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Feasibility Study Analysis of Biomass-Based Co-Firing Energy at the Pangkalan Susu Power Plant

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Abstract. This study examines the implementation of biomass co-firing with a mixing ratio ranging from 3% to 45% as an alternative to reduce dependency on coal. The research evaluates feasibility from technical, environmental, and economic perspectives. Technically, the heat produced from co-firing is comparable to that generated from pure coal combustion. The analysis was conducted using daily operational data, including coal consumption, electric load, furnace temperature, and Specific Fuel Consumption (SFC) measurements. The results show that adding rice husks up to 45% does not compromise the operational stability of the power plant. Coal consumption decreased as the percentage of rice husk increased, without sacrificing electrical output, which remained stable between 126–139 MW. Furnace temperature also remained stable, with the 45% blend exhibiting higher stability compared to other blends. Although SFC slightly increased with rice husk blends, overall system efficiency remained well-maintained. This is attributed to the rice husk's easy combustibility and cleaner emissions, despite its lower calorific value compared to coal. Environmentally, the application of co-firing resulted in greenhouse gas (GHG) emissions that remained below the established limits. Economically, at a 5% co-firing scenario, annual savings amounted to IDR 6,251,729,419 and reached a peak of IDR 27,702,681,170 per year at 45% co-firing, indicating financial feasibility. The co-firing process was modeled using ASPEN PLUS software and validated with experimental data, showing highly consistent results. A higher biomass-to-air ratio led to lower temperatures but improved efficiency. Higher combustion temperatures contributed to increased levels of NO, CO_2, and SO_2. The study recommends further research on coal-fired power plants with capacities over 2 × 200 MW, utilizing biomass blends exceeding 50% and alternative types of biomass beyond rice husks, to optimize and expand the application of biomass co-firing technology.

Keywords:*Cofiring,Biomassa,Aspen Plus,emissions,ricehusk,sustainability.*

1. Introduction

Power generation is one of the main contributors to greenhouse gas (GHG) emissions globally. The future transition to a low-carbon global energy economy will require major investments in cleaner technologies, including renewable energy sources. In terms of GHG emissions from electricity generation activities, coal transportation has been identified as the second largest contributor after coal combustion during the electricity production process [2,14]. The use of energy for power plants in Indonesia still relies heavily on fossil energy, such as coal, petroleum and gas. Based on 2021–2030 RUPTL data, the majority of electricity needs in Indonesia are supplied by fossil fuel power plants, namely 41,886 MW or 88.94% of the total electricity supply [1.12,19**]. The** main focus in dealing with global climate change is reducing CO_2 emissions, because this gas is the most dominant component of greenhouse gas emissions. The increase in global temperatures due to increased emissions has reached an average of 1 to 1.2 °C per year compared to pre-industrial temperature levels [8,22]. Figure I.1 illustrates information on the Representative Concentration Pathway (RCP), which provides scenarios on how the climate may change in the future. Based on 2014 estimates, represented by the red dotted line, our current climate conditions are aligned with RCP 8.5, the highest baseline emissions scenario where emissions continue to increase throughout the 21st century. According to the data shown in Figure I.1, limiting global temperature rise to 1.5 °C (blue dotted line) is considered very important to prevent climate disasters.

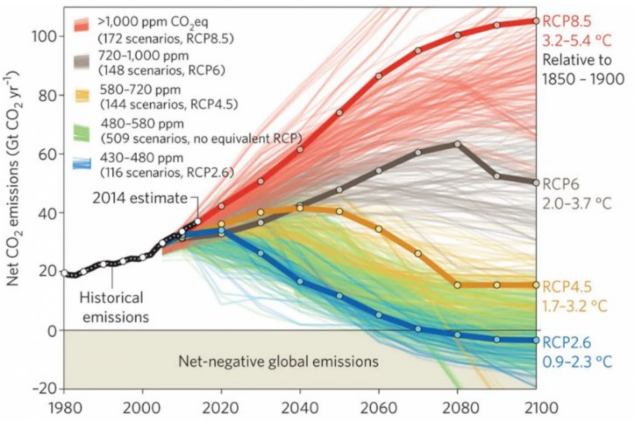


Figure 1 Representative Concentration Pathway [15]

To prevent a climate catastrophe, through the Paris Agreement in 2015, Indonesia along with 195 other countries committed to a global effort to limit the rise in global temperatures to below 2 °C and to pursue efforts to restrict the increase to 1.5 °C above pre-industrial levels by reducing CO_2 emissions. Indonesia's commitment, as a follow-up to the Paris Agreement, is reflected in the Nationally Determined Contribution (NDC), which was ratified through Law No. 16 of 2016. In the NDC, Indonesia set an emission reduction target of 29% through domestic efforts and up to 41% with international assistance compared to the Business as Usual (BaU) scenario by 2030.

To support this target, Presidential Regulation No. 98 of 2021 was issued, outlining provisions on the Implementation of Carbon Economic Value (NEK) for achieving the nationally determined contribution targets and for controlling greenhouse gas emissions in national development.

The emission reduction targets by sector outlined in the NDC are shown in Table I.1, with the energy sector ranked second in terms of the largest reduction target, expected to reach 314 million tons of CO_2e by 2030 under the CM1 scenario (domestic efforts only). Within the energy sector targets, emission reductions are further broken down into several sub-sectors, as illustrated in Figure I.2. Of these, renewable energy mix efforts are expected to contribute a reduction of 183.7 million tons of CO_2e. The majority of this reduction is expected to come from the power generation sub-sector, which is projected to contribute 93.7 million tons of CO_2e reduction by 2030.

Table 1 Emission Reduction Targets by Sector in Indonesia [21]

Sector	**Emissions in BaU Scenario (million tons CO_2e)**	**GHG Emission Reduction (million tons CO_2e)**	**Emission Reduction from BaU (%)**
		CM 1	CM 2
Forestry**	714	497	650
Energy*	1,669	314	398
Waste	296	11	26
Agriculture	119.7	9	4
IPPU	69.6	2.75	3.25
Total	**2,869**	**834**	**1,081**

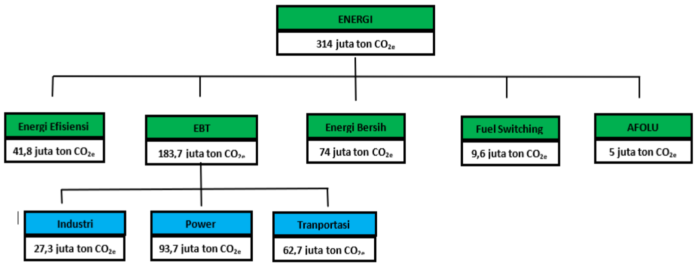


Figure 2 Emission Reduction Targets in the Energy Sector (Construction Sub-sector) [16]

Based on the data presented in Figure 2, the contribution of the power generation sub-sector in reducing CO_2 emissions is highly significant. Emission reduction mitigation efforts in the power generation sub-sector are outlined in the Electricity Supply Business Plan (RUPTL) 2021–2030, which includes the implementation of biomass co-firing technology. This technology is expected to contribute a capacity of 2.7 GW by 2025. The implementation of biomass co-firing in coal-fired power plants (CFPPs) can support the achievement of the renewable energy mix target of 24.2% in the power generation sector by 2030, with 11.5% already achieved as of 2021. In response to this situation, Indonesia ratified the Paris Agreement through Law No. 16 of 2016 and submitted its Nationally Determined Contribution (NDC), which targets a 29% reduction in greenhouse gas (GHG) emissions through domestic efforts and up to 41% with international assistance compared to the Business as Usual (BaU) scenario by 2030. To support this target, Presidential Regulation No. 98 of 2021 on Carbon Economic Value (Nilai Economic Carbon, or NEK) was issued as a framework for controlling national GHG emissions. Within the NDC document, the energy sector is identified as the second-largest contributor to emission reductions after the forestry sector, with a domestic reduction target of 314 million tons of CO_2e. The power generation sub-sector is recognized as a key component in achieving this target, particularly through the increased share of renewable energy in the national energy mix. One of the strategies outlined in the Electricity Supply Business Plan (RUPTL) 2021–2030 is the application of biomass co-firing technology, which involves blending biomass fuel with coal in coal-fired power plants (CFPPs) [8,11]. This technology is projected to add 2.7 GW of capacity by 2025 and support the achievement of a 24.2% share of renewable energy by 2030. Biomass co-firing program has also been effective in reducing greenhouse gas emissions,serving as cost-effective strategy for developing biomass supply infrastructure [6,7,18].

Previous research by [23] has shown that biomass co-firing has the potential to significantly reduce GHG emissions without requiring a complete overhaul of existing power plant infrastructure. Meanwhile, the application of co-firing biomass to the Pangkalan Susu PLTU can indeed reduce emissions but should not interfere with the performance of the overall electric power generation process. Parameters that usually measure the performance of co-firing biomass applications include Furnace Exit Gas Temperature (FEGT) and Specific Fuel Consumption (SFC) [5,26]. In addition, a report from PLN confirms that although implementation of this technology has begun in several PLTUs in Indonesia, its success depends largely on policy support, fiscal incentives, as well as the involvement of the private sector and local communities [17]. However, comprehensive studies evaluating the effectiveness of biomass co-firing implementation in Indonesia particularly in the context of achieving NDC targets and national energy transition strategies remain limited. Existing studies are generally technical or focused on localized case studies, while broader approaches to measure its impact on national GHG reduction, infrastructure readiness, implementation challenges, and the sustainability of biomass supply have not been widely addressed. This highlights a critical research gap that needs to be filled. This research is important because biomass co-firing technology offers a realistic medium-term solution to support Indonesia's energy transition. By utilizing the existing CFPP infrastructure, this technology has the potential to accelerate the achievement of GHG emission targets and the renewable energy mix without requiring large investments in new power plants [3,24]. However, its successful implementation strongly depends on system readiness, inter-sectoral coordination, and the effectiveness of supporting policies. Based on this background, the main objective of this study is to evaluate the potential contribution of biomass co-firing technology in supporting GHG emission reduction in Indonesia's power generation sub-sector. This research also aims to identify the technical, policy, and economic challenges associated with the implementation of this technology and provide strategic recommendations for relevant stakeholders, including the government, industry players, and local communities.

2. (Methods / Methodology)

This study uses a combination of primary and secondary data. Primary data was collected through direct testing at the Pangkalan Susu Power Plant using a Distributed Control System (DCS). The parameters measured included biomass mixing ratio (%), combustion temperature (°C), boiler pressure (bar), fuel flow rate (kg/h), and exhaust gas emissions such as CO_2. Data collection was carried out while the plant was operating under stable conditions to ensure data accuracy. Meanwhile, secondary data was obtained from scientific literature, technical reports, and relevant national and international policy documents. This data included the calorific values of biomass and coal, the thermochemical properties of the fuel, and standard emission factors. The thermodynamic system was modeled and analyzed using Aspen Plus software version 14. This software was used to simulate the combustion process and energy conversion in various biomass-coal mixture combustion scenarios. To improve transparency and reproducibility, it is recommended that all input data used in the simulation be presented in tables, including units, values, and sources.

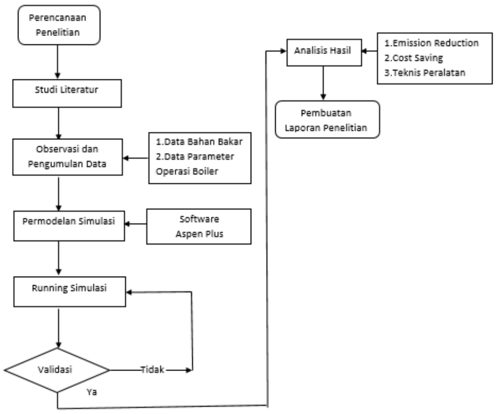


Figure 3 Research Procedure

Coal-fired power plant inspected in Langkat Regency, North Sumatra. The power plant uses a pulverized coal boiler with a total capacity of 2 x 200 MW. Based on the location of the reviewed power plant, the areas with potential to serve as biomass suppliers for biomass co-firing applications include Langkat Regency, Binjai City, Medan City, Deli Serdang Regency, and Serdang Bedagai Regency, all of which are within a 100 km radius of the power plant. The total rice husk production from these areas reached 0.6 million tons in 2022 and 2023 [9,25].

2.1 Data

This study uses Aspen Plus software as the main tool for modeling and simulating the biomass co-firing process at the Pangkalan Susu coal-fired power plant. Before modeling, operational data from the power plant was collected and analyzed to obtain the parameters needed for the model. This study uses data obtained from testing rice husk biomass co-firing at the Pangkalan Susu coal-fired power plant as validation. Simulation modeling was then carried out using Aspen Plus software. The main variable observed was the percentage of biomass mixture, which varied between 3% and 45%.

Table 2 *Results* of Fuel Characteristics Analysis *Performance Test* [20]

Parameter	**Satuan**	**Batubara (Coal Firing)**			**Sekam Padi**		
		AR	ADB	DB	AR	ADB	DB
		Proxymate Analysis					
Moisture Content	%Wt	36,47	14,05	-	10,47	10,18	-
Ash Content	%Wt	4,52	6,11	7,11	14,78	14,82	16,5
Volatile Matter	%Wt	31,25	42,28	49,20	60,95	61,15	68,08
Fixed Carbon	%Wt	27,75	37,55	43,69	13,80	13,85	15,41
Ash Content	%Wt	4,52	6,11	7,11	14,78	14,82	16,5
Gross Calorivice Value	kCal/kg	3932	5320	6190	3514	3526	3925
		Ultimate Analysis					
Carbon	%Wt	41,48	56,12	65,26	36,96	37,09	41,29
Hydrogen	%Wt	3,10	4,19	4,88	5,70	5,72	6,37
Nitrogen	%Wt	0,62	0,83	0,97	0,48	0,49	0,54
Oxygen	%Wt	13,64	18,45	21,47	31,36	31,46	35,03
Total Sulfur	%Wt	0,18	0,24	0,28	0,24	0,24	0,27

In Aspen Plus V.14, fuel analysis data is used as the basis for analysis as received. The composition of coal and rice husk biomass fuels used in biomass co-firing applications is as follows. The low calorific value of biomass compared to coal can also reduce specific fuel consumption by up to 4.4% from combustion conditions with 100% coal [4,13].

To validate the model, several key parameters were obtained from the operating conditions during the performance test. The parameter data is shown in Table 3

Table 3 Operational Data for Combustion Testing and Simulation

Parameter	**Hasil**	**Unit**
Beban (Load)	134.15	MW
Aliran Udara Total	615.82	T/h
Total Laju Bahan Bakar	95.69	T/h
Feed Water Pressure	12.75	Mpa
Feed Water Temperatur	191	◦C
Main Steam Pressure	9.6	Mpa
Main Steam Temperatur	528.5	◦C
Furnace Exit Gas Temp	865	◦C
Flue Gas Temp	151	◦C

Process Simulation

The process simulation was carried out using the following approach:

1. Data Input
   The data entered included:
   a. Fuel characteristics (coal and biomass), including calorific value, carbon content, and moisture content.
   b. Boiler operating parameters, such as temperature, pressure, and combustion air flow.
   c. Variations in biomass ratio (3%, 15%, 30%, and 45%).

2. Modeling:
   a. The Pulverized Coal (PC) boiler is modeled by considering parameters such as furnace exit gas temperature and combustion efficiency.

b. Variations in biomass ratio are performed to assess their impact on overall plant efficiency.

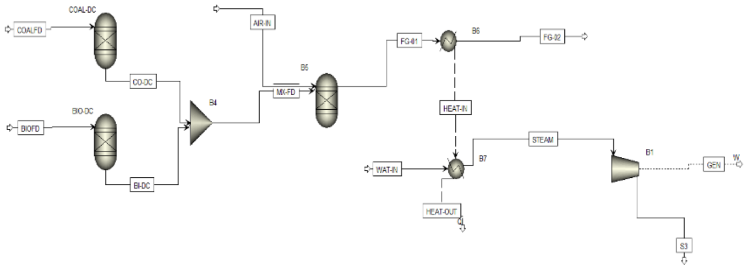


Figure 4. Combustion modeling scheme with Aspen Plus

3. Results and Discussions

3.1 Validation Process for Cofiring Test Results

3.1.1 Technological Aspect

After the overall modeling was created using Aspen Plus V.14 software, the results of the operating parameters were obtained. The results of the modeling process were then compared with the actual condition parameter data used as a reference. In this study, the comparative data used as a reference was performance test data. Currently, the cofiring tests of coal and biomass conducted at the Pangkalan Susu Power Plant use a composition of 97% coal and 3% rice husks. In this study, validation was also performed on the simulation results and test results conducted by PT.PLN (Persero) Puslitbang. In Table IV the validation results of the cofiring testing can be seen. The simulation data created using Aspen Plus V14 can be considered valid because there are no errors exceeding 10%.

Table 4 Simulation validation results for the 3% composition test

Parameter	Uji Cofiring 3%	Simulasi 3%
Load (MW)	134.15	138.84
Furnace Exit Gas Temp (◦C)	865	858
Main Steam Temperature (◦C)	528.5	528

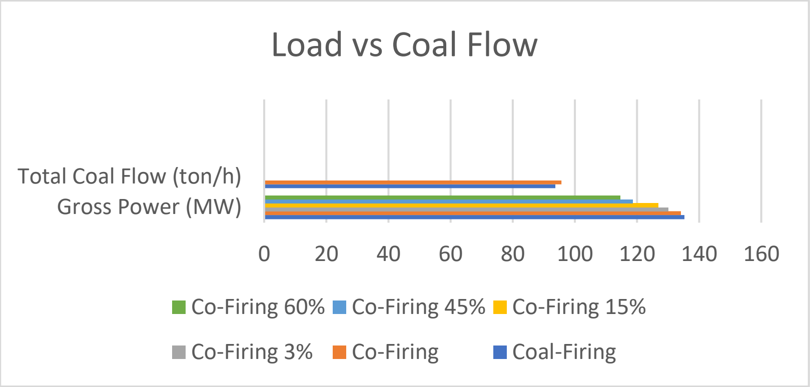


Figure 5 Total Coal Consumption (Average) during Co-firing, Coal Firing, and Simulation

Figure V illustrates the fuel consumption rate in relation to the gross power output, where during 100% coal operation, the coal flow rate is lower than during cofiring, with the gross power output being higher than during cofiring. Based on the validation results under conditions before and after cofiring, it can be concluded that the modeling performed in Aspen Plus V.14 has approached the expected validation values, so the modeling can be continued for cofiring compositions of 3%, 15%, 30%, and 45% biomass.

3.1.2 Environmental Aspect

The greenhouse gas (GHG) emissions calculated only include emissions from fuel combustion. Based on the calculations, the implementation of co-firing with a biomass ratio of 3-45% can reduce GHG emissions by 2.3-8.6% from approximately 0.127 million tons of CO2e/year when burning 100% coal, to 0.116-0.127 million tons of CO2e/year, as shown in Table IV. Furthermore, GHG emissions generated during co-firing implementation are compared with the Cap (upper limit of GHG emissions). The Cap is the product of the Upper Limit of Power Plant Emissions and the gross electricity production of the power plant, as shown in Table IV. In co-firing and as a comparison, Table V also includes co-firing implementation that results in GHG emissions below the Cap, with biomass ratios of 30 and 45. This means that co-firing can reduce GHG emissions.

Table 5 Data used for GHG Emission Cap calculations [10]

Batas Atas Emisi Pembangkit (ton CO_{2e}/Mwh)	Produksi Listrik Bruto (Mwh)	*Cap* (juta ton CO_{2e}/tahun)
0.918	135.260	0.124

Data on the amount of CO_2 emissions generated directly at the Pangkalan Susu Power Plant Simulation Version based on fuel combustion.

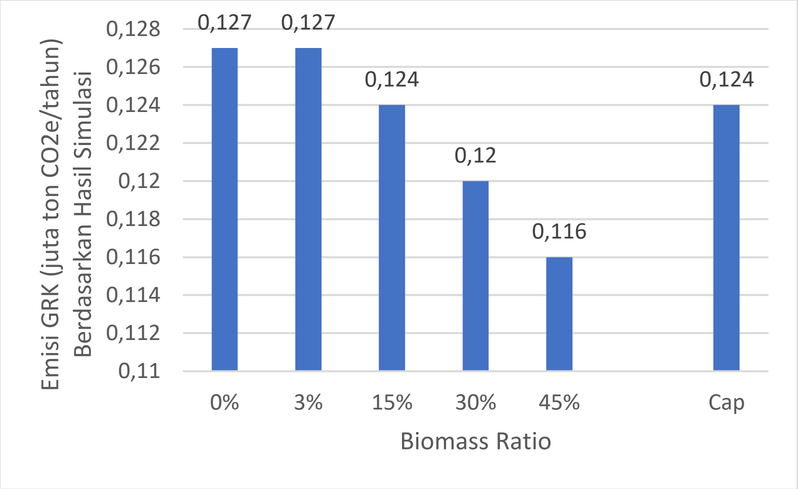


Figure 6 GHG Emissions at Pangkalan Susu Power Plant – Simulation Version

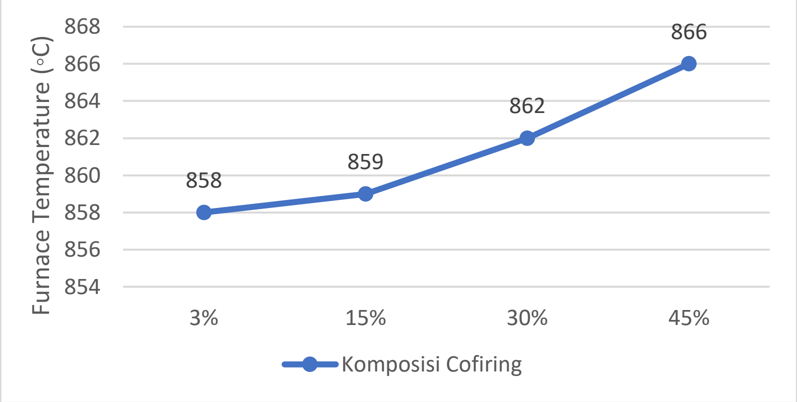


Figure 7 Furnace Temperature during Co-firing Operation

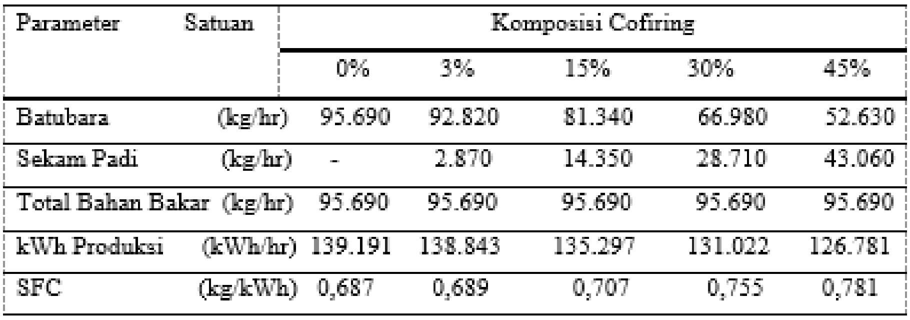
Each cofiring composition produces different exhaust gas parameters, which are influenced by the amount of coal and biomass burned. The simulation results show that the amount of fuel composition used during cofiring affects the emissions produced from the combustion process.

3.1.3 Economic Aspect

The costs considered in the Economic Aspect are fuel costs (Component C), which are influenced by the specific fuel consumption (SFC) value and the price of fuel used in the co-firing process. All prices listed are plant gate prices. There are fuel cost savings due to the reduced use of coal, which is replaced by rice husks. Coal cost savings are obtained from the difference between coal consumption without co-firing implementation and coal consumption after co-firing implementation. To obtain performance parameters, Specific Fuel Consumption (SFC) calculations are performed using the input energy – output energy method, where gross electricity production is taken from the totalizer counter readings on the kWh meter and fuel consumption is taken from the totalizer data on all operating coal feeders. Production cost analysis (component C) was conducted using SFC performance data at maximum load (135 MW Gross) plus the fuel prices for both coal and rice husks used in the co-firing test at the Pangkalan Susu Power Plant.

The SFC comparison calculation was performed on a gross load of 135 MW in two fuel scenarios, namely the existing condition using 100% coal and the co-firing condition using 3% biomass, as well as simulations according to the tested percentages as shown in Table VI below.

Table 6 SFC Values from the Simulation of Pangkalan Susu Power Plan**t**



Parameter	Satuan	Komposisi Cofiring				
		0%	3%	15%	30%	45%
Batubara	(kg/hr)	95.690	92.820	81.340	66.980	52.630
Sekam Padi	(kg/hr)	-	2.870	14.350	28.710	43.060
Total Bahan Bakar	(kg/hr)	95.690	95.690	95.690	95.690	95.690
kWh Produksi	(kWh/hr)	139.191	138.843	135.297	131.022	126.781
SFC	(kg/kWh)	0,687	0,689	0,707	0,755	0,781

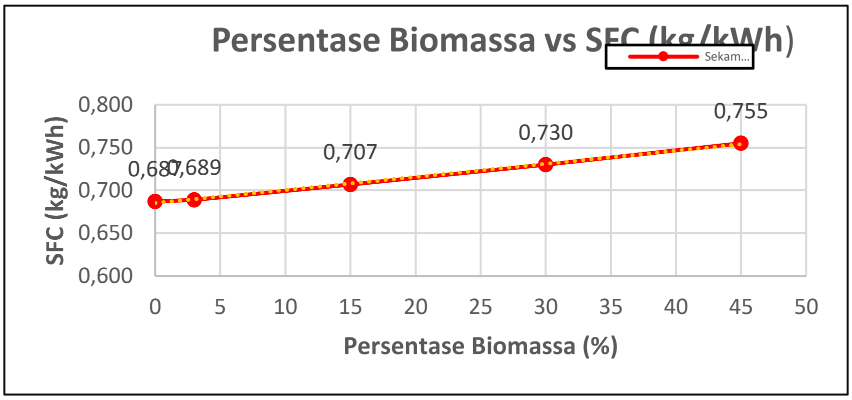
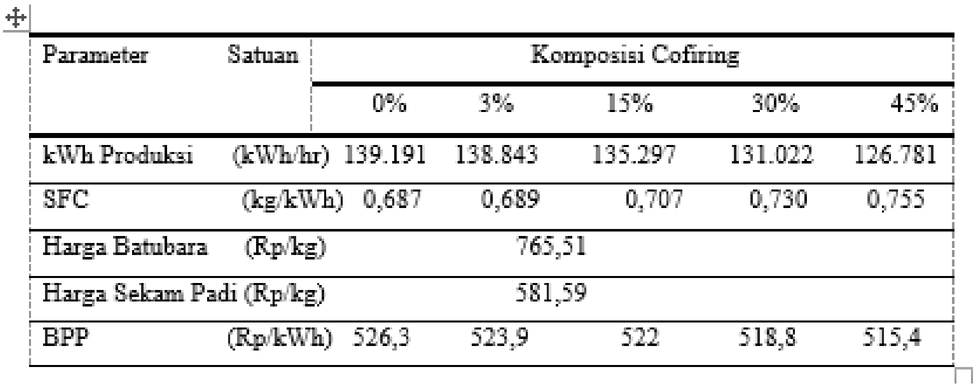


Figure 8 Biomass Percentage versus SFC Results

Using the realized prices of coal and rice husks at the Pangkalan Susu PLTU, the price of coal was calculated to be Rp 765.61/kg and rice husks to be Rp 581.59/kg. The reduction in BPP Component C obtained in the 45% co-firing composition reached 2.07%, as can be seen in Table VI.

Table 7 Cost Analysis of Component C Production at Pangkalan Susu Power Plant



Parameter	Satuan	Komposisi Cofiring				
		0%	3%	15%	30%	45%
kWh Produksi	(kWh/hr)	139.191	138.843	135.297	131.022	126.781
SFC	(kg/kWh)	0,687	0,689	0,707	0,730	0,755
Harga Batubara	(Rp/kg)	765,51				
Harga Sekam Padi	(Rp/kg)	581,59				
BPP	(Rp/kWh)	526,3	523,9	522	518,8	515,4

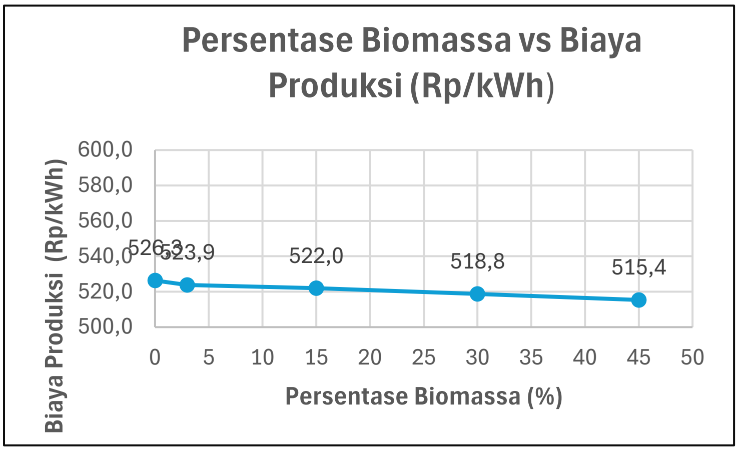


Figure 9 Relationship between Biomass Percentage and Production Cost

The results of the calculations show a trend of annual operational cost savings as a result of the implementation of rice husk biomass co-firing at the coal-fired power plant. It is clear that an increase in the percentage of biomass directly contributes to a significant increase in annual cost savings.

In the 5% co-firing scenario, the savings recorded were Rp6,251,729,419 per year. When the biomass percentage was increased to 15%, the savings rose to Rp10,976,295,721 per year. Furthermore, at 30% co-firing, this figure increases significantly to IDR 18,918,074,381 and reaches a peak of IDR 27,702,681,170 per year at 45% co-firing.

This trend indicates that the higher the percentage of biomass used, the greater the savings that can be achieved. In addition, the graph shows a fairly linear rate of savings increase, with no indication of significant slowdown, opening up opportunities for greater cost efficiencies if biomass use continues to be increased gradually.

Thus, the application of rice husk co-firing not only supports the energy transition to renewable sources but also provides tangible economic benefits for power plant operations.

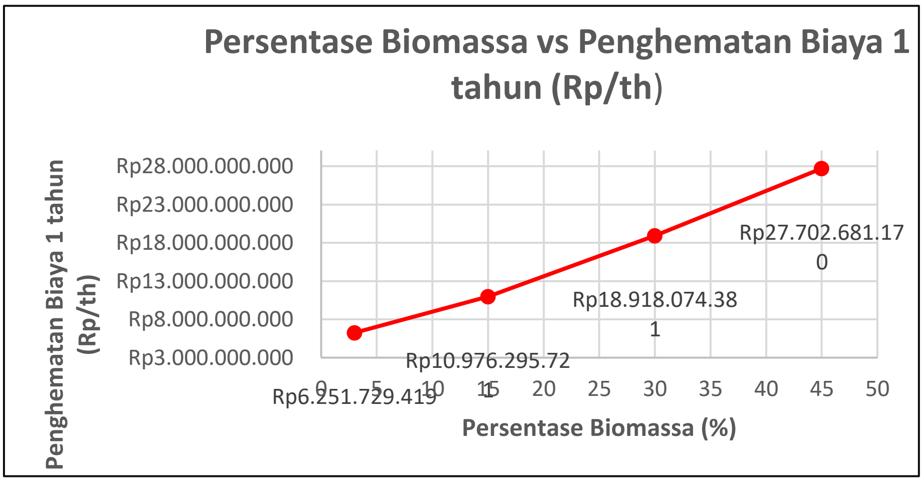


Figure 10 Biomass Percentage versus Annual Cost Savings

4. Conclusion

From the research that has been conducted, it is concluded that the implementation of co-firing with a biomass ratio (3% - 45%) is feasible, based on the following aspects:

1) Technical aspects, with the electricity generated not far from that of full coal firing.
2) Environmental aspects, with the implementation of co-firing producing GHG emissions below the cap and meeting emission quality limits.
3) Economic aspects, as it has been proven to reduce electricity production costs and generate significant annual cost savings.
4) Co-firing modeling between biomass and coal has been successfully conducted using ASPEN PLUS software, and the results are not significantly different from experimental results. A higher biomass ratio causes a decrease in temperature. High combustion gas temperatures lead to increased levels of NO, CO_2, and SO_2.

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