted research related to processing domestic waste biomass into electrical energy on a large-scale using gasification. In this research, the results obtained were that the biomass power plant could produce 124 MW of electrical energy and had an IRR of 47.63% with a payback period of 3 years.

Based on the findings presented in the literature and to the best of our knowledge, research on the techno-economic aspects of electrical energy production from rice husks using simulation process software Aspen Plus with the economic analysis based on demand for electric vehicles has not been carried out. Considering that Indonesia is an agricultural country and rice is the staple food, rice husks, which are currently still mostly considered agricultural waste, have the potential as raw materials for producing electricity through biomass gasification which is more environmental friendly and the rice husk price is Rp. 1,000/kg. Therefore, this research will discuss the production of electrical energy sourced from syngas produced from the rice husk biomass gasification process based on actual data on Indonesian paddy production with the economic analysis.

The evaluation of rice husk's potential as a renewable energy resource was previously initiated by some studies (Shackley et al., 2012; Silva et al., 2021). Rice husk, one of the biomass resources, is an abundant agricultural waste in agrarian countries with high rice production, such as Indonesia and some countries in Southeast Asia. The region with the largest paddy production in 2022 in Indonesia is the East Java Province, with a production quantity of 9.7 million tons per year (Badan Pusat Statistik, 2023). Rice husk is produced as waste from the rice milling

process, in which 20% of the weight of the grain is rice husk and is often ignored or just thrown away and even burned openly causing air pollution and other environmental problems.

In Indonesia, the Directorate General of New, Renewable, and Energy Conservation (EBTKE) targeted the utilization of renewable energy to reach at least 23% of the national primary energy mix by 2025 and reach a level of at least 31% by 2050. The status of renewable energy utilization in the national energy mix in 2020 just reached 11.51% of the primary energy supply, which was far below that was already targeted (Kusdiana, 2021). In addition, based on the policy issued by the government through Presidential Decree No. 55/2019 regarding the acceleration of the battery-based electric vehicle program for road transportation, the government set a target of 20% of vehicles to be electric by 2025. To expedite its implementation, the Indonesian government declared incentives for industries so that the acceleration of electric-based or battery-based vehicle programs can be achieved. With the current status of renewable energy implementation and ambitious plans of the government, this study evaluates the electricity generation based on demand for electric vehicles, with the considered biomass power plant location being in the East Java province in Indonesia.

2. Methodology

2.1. Power Plant Location

This research investigates the electricity production from rice husks based on the demand for electric vehicles in Surabaya City, the second largest city in Indonesia. Surabaya is located in the East Java province, the largest rice producer in Indonesia. The cities of Lamongan and Gresik, which are located 46 km and 20 km, respectively, from Surabaya, were chosen as the rice husk suppliers as they are within five cities producing rice at most and they have relatively closest distance to Surabaya. The selection of power plant location needs to consider several aspects, including access road aspects, physical location aspects, environmental aspects, electrical aspects, and cost aspects. In this study, it is planned to build a Biomass power plant in the Watangrejo area with a land area of ± 20 hectares, with 4 hectares allocated for development. Watangrejo Village is located between the cities of Lamongan and Gresik, with distances of 18 km and 13 km, respectively.

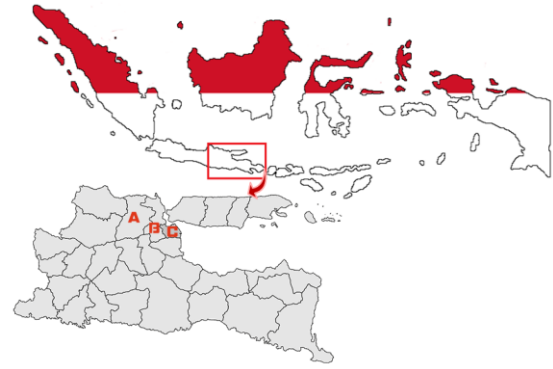


Figure 1. (A) Lamongan city, (B) Gresik city, (C) Surabaya city

In terms of road aspects, the power plant location is traversed by an arterial road, namely Jl. Raya Gresik – Babat. Regarding the environmental aspect, there are drainage channels around the PLTBm location that can be utilized. The cost aspect is closely related to investment and operational costs when the power plant is in operation, such as transportation costs, maintenance costs, and the cost of fuel used by vehicles when delivering biomass to the power plant.

2.2. Electricity Demand Vehicles

Data obtained from Badan Pusat Statistik states that the number of ICE vehicles in Surabaya City in 2020-2022 was 503,066 – 610,171 car units and 2,599,332 – 2,922,335 motorcycle units.

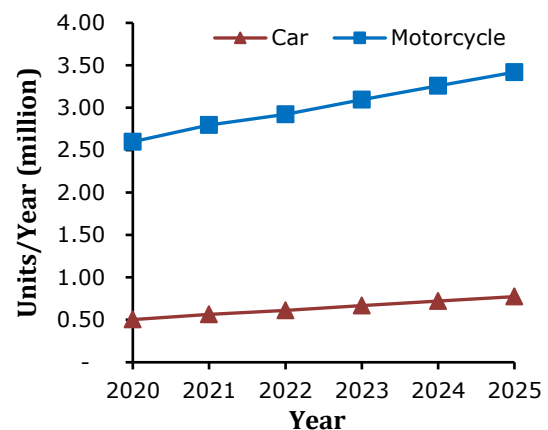


Figure 2. Surabaya city vehicle data projections

Based on this data, the number of motorized vehicles can be projected until 2025 as shown in Fig. 2. In 2043 the number of ICE vehicles was 773,617 cars and 3,418,490 motorcycles. Based on data obtained from the Coordinating Minister for Maritime Affairs and Investment, the average fuel consumption is 1,500 liters per year for one car unit and 305 liters per year for one motorcycle unit.

The average mileage for one car is 15 km/liter and for one motorcycle is 53 km/liter. Meanwhile, electric vehicles have an average mileage of 7 km/kWh for one car (Ioniq 5) and 33.3km/kWh for one motorcycle (NIE N Lite). So it can be calculated using Eq. 1 for electricity demand per year from electric vehicles.

$$EC \left(\frac{kWh}{Year} \right) = \frac{FuelC (l/year) \times D_{Fuel} (km/l)}{D_{EV} (km/kWh)} \quad (1)$$

Remark:

EC : electricity consumption
 FuelC : fuel consumption
 D_{Fuel} : fuel mileage
 D_{EV} : electricity mileage

2.3. Characteristics of Rice Husk Biomass

Biomass fuels have more complex properties and characteristics than fossil fuels and require more specialized preparation and processing. It is characterized by a small specific gravity a high amount of ash resulting from the combustion process, and a low ash melting point temperature. The ash generated from combustion ranges from 16-23%. The moisture content of biomass is generally higher than that of fossil fuels, but the moisture content of rice husk is relatively low because rice husk is the dry husk of rice left over from the milling process. Another characteristic of rice husk fuel is its high-volatile matter content, which is volatile matter. The volatile matter content ranges from 60-80%, compared to fossil fuels which only range from 20-30% for medium coal.

Table 1. Proximate and ultimate analysis of Indonesian rice husk (Purwanto, 2010)

Feed		Result
Proximate Analysis (%)	Moisture Content	7.78
	Ash Content	21.84
	Volatile Matter	57.05
	Fixed Carbon	13.33
Ultimate Analysis (wt%)	C (%)	35.18
	H (%)	4.46
	N (%)	0.15
	S (%)	0.01
	O (%)	38.36

Before simulation using Aspen Plus software, experimental data is needed related to the value of proximate analysis and ultimate analysis of rice husk in Indonesia, and the following is the data of proximate and ultimate analysis of rice husk in Indonesia obtained from Basu (2010) as can be seen in Table 1.

2.4. Process Modeling

Process modeling is a useful method for comprehensively studying a process's properties and structure and representing a process. In general, the process of converting biomass into syngas through a gasification process and then from syngas into electrical energy can be seen in Fig. 3.

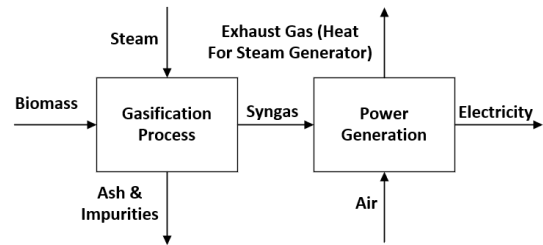


Figure 3. Block flow diagram of generating electricity from biomass

Among several reactor types, fluidized bed reactor is one of the most practical types used for gasification (Natarajan et al., 1998; Warnecke et al., 2000; Park et al., 2021). Since a dual fluidized bed gasification unit is the primary process of the proposed scheme, the primary focus has been on creating a straightforward yet precise model to describe the gasifier. It is possible to represent the behavior of the fluidized bed for biomass gasification while conducting design and optimization studies by using modeling tools. The Aspen Plus process model simulator was used to construct the study's model.

This program is made up of many components which integrated, and provide a comprehensive view of the behavior of a fluidized bed gasifier. The following presumptions are taken into account in this simulation study (Muthia and Pratama, 2023).

1. The process is steady state, dimensionally negligible, and isothermal.
2. Devolatilization of biomass occurs instantly and volatile products consist of H_2 , CO , CO_2 , CH_4 , and H_2O .
3. All gases are evenly distributed in the reactor.
4. The hydrodynamic equations in the fluidized bed reactor have not been taken into consideration.
5. Tar formation is so small that it can be ignored.
6. Reactions of sulfur and nitrogen have not been taken into consideration.

In this research, the overall scheme to be employed involves feeding biomass in the form of rice husks into a gasification reactor

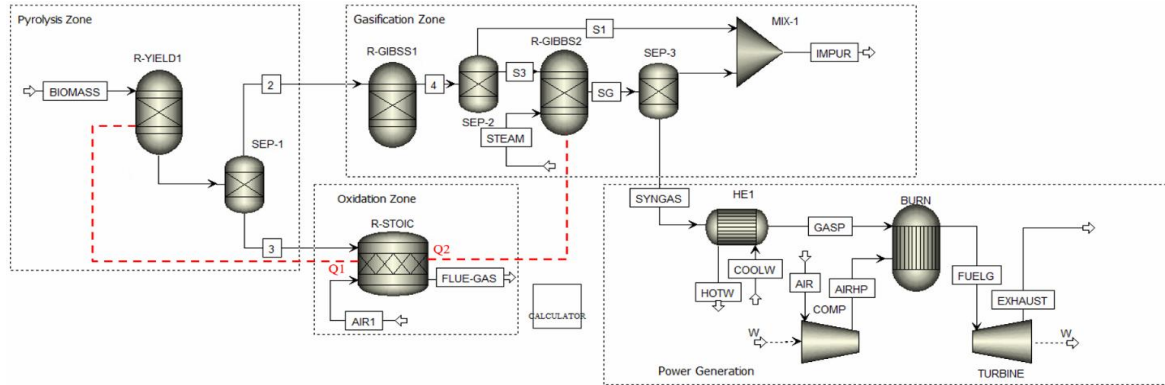


Figure 4. Process flowsheeting of the proposed system

which will be reacted with steam as the gasifying agent (Fig. 4). In this process, by-products such as ash and impurities gas will be generated and will be separated using a separator.

The primary product of this gasification is syngas with a high composition of flammable gases such as Hydrogen (H_2), Carbon Monoxide (CO), and Methane (CH_4) which will be utilized as fuel which will react with air in the power generation stage, to produced hot gas with high pressure then used for rotating the gas engine to produce electrical energy and a by-product of hot gas (exhaust gas) will be used in the steam formation process to supply the requirement of steam in gasification zone. In this study, the type of gasifier used is a Dual Fluidized Bed Gasifier with a scheme as shown in Fig. 5.

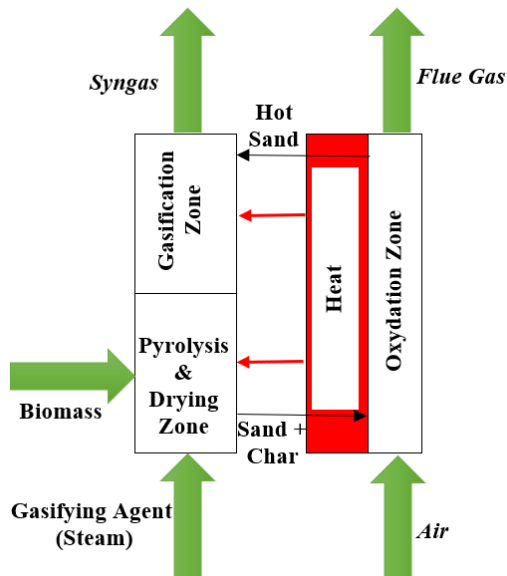


Figure 5. Schematic of dual fluidized bed gasifier

With parameter indirect heating gasification as heat sink, heat source from combustion using char and steam as gasifying agent. The

modeling of the gas behavior is achieved by using the Peng– Robinson equation of state.

2.4.1. Chemical Reaction

It is assumed that biomass contains the elements hydrogen (H), carbon (C), and oxygen (O). The chemical formula of biomass is defined as CH_xO_y . The chemical reactions discussed in this study can be seen in Table 2, which includes reactions that occur in the oxidation zone and gasification zone.

Table 2. Chemical reaction in oxidation zone and gasification zone

Reaction	ΔH (kJ/mol)	Reaction No.
Oxidation Zone		
$C + O_2 \rightarrow CO_2$	-394	R1
Gasification Zone		
<i>Boudouard Reaction</i>		
$C + CO_2 \rightarrow 2 CO$	+172	R2
<i>Water-gas Reaction</i>		
$C + H_2O \rightarrow CO + H_2$	+131	R3
<i>Water Shift Reaction</i>		
$CO + H_2O \rightarrow CO_2 + H_2$	-41	R4
<i>Methane Reaction</i>		
$C + 2H_2 \rightarrow CH_4$	-75	R5

2.4.2. Gasification Simulation

In this research in Aspen Plus, the components that will be used in the simulation are yield (RYield), Gibss (RGibss), and Stoichiometry (RStoic) reactors. Other components that will be used are a separator, mixer, heat exchanger, turbine, and compressor. The yield type reactor will simulate the process that occurs in the pyrolysis zone by decomposing biomass into single components such as ash, carbon, hydrogen, nitrogen, chlorine, sulfur, and oxygen based on the results of proximate and ultimate analysis of the feed, using Eq. 2.

$$YoC = (1 - XW_B) \times X_B \quad (2)$$

Remark:

YoC : the yield of the component
 XWB : the fraction of water in biomass
 XB : the fraction of component biomass

RGibss will be used to simulate the processes that occur in the gasification and power generation zones which single compounds such as carbon, hydrogen, and nitrogen will react and form more complex compounds such as methane, and carbon monoxide. The operating conditions that are considered the most optimum in the gasification zone are listed in Table 4. The stoichiometric reactor will simulate the process that occurs in the combustion zone. In this zone, as much as 80% of C (carbon) will be used as fuel, to generate heat that will be supplied to the gasification zone. Other components such as separators are used to simulate the separation process, mixers are used to simulate the process of mixing or merging streams during the process.

Table 3. Model inputs used for gasification simulation

Input for gasification simulation	Value
Gasifier feed (kg/h)	32,906.9
S/B ratio	0.3
Gasification process temperature (°C)	800
Gasification process pressure (atm)	1
Steam temperature (°C)	120
Steam pressure (atm)	1

In the Power generation phase, syngas will be used as fuel in the combustion reactor (BURN) which will be reacted with air. The RGibss reactor is used to simulate the process. The compressor is used to increase the pressure of the air before it enters the combustion reactor and then the pressurized hot gas will be used to rotate the turbine to produce electrical energy. After obtaining the optimum conditions of the biomass gasification process with the final product of syngas, at this stage syngas will be used as fuel to produce pressurized gas which will be used to drive a gas turbine and ultimately produce electrical energy. At this stage, the thing that needs to be set is the air flow rate used for the syngas combustion process. To produce complete combustion, the airflow rate used can be calculated using Eq. 7.

Mole flow each component in syngas:

$$\text{Mole flow } H_2 = S_F \times X_{H_2} \quad (3)$$

$$\text{Mole flow } CO = S_F \times X_{CO} \quad (4)$$

$$\text{Mole flow } CH_4 = S_F \times X_{CH_4} \quad (5)$$

Remark:

S_F : syngas mole flow
 X_{H_2} : the mole fraction of H_2
 X_{CO} : the mole fraction of CO

X_{CH_4} : the mole fraction of CH_4 .

Air mole flow stoichiometric:

$$A_{FS} = \frac{(0.5 \times FH_2) + (0.5 \times FCO) + (2 \times FCH_4)}{0.21} \quad (6)$$

Remark:

FH_2 : mole flow of H_2
 FCO : mole flow of CO
 FCH_4 : mole flow of CH_4

Air mole flow:

$$A_F = A/F \text{ Factor} \times A_{FS} \quad (7)$$

where the A/F factor is the air-fuel ration, which is in the range of 3.3 – 4.1 (Al-Attab and Zainal, 2018). The operating conditions at the power generation stage can be seen in Table 4.

Table 4. Model inputs used for power generation simulation

Input for power generation simulation	Value
Water Cooling Temperature (°C)	20
Water Cooling Pressure (atm)	1
Syngas Mole Flow (kmol/hr)	1,538
Syngas Temperature (°C)	800
Syngas Pressure (atm)	1
Air Mole Flow (kmol/hr)	9,779
Air Temperature (°C)	25
Air Pressure (atm)	15
A/F Ratio for Syngas	4
Gas Turbine Isentropic Efficiency	0.3

2.5. Potential CO₂ Emission Reduction

One of the benefits of using renewable energy sources is that it can help reduce CO₂ gas emissions in the air. For CO₂ emission reduction values, you can use the Eq. 8 (Muhyiddin, 2014).

$$CO_2 \text{ Emission Reduction} = EP \times GEF \quad (8)$$

Remark:

EP : electricity production (MW/year)
 GEF : greenhouse gas emission factor (tCO₂/MW)

The greenhouse gas emission factor value is 0.963 tCO₂/MW (Muhyiddin, 2014).

2.6. Economic Analysis

In this research, the parameters in the economic analysis are Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period (PP). With the expectation that NPV will be greater than 0, IRR is greater than Bank interest, and PP is smaller than the lifetime of the Biomass power plant.

2.6.1. Investment & Operational Cost

The Biomass power plant development project which includes the plant configuration, technical data, and project costs can use Eq. 9 (MEMR 2021) by using the basis for the cost estimation of a Biomass power plant with a capacity of 4 MW. In this research, the production capacity of the Biomass power plant will continue to increase every year and in 2025 reach 25 MW, so it has been determined for the calculation of investment costs using a capacity of 25 MW.

$$PC_{Plan} = PC_{Ref.} \times \left(\frac{Capacity_{Plan}}{Capacity_{Ref.}} \right)^{0.7} \quad (9)$$

Remark:

PC_{Plan} : the project cost plan

PC_{Ref.} : the project cost reference

2.6.2. Electricity Production

The electricity production of power plant with capacity 25 MW can be calculated by Eq. 10, and Capacity Factor can be calculated by Eq. 11.

$$EP_{PLTBm} = Net\ E \times OT \times CF \quad (10)$$

$$CF = EY \times \frac{1}{OT} \times \frac{1}{PC} \quad (11)$$

Remark:

Net E : net electricity production (MWh/year)

OT : operation time (year/hour)

PC : production capacity (MW)

CF : capacity factor

EY : energy yield (Mwh)

2.6.3. Net Present Value (NPV)

The NPV value can be calculated using Eq. 12.

$$NPV = \sum_{t=n}^n \frac{CF_n}{(i+1)^n} - CF_0 \quad (12)$$

Remark:

CF_n : Cash Flow In at year-n (Rp)

i : discount rate (%)

n : year

CF₀ : initial investment value (Rp)

Details of NPV calculation parameters can be seen in Table 5.

Table 5. NPV calculation parameters (KESDM, 2021).

Electricity selling price/kWh year 1-10	Rp. 1,442
Electricity selling price/kWh year 11- 20	Rp. 1,154
Discount Rate (%)	15
Income Tax (%)	25

For Cash Flow In, the calculation was done by using Eq. 13.

$$Cash\ Flow\ In = Net\ E \times ESP \times 0.75 \quad (13)$$

Remark:

Net E : net electricity production (kWh/year)

ESP : electricity selling price per kWh

It is planned that the Biomass power plant project will operate for 20 years from 2024 – 2043.

2.6.4. Internal Rate of Return & WACC

The IRR value can be calculated using Eq. 14.

$$IRR = i_1 + \frac{NPV_1}{(NPV_1 - NPV_2)} \times (i_2 - i_1) \quad (14)$$

Remark:

i₁ : the interest rate with positive NPV

i₂ : the interest rate with negative NPV

NPV₁ : positive NPV value

NPV₂ : negative NPV value

The WACC can be calculated using Eq. 15.

$$WACC = \frac{D}{D+E} \times K_d \times (1 - t) + \frac{E}{D+E} \times K_c \quad (15)$$

Remark:

D : debt

E : equity

K_d : debt interest rate

t : tax

K_c : rate of return

2.6.5. Payback Period

The Payback Period value can use Eq. 16 (Malek, 2017).

$$PP = \frac{Initial\ Investment}{Profit\ Per\ Year} \quad (16)$$

2.6.6. Levelized Cost of Electricity

The LCOE value was calculated using Eq. 17 (Abdelhady et al., 2018).

$$LCOE = \frac{Total\ Cash\ Out\ (Rp./Year)}{Total\ Energy\ Production\ (kWh/Year)} \quad (17)$$

3. Result and Discussion

3.1. Effect of Operating Temperatures on Syngas Product Composition

The goal of the gasification process is to produce as much gas as possible with a high heating value, which will enable efficient utilization of the gas for power generation. The ratio of steam to biomass and temperature are the two primary factors that influence the composition of gas production. In this study, an attempt has been made to determine the optimal values of the process operating parameters mentioned above to facilitate the release of volatiles from biomass and convert it into energy with the highest possible energy

efficiency. Thus, a sensitivity analysis was carried out to determine how these two crucial parameters affected the syngas yield.

A good quality syngas has a high composition of combustible gases such as H_2 , CO, and CH_4 . As shown in Fig. 6., the difference in operating temperature has a significant effect on the composition of syngas produced. The operating temperature variation used is from 500°C to 1,000°C. The higher the gasification operating temperature, the composition of H_2 and CO in syngas will increase while the composition of CH_4 and CO_2 will decrease. This phenomenon has similarities and can be validated based on experimental results regarding fluidized bed steam gasification of biomass by Loha and Chattopadhyay (2010).

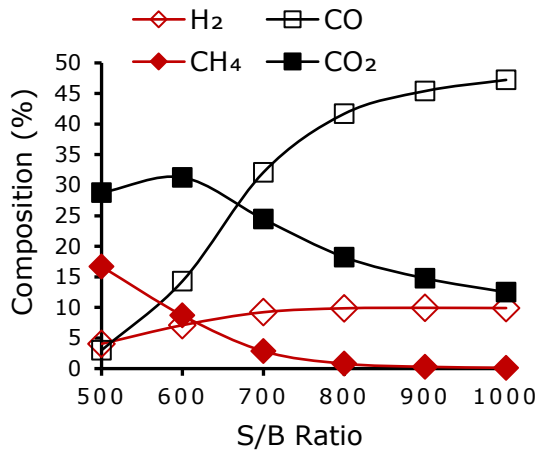


Figure 6. Effect of temperature variation on syngas composition

3.2. Effect of Different S/B Ratio on Syngas Product Composition

As shown in Fig. 7, the different steam ratios have a significant effect on the composition of the syngas produced. In this study, the S/B ratio used was 0.1 to 1.0.

The higher the steam ratio used, the composition of H_2 , CO, and CH_4 will decrease while the composition of CO_2 will increase. Based on the simulation results carried out by varying the temperature and S/B ratio in Fig. 6 and Fig. 7, it can be concluded that the optimal operating conditions are at a temperature of 800°C with an S/B of 0.3. With the following considerations, if the temperature and S/B ratio are increased, the composition of H_2 and CO no longer rises significantly, and the composition of CO_2 produced does not experience a significant decrease. So that the operating conditions of the gasification simulation can be obtained as in Table 3.

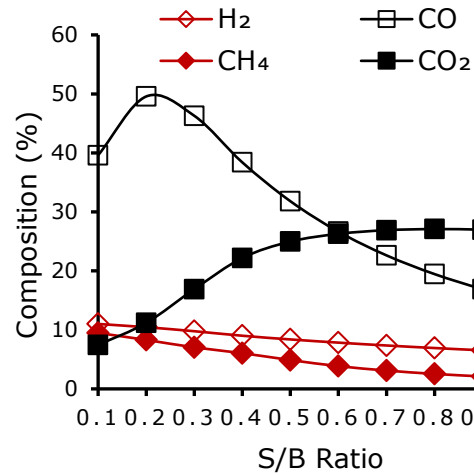


Figure 7. Effect of S/B ratio variation on syngas composition

3.3. Power Generation Process Result

The syngas flow rate of 1,538 kmol/hr will be burned with the air of 9,779 kmol/hr in the Gibss reactor which acts as a combustor (BURN) operating at a temperature of 1,700°C and pressure at 15 atm. The product of this combustor is pressurized gas which will be used to rotate the turbine. Turbine output gas with a temperature of 890 ° C and a pressure of 1 atm will be used to help supply heat to the steam generation process used for the gasification process.

3.4. Simulation Result

Based on data projections carried out until 2025, the results of net system power calculated in the simulation with capacity factor 0.735 and operation time 7,920 hours in a year. Electricity generated by the turbine is 365,344 MWh/year and electricity demand for operational is 217,254 MWh/year so the net electricity is 148,090 MWh/year.

3.5. Electricity Demand for Vehicles

Based on the projection of vehicle user data, especially for the city of Surabaya Figure 2., to achieve the government's target of 20% electric vehicle users in 2025, 773,617 cars and 3.4 million motorcycles must be converted into electric vehicles. So, we can calculate the total electrical energy needed to meet the needs of electric vehicles, which is 828,884 MW/year. So, with the electricity production capacity of the Biomass power plant being designed, the Biomass power plant is only able to supply 19% of the total electricity demand for electric vehicles in 2024 and 18% in 2025.

3.6. CO₂ Emission Reduction

Using Eq. 8, we can calculate the potential of CO₂ emission reduction by using a Biomass power plant as an alternative way to produce electricity. The greenhouse emission factor is 0.963 tCO₂/MW. Then based on the simulation Biomass power plants can produce electrical energy of 148,089.83 MWh per year, so the potential for reducing CO₂ emissions is 142,610.51 tCO₂/year.

3.7. Economic Analysis

3.7.1. Investment Cost & Operational Cost

Using Eq. 9, it can be obtained that the Investment Cost of the Biomass power plant with a production capacity of 25 MW is Rp. 510 billion which can be used as a CAPEX value. The points included in the OPEX calculation are O&M costs, fuel costs in the biomass power plant, and those used for transportation of raw material shipments. The OPEX calculation can be done using Eq. 9 and results in an OPEX value of Rp. 91 billion/year. The assumptions in the Economic Analysis of PLTBm Capacity 25 MW is shown in Table 6.

Table 6. Assumptions in economic analysis of PLTBm capacity 25 MW

Description	Unit
Investment sources equity/debt	30/70% from TCI
Lifetime	20 Year
Tax	25% Per Year
Debt interest rates	8.5% Per Year
Construction period	1 Year
Discount rate	15%

3.7.2. Cash In

Cash Cash-in calculations can be determined by applying Equation 13, which incorporates the revenue generated from electricity sales. The selling price of electricity used in this calculation is based on the official tariff stipulated in the Indonesian Government Regulation PP No. 112 of 2022. According to this regulation, the electricity selling price is set at 9.29 cents USD per kilowatt-hour (kWh), which is equivalent to Rp 1,442 per kWh during the first to the tenth year of the project operation. For the eleventh to the twentieth year, the tariff is adjusted to a lower rate of 7.43 cents USD per kWh, or Rp 1,154 per kWh. These values are essential inputs for estimating the total cash inflow over the operational lifespan of the energy generation project, as they reflect the income received

from selling the produced electricity to the national grid or authorized off-takers. By using these tariff rates within Equation 13, the projected financial returns from electricity sales can be accurately quantified for both pricing periods over the 20-year project horizon.

Table 7. Cash In of PLTBm capacity 25 MW

Year	Electricity Production (kWh/Year)	Cash In (Rupiah)
2024	146,876,794	180,060,906,344
2025	148,089,834	181,548,011,047

3.7.3. Net Present Value (NPV)

Using Eq. 12, the NPV value for 20 years from the biomass power plant is Rp.169 million. The NPV value is greater than 0 so that when viewed from the NPV value, the biomass power plant project is feasible to be realized.

3.7.4. Internal Rate of Return & WACC

Using Eq. 14, the IRR value for the planned Biomass power plant project is 15.01%. The IRR value is greater than the value of bank interest which is 15% and with debt interest rate of Indonesia 8.5% and average equity in Indonesia 9.57% (Shanty D., 2021) the calculated WACC is 7.34%, so when viewed from the IRR and WACC value, the biomass power plant project is feasible to be realized.

3.7.5. Payback Period

Using Eq. 16, it can be obtained that the Payback Period value of the biomass power plant project is 6 years. The PP value is lower than the planned biomass power plant lifetime of 20 years so when viewed from the PP value, the biomass power plant project is feasible to be realized.

3.7.6. Levelized Cost of Electricity

Using Eq. 17, the LCOE for the power plant can be calculated. The total cash out is 601 billion/year and the electricity production is 148,089,834 kWh/year, so the value of LCOE for power plant with capacity 25 MW is 4,063 Rupiah/kWh.

4. Conclusion

Here are the results of studies conducted in a Fluidized Bed Dual Reactor Gasifier to gasify rice husk using steam. Researchers have examined how the temperature during gasification and the amount of steam to

biomass affect the composition of the syngas. It can be shown from the study that when the temperature of gasification rises, more H₂ and CO are produced, but less CH₄ and CO₂ are formed. However, as the ratio of steam to biomass increased, CO₂ production increased while H₂, CO, and CH₄ production declined. Consequently, 800°C and a S/B ratio of 0.3 represent the ideal conditions for the gasification simulation.

With these operating conditions, produced syngas with a flow rate of 1,538 kmol/hr will be used as fuel in the process of forming high-pressure hot gas which will be used to rotate the gas turbine. The net electrical energy that can be generated in this simulation is 148,090 MWh/year which is targeted to help supply electricity to electric vehicle users. In this study, the biomass power plant can help supply electricity to electric vehicle users by 18% of the total demand in 2025, and have potential CO₂ emission reduction 142,610.51 tCO₂/year. Economic analysis, the NPV value of this biomass power plant is Rp. 169 million, with an IRR of 15.01%, WACC 7.34%, LCOE 4,063 Rupiah/kWh and has a Payback Period of 6 years.

Author Contributions Statement

M.R.A.W.P.: data collection, analysis, writing-original draft, R.M.: analysis, conceptualization, writing-original draft, review, validation.

Data Availability Statement

Available on request to the corresponding author.

Declaration of Competing Interest

The author declares that there is no conflict of interest regarding the publication of this manuscript.

References

- Abdelhady, S., Borello, D., & Shaban, A. (2018) Techno-economic assessment of biomass power plant fed with rice straw: Sensitivity and parametric analysis of the performance and the LCOE, *Renewable Energy*, 115, 1026–1034. <https://doi.org/https://doi.org/10.1016/j.renene.2017.09.040>
- Akudo, C.O. (2008) Quantification of Tars and Particulates from A Pilot Scale, Downdraft Biomass Gasifier. Master of Science. Thesis in Biological and Agricultural Engineering, Faculty of the Louisiana State University Agricultural and Mechanical College.
- Al-attab, K. A., & Zainal, Z. A. (2018). Micro gas turbine running on naturally aspirated syngas: An experimental investigation, *Renewable Energy*, 119, 210–216. <https://doi.org/10.1016/J.RENENE.2017.12.008>
- Badan Pusat Statistik. (2023). Data Produksi Padi Seluruh Indonesia.
- Basu, P. (2010) Biomass Gasification and Pyrolysis, Piratical Design and Theory. Elsevier, USA.
- Bridgwater, A. V. (2012) Review of fast pyrolysis of biomass and product upgrading, *Biomass and Bioenergy*, 38, 68–94. <https://doi.org/10.1016/j.biombioe.2011.01.048>
- Cardoso, J., Silva, V., & Eusébio, D. (2019) Techno-economic analysis of a biomass gasification power plant dealing with forestry residues blends for electricity production in Portugal, *Journal of Cleaner Production*, 212, 741–753. <https://doi.org/https://doi.org/10.1016/j.jclepro.2018.12.054>
- Curcio, A., Rodat, S., Vuillerme, V., Abanades, S. (2025) A review of biomass thermochemical gasification: Toward solar hybridized processes for continuous and controllable fuel production, *Next Energy*, 8, 100277, <https://doi.org/10.1016/j.nxener.2025.100277>
- Damartzis, T., Michailos, S., & Zabaniotou, A. (2012) Energetic assessment of a combined heat and power integrated biomass gasification–internal combustion engine system by using Aspen Plus®, *Fuel Processing Technology*, 95, 37–44. <https://doi.org/10.1016/J.FUPROC.2011.11.010>
- De, S., Assadi, M. (2009) Impact of cofiring biomass with coal in power plants – A techno-economic assessment, *Biomass and Bioenergy*, 33 (2), 283–293. <https://doi.org/https://doi.org/10.1016/j.biombioe.2008.07.005>
- IRENA. (2012) Biomass for power generation, renewable energy technologies: Cost

- Analysis Series, IRENA Working Paper, International Renewable Energy Agency.
- Khan, A. A., de Jong, W., Jansens, P. J., & Spliethoff, H. (2009) Biomass combustion in fluidized bed boilers: Potential problems and remedies, *Fuel Processing Technology*, 90(1), 21–50. <https://doi.org/https://doi.org/10.1016/j.fuproc.2008.07.012>
- Kusdiana, D. (2021) Direktorat Jenderal Energi Baru Terbarukan Dan Konservasi Energi (EBTKE), <https://ebtke.esdm.go.id/post/2021/01/15/2767/capaian.kinerja.2020.dan.rencana.kerja.2021.sub.sektor.ebtke> (Accessed on 20 April 2023)
- Loha, C., Chatterjee, P. K., & Chattopadhyay, H. (2011) Performance of fluidized bed steam gasification of biomass – Modeling and experiment. *Energy Conversion and Management*, 52(3), 1583–1588. <https://doi.org/10.1016/J.ENCONMAN.2010.11.003>
- Malek, A. B. M. A., Hasanuzzaman, M., Rahim, N. A., Turki, Y. A. (2017) Techno-economic analysis and environmental impact assessment of a 10 MW biomass-based power plant in Malaysia, *Journal of Cleaner Production*, 141, 502–513. <https://doi.org/https://doi.org/10.1016/j.jclepro.2016.09.057>
- Muhyiddin Azmi. (2014) Analisis Teknik dan Ekonomi Pemanfaatan Biomassa sebagai Pembangkit Energi Listrik di Surabaya, *Jurnal Teknologi Lingkungan*, Vol. 23 No. 2, 126–134. <https://doi.org/10.29122/jtl.v23i2.5302>
- Muthia, R., Pratama, M.R. (2023) Effects of Steam-To-Biomass Ratio and Temperature in Gasification on The Methanol Conversion and Selectivity: A Simulation Study of Biomass to Methanol, *Jurnal Bahan Alam Terbarukan*, 52–62. <https://doi.org/10.15294/jbat.v12i1.42365>
- Narega, S. O., Apriansyah Ysf, R., Aswan, A., Fatria, F., Erlinawati, E., & Hilwatullisan, H. (2022) Produksi Syngas Dari Proses Gasifikasi Biomassa Menggunakan Downdraft Gasifier Sebagai Gas Bakar Pada Motor Bakar Empat Tak, *Jurnal Pendidikan Dan Teknologi Indonesia*, 2(11), 469–474. <https://doi.org/10.52436/1.jpti.245>
- Natarajan, E., Nordin, A., & Rao, A. N. (1998) Overview of combustion and gasification of rice husk in fluidized bed reactors, *Biomass and Bioenergy*, 14(5–6), 533–546. [https://doi.org/10.1016/S0961-9534\(97\)10060-5](https://doi.org/10.1016/S0961-9534(97)10060-5)
- Park, S. J., Son, S. H., Kook, J. W., Ra, H. W., Yoon, S. J., Mun, T.-Y., Moon, J. H., Yoon, S. M., Kim, J. H., Kim, Y. K., Lee, J. G., Lee, D.-Y., Seo, M. W. (2021) Gasification operational characteristics of 20-tons-Per-Day rice husk fluidized-bed reactor, *Renewable Energy*, 169, 788–798. <https://doi.org/https://doi.org/10.1016/j.renene.2021.01.045>
- Purwanto, W., Supramono, D., Fisafarani, H. (2010) Biomass Waste and Biomass Pellets Characteristics and Their Potential in Indonesia. The 1st International Seminar on Fundamental and Application ISFACHe 2010 of Chemical Engineering. November 3–4.
- Salisu, J., Gao, N., & Quan, C. (2021) Techno-economic Assessment of Co-gasification of Rice Husk and Plastic Waste as an Off-grid Power Source for Small Scale Rice Milling - an Aspen Plus Model, *Journal of Analytical and Applied Pyrolysis*, 158, 105157. <https://doi.org/10.1016/J.JAAP.2021.105157>
- Shackley, S., Carter, S., Knowles, T., Middelink, E., Haefele, S., Sohi, S., Cross, A., Haszeldine, S. (2012) Sustainable gasification-biochar systems? A case-study of rice-husk gasification in Cambodia, Part I: Context, chemical properties, environmental and health and safety issues, *Energy Policy*, 42, 49–58. <https://doi.org/https://doi.org/10.1016/j.enpol.2011.11.026>
- Silva, L. A., Santos, I. F. S. dos, Machado, G. de O., Tiago Filho, G. L., & Barros, R. M. (2021) Rice husk energy production in Brazil: An economic and energy extensive analysis. *Journal of Cleaner Production*, 290, 125188. <https://doi.org/10.1016/J.JCLEPRO.2020.125188>
- Warnecke, R. (2000) Gasification of biomass: comparison of fixed bed and fluidized bed gasifier, *Biomass and Bioenergy*, 18 (6), 489–497.

[https://doi.org/https://doi.org/10.1016/S0961-9534\(00\)00009-X](https://doi.org/https://doi.org/10.1016/S0961-9534(00)00009-X)

You, S., Tong, H., Armin-Hoiland, J., Tong, Y. W., Wang, C.-H. (2017) Techno-economic and greenhouse gas savings assessment of decentralized biomass gasification for electrifying the rural areas of Indonesia, *Applied Energy*, 208, 495–510.

<https://doi.org/https://doi.org/10.1016/j.apenergy.2017.10.001>

Zhai, M., Zhang, Y., Dong, P., & Liu, P. (2015) Characteristics of rice husk char gasification with steam, *Fuel*, 158, 42–49.
<https://doi.org/10.1016/J.FUEL.2015.05.019>