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Performance Analysis of Woodchip Cofiring in a 100 MW CFB Boiler at Tarahan Power Plant Unit 3

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Abstract. The transition to renewable energy in Indonesia is being accelerated through biomass cofiring in coal-fired power plants (CFPP), advertising a low-investment strategy to decrease greenhouse gas emissions. This study presents the performance analysis of cofiring between coal and woodchip at PLTU Tarahan Unit 3, which uses a Circulating Fluidized Bed (CFB) boiler. The experiment was done using three cofiring scenario of 10%, 15%, and 20% woodchip beneath a steady 95 MW load condition. Comprehensive evaluations were carried out including fuel characterization, plant operation stability, emission measurements, and economic analysis. The results showed that cofiring up to 20% woodchip was technically feasible without major modifications to the boiler system. Emissions of SO_2 and NO_x decreased in proportion to the biomass share, and operational stability was maintained. Although the specific fuel consumption (SFC) slightly increased, the production cost remained competitive due to the low cost of biomass. The study concludes that woodchip cofiring is a viable and sustainable alternative for supporting Indonesia's net zero emission goals while optimizing the use of existing infrastructure.

Keywords: *Biomass Cofiring, Woodchip, Circulating Fluidized Bed (CFB) Boiler, Emission Reduction, Power Plant Efficiency.*

1 Introduction

Coal ranks as the predominant solid fuel used globally for generating electricity, including in Indonesia, rendering it a more financially viable option compared to other solid fuels. Nevertheless, as its consumption grows, the resulting environmental consequences are also rising, prompting power generation facilities to explore alternatives and innovative methods to create electricity that is more sustainable and ecologically sound. The Indonesian government has implemented an energy policy initiative known as the 'Indonesia Long-Term Strategy for Low

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Carbon and Climate Resilience 2050 (Indonesia LTS-LCCR 2050), to achieving fossil fuel-free power plants by the year 2050 [1]. Indonesia is a country with a high dependency on coal fired in its power plant (PLTU). This condition is significant challenges for us to achieve the target for energy transition toward net zero emission (NZE) by 2060. One of the main strategies promoted by the Indonesia government is the implementation of biomass cofiring in PLTU to reduce carbon emission and also increase the share of renewable energy. Multiple benefits of burning coal with biomass have been noted, such as serving as an alternative for managing biomass waste and boosting the efficiency of boiler combustion when done correctly and overseen throughout the combustion procedure [2]. In a steam power plant, biomass cofiring is the process of burning coal and one or more forms of biomass fuel together in a predetermined ratio to partially replace coal while taking the system's fuel quality requirements into account [3]. For State Electricity Company of Indonesia PT PLN, mixing biomass with coal in power plants is one of the key programs designed to boost the use of renewable energy without needing large investments.

The roadmap for cofiring [4] implementation within the PLN Group shows as of December 2024, cofiring has been successfully implemented in 47 CFPP units out of the planned 52, utilizing a total of 1,624,889 tons of biomass. This cofiring project has generated 1,672,684 MWh of renewable energy while reducing CO_2 emissions by 1,870,035 tons. PLTU Tarahan, located in Lampung province, serves as a vital coal-fired power station to fulfill the electricity requirements of the Sumatra power network, boasting a capacity of 2 x 100 MW (net output). The facility employs CFB boilers, providing numerous benefits such as versatility in fuel use, elimination of coal mills, high efficiency in combustion, effective sulfur absorption when limestone is added, low emissions of SO_2 and NO_x, and a reduced furnace cross-section. Given these attributes of CFB boilers, along with the accessible woodchip biomass resources in Lampung Province, PLTU Tarahan 2x100 MW is perfectly positioned for cofiring with the locally sourced woodchip biomass.

Several investigations have examined the practicality and environmental advantages of incorporating biomass into coal-fired power plant operations. For example, IEA and IRENA [5] provided a comprehensive summary of biomass cofiring methods, emphasizing the potential to lower CO_2 and sulfur oxide (SOx) emissions through partial coal replacement in existing boilers. Similarly, Chang et al [6] assessed the bioenergy potential from forestry and agricultural residues, underscoring the role of locally sourced biomass in enhancing sustainability and minimizing transport-related emissions. Meanwhile, Tanbar et al [7] implemented cofiring experiments with sawdust in pulverized coal units and found that high cofiring percentages demanded operational adjustments and equipment modifications. However, the majority of these investigations focus on pulverized coal combustion systems or laboratory setups, with limited insights from commercial-scale plants employing CFB technology. Furthermore, little research has been published on the operational, economic, and environmental implications of woodchip cofiring at high ratios (≥20%) in CFB boilers under stable load conditions and without requiring system retrofits.

This current study addresses that gap by presenting a detailed performance analysis of woodchip cofiring done at PLTU Tarahan Unit 3, a 100 MW CFB-based power plant in Lampung, Indonesia. The study encompasses fuel characterization, plant operation stability, emission outcomes, and economic evaluation, providing valuable evidence on the feasibility and effectiveness of implementing biomass cofiring within Indonesia's existing coal-based energy infrastructure.

2 Material and Methodology

Biomass can come from a variety of sources that can be cofired with coal in Indonesia, such as extensive oil palm plantations and plantations [6], waste from tree timber felling, land clearing for mining and plantations [8]. Woodchips are selected as cofiring pairs with coal used as the main fuel for the steam power plant Tarahan unit 3 which was used as an actual laboratory for combustion. The team from PLN UP Tarahan, PLN Nusantara Power, and PLN Research and Development Center (PUSLITBANG) conducted the cofiring test, where we had the opportunity to directly learn and observe the process during the test implementation [9].

The selection of woodchip biomass for the cofiring trial was guided by the requirements outlined in SNI 8676:2018, which regulates quality standards for solid biofuels such as moisture content, calorific value, and particle uniformity [10]. During the testing phase, samples of both coal and woodchips were systematically collected and sent to PT Sucofindo, an accredited laboratory, for standardized analysis. To obtain valid and consistent results, laboratory analyses followed national and international testing standards. The proximate properties (moisture, ash, volatile matter, and fixed carbon) were analyzed according to SNI 01-5015-1998 [11], while elemental composition such as carbon, hydrogen, and nitrogen was determined using ASTM D5373 [12], and sulfur content was analyzed using ASTM D4239 [13]. The energy content of the fuels was measured with a bomb calorimeter in accordance with ASTM D5865 [14]. Meanwhile, ash fusion behavior, including the onset of deformation and fusion temperatures, was evaluated based on ASTM D1857 [15], and coal grindability was tested using the ASTM D409 method for HGI [16].

The cofiring studies at PLTU Tarahan Unit 3 using woodchip which met SNI standards and was suitable in terms of shape and quality for testing in a CFB boiler type at 0%, 10%, 15%, and 20% blending ratios were conducted according 15-18 January 2024. These relatively high persentages, implemented without equipment modifications, were chosen to ensure that the power plant unit was capable of operating with a high cofiring ratio to support the targets of biomass utilization, green kWh production and CO_2 emission reduction. The total coal flow is 52 tons/hour (at a 95 MW load). Eight hours were spent on testing, and four hours were spent gathering data. Therefore, 41 tons (10%), 63 tons (15%), and 84 tons (20%) of woodchips were the minimal requirements for the cofiring study at PLTU Tarahan. Table 1 shows the total amount of coal and biomass used for the 10%, 15%, and 20% cofiring trials. The woodchips cost IDR 461.56 /kg when they arrived at PLTU Tarahan.

Table 1. Coal and biomass needs for co-firing testing

No	Co-Firing Scenario (%Biomass)	Duration (hour)	Biomass (ton)	Coal (ton)	Sum (ton)
1	0% Bio 100% Coal (coal flow=52 t/hours)	8	0.0	416	416
2	10% Bio 90% Coal	8	41	375	416
3	15% Bio 85% Coal	8	63	353	416
4	20% Bio 80% Coal	8	84	332	416
	Sum		188	1476	1664

The testing stages conducted were literature studies, reference journal study, biomass survey, operational trial, fuel quality testing (ultimate and proximate analyses of the coal and biomass to be used in the test), and then the last stages is analysis and evaluation including concludes and report to the test result : aspect of fuel characteristic, analysis of slagging, fouling and corrosion potential from calculation of basic to Acid ratio (B/A), slagging index (Rs) and fouling index (Rf) [17], technical operation, economis factors and environmental impact. A load setting of roughly ±95 MW was used for operational monitoring. Load, total unit air flow, total coal feed rate, Furnace Exit Gas Temperature (FEGT) were the primary or critical parameters that were observed. Data recording intervals of every 30 minutes were used during the 4 hour operational data gathering period. As soon as the unit load circumstances stabilized, recording commenced. To get precise results, these samples were performed using calibrated and standardized laboratory equipment, including thermogravimetric analyzers, elemental analyzers (CHNS), and X-ray fluorescence (XRF) spectrometers. These methods ensured accurate characterization of the fuel properties, which were crucial for analyzing boiler performance, emission behavior, and overall operational efficiency during the cofiring process.

In order to assist the future use of biomass cofiring, conclusions and suggestions were finally developed based on the findings. The energy input–energy output method was adopted to calculate the Specific Fuel Consumption (SFC) in order to determine the performance parameters [7]. The fuel consumption was taken from the totalizer data of all coal feeders that were in operation, and the gross electrical energy production was obtained from the totalizer counter recorded on the kWh meter. The SFC performance data at the DMN load (95 MW Gross) and the fuel prices of the coal and woodchips utilized in the cofiring test at Tarahan Power Plant were used to conduct the production cost analysis [17].

3 Results and Discussion

3.1 Analysis of fuel characteristics

The woodchips biomass has characteristic properties as shown in table 2. The calorific value of woodchips is lower than of coal as shown at 2999 kcal/kg (ar) in the sample that slightly below the SNI requirement foe woodchips, which have minimum value of 3009 kcal/kg (ar). Therefore, this condition should be a point attention during the procurement and acceptance process of biomass. The moisture total of coal is 29.60% (ar) which slightly exceeds the SNI requirement of a maximum of 25% therefore a dryng process is necesarry beforehand. The addition of biomass in the combustion process increases the fuel's moisture content, as biomass inherently contains higher water content. This leads to a reduction in combustion efficiency due to the greater energy required for moisture evaporation. Therefore, it can be concluded that the use of 100% biomass as fuel is not recommended. Instead, a mixture of coal and biomass is preferred to achieve optimal combustion efficiency.

The volatile matter content of woodchips containing 51.16% (ar) is higher than coal (40,36) that shows the devolatilization process in woodchips occur faster than in coal, which affect combustion in the boiler furnace. The volatile matter increases with higher biomass content, thereby enhancing the combustion rate and fuel reactivity. This is particularly beneficial for co-firing applications that require fast and stable combustion. The sulfur content in 100% coal was 44.43%, whereas in cofiring scenarios with 10%, 15%, and 20% biomass, the values decreased to 44.36%, 41.94%, and 39.71%, respectively all lower than that of pure coal. This reduction in fixed carbon indicates a gradual decrease in the total available energy during the slow-burning phase.

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5839 kcal/kg adb, respectively. These findings are consistent with Speight [18], who reported that fuel calorific value is directly proportional to fixed carbon content and inversely proportional to moisture and ash content.

Table 2. The characteristic composition of fuel samples

Parameter		Unit	Coal	Woodchip	10%	15%	20%
Total Moisture		%ar	29.60	35.18	29.78	30.28	30.45
Proximate	Moisture in the Analys	%adb	11.46		10.33	11.74	11.7
	Ash Content	%adb	3.85		5.53	3.55	4.54
		%ar	3.06	2.88	4.33	2.80	3.58
		%db		4.44			
	Volatile Matter	%adb	40.26		39.78	42.77	44.05
		%ar	32.01	51.16	31.15	33.78	34.69
		%db		78.9			
	Fixed Carbon	%adb	44.43		44.36	41.94	39.71
		%ar	35.33	10.78	34.74	31.14	31.28
		%db		16.63			
Total Shulpur		%adb	0.82		0.76	0.7	0.7
		%ar	0.650	0.07	0.60	0.55	0.55
		%db	0.926	0.11	0.848	0.793	0.793
Chlorine		%wt	0.01	0.01	0.01	0.01	0.01
Gross Calorific Value (GCV)		kcal/kg,adb	6173		6112	6074	5839
		kcal/kg,ar	4908	2999	4786	4798	4599
		kcal/kg,db		4627			
Ultimate	Total Carbon	%adb	63.84		76.92	62.72	60.63
		%ar	50.76	31.3	60.23	49.54	47.76
		%db		48.25			
	Total Hydrogen	%adb	4.38		4.43	4.43	4.33
		%ar	3.48	3.73	3.47	3.5	3.41
		%db		5.75			
	Nitrogen	%adb	1.2		1.19	1.13	1.08
		%ar	0.95	0.29	0.93	0.89	0.85
		%db		0.45			
	Oxygen	%adb	14.45			15.73	17.02
		%ar	11.5	26.59		12.44	13.4
		%db		41			
Hardgrove Grindability Index		Index Point	49		52		
Ash Fusion Temperature (Reduction)	Initial Deformation Te	°C	1100	1250	1160	1080	1060
	Spherical Temp.	°C	1150	1260	1180	1100	1120
	Hemispherical Temp.	°C	1170	1270	1220	1110	1150
	Fluidized Temp./Fluid	°C	1210	1280	1260	1120	1170
Ash Analysis Parameter	SiO_2	%	40.89	23.12	44.34	36.63	42.61
	Al_2O_3	%	23.67	6.27	26.29	23.68	24.06
	Fe_2O_3	%	8.54	2.96	5.11	5.43	5.39
	CaO	%	4.15	39.72	3.23	5.27	4.92
	MgO	%	3.45	10.5	2.66	3.95	3.72
	SO_3	%	9.17	2.33	8.07	11.77	8.18
	P_2O_5	%	0.22	4.08	0.3	0.55	0.47
	Na_2O	%	8.26	0.28	8.36	10.6	8.2
	K_2O	%	0.74	9.23	0.79	1.17	1.55
	TiO_2	%	0.57	0.38	0.58	0.48	0.51
	MnO_2	%	0.06	0.71	0.04	0.06	0.07
Bulk Density		kg/m3	814.08	277.63	801.09	605.31	705.05

Based on the total sulfur content (adb), the sulfur levels decreased from 0.82% (100% coal) to 0.76% (10% cofiring), 0.70% (15% cofiring), and 0.70% (20% cofiring). Similarly, sulfur content on an as-received basis (ar) also declined from 0.650% (100% coal) to 0.60% (10%), and 0.55% for both 15% and 20% cofiring. This indicates that cofiring coal with biomass is effective in reducing SO_2 emissions. During combustion, nearly all sulfur is converted into SO_2 gas. The reduction of SO_2 emissions has important implications for boiler systems, as it facilitates compliance with environmental regulations, lowers the risk of boiler corrosion caused by sulfuric acid formation at low temperatures, and supports the transition toward low-carbon, low-sulfur energy sources.

The fixed carbon value is also below the SNI requirement of a minimum of 12%. Therefore needs to be a consideration during biomass procurement and acceptance. The fuel mixing biomass-coal from coal feeder is shown in Fig 1.

Figure 1. Fuel mixing Woodchips-Coal

3.2 Analysis of Slagging, Fouling and Corrosion Potential

The potential of slagging, fouling and corrosion caused by the presence of sulphur, chlorine, acidic and alkaline compound in fuel were determined from calculating of B/A, Rs, Rf and 2S/CI ratio [19] that shown in Table 3. The B/A of the mixed fuel during cofiring falls within the low category, as its value remains below 0.4 where a B/A ratio of less than 0.5 is associated with a low slagging potential [20]. If a B/A is high, low-melting point oxides and alkali compounds are more likely to form, thereby increasing the risk of slagging. Although the specific contents of Fe_2O_3, CaO, SiO_2, Al_2O_3, and other oxides also influence slagging behavior, nearly all ash samples demonstrated a tendency toward lower ash fusion temperatures and higher slagging potential within the B/A range of 0.4 to 0.7. The Rs for both coal combustion and cofiring scenarios falls within the medium category, indicating that operational conditions are still considered safe. However, the Rf for coal, woodchip, and their mixtures is categorized as severe, with values exceeding 0.2–0.3. In particular, pure woodchip recorded an Rf value of 20.03, which is likely to cause deposition and contamination on heat exchanger surfaces. The fouling is directly related to the concentration of alkali metal oxides, where values above 0.2 indicate a significant fouling risk, and thus, should be considered carefully in power plant operation [21].

Fouling characteristics are primarily evaluated based on the B/A and the Na_2O content in the ash. An increase in the Rf can lead to a decrease in steam temperature at the superheater outlet, as well as narrowing or blockage of gas flow paths.

Table 3. Calculation result of Slagging, fouling and corrosion potential

Parameter	Unit	Coal	Woodchip	10%	15%	20%
		0.39	2.1	0.28	0.4	0.35

Base to Acid Ratio (B/A)	Index	low	medium	low	low	low
Slagging Index (Rs)		1.0	0.4	1.4	1.5	1.2
	Index	medium	low	medium	medium	medium
Fouling Index (Rf)		3.47	20.03	2.59	5.12	3.45
	Index	severe	severe	severe	severe	severe
Rasio 2S/Cl		204.80	24.32	187.42	175.38	175.30
	Index	minor	minor	minor	minor	minor

Na and K are volatile alkalis that contribute significantly to fouling formation. High fouling values should be mitigated through ash management systems, the design of fouling-resistant superheater surfaces, and the use of additives such as kaolin. Meanwhile, the 2S/Cl ratio for coal, woodchip, and their mixtures remains within the low-risk category, indicating that the operation is still considered safe. A 2S/Cl ratio greater than 10 suggests a low risk of high-temperature corrosion, as it implies insignificant levels of chlorine and sulfur-related compounds [22].

3.3. Tests Result Analysis of Operating Parameter

For actual data comparison, the observation of operating parameter is conducted for 100% coal firing for baseline were collected January 15, 2024, for comparison with the co-firing operational data (10%, 15% and 20%) were collected January 16 until 18, 2024.

The coal type is coal rank medium (from PT Bukit Asam). Operational parameter monitoring was carried out at a load setting of approximately 95 MW included load, total coal feed, total flow steam and Furnace exit gas temperature (FEGT). Figure 2.a-d show the obseravation result for baseline. The unit load remained stable within the range of 95.4–95.7 MW (fig 2.a), indicating a constant load operation. The slight fluctuations in the coal feed rate between 47.9 and 50.8 T/h, reflecting active fuel control (fig 2.b). The total steam flow was stable, ranging from 349 to 351 T/h, which supports the steady operation of the steam generation system (fig 2.c). Meanwhile, FEGT varied slightly between 855°C and 863°C, remaining within the safe operational range (fig 2.d).

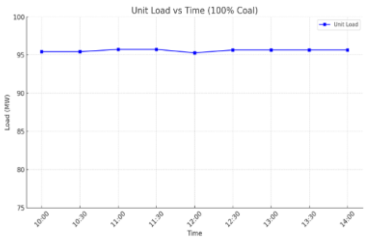

Figure 2.a

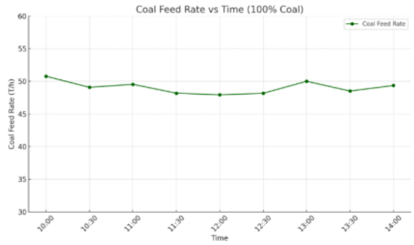

Figure 2.b

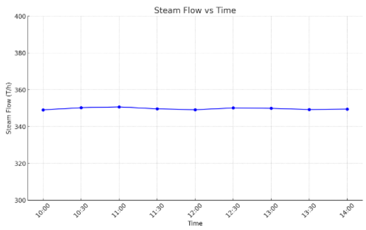

Figure 2.c

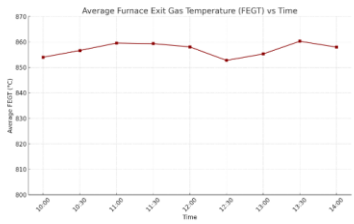

Figure 2.d

The observed data for unit load, coal feed rate, total steam flow, and FEGT for the 10% cofiring case are presented in the graphs in figure 3.a-d, where the unit load remained stable within the range of 95.4–95.9 MW, indicating steady load operation with minimal variation, which reflects good combustion and fuel feeding control.

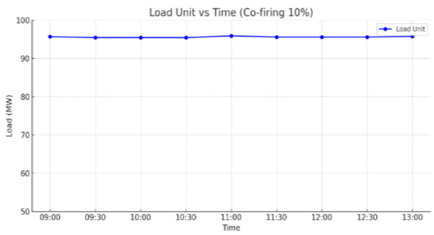

Figure 3.a

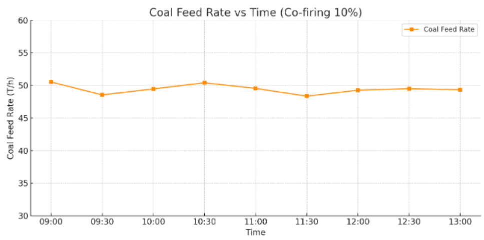

Figure 3.b

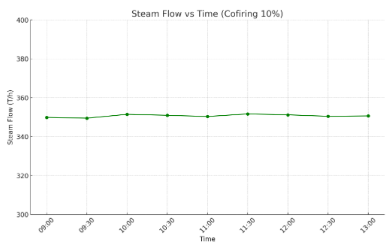

Figure 3.c

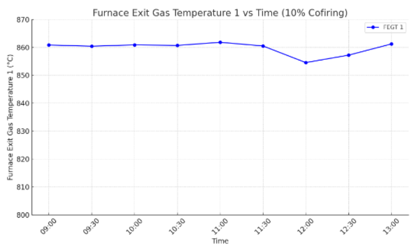

Figure 3.d

Fig 3.b shows a slight but consistent decrease in coal feed rate, ranging from 48 to 51 T/h, indicating stable coal feeder operation during the 10% cofiring trial. Fig 3.c demonstrates that the total steam flow remained stable around 350 T/h, supporting consistent steam generation. Meanwhile, Fig 3.d shows that the FEGT fluctuated slightly between 852°C and 858°C, remaining within a safe operational range. The observed data for unit load, coal feed rate, total steam flow, and FEGT for the 15% cofiring case are same with cofiring 10%.

Finally the observed data for unit load, coal feed rate, total steam flow, and FEGT for the 20% cofiring case are presented in the graphs in figure 4.a-d where the load unit shows stability around 95.42–95.59 MW, indicating constant load operation with minimal fluctuations, which reflects good combustion and fuel feeding control. The 20% cofiring does not disrupt output power stability.

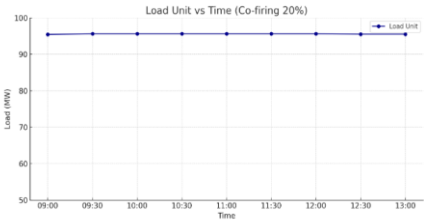

Figure 4.a

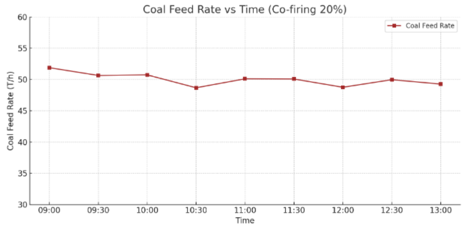

Figure 4.b

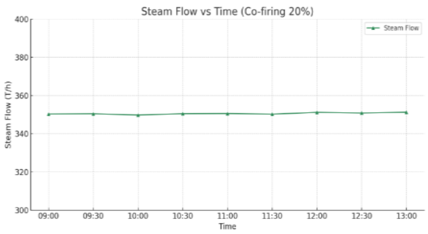

Figure 4.c

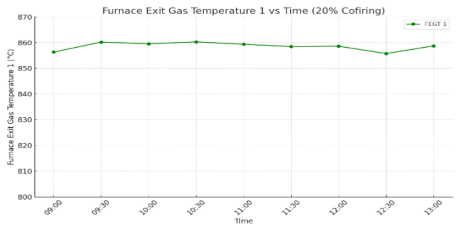

Figure 4.d

Whereas base on the observation of the Air Heater Out Flue gas Temperature can be analyze that for cofiring test of 10%, 15% and 20% woodchips, air heater aout flue gas temperature have the average value at 144.29 °C, 144.54°C and 126.10 °C respectively. That's all lower than 100%coal firing operating at 149.54 °C as shown on Fig 5. Generally, the trend of AH out flue gas temperature under co-firing operation fall into lower than 100% coal firing because of there are the shif in the combustion flame.

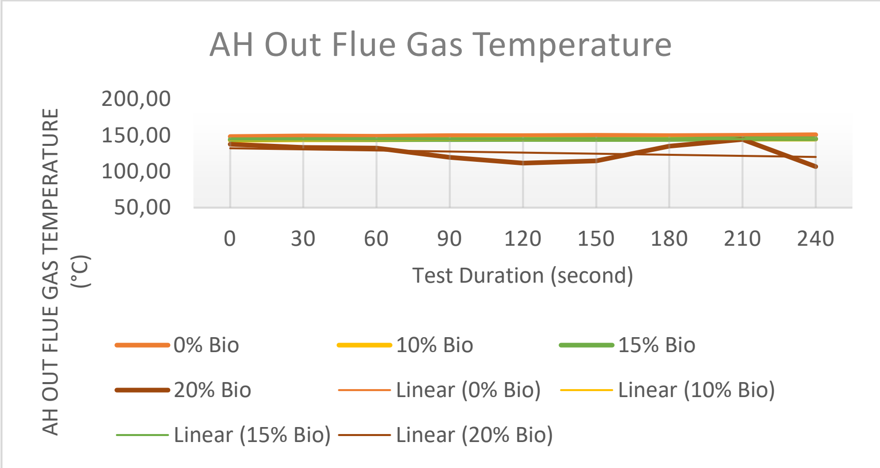

Figure 5. Comparison AH Out Flue gas temperature coalfiring and co-firing

The data collection of FEGT was carried out using instrumentation facilities in DCS at several measurement points located in furnace's different areas. The average results during co-firing tests with 10%, 15%, and 20% woodchip tend to be similar to the conditions observed during 100% coal combustion. These indicate that adding woodchip up to 20% does not cause significant changes in the FEGT. This finding is consistent with previous studies, where a 0,7% reduction in FEGT was observed during co-firing with 5% biomass, suggesting that the addition of a small amount of biomass does not drastically affect the flue gas temperature [23]. However, it is important to note that although temperature changes may not be significant, combustion characteristics can still be influenced by fuel composition. Therefore, continuous monitoring and further analysis are necessary to ensure the efficiency and safety of power plant operations

Table 4. The observations result of FEGT under coal firing and co-firing

Location	Average Temperature (°C)			
	100% Coal	10% Bio	15% Bio	20% Bio
FEGT 1	859.90	860.66	859.79	858.58
FEGT 2	854.24	854.82	853.96	852.96
Average	857.07	857.74	856.88	855.77

.3.4 Evaluation of Specific Fuel Consumption (SFC) and Production Cost

The calculation of SFC ratio is carried out on load setting 95 MW Gross under two scenarios including existing condition using coal firing and cofiring condition at 10%, 15% and 20% woodchips as shown on table 4.

Table 5. Comparison of result calculation of SFC of coal firing and cofiring

No	Parameter	Unit	Co-firing Scenario			
1	Load Gross average	MW	0%	10%	15%	20%
2	Gross Electric Energy	MWh	95.59	95.60	95.58	95.55
3	Netto Electric Energy	MWh	377.03	376.62	376.44	375.77
4	Duration	hour	4.00	4.00	4.00	4.00
5	Fuel Consumption CF A	ton	65.50	65.80	65.40	66.60
6	Fuel Consumption CF B	ton	65.50	65.70	65.30	66.60
7	Fuel Consumption CF C	ton	65.53	65.58	65.23	66.46
8	Fuel Consumption Total	ton	196.35	197.08	195.93	199.66
9	SFC	kg/kWh	0.521	0.523	0.520	0.531
10	Fuel NK	kCal/kg	4908	4786	4798	4599

The SFC of co-firing is higher than SFC of coal firing because of the calorific value of woodchips lower than coal. Therefore, there are an increasing in fuel consumption at the same load. Previous studies have shown that biomass co-firing, including woodchip, tends to increase the SFC. For example, in a previous study [23], co-firing with woodchip increased SFC by 0.2% to 4.4% compared to pure coal combustion. This increase is primarily attributed to the lower calorific value of biomass compared to coal, requiring more fuel to produce the same amount of energy. Although co-firing may increase fuel consumption, this approach remains an effective strategy to reduce greenhouse gas emissions and support the transition toward renewable energy.

Based on data, the purcase price of coal is IDR 865.35/kg and the purcase price of woodchips is IDR 461.56/kg. Therefore, the production cost can be calculated as shown on table 5. It was found that production cost savings during the 10%, 15%, and 20% co-firing test is still cheaper by 18.97 IDR/kWh, 31.78 IDR/kWh and 33.78 IDR/kWh respectively. This is because the price of woodchips is more lower than the price of coal with a relatively high calorific value, despite the increase in fuel consumption. The price of woodchips still meets the PLN regulation with data on price and calorific value according to the assumptions and calculations above.

Table 6. The calculation of Production Cost Savings

Parameter	Unit	Value
Coal Price	IDR/kg	865.35
Woodchis Price	IDR/kg	461.56
Production Cost 100% Coal	Rp/kWh	450.66
Production Cost 10% Bio	Rp/kWh	431.69
Production Cost 15% Bio	Rp/kWh	418.88
Production Cost 20% Bio	Rp/kWh	416.87
Saving 10% Bio	Rp/kWh	18.97
Saving 15% Bio	Rp/kWh	31.78
Saving 20% Bio	Rp/kWh	33.78

3.5 The Analysis of Co-firing impact for the environmental

A portable gas analyzer was used to test the emissions during the cofiring implementation. Data was gathered from the air heater's input and outflow sides. The graph in Fig 6 below show the average exhaust gas emission measurement findings.

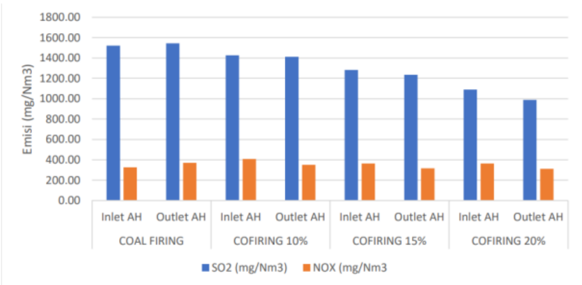

Figure 6. The graph of emission measurement result in AH inlet and outlet

The average SO_2 emission show a decreasing trend from 1544.8 mg/Nm³ during coal firing tests to 1411,4 mg/Nm³ during the 10% cofiring test, 1235 mg/Nm³ during the 15% cofiring test, and finally to 987.49 mg/Nm³ during the 20% cofiring test. This suggests that as the fraction of cofiring increases, SO_2 emissions will significantly decrease. This decrease is explained by woodchips' lower sulfur concentration (0.07% ar) in comparison to coal. The average NOx emission show a decreasing trend from 369.9 mg/Nm^3 during coal firing to 350.0 mg/Nm^3 during the 10% cofiring test, 315.7 mg/Nm³ during the 15% cofiring test, and finally to 310.8 mg/Nm³ during the 20% cofiring test. This suggests that as the fraction of cofiring increases, NO_x emissions will significantly decrease while still complying with The Ministry of Environment and Foresty (KLHK) emission standard of 550 mg/Nm³. Whereas particulate and mercury emission during coal firing (100% coal), 10%, 15%, and 20% cofiring could not be measured using the portable testing equipment utilized. Therefore this is the recommendation for unit to improve the emission monitoring tools to ensure compliance with the emission standard.

Conclusions

This study demonstrates that woodchip cofiring in a 100 MW CFB boiler at PLTU Tarahan Unit 3 is technically and economically feasible without requiring major retrofits. Fuel characterization revealed that while woodchips have higher moisture and volatile content and lower calorific value than coal, blending up to 20% did not significantly affect furnace exit gas temperature (FEGT) or disturb operational stability. The observed emissions of SO_2 and NO_x decreased proportionally with increasing biomass fraction, supporting environmental benefits. Although Specific Fuel Consumption (SFC) slightly increased, production costs were reduced due to the lower price of biomass compared to coal. These findings validate woodchip cofiring as a practical and sustainable strategy to reduce greenhouse gas emissions and support Indonesia's energy transition, particularly when supported by proper fuel quality control and continuous monitoring.

References

[1] Government of Indonesia. *Indonesia Long-Term Strategy for Low Carbon and Climate Resilience 2050*. Jakarta, Indonesia: Minister of Environment and Forestry, 2021

[2] IEA-ETSAP, IRENA. *Biomass Co-Firing Technology Brief.* Abu Dhabi, United Arab Emirates: IRENA, 2013.

[3] Permen ESDM No. 12 Tahun 2023 tentang *Pemanfaatan Bahan Bakar Biomassa Sebagai Campuran Bahan Bakar Pada Pembangkit Listrik Tenaga Uap*

[4] Kementrian ESDM Ketenagalistrikän, 2021, *Rencana Usaha Penyediaan Tenaga Listrik (RUPTL)*, PT PLN (Persero) Tahun 2021 – 2030.

[5] IEA-ETSAP and IRENA, *Biomass Co-Firing Technology Brief*, Abu Dhabi, United Arab Emirates: International Renewable Energy Agency, 2013.

[6] Chang, K.H, Lou, K.R, Ko, C.H, *Potential of Bioenergy Production from Bioamass wastes of Rice Paddies and Forest Sectors in Taiwan*, Journal of Cleaner Production, 206, pp 460-476, January 2019.

[7] Tanbar, F, Purba, S, Samsudin, A.S, Supriyanto, E, Aditya, I.A, *Analisa Karakteristik Pengujian Co-Firing Biomassa Sawdust Pada PLTU Type Pulverized Coal Boiler Sebagai Upya Bauran Renewable Energy*, Jurnal Offshore, %, pp 50-55, Desember 2021.

[8] Lewia, T, Verstraten, L, Hogg, B, Wehr, B.J, Swift, S, Tindale, N, Menzies, N.W, Dalal, R.C, Bryant, P, Francis b, Smith, T.E, *Reforestation of Agricultural land in The Tropics: The Relative Contribution of Soil, Living*

Biomass and Debris Pools to carbon Sequestration, Science of The Total Environmental, 649, pp 1502-1513, Februari 2019.

[9] Hariyostanto, E, Winahyu, T. D. H, Aprilana, A, Fitriani, V, Yolensha, A.D, Analisis Karakteristik Pengujian Cofiring Woodchip di PLTU Tarhan Unit 3, Lap Kajian, PT PLN Persero, 2025

[10] Badan Standardisasi Nasional, SNI 8676:2018 – Bahan Bakar Padat – Kayu Cacah (Woodchips), Jakarta: BSN, 2018.

[11] Badan Standardisasi Nasional, SNI 01-5015-1998 – Batubara dan Arang – Penentuan Analisis Proksimat, Jakarta: BSN, 1998.

[12] ASTM D5373-16, Standard Test Methods for Instrumental Determination of Carbon, Hydrogen, and Nitrogen in Laboratory Samples of Coal, ASTM International, 2016.

[13] ASTM D4239-18, Standard Test Method for Sulfur in the Analysis Sample of Coal and Coke Using High-Temperature Tube Furnace Combustion, ASTM International, 2018.

[14] ASTM D5865-13, Standard Test Method for Gross Calorific Value of Coal and Coke, ASTM International, 2013.

[15] ASTM D1857-04(2010), Standard Test Method for Fusibility of Coal and Coke Ash, ASTM International, 2010.

[16] ASTM D409-08, Standard Test Method for Grindability of Coal by the Hardgrove-Machine Method, ASTM International, 2008.

[17] T. Rizvi, M. Pourkashanian, J. Jones, L. Darvell, P. Xing, W. Nimmo. *Prediction Of Biomass Ash Fusion Behaviour by the Use of Detailed Characterization Methods Coupled with Thermodynamic Analysis,* Fuel, 141, pp 275-284, February 2019.

[18] Speight, James G. *The Chemistry and Technology of Coal. 3rd ed*. Boca Raton, FL: CRC Press, 2015.

[19] Kitto, J. B., & Stultz, S. C. *Steam: Its Generation and Use (41st ed.).* Barberton, Ohio: The Babcock & Wilcox Company, (2005).

[20] Vassilev, S. V., Baxter, D., Andersen, L. K., & Vassileva, C. G. *An overview of the chemical composition of biomass.* Fuel, 89(5), 913–933, 2010.

[21] Miles Jr., T.R., Jenkins, B.M., & Oden, L.L. Alkali deposit formation during biomass combustion. National Renewable Energy Laboratory (NREL), pp 1-137, 1996.

[22] Robinson, T., Junker, H., & Beck, J. *Corrosion investigations of superheater materials from biomass-fired power plants*. Biomass and Bioenergy Vol 23, Issue 3, pp195–208, 2002.

[23] Basu P, *Biomass Gasification, Pyrolysis and Torrefaction*: Practical Design and Theory, 1st ed. Burlington, MA: Academic Press, 2011.

[24] Cahyo N, Tanbar F, and Zahoor M. *Characteristics of co-firing solid recovered fuel with sub-bituminous coal on pulverized coal boiler power plant 300 MWe.* E3S Web of Conferences. vol. 432, article 00009, Oct. 2023.