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Comparative Study of Biomass Gasification for Electricity and Methanol Production

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ABSTRACT. The Indonesian government has established several programs and policies to support the development of new and renewable energy as part of the energy transition and carbon emission reduction efforts, with a national energy mix target of 23% in 2025 and 31% in 2050. Based on data released by the Central Statistics Agency of Indonesia in 2023, East Java has a wealth of sugar cane, rice, and corn kernels of 1,129,000 tons, 9,591,420 tons, and 5,991,810 tons, respectively. Therefore, biomass wastes are attractive as a gasification feedstock. Electricity and methanol are commodities that can support the government. This study evaluated and compared both the technical performance and economic feasibility between various combinations of biomass waste feed scenarios from bagasse, rice husk, and corncob to produce various combinations of product scenarios using Aspen Plus V14 simulation which constitutes the novelty of this research. The evaluation process was conducted using the Aspen Plus V14. The operating conditions of the gasification process were determined through a sensitivity analysis of key process variables, namely temperature, pressure, and steam-to-biomass ratio, to identify their effects on the optimal composition of the produced syngas. The utilization of syngas for electricity and methanol production was also simulated using Aspen Plus V14, where the operating conditions and resulting products were evaluated based on the required energy input and the corresponding carbon emissions. The economic feasibility of the process was assessed using key financial indicators, including payback periods, Return on Investment (ROI), Internal Rate of Return (IRR), and Net Present Value (NPV). The evaluation results indicate that single feed scenario from corncob is technically and economically feasible to produce methanol and electricity under separate production scenarios. Bagasse is feasible for electricity generation, while the other biomass scenarios did not meet the evaluation criteria.

1. INTRODUCTION

Indonesia, as a country with abundant natural resources, especially in the agricultural and forestry sectors, produces a large amount of biomass waste. This waste has the potential to be converted into renewable energy that supports the transition towards a more sustainable energy system. One of the promising technologies to utilize this waste is biomass gasification. Gasification is a thermochemical conversion process that transforms solid biomass into gas known as syngas (synthetic gas) through partial oxidation at elevated temperatures.

In general, gasification performance (i.e., syngas production, H_2/CO ratio and syngas composition) is significantly affected by operating conditions such as temperature, pressure, and ratio of gasifying agent [1]. According to Le Chatelier's principle, increasing the gasification temperature shifts the chemical equilibrium toward the reactants in exothermic reactions and toward the products in endothermic reactions. Therefore, selecting the appropriate gasification temperature is crucial. The operating temperature above 1000°C may lead to ash melting and sintering, which are undesirable for stable gasification processes. Temperature was found to have a significant impact on the main components of syngas. The gasification process was carried out at temperatures ranging from 750°C to 950°C. The results showed that the concentrations of H_2 and CO increased with rising gasification temperature at a steam-to-biomass (S/B) ratio of 0.8, specifically, H_2 increased from 23% to 42%, and

CO from 7% to 27%. In contrast, the concentrations of CO_2 and CH_4 decreased as temperature increased from 32% to 15% for CO_2, and from 21% to 1% for CH_4 [2].

High gasification pressure shifts the equilibrium of non-equimolar reactions toward the side with lower volume. Additionally, high-pressure gasification produces syngas at elevated pressure, which can be directly utilized in turbines or synthesis reactors. However, high-pressure gasification also presents challenges in the biomass feeding system. In the other study [1], gasification was performed at pressures ranging from 1 bar to 15 bar with a steam-to-biomass (S/B) ratio of 1. The results showed a decrease in the concentrations of H_2 and CO as the gasification pressure increased, from 51.2% to 23.5% for H_2 and from 25% to 15% for CO. This observation aligns with Le Chatelier's principle, which states that high pressure promotes the consumption of H_2 and CO. In contrast, the concentrations of CO_2 and CH_4 increased with rising pressure, from 19% to 30% for CO_2, and from 5% to 25% for CH_4.

The presence of steam in the gasification process accelerates the endothermic steam gasification reactions, leading to increased production of H_2 and CO. Therefore, steam injection is commonly employed to control the H_2/CO ratio in the syngas. In the other study [1], the steam-to-biomass (S/B) ratio was varied from 0.5 to 1.5. The results indicated that the H_2 content increased with higher S/B ratios, from 44% to 58 mol%. CO_2 content also showed a slight increase, from 15% to 18%. In contrast, CO and CH_4 concentrations decreased as the S/B ratio increased from 31% to 22% for CO, and from 9 % to 2% for CH_4.

In general, syngas derived from biomass consists of approximately 40% combustible gases, such as H_2, CO, and CH_4, while the remaining components are non-combustible gases like N_2 and CO_2 [3]. Hydrogen (H_2) is the main component of syngas and is known for its clean combustion characteristics. A higher concentration of H_2 in syngas leads to shorter combustion duration, thereby improving the efficiency of internal combustion engines commonly used in power generation [4].

The characteristics of syngas are influenced by several factors, one of which is the choice of gasifying agent. When air is used as the gasifying agent to produce syngas for power generation, a significant drawback is the nitrogen (N_2) content. The presence of N_2 dilutes the syngas, resulting in a lower Lower Heating Value (LHV).

The composition of syngas derived from biomass differs from that of syngas produced from natural gas and coal. Syngas from gas and coal typically contains higher concentrations of H_2 and CO with lower levels of CO_2. In contrast, biomass-derived syngas generally contains higher amounts of CO_2, a lower H/C ratio, and a higher CO_2/CO ratio. As a result, biomass syngas is less favorable for methanol synthesis. Theoretically, the optimal syngas composition for methanol synthesis requires an H_2/CO ratio of 2.0 [5].

The methanol synthesis process from syngas involves the following main reactions:

$$CO + 2H_2 \rightarrow CH_3OH \quad \text{(R1)}$$

$$CO_2 + H_2 \rightarrow CO + H_2O \quad \text{(R2)}$$

$$CO_2 + 3H_2 \rightarrow CH_3OH + H_2O \quad \text{(R3)}$$

In the other study [5], a comparison was made using syngas with varying $H_2/(CO+CO_2)$ and CO_2/CO ratios. The results showed that syngas with a high $H_2/(CO+CO_2)$ ratio and a low CO_2/CO ratio yielded the highest methanol production. The CO_2/CO ratio significantly influences methanol synthesis selectivity; the lower the CO_2/CO ratio, the higher the selectivity toward methanol production.

The Indonesian government targets a renewable energy mix of 23% by 2025 and 31% by 2050. To support this target, it is necessary to develop renewable energy sources that are environmentally friendly, sustainable, and economically viable. East Java is one of the regions in Indonesia that has significant biomass potential due to the large amount of agricultural production, such as sugarcane, rice, and corn. Based on data released by the Central Statistics Agency in 2023, East Java has a wealth of sugar cane, rice, and corn kernels of 1,129,000 tons, 9,591,420 tons, and 5,991,810 tons, respectively. The waste from these commodities, such as bagasse, rice husks, and corn cobs, can be utilized as raw materials for gasification.

The utilization of syngas produced from the gasification process can be directed towards electricity generation and chemical production, such as methanol. The national demand for methanol remains high, while the government still relies on imports for approximately 80% of the supply. Methanol is one of the basic chemicals that has broad applications in the chemical industry, energy, and transportation. The study on biomass utilization through thermal conversion routes are extensively reported, a comparative study of bagasse, rice husk, and corncob as a feedstock for both electricity and methanol production in various combination of feed and product scenario are rarely discussed. In this study, a comprehensive evaluation of biomass gasification such as technical performance and technoeconomic analysis were conducted on the production of syngas and its derivatives from sugarcane bagasse, rice husk, and corncob through the gasification process.

2. MATERIALS AND METHODS

This study begins by identifying biomass potential in East Java from agricultural commodities. After selecting biomass types (bagasse, rice husk, corncob), the next step is to perform proximate and ultimate analyses to determine the composition of the raw materials by journal research. The process continues with modeling the gasification process using Aspen Plus V14, which has validated, to determine the syngas composition produced from each biomass type. After technical simulations are conducted, an evaluation sensitivity is performed to analyse the effect of gasification process variabel such as temperature, pressure, and S/B ratio to syngas composition. Subsequently, three utilization scenarios of syngas are evaluated: electricity generation using internal combustion gas turbines, methanol synthesis through catalytic processes and product combination. A process evaluation is performed for each scenario using CGE, energy consumtion per product, and CO_2 emmission per product. an economic feasibility analysis is also performed for each scenario using financial indicators including CAPEX, OPEX, Payback Period (PBP), ROI, NPV, and IRR which will be explained in detail in the process and economic evaluation section.

2.1 Biomass Properties

In this study, bagasse, rice husk, and corncob are used as feedstock. The quantity of each is based on data released by the Central Statistics Agency of Indonesia in 2023, as summarized in Table 1. The proximate and ultimate analysis data of the biomass were obtained through a review of various journals relevant to the type and location of the biomass.

Table 1. Biomass Properties Data

Data	Bagasse [6]	Rice Husk [7]	Corn Cob [8]
Proximate Analysis, wt %			
Moisture	38.25	10.41	10.15
Fixed Carbon	7.4	13.40	0.15
Volatile Matter	46.48	53.78	87.9
Ash	2.41	22.76	1.8
Ultimate Analysis, wt %			
C	24.46	32.37	47.6
H	3.22	5.27	5.91
N	0.02	0.60	0.84
O	24.1	38.89	38.7
S	0.08	0.11	0.15
Quantity, ton/year	372.570	2.330.148,3	2.685.597,6
Waste Biomass, wt %*	30-35	25	70-75

*Percetage of waste weight of total biomass weight

2.2 Process Modelling

All simulations were performed in Aspen Plus V14. Simulation flowshet of gasification process and its derivatives process is shown in Figure 1. The biomass is assumed to have undergone pre-treatment, ensuring that the particle sizes of sugarcane bagasse, rice husk, and corn cob are suitable for subsequent processing. The pre-processed biomass feedstock is then introduced into a gasification reactor, where syngas is produced based on the constituent elements identified in the proximate and ultimate analysis data. The biomass properties data and gasification data set can be seen in Table 2 and Table 3, respectively. The syngas is subsequently refined and utilized to produce value-added derivatives, including electricity and methanol.

In the gasification process, biomass undergoes pyrolysis in the RYield block (Decomp) to decompose its organic compounds at a temperature of 800°C and a pressure of 1 bar. A calculator block with an elemental balance equation (Fortran) is embedded to Decomp. The pyrolysis products are then fed into the RGibbs block (Gasifier), where gasification occurs under the optimal condition. The gasifying agent used is steam, introduced at 100°C and 1 bar, with a steam-to-biomass mass flow ratio of 0.5 (optional). These two sequential steps constitute the gasification process, which produces syngas that still contain ash. The syngas stream is then sent to a separator to remove ash, allowing for further processing toward the desired downstream products.

The gasification simulation is modeled using the RYield and RGibbs reactor blocks available in Aspen Plus. The RYield block represents the pyrolysis (thermal decomposition) of biomass into intermediate components, while the RGibbs block simulates the gasification of these intermediates into syngas based on Gibbs free energy minimization.

The gasification process simulation was validated by comparing the simulation results with experimental data from a gasification process. Because gasification process is the main process, it is considered valid when the deviation between the simulated and experimental results does not exceed 10%.

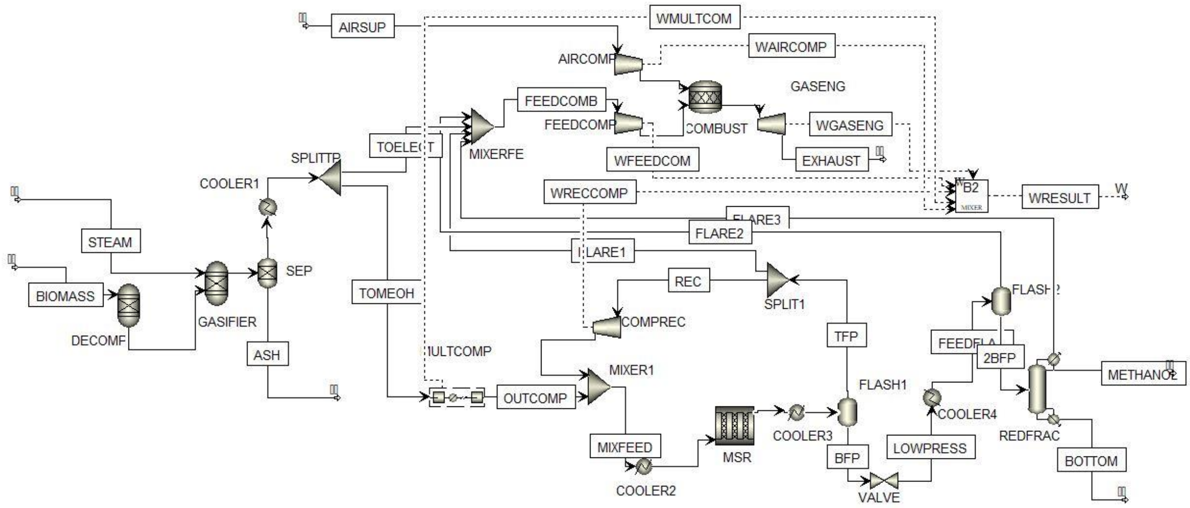


Figure 1. Schematic diagram of biomass gasification

Table 2. Biomass properties data

Data	Set
Component	Conventional
	Non-conventional (biomass dan ash)
Base Method	Peng-Robinson
Method Filer	Common
Property Methods	
Enthalpy	HCOALGEN
Density	DCOALIGT
Global Settings	
Mode Input	STEADY-STATE
Stream Class	MIXCINC

Table 3. Gasification data set

Data	RYields (Decomp)	RYields (Gasifier)	Steam (Gasification Agent)
Temperature, ºC	700 – 1000	700 – 1000	100
Pressure, bar	1	1	1
Base Method	Peng-Robinson	Peng-Robinson	0,2 – 1*

*S/B: Steam/ Biomass Ratio

For the electricity generation pathway, the syngas is first directed to a cooler to reduce its temperature to 80 °C. The cooled syngas is then compressed using a compressor to a pressure of 17 bar and fed into a gas engine generator, along with air supplied at the same pressure. The mass flow rate of the air corresponds to 120% of the stoichiometric oxygen required for the combustion of CH_4, H_2, and CO contained in the syngas. In the simulation, the gas engine combustion process is represented by the RStoic block (Combust) (Table 4). The combustion products are subsequently sent to an expander (Gas engine) to generate electricity.

Table 4. Electricity generator data set

Data	Set
RStoic (Combust)	
Duty, cal/sec	0
Pressure, bar	1
Base Method	Peng-Robinson
Expander (Gaseng)	
Type	Isentropic
Discharge, bar	1
Base Method	Peng-Robinson

For the methanol production pathway, the syngas is first passed through a cooler to reduce its temperature to 80 °C. The cooled syngas is then compressed to a pressure of 69 bar and subsequently cooled again to 93 °C. The compressed and cooled syngas are then fed into the methanol synthesis reactor. The methanol synthesis reactor adopted the kinetic parameter reported by Adnan and Kibria [9]. In the simulation of methanol synthesis from syngas, the reaction is modeled using the RPlug reactor block, representing the Methanol Synthesis Reactor (MSR). The downstream purification of crude methanol is carried out using a distillation column, simulated with the REDFRAC block (Redfrac) (Table 5).

In the utilization of mixed derivative products, namely methanol and electricity, the syngas stream is split evenly with a 1:1 ratio for each downstream process using a splitter. The subsequent processing steps are the same as those described for individual product pathways. However, to optimize syngas utilization, certain off-gas streams, such as the overhead products from the flash separator and the distillation column (REDFRAC), are redirected to the gas engine generator for conversion into electricity.

Table 5. Methanol synthesis data set

Data	Set
RPlug (MSR)	
Specification	
Coefficient thermal fluid, Watt/m^{2}K	600
Thermal Fluid Temperature, K	511
Reactor Type	Reactor with constant thermal fluid temperature
Configuration	
Tube Reactor, cm	4650
Tube Length, cm	120
Tube Diameter, cm	4.6
Base Method	SRK
RadFrac (REDFRAC)	
Calculation type	Equilibrium
Configuration	
Number of Tray	26
Condenser Type	Vapor-liquid Ratio
Reboiler Type	Kettle
Reflux Ratio	3.5
Base Method	NRTL

2.3 Sensitivy

A sensitivity analysis was conducted on key gasification process variables, including temperature (ranging from 500 °C to 1000 °C), pressure (ranging from 1 bar to 10 bar), and the steam-to-biomass (S/B) ratio (ranging from 0.2 to 1.0). The selection of the most optimal operating conditions in the gasification process is based on maximizing the hydrogen (H_2) content in the resulting syngas. This is because a higher H_2 content leads to more efficient and effective energy conversion when utilized for electricity generation. Additionally, for methanol production, a higher H_2 content increases the H_2/CO ratio, thereby enhancing the performance of the methanol synthesis reactor.

The economic evaluation was conducted based on biomass–product pairing scenarios is shown in Table 6. This is necessary to identify which scenario or combination of scenarios offers the greatest economic benefit.

Table 6. Biomass Feed-Product Scenario

Scenario	Biomass	Product 1	Product 2	Product 3
1	Bagasse	Electricity	Methanol	Combination
2	Ricehusk	Electricity	Methanol	Combination
3	Corncob	Electricity	Methanol	Combination
4	Combination	Electricity	Methanol	Combination

The feedstock scenarios are divided into single-feedstock cases, consisting of each type of biomass waste individually, and combined-feedstock cases, which integrate all biomass types. The same approach is applied to the product scenarios. The combined feedstock consists of a mixture of all raw materials without specifying composition ratios, whereas in the combined product scenario, the syngas produced is evenly distributed, with 50% allocated to each product.

2.4 Process Evaluation

Cold gas efficiency (CGE) is defined as the ratio between the chemical energy contained in the product gas and the chemical energy contained in the original feedstock. It is used to evaluate the performance and effectiveness of the conversion process of solid fuels into gas. The actual Cold Gas Efficiency (CGE) values in industrial applications range from 50% to 70%. A higher CGE percentage indicates better process efficiency. The lower the amount of energy required for the conversion of each kilogram of biomass, the better the performance. The CO_2 emissions per unit of product should not exceed 0.9 kg CO_2, which corresponds to the average emission level of coal-fired power plants. The effectiveness of a gasification process can be assessed by evaluating the percentage of product conversion achieved. In gasification, this is typically measured using the Cold Gas Efficiency (CGE).

$$\text{CGE}=\left(\frac{\text{Heating value of Syngas }(\text{LHV}_{syngas})}{\text{Heating value of biomass }(\text{LHV}_{biomass})}\right)\text{ x }100\% \quad (1)$$

An empirical approach for estimating the Lower Heating Value (LHV) of biomass feedstock could use the following equation [10]:

$$\text{LHV}_{\text{biomass}}(\text{MJ/kg})= -5.5232+0.2373\text{ N}+0.4334\text{ C}+0.2360\text{ H}+0.3732\text{ S}+0.000838\text{ O} \quad (2)$$

The calculation of syngas Lower Heating Value (LHV), used the following equation [1]:

$$\text{LHV}_{\text{syngas}}\left(\text{MJ/NM}^3\right)=10{,}788\ _{\text{H}_2}+12{,}622_{\text{CO}}+35{,}814_{\text{CH}_4} \quad (3)$$

2.5 Economic Evaluation

In an economic feasibility evaluation, the capital expenditure (CAPEX)—which consists of the Fixed Capital Cost and Installed Cost—must be calculated to determine the total amount of investment required. Meanwhile, to assess the potential profitability of the project, the operational expenditure (OPEX)—which includes the operating cost and utility cost—must be identified, as these expenses are deducted from the product's selling price to estimate the net profit. The economic parameters are considered feasible when several financial criteria are met. These include a positive annual cash flow, indicating consistent yearly profitability, a positive net present value (NPV), which shows that the present value of expected cash flow exceeds the initial investment, the internal rate of return (IRR) should be greater than 10%, assuming a discount rate of 10%, it represents the actual rate of return generated by a project, taking into account the timing of cash flows throughout the project's lifetime, the return on investment (ROI) must also exceed 10%, it is a ratio that indicates how much profit (return) is obtained from an investment compared to the cost of that investment. ROI reflects the efficiency and profitability of an investment., and the payback period should not exceed 10 years, indicating that the investment can be recovered within a reasonable time frame.

3. RESULTS AND DISCUSSION

3.1 Simulation and Validation

The gasification process simulation was developed in Aspen Plus V14 using RGibbs as the main reactor model. The RGibbs reactor does not require kinetic data (such as reaction rates or mechanisms). Instead, it determines the product composition by finding the state at which the total Gibbs free energy of the system is minimized, in accordance with the thermodynamic laws governing chemical equilibrium. Consequently, the constructed gasification process simulation is not designed for specific operating conditions but represents a general case. Therefore, the developed process simulation can be validated by comparing its results with experimental data.

The validation was performed using biomass feedstock with an empirical formula of $CH_{1.4}O_{0.6}$ and carbon dioxide (CO_2) as the gasifying agent. The experiments were carried out at operating temperatures of 800 °C, 1000 °C, and 1200 °C under atmospheric pressure (1 atm) [11] [12].

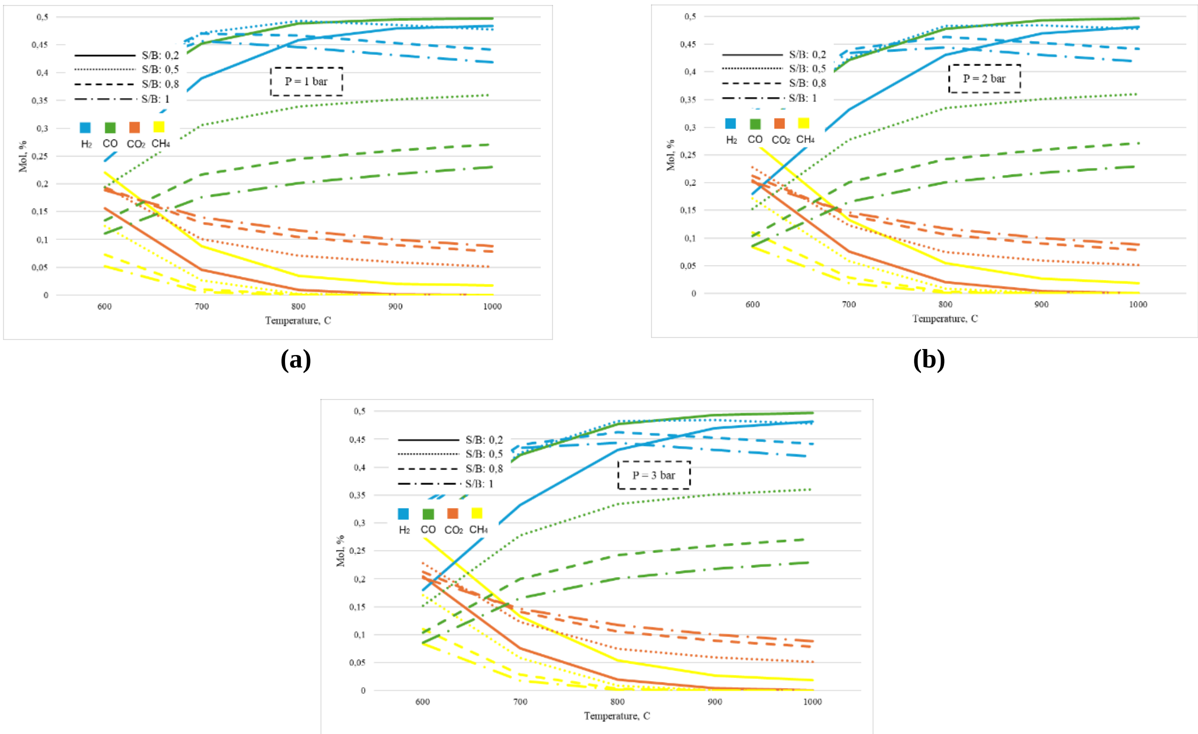
The comparison between the composition results obtained from the process simulation and those from the experimental studies shows a deviation of no more than 10%, as shown in Table 7. This indicates a high level of accuracy under the three different operating conditions. Therefore, the developed gasification process simulation using Aspen Plus V14 is considered valid and can be reliably used for further analysis in different condition and agen gasification.

Table 7. Validation Comparation

	Simulation	[12]	[11]	Error	
				Renganathan	Chaiwatanodom
T = 800 °C					
H_2	31.0%	30.7%	31.0%	1.0%	0.1%
CO	63.1%	60.0%	59.8%	5.2%	5.6%
CO_2	6.0%	9.8%	9.0%	-	-
CH_4	0.4%	0.0%	4.3%	-	-
T = 1000 °C					
H_2	30.3%	29.0%	30.3%	4.6%	0.3%
CO	67.0%	62.5%	62.4%	7.2%	7.4%
CO_2	2.7%	8.1%	7.3%	-	-
CH_4	0.0%	0.0%	5.9%	-	-
T = 1200 °C					
H_2	30.0%	29.0%	29.4%	3.6%	2.1%
CO	67.7%	65.0%	64.3%	4.2%	5.4%
CO_2	2.2%	6.7%	6.3%	-	-
CH_4	0.0%	0.0%	7.1%	-	-

3.2 Sensitivity

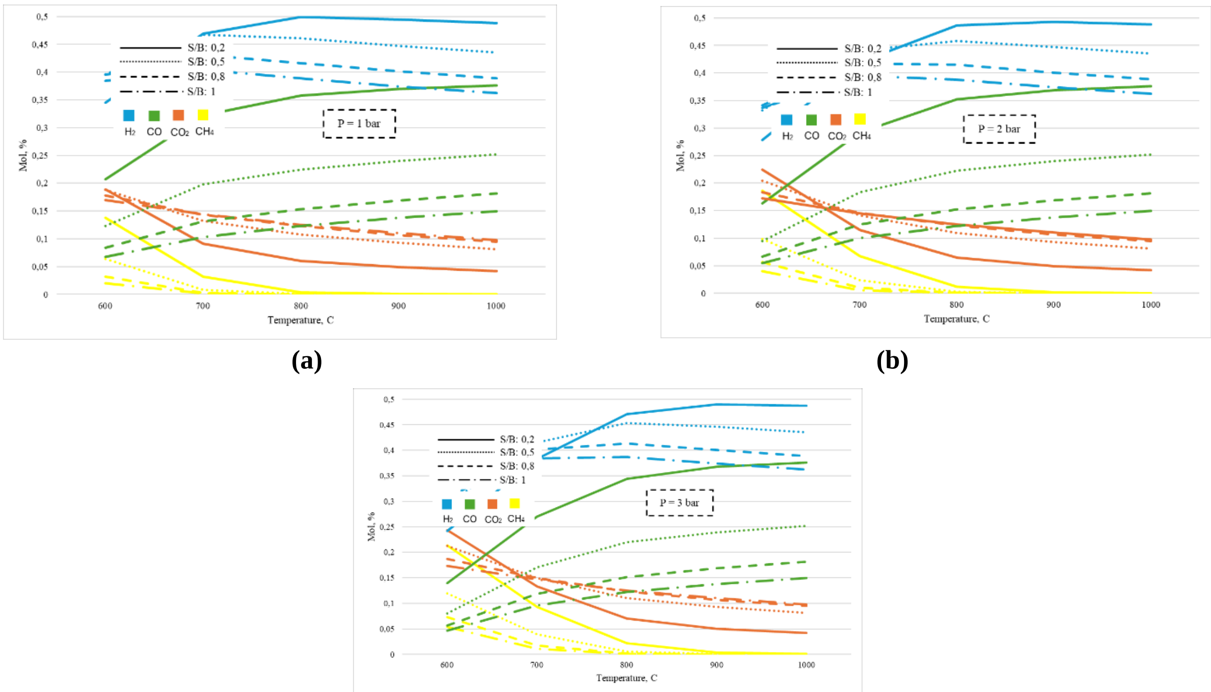
The sensitivity evaluation of gasification process variables, specifically the relationship between temperature, pressure, and steam-to-biomass (S/B) ratio, and their effect on syngas composition using sugarcane bagasse as feedstock is illustrated in Fig. 2. The results show that the highest composition of H_2 (49.3%) in the syngas was achieved at a gasification temperature of 786 °C, pressure of 1 bar, and an S/B ratio of 0.5. Under these conditions, the compositions of CO, CO_2, and CH_4 were 33.7%, 7.3%, and 0.36%, respectively.



(a) (b)

(c)

Figure 2. Syngas Composition from Bagasse Based on The Influence of: (a) S/B Ratio and Temperature in 1 bar, (b) S/B Ratio and Temperature in 2 bar, (c) S/B Ratio and Temperature in 3 bar.

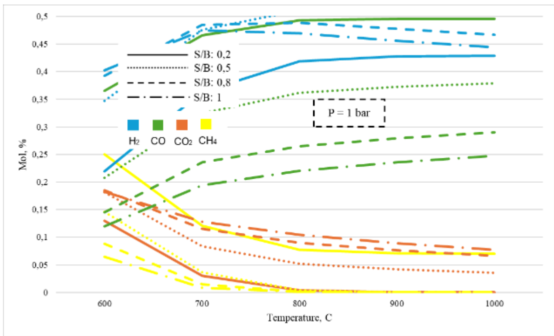


(a) (b)

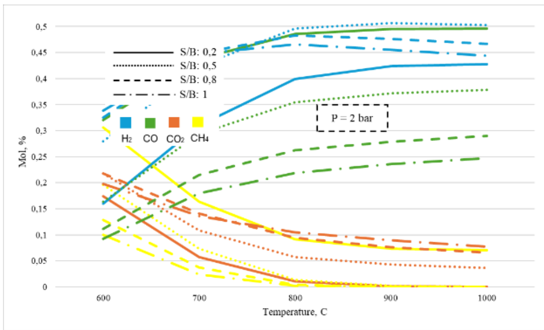
(c)

Figure 3. Syngas Composition from Rice Husk Based on The Influence of: (a) S/B Ratio and Temperature in 1 bar, (b) S/B Ratio and Temperature in 2 bar, (c) S/B Ratio and Temperature in 3 bar.

Rice husk produced the highest H_2 concentration of 46.9% in the syngas. This value was obtained at a gasification temperature of 725°C, a pressure of 1 bar, and an S/B ratio of 0.2. Under these conditions, the molar compositions of CO, CO_2, and CH_4 were 20.7%, 12.4%, and 0.44%, respectively. Corncob yielded the highest H_2 concentration of 51.2% in the syngas. This value was achieved at a gasification temperature of 827°C, a pressure of 1 bar, and an S/B ratio of 0.5. Under these conditions, the molar compositions of CO, CO_2, and CH_4 were 36.5%, 4.87%, and 0.23%, respectively.



(a)



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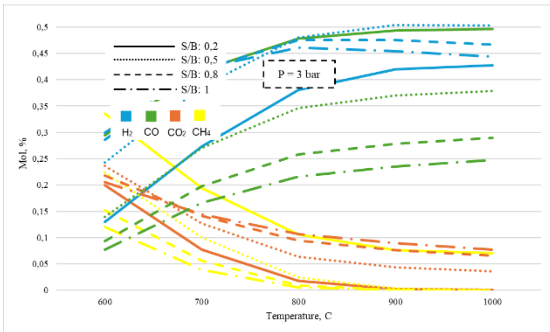
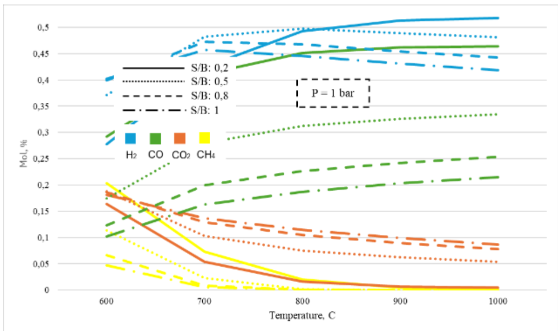


(c)

Figure 4. Syngas Composition from Corncob Based on The Influence of: (a) S/B Ratio and Temperature in 1 bar, (b) S/B Ratio and Temperature in 2 bar, (c) S/B Ratio and Temperature in 3 bar.



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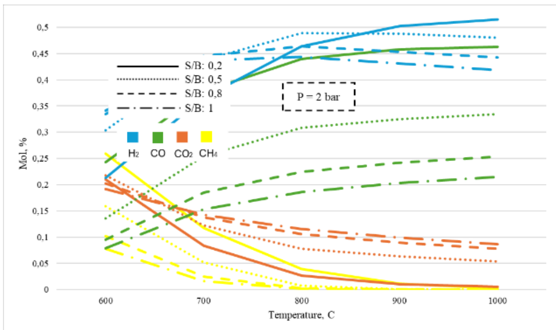

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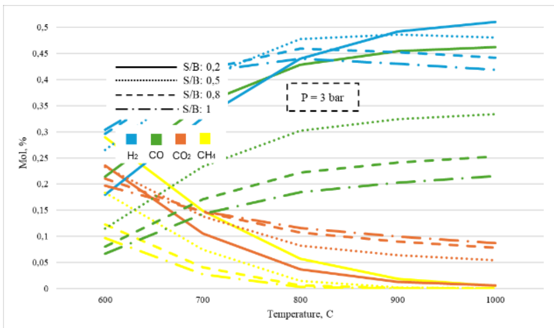

(c)

Figure 5. Syngas Composition from Combination Biomass Based on The Influence of: (a) S/B Ratio and Temperature in 1 bar, (b) S/B Ratio and Temperature in 2 bar, (c) S/B Ratio and Temperature in 3 bar.

Meanwhile, the mixed biomass showed the highest H_2 concentration of 51.8% in the syngas. This value was obtained at a gasification temperature of 1000°C, a pressure of 1 bar, and an S/B ratio of 0.2. Under these conditions, the molar compositions of CO, CO_2, and CH_4 were 46.4%, 0.46%, and 0.08%, respectively.

The application of optimal operating conditions such as temperature, pressure, and S/B ratio for each type of biomass in the gasification process results in syngas compositions that vary accordingly, as shown in Table 8. In Table 9, Corncob exhibits the most favorable ratio between combustible and non-combustible gases, making it highly promising for power generation applications. In contrast, rice husks show the lowest ratio, indicating lower potential for energy production. Table 10 shows that the H_2/CO ratio in all types of syngas is relatively low, considering that the ideal value for methanol production is 2. However, it is important to note that corn cob syngas exhibits a very low CO_2/CO ratio, which supports methanol synthesis. As explained by [5], their research demonstrated that syngas with a high H_2/(CO + CO_2) ratio and a low CO_2/CO ratio yields the highest methanol output. The CO_2/CO ratio affects methanol synthesis selectivity the lower the ratio, the higher the selectivity toward methanol production.

Table 8. Syngas Component

Component, kmol/h	Biomass			
	Bagasse	Ricehusk	Corn Cob	Mix Biomass
H_2O	373.80	1,467.3	799.34	1,821.14
H_2	1,982.92	9202.54	23,400.04	13,636.32
CO	1,355.60	6,398.98	20,510.41	9,738.18
CO_2	294.55	1,494.59	428.02	1,297.99
CH_4	14.33	368.71	17.53	60.27
NH_3	0.0064	0.22	0.14	0.17
H_2S	1.88	10.52	25.46	13.09
N_2	0.54	65.6	153.5	83.87
O_2	0.00	0.00	0.00	0.00
S	0.00	0.00	0.00	0.00
C	0.00	0.00	0.00	0.00
C_3HOH	0.000005	0.000046	0.000011	0.000024

Table 9. Ratio Component for Electricity

Data	Biomass			
	Bagasse	Ricehusk	Corn Cob	Mix Biomass
H_2+CO+CH_4, kmol/h	3,352.87	15,970.24	43,927.98	23,434.77
CO_2+N_2, kmol/h	295.09	1,560.14	581.54	1,381.86
Ratio	11.36	10.24	75.54	16.96

Table 10. Ratio Component for Methanol Synthesis

Data	Biomass			
	Bagasse	Ricehusk	Corn Cob	Mix Biomass
H_2/(CO+CO_2)	1.2	1.17	1.12	1.24
CO_2/CO	0.22	0.234	0.021	0.13
H_2/CO	1.46	1.44	1.14	1.4

The composition of syngas from various types of biomasses is presented in Table 8. The H_2S content in each syngas sample is relatively high. For generator engine applications, the acceptable H_2S concentration is below 100 ppm. The presence of H_2S in the fuel gas for generator engines can lead to corrosion, thereby shortening the operational lifespan of the engine and its auxiliary equipment. In addition, combustion of such gas may produce SO_2 emissions, which can cause adverse environmental impacts such as acid rain. Therefore, the author intends to conduct further research on the syngas sweetening process to reduce H_2S concentration in the production of derivative products.

3.2 Derivative Product

Syngas produced from each type of biomass feedstock is utilized for derivative products such as electricity and methanol. Each syngas yields different product quantities, as shown in Table 11. In the case of electricity generation, bagasse produces the highest output at 3 kWh/kg, while rice husk yields the lowest at 0.85 kWh/kg. This observation is consistent with the syngas compositions for each biomass listed in Tables 9 and 10. The highest ratio of combustible to non-combustible gases is observed for corn cobs; however, the syngas from corn cobs also exhibits a substantially higher moisture content compared with the other feedstocks. Consequently, this elevated water content adversely affects generator engine performance and electrical output. Conversely, biomass combination display conditions comparable to those of corn cobs; therefore, sugarcane bagasse produced the greatest electrical yield among the materials studied.

In the methanol production process, the product-to-biomass ratios presented in Table 11 represent methanol yields after purification by distillation to a purity of 99%. In contrast, the ratios shown in Table 10 merely illustrate the potential methanol production capacity of each biomass type. The composition of the effluent from the methanol synthesis reactor, as well as the extent of effluent recycling and reprocessing, significantly influence the amount of high-purity methanol obtained at the specified purity level. Consequently, the highest methanol-to-biomass ratios are achieved with sugarcane bagasse and corncob.

3.3 Evaluation

In the process evaluation, the LHV values of biomass and syngas were calculated using Equations (2) and (3), respectively. The Cold Gas Efficiency (CGE) was determined using Equation (1). The results for each type of biomass are presented in Table 12. The highest CGE value was obtained from mixed biomass, at 87.77%, while the lowest CGE value was observed in corn cob, at 56.85%. The CGE of syngas is significantly influenced by the presence of CH_4 and CO, whereas the selection of optimal gasification operating conditions is primarily based on H_2 content. Nevertheless, the CGE values for all biomass types remain within a normal range 50% to 70%.

Table 11. Derivative Products

Derived Product	Bagasse	Ricehusk	Corn Cob	Mix Biomass
Electricity, kWh	115,207	261,857	553,896	1,173,070
Specific consumption, kWh/kg	3	0.854	2.08	1.9
Methanol, ton/year	280.600	883,694	1,653,892	2,397,916
Methanol purity	99%	99%	99.6%	99.67%
Methanol/Biomass	0.753	0.329	0.71	0.445
Combination				
Electricity, kWh	40,432	213,892	239,645	-
Methanol, ton/year	137,396	380,311	111,697	1,332,161
Methanol purity, %	99.7	99.7	99.7	99.6

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Rice husk showed the highest energy consumption per 1 kWh of electricity produced, at 9.589 MJ. In contrast, sugarcane bagasse demonstrated the most efficient energy use, requiring only 2.738 MJ to generate 1 kWh. Additionally, the CO_2 emission associated with producing 1 kWh from bagasse was 0.64 kg, followed by corn cob and then biomass combination feed. In methanol production, rice husk exhibited the lowest energy efficiency, with 26.99 MJ required per kilogram of methanol produced, followed closely by corn cob at 28 MJ/kg. Corncob also produced the lowest CO_2 emissions per kilogram of methanol, at 0.63 kg. On the other hand, rice husk showed the highest values for both energy consumption and CO_2 emissions per kilogram of methanol, at 53.75 MJ and 1.8 kg, respectively.

Table 12. Process Evaluation

Data	Biomass			
	Bagasse	Ricehusk	Corn Cob	Mix Biomass
$LHV_{biomass}$, MJ/kg	16.3	9.97	17.96	13.8
LHV_{syngas}, MJ/NM^3	9.7	7.8	10.2	12.1
CGE, %	59.5	78.6	56.8	87.8
Eletricity				
Emmision CO_2, kg/h	73,204.07	313,318.58	488,017.83	1,058,718.26
Energy, MJ/h	315,256.03	2,510,902.08	1,940,037.12	5,538,444.48
Electricity, kWh	115,127	261,857.60	553,896	1,173,070
Energy MJ/ kWh	2.738	9.589	3.503	4.721
Emmision CO_2/kWh	0.64	1.20	0.88	0.90
Methanol				
Emmision CO_2, kg/h	30,314.75	181,441.64	119,004.02	336,813.34
Energy, MJ/h	864,431.14	5,422,464.00	5,286,902.40	13,018,432.32
Methanol, kg/h	32,032	100,878	188,800	273.735
Energy/Methanol, MJ/kg	26.99	53.75	28.00	47.56
Emmision CO_2/Methanol, kg/kg	0.95	1.80	0.63	1.23
Combination				
Emmision CO_2, kg/h	51,704.87	267,809.53	322,452.37	117,625.68
Energy, MJ/h	621,022.75	3,247,453.44	3,069,717.12	8,831,085.12

In an economic evaluation, the pricing of biomass and methanol is determined based on the market conditions in the year 2025. Meanwhile, the electricity price, which is part of both the production cost and utility cost and is automatically included in the calculation within Aspen Plus V14, follows the price predetermined in Aspen Plus (Table 13). The investment cost data is classified based on the processing units for the derivative products generated from syngas utilization, namely electricity, methanol, and a combination of both electricity and methanol (Table 14). Different types of biomasses yield different investment values, even when used to produce the same derivative products from syngas. This variation is influenced by several factors, including the characteristics of the syngas components produced from different biomass sources and the quantity of feedstock processed.

Table 13. Biomass and Product Price

Item	Price	Source
Feedstock		
Bagasse	Rp 200,000.00/ton	Pertanian.go.id
Corn Cob	Rp 300,000.00/ton	Pertanian.go.id
Riec Husk	Rp 250,000.00/ton	Pertanian.go.id
Product		
Methanol	379 USD/ton	tradingeconomics.com
Electricity	0.129 USD kW/h	Aspen Plus

In the syngas-to-electricity conversion process, the amount of air required for the gas generator engine depends on the concentration of H_2, CO, and CH_4 present in the syngas. Meanwhile, the conversion of syngas into methanol requires multiple separation units, including basic equipment such as flash separators and more advanced units like distillation columns (RadFrac) in Aspen Plus. The extensive use of separation units in the methanol production process is due to the strict product specifications required for methanol to be marketable. Methanol purity is a key specification demanded by consumers.

Table 14. Components of Investment Cost

Component	Biomass				
	Bagasse	Ricehusk	Corn Cob	Combination	Unit
Electricity					
Fixed Capital Cost	262,422,796	825,456,242	1,115,821,956	2,671,844,901	USD
Installed Cost	140,812,800	406,470,700	627,460,000	1,457,264,000	USD
Operating Cost	47,800,900	150,336,000	199,806,000	473,654,000	USD/year
Utilities Cost	549,619	2,208,210	3,786,953	8,077,823	USD/year
Income Price	130,131,165	295,983,562	626,080,849	1,325,946,956	USD/year
Methanol					
Capital Cost	91,395,400	284,148,000	281,039,000	811,212,000	USD
Fixed Capital Cost	187,716,296	501,203,942	747,135,764	1,921,679,369	USD
Installed Cost	104,279,700	332,259,000	328,758,100	958,620,900	USD
Operating Cost	47,839,700	136,372,000	187,411,000	378,939,000	USD/year
Utilities Cost	37,891,400	108,859,000	156,085,000	306,700,000	USD/year
Income Price	106,442,945	335,220,511	627,387,360	909,625,509	USD/year
Combination					
Fixed Capital Cost	240,793,196	840,311,054	1,191,149,980	1,687,335,857	USD
Installed Cost	128,283,400	491,932,200	643,732,300	616,822,400	USD
Operating Cost	45,424,400	165,777,000	194,363,000	282,517,000	USD/year
Utilities Cost	10,002,246	32,983,297	28,087,806	238,174,000	USD/year
Income Price	97,820,775	386,034,539	313,247,510	505,342,054	USD/year

Table 15. Economic Feasibility

Component of Evaluation	Biomass			
	Bagasse	Ricehusk	Corn Cob	Combination
Electricity				
Annual Cash Flow, USD/year	77,083.893	101,119,818	378,425,841	742,324,507
Payback Periode, year	5,23	12,18	4,61	5,56
Rate on Investment, %	19,12	8,21	21,71	17,98
Net Present Value, USD	253,023,036	-371,036,925	1,478,470,557	-3,472,860,269
Internal Rate of Return, %	18,472	5,269	21,247	-7,977
Methanol				
Annual Cash Flow, USD/year	16,01,.091	47,669,977	239,829,306	122,095,884
Payback Periode, year	18,23	17,48	4,49	23,59
Rate on Investment, %	5,48	5,72	22,29	4,24
Net Present Value, USD	-155,650,496	-427,621,553	965,908,214	-1,840,829,181
Internal Rate of Return, %	0,898	1,316	21,864	-1,523
Combination				
Annual Cash Flow, USD/year	37,697,375	144,954,709	46,734,650	-
Payback Periode, year	9,79	9,19	39,26	-
Rate on Investment, %	10,21	10,88	2,55	-
Net Present Value, USD	-48,137,593	-98,162,101	-1,437,003,860	-
Internal Rate of Return, %	8,038	8,905	-5,713%	-

The economic feasibility assessment of biomass utilization projects is presented in Table 15. From the table, it can be observed that not all types of biomass utilization for producing electricity and methanol as derivative products yield favorable economic values. Four components are used to evaluate whether biomass utilization projects in East Java are feasible: Payback Period, Rate of Inventment (ROI), Net Present Value (NPV), and Internal Rate of Return (IRR). Sugarcane bagasse is economically feasible only for electricity production. This is indicated by economic criteria that meet the specified thresholds: a payback period of 5.23 years (less than the 10-year benchmark), an IRR of 18.47% (which exceeds the 10% discount rate), a positive NPV, and an ROI of 19.12%, which is considered attractive. Rice husk is not feasible for electricity, methanol, or combined product generation when assessed using the economic criteria. Although the annual cash flow is positive, the other economic indicators fail to meet the required parameters. Corncob biomass is considered feasible for both electricity and methanol production. Both options satisfy the economic feasibility criteria, with payback periods of 4.61 and 4.49 years, IRRs of 21.247% and 21.864%, and ROI of 21.71% and 22.29%, respectively. The NPV values for both scenarios are also positive. Conversely, the mixed biomass feedstock is not feasible for either electricity or methanol production. In fact, the mixed product scenario shows a negative annual cash flow.

4. CONCLUSION

Technoeconomic study is essential to determine the optimal process conditions for producing high-value products. Through a series of process simulations and sensitivity analyses—both technical and economic, it can be concluded that corncob biomass offers distinct advantages. This feedstock can be used to produce both electricity and methanol. Simulation results indicate that each kilogram of corncob can yield approximately 2.08 kWh of electricity and 0.71 kg of methanol. From both a technical and economic perspective, these pathways are deemed feasible.

Sensitivity analysis of the gasification process revealed optimal operating conditions: a temperature of 827 °C, pressure of 1 bar, and a steam-to-biomass ratio (S/B) of 0.5. Under these conditions, the Cold Gas Efficiency (CGE) achieved was 56.85%. In the conversion processes for methanol and electricity, the energy consumption requirements are 28 MJ/kg methanol and 3.5 MJ/kWh, respectively. The corresponding emissions are 0.88 kg CO_2/kWh for electricity and 0.63 kg CO_2/kg for methanol.

From an economic standpoint, the utilization of corncob biomass for electricity production yields a payback period of 4.61 years, while methanol production yields a payback period of 4.49 years. The Return on Investment (ROI) is 21.71% for electricity and 22.29% for methanol—both exceeding the standard benchmarks of 10%, and even 15%, indicating a financially viable project. The Internal Rate of Return (IRR) for electricity and methanol production is 21.25% and 21.86%, respectively, both well above the discount rate.

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REFERENCES

[1] I. L. Motta, N. T. Miranda, R. M. Filho and M. R. Wolf Maciel, "Sugarcane bagasse gasification: Simulation and analysis of different operating parameters, fluidizing media, and gasifier types," vol. Biomass and Energy 122, 2019.
[2] N. Shilling and D. Lee, "IGCC-Clean power generation alternative for solid fuels," 2003.
[3] S. B. Shrestha and G. Karim, "Hydrogen as an additive to methane for spark ignition engine applications," vol. Hydrogen Energy, 1999
[4] X. Yin and D. Y.C. Leung, "Characteristics of the Synthesis of Methanol Using Biomass-Derived Syngas," vol. Energy & Fuels, 2004.
[5] R. Destalia and E. Aryanny, "Analisa Karakteristik Pengujian Co-FiringBiomassaBagasseTebu di PLTU Rembang Kapasitas 2×315 MW," 2024.
[6] H. B. Adja and A. Anam, "Study Komparasi Sekam Padi Sebagai Bahan Bakar Alternatif Berbasis Proximate And Ultimate Analysis," vol. 2, 2021.
[7] I. Irawan, N. Amir and K. Budiarto, "Pengembangan Gasifikasi Tongkol Jagung untuk Meningkatkan Performa Reaktor Downdraft dengan Masukan Dua Udara Bertingkat," 2021.
[8] M. A. Adnan and M. G. Kibria, "Comparative techno-economic and life-cycle assessment of power-to-methanol synthesis pathways," 2020.

[9] P. Chaiwatanodom, S. Vivanpatarakij and S. Assabumrungrat, "Thermodynamic analysis of biomass gasification with CO2 recycle for synthesis gas production," vol. Applied Energy, 2014.
[10] T. Rengenathan, M. Yadav, S. Pushpavanam, R. Voolapalli and Y. Cho, "CO2 utilization for gasification of carbonaceous feedstocks: A thermodynamic analysis," vol. Chemical Engineering Science, 2012
[11] R. H. White, "Effect of Lignin Content and Extractives on the Higher Heating Value of Wood," *Research Forest Products Technologist*, 1986
[12] T. Waldheim and L. Nilsson, "Heating Value of Gases from Biomass Gasification," 2001.
[13] N. Van Nung, M. Maguyon-Detras, M. Migo, C. Balingbing, P. Chivenge and M. Grummert, "Rice Straw Overview: Availability, properties, and management practices. In sustainable Rice Straw Management.," 2020.
[14] A. Shariff, N. S. M. Aziz, N. I. Ismail and N. Abdullah, "Corn Cob as aPotential Feedstock for Slow Pyrolysis of Biomass," *Journal of Physical Science*, 2016.
[15] J. Sanchez, M. D. Curt, N. Robert and J. Fernandes, "Biomass Resources," 2019.
[16] A. Pradhan, P. Baredar and A. Kumar, "Syngas as An Alternative Fuel Used in Internal Combustion Engines: A Review," vol. Journal of Pure and Applied Science & Technology, 2015
[17] F. Pinto, R. Andre, M. Miranda, D. Neves, F. Varela and J. Santos, "Effect of gasification agent on co-gasification of rice production wastes mixtures," vol. Fuel 180, 2016
[18] B. Patel and B. Gami, "Biomass Characterization and its Use as Solid Fuel for Combustion," *Iranica Journal of Energy & Environment*, 2012
[19] A. Molino, S. Chainese and D. Musmarra, "Biomass gasification technology: The state of the art overview," 2016.
[20] M. Mohammed, A. Salmiaton, W. Wan Azlina, M. M. Amran and A. Fakhru'l-Razi, "Air gasification of empty fruit bunch for hydrogen-rich gas production in a fluidized-bed reactor," 2011.
[21] P. Lv, Z. Yuan, L. Ma, C. Wu, Y. Chen and J. Zhu, "Hydrogen-rich gas production from biomass air and oxygen/steam gasification in a downdraft gasifier," vol. Renewable Energy, 2006
[22] J. Li, Y. Yin, X. Zhang, J. Liu and R. Yan, "Hydrogen-rich gas production by steam gasification of palm oil wastes over supported tri-metallic catalyst," vol. 34, 2009.
[23] F. Kargbo, J. Xing and Y. Zang, "Property analysis and pretreatment of rice starw for energy use in grain drying: A review," 2010.
[24] S. Kaniapan, H. Suhaimi, Y. Hamdan and J. Pasupuleti, "Experiment analysis on the characteristic of empty fruit bunch, palm kernel shell, coconut shell, and rice husk for biomass boiler fuel," *Journal Of Mechanical Engineering And Sciences (JMES)*, 2021.
[25] S. Kaniapan and J. Pasupuleti, "A Review of the Sustainable Utilization of Rice Residues for Bioenergy Conversion Using Different Valorization Techniques, Their Challenges, and Techno-Economic Assessment," *International Journal of Environment Research and Public Health*, 2022.
[26] B. Jenkins, L. Baxter, T. Miles Jr. and T. Miles, "Combustion properties of biomass," *Fuel Processing Technology*, 1998.
[27] M. Fang, L. Yang, G. Chen, Z. Shi, Z. Luo and K. Chen, "Experimental study on rice husk combustion in a circulating fluidized bed," *Fuel Processsing Technology*, 2004.
[28] A. Demirbas, "Relationships Between Heating Value and Lignin,Moisture, Ash and Extractive Contents of Biomass Fuels," *Energy Exploration & Exploitation*, 2002.
[29] A. C. Chang, H.-F. Chang, F.-J. Lin, K.-H. Lin and C.-H. Chen, "Biomass gasification for hydrogen production," vol. International Journal of Hydrogen Energy 34, 2011.
[30] A. A. Ahmad, N. A. Zawawi, F. H. Kasim, A. Inayat and A. Khasri, "Assessing the gasification performance of biomass: A review on biomass gasification process conditions, optimization and economic evaluation," vol. Renewable and Sustainable Energy Review, 2015