Proceedings of the 6th ITB International Graduate School Conference
Multidisciplinary Collaboration for Sustainable Energy: Science,
Technology, Policy, and Society

Co-Firing Performance Simulation of Refuse-Derived Fuel (RDF) in a 400 MW Pulverized Coal Power Plant

Wisnu Aji Prabawa[1,2], Winny Wulandari[1] & Dwiwahju Sasongko[1]

[1] Chemical Engineering Department, Faculty of Industrial Technology, Institut Teknologi Bandung
[2] PT PLN (Persero)
Email: wisnu.prabawa@pln.co.id

Abstract. This study evaluates the technical and economic feasibility of co-firing Refuse-Derived Fuel (RDF), locally known in Indonesia as Bahan Bakar Jumputan Padat (BBJP) with coal in a 400 MW Pulverized Coal (PC) power plant located in Cilegon, Indonesia. Simulations using Aspen Plus software assessed fuel consumption, thermal efficiency, emissions, and production costs. The BBJP used has an average calorific value of 3,589 kcal/kg and sulfur content of 0.13%, compared to the coal's 4,557 kcal/kg and 0.55% sulfur. Co-firing with up to 20% BBJP reduced coal consumption by 35.3 tons/hour while increasing overall fuel mass flow. Sulfur dioxide (SO_2) emissions decreased from 442 mg/Nm³ to approximately 370 mg/Nm³ at a 10% BBJP blend. Economically, co-firing slightly lowered total fuel costs and reduced the cost of electricity production from Rp450.90/kWh to Rp447.74/kWh. These findings indicate that BBJP co-firing is a viable strategy to reduce emissions, support Indonesia's decarbonization efforts, and improve operational cost efficiency in coal-fired power plants.

Keywords: *co-firing, BBJP, pulverized coal boiler, Aspen Plus, emission reduction, fuel consumption, production cost.*

1 Introduction

The growing global demand for energy remains predominantly met by fossil fuels such as coal, oil, and natural gas, whose availability continues to decline [1]. Alongside this, the urgent threat of climate change necessitates significant decarbonization efforts within the energy sector [2]. In Indonesia, the 2023 primary energy mix only achieved 13.1% renewable energy, falling short of the 17.9% target, with coal still contributing 40.46% [3]. To accelerate the energy transition, PT PLN (Persero) initiated various programs, including the adopting of co-firing technology, which enables the simultaneous combustion of biomass and coal to reduce greenhouse gas emissions and reliance on fossil fuels [4].

Co-firing trials in Indonesia have involved various biomass types, including sawdust, rice husk, palm shells, and processed biomass like woodchips and pellets [5]. An innovative solution to biomass supply challenges is the use of

BBJP produced from municipal solid waste [6]. Despite positive impacts on greenhouse gas emission reductions [7], the current implementations generally remain at low co-firing ratios (~5%) and face technical challenges such as fouling, corrosion, and increased boiler maintenance [8]. Pilot projects, including the BBJP initiative at Bagendung landfill site in Cilegon, aim to demonstrate the feasibility of large-scale BBJP use to address both energy and waste management issues [6].

Co-firing in pulverized coal power plants involves the simultaneous combustion of coal and biomass in the same boiler system [4]. Various types of co-firing technologies include direct co-firing, indirect co-firing, and parallel co-firing. Direct co-firing, where biomass is directly introduced into the coal boiler, is the most common due to its low modification requirements [2]. Co-firing offers numerous advantages, such as reduced greenhouse gas emissions [7], lower sulfur oxide emissions [4], diversification of energy sources, and enhanced energy security [1]. However, challenges remain, particularly regarding combustion stability, slagging, fouling, corrosion, and the supply chain reliability of biomass fuels [8].

As a solution, Indonesia has introduced Refuse-Derived Fuel (RDF), locally known as Bahan Bakar Jumputan Padat (BBJP), produced from processed municipal solid waste through mechanical-biological treatment, drying, and shredding to improve fuel quality and uniformity. The utilization of BBJP aims to reduce landfill dependency, promote renewable energy use, and support urban waste management solutions [6]. BBJP generally features higher moisture and volatile matter compared to coal, but has lower sulfur and ash contents, making it environmentally advantageous [4]. According to SNI 8966:2021, BBJP must have moisture content below 20%, ash content below 20%, a calorific value exceeding 15 MJ/kg (3,585 kcal/kg), and sulfur content not exceeding 1.5% to ensure safety and efficiency in coal-fired power plant applications [3].

Several studies have employed simulation tools to predict the behavior of co-firing processes. Liu et al. in [9] successfully modeled biomass and coal co-firing scenarios, validating the software's ability to replicate combustion thermodynamics and predict key performance metrics such as efficiency and emission profiles. Nur Cahyo [5] also demonstrated that continuous co-firing operation with sawdust could maintain operational parameters within acceptable ranges while improving environmental performance. Other studies using Aspen Plus or similar process simulators indicated that co-firing biomass ratios between 5% and 20% could maintain boiler performance within acceptable limits while significantly reducing SO_2 and CO_2 emissions [4] [7]. These findings highlight the effectiveness of simulation tools in optimizing co-firing strategies, reducing experimental costs, and minimizing operational risks prior to real-world implementation [9] [2].

2 Methods

2.1 Simulation Approach

A simulation model of a 400 MW Pulverized Coal power plant was developed using Aspen Plus V14 software. The model was constructed to replicate the actual operating conditions, allowing for analysis of combustion processes and energy generation.

2.2 Fuel Properties and Data Sources

Comprehensive fuel characterizations were performed through laboratory analysis. The proximate and ultimate compositions of both coal and BBJP were incorporated into the simulation model. Key attributes considered include moisture content, ash content, volatile matter, fixed carbon, and elemental composition (C, H, O, N, S). Plant operational data, including boiler pressure, temperature, and fuel feed rates, were gathered from on-site measurements and the plant's Distributed Control System (DCS).

Table 1 Proximate and Ultimate Analysis of Coal and BBJP

Parameters	Units	Coal	BBJP		
			Sample 1	Sample 2	Sample 3
Proximate:					
Total Moisture	*% wt*	28.87	9.43	9.16	8.93
Ash Content	*% wt*	4.49	29.36	31	30.7
Volatile Matter	*% wt*	34.44	53.29	49.43	53.68
Fixed Carbon	*% wt*	32.20	8.35	8.15	8.54
Total Sulfur	*% wt*	0.55	0.13	0.13	0.13
Gross Calorific Value	*Kcal/Kg*	4557	3521	3692	3553
Ultimate:					
Carbon	*% wt*	43.58	33.21	32.68	34.67
Hydrogen	*% wt*	3.15	4.6	4.64	4.72
Nitrogen	*% wt*	0.60	1.05	1.1	1.1
Oxygen	*% wt*	18.76	21.04	21.27	20.99

2.3 Research Procedure

The development of the simulation model adopts an approach that closely follows the actual configuration of the power plant, ensuring that the simulated system reflects real operational conditions. Detailed fuel properties, including proximate and ultimate analyses, calorific value, and essential operational parameters such as temperature, pressure, and fuel flow rate, are inputted into the model. Simulations are conducted at various BBJP co-firing ratios—0%, 5%, 10%, 15%, and 20%—to evaluate their impact on plant performance. The simulation results are analyzed with a focus on fuel consumption, thermal efficiency, and the emission levels of SO_2 and NO_x. The performance of each co-firing scenario is then compared against the standards set by the Indonesian National Standard (SNI) to assess the technical feasibility of using BBJP. In addition, an economic evaluation is performed to assess the changes in fuel costs and their implications on the cost of electricity production.

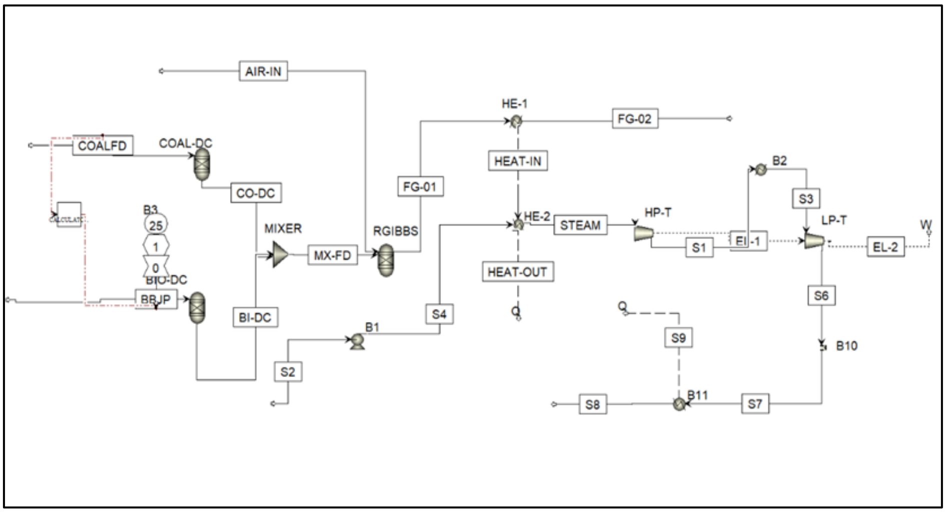

Figure 1 Process Flow Diagram of PC Power Plant in Aspen Plus

Figure 1 depicts the process flow diagram (PFD) for the Pulverized Coal (PC) power plant modeled in Aspen Plus consists of several key units representing the major components of a typical coal-fired power generation system. The fuel preparation section includes a RYIELD block where coal and biomass are decomposed into their elemental constituents (C, H, O, N, S). These elements then enter the RGIBBS reactor, which simulates the combustion process under equilibrium conditions without considering reaction kinetics. Following the combustion reactor, the HEATER blocks model the heat exchangers responsible for steam generation. The generated flue gases pass through coolers and filters, representing the economizer, air preheater, and dust collection systems, respectively. The flue gas composition is analyzed after exiting the system to determine the concentrations of major emissions such as CO_2, SO_2, and NO_x. The steam produced is directed to a simplified TURBINE block, representing the steam turbine-generator set, which converts thermal energy into electrical energy. The turbine exhaust is cooled down and condensed in a COOLER unit, simulating the condenser system. Makeup water and condensate recovery loops are also incorporated to maintain the boiler feedwater cycle. All major process units are connected via material and energy streams, operating under steady-state conditions. Pressure losses in pipelines and equipment are neglected, and the system is assumed to be adiabatic, with no heat losses to the environment.

2.4 Validation of Simulation

To ensure the reliability of the developed simulation model, validation was conducted by comparing the simulation results with actual operational data from the pulverized coal power plant. The validation focused on key performance indicators, namely boiler thermal efficiency, specific fuel consumption (SFC), and flue gas emissions. The base case simulation was configured to represent 100% coal combustion without any biomass co-firing. Input data, including coal properties (proximate and ultimate analyses), boiler operating conditions (temperature, pressure, air flow rates), and flue gas characteristics, were collected directly from the Distributed Control System (DCS) records of the 400 MW PC boiler unit. The simulation outputs were compared against the plant's actual measured data. The comparison results are summarized in Table 4.1.

Table 2 Comparison of Simulated and Actual Operating Parameters under Coal-Firing Conditions (100% Coal).

Parameter	Actual Data	Simulation Result	Deviation (%)
Fuel Consumption (ton/hour)	224.55	224.55	0.00
Gross Power Output (MW)	398.94	399.89	0.24
Fuel Exit Gas Temperature (°C)	1373	1312	4.37
SO_2 Emissions (mg/Nm^3)	442	455	2.96
Average Deviation (%)			**1.64**

3 Results and Discussion

3.1 Fuel Consumption Analysis

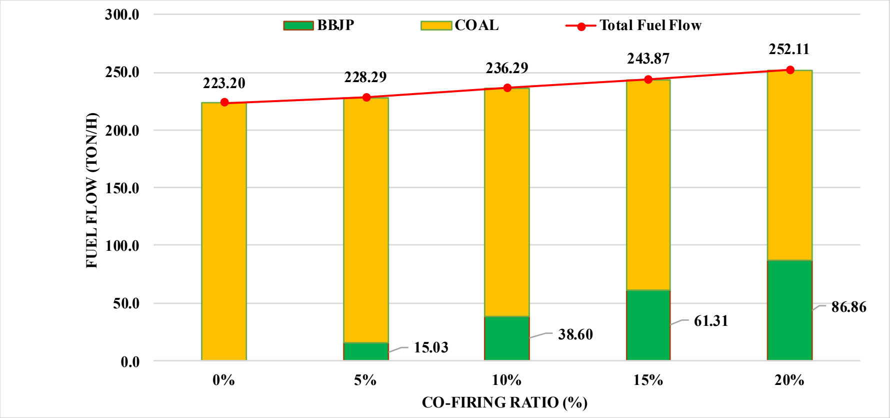

Figure 1 Effect of Co-Firing Ratio on Fuel Flow Rate

The simulation results indicate that increasing the BBJP co-firing ratio reduces the coal consumption significantly. As illustrated in Figure 4.1, coal consumption shows a steady decline as the BBJP ratio increases. For a 5% BBJP ratio, the coal consumption decreased by approximately 11 tons/hour compared to 100% coal-firing. At a 20% BBJP ratio, coal consumption reduction reached about 35 tons/hour. However, due to the lower calorific value of BBJP compared to coal [10], the total mass flow of fuel (coal + BBJP) increased to maintain the same boiler thermal input [11].

3.2 Thermal Efficiency Analysis

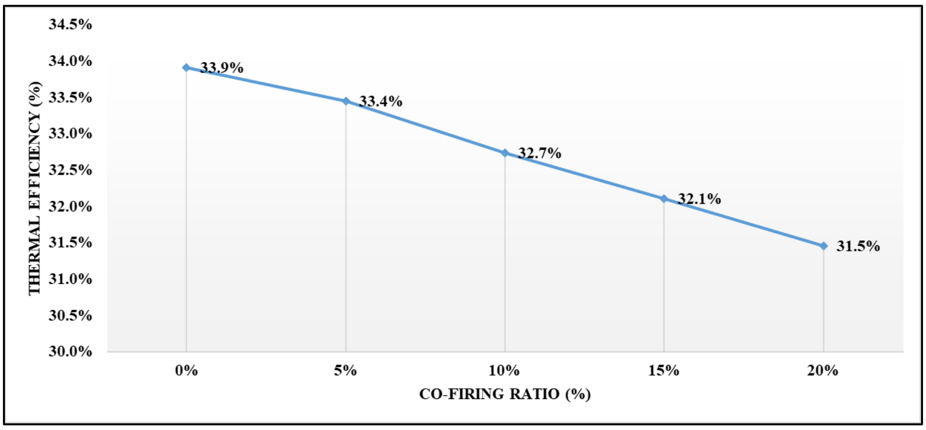

Figure 2 Effect of Co-Firing Ratio on Thermal Efficiency

A slight decline in boiler thermal efficiency was observed with increasing BBJP ratio, as shown in Figure 4.2. The efficiency drop ranged from 0.15% at 5% BBJP co-firing to around 0.75% at 20% BBJP. This reduction is attributed to the higher moisture and volatile matter content of BBJP, requiring more energy for drying and combustion, and resulting in lower overall heat transfer efficiency.

3.3 Flue Gas Emissions Analysis

SO_2 emissions decreased consistently as the BBJP co-firing ratio increased, driven by the significantly lower sulfur content in BBJP compared to coal. As presented in Figure 4.3, at 10% BBJP co-firing, the SO_2 concentration in flue gas decreased from 442 mg/Nm³ to approximately 370 mg/Nm³, achieving a 16.3% reduction. At 20% BBJP, the SO_2 emissions further reduced to around 330 mg/Nm³, equivalent to a 25.3% reduction compared to the baseline.

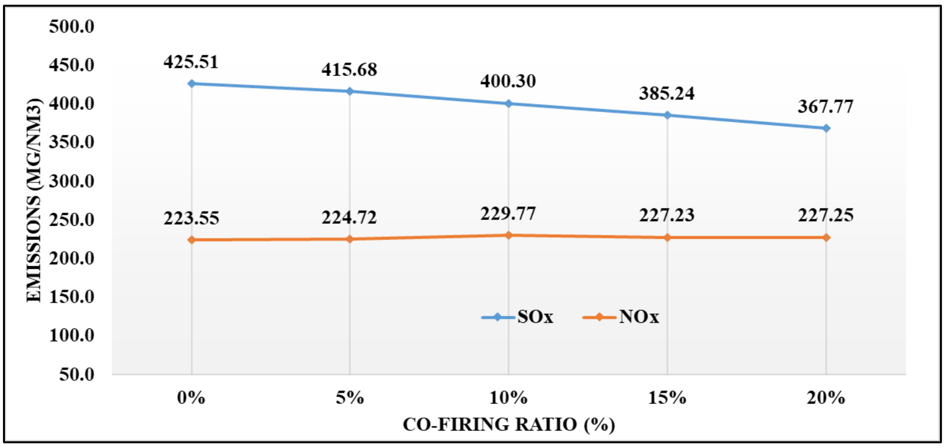

Figure 3 Effect of Co-Firing Ratio on SO_2 & NOx Emissions

NO_x emissions exhibited minimal variation across different BBJP ratios, as indicated in Figure 4.4. As NO_x formation is closely related to peak combustion temperature and nitrogen content, the addition of BBJP did not significantly affect NO_x emissions under the modeled conditions. However, it is important to note that Aspen Plus has limitations in accurately predicting NO_x emissions [12]. The software relies on equilibrium thermodynamic calculations and does not incorporate detailed kinetic mechanisms required for NO_x formation modeling, such as thermal NO_x, prompt NO_x, and fuel NO_x pathways [13]. Therefore, the NO_x emission trends observed in this simulation should be interpreted qualitatively. For a more precise assessment, experimental validation or the use of advanced combustion kinetics simulation tools, such as Computational Fluid Dynamics (CFD) models like ANSYS Fluent, which can simulate detailed chemical reactions and fluid dynamics, is recommended [14].

3.4 Economic Analysis

The total fuel cost decreased slightly as the BBJP ratio increased, owing to the lower price of BBJP compared to coal. Consequently, the Levelized Cost of Electricity (LCOE) dropped from Rp450.90/kWh under 100% coal-firing to Rp447.74/kWh at 20% BBJP co-firing, as depicted in Figure 4.5. Table 4.1 summarizes the relationship between BBJP co-firing ratios and the resulting LCOE values. Although the reduction appears modest, it demonstrates the economic advantage of BBJP utilization alongside environmental benefits. Given the straightforward calculation method, involving the division of total fuel costs by net power output.

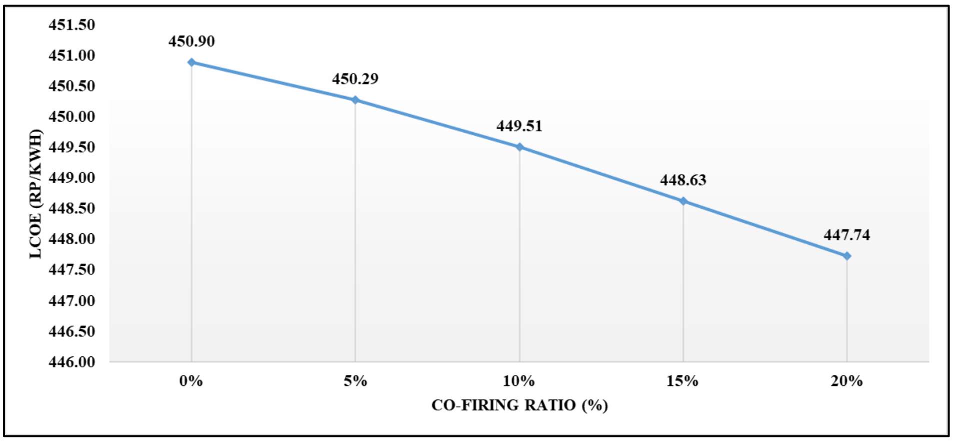

Figure 4 Effect of BBJP Co-Firing Ratio on Levelized Cost of Electricity (LCOE)

However, it is important to note that this calculation only considers direct fuel costs and does not account for various indirect or hidden costs. For example, the high ash content of BBJP could potentially cause operational disturbances in the boiler due to increased slagging and fouling during combustion, leading to higher maintenance costs [15]. Moreover, according to Alfaruq et al. [16], Indonesian coal generally possesses a high Hardgrove Grindability Index (HGI), making it relatively easy to pulverize and suitable for pulverized coal combustion systems. In contrast, BBJP used in this co-firing scenario has a very low HGI, indicating that it is difficult to pulverize, requiring higher energy consumption for milling and potentially reducing mill capacity and efficiency [17]. Although BBJP co-firing offers a fuel cost advantage, these potential hidden technical costs must be considered to ensure long-term operational feasibility.

3.5 Compliance with SNI Standards

The BBJP utilized in the simulation met the requirements set forth in SNI 8966:2021, which specifies a maximum moisture content of 20%, a maximum ash content of 20%, a minimum net calorific value of 15 MJ/kg, and a maximum sulfur content of 1.5%. The BBJP tested had a moisture content of 9.17%, ash content of 7.41%, a net calorific value of 15.02 MJ/kg, and sulfur content of 0.13%, thus fully complying with the national standard.

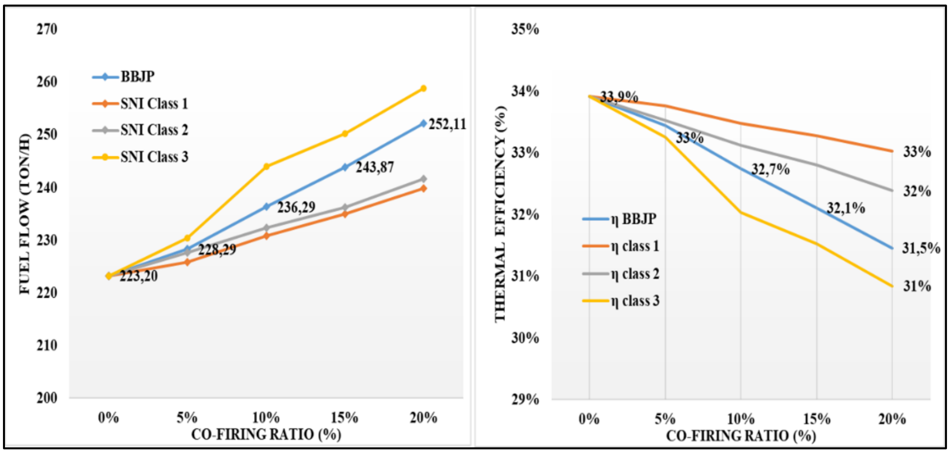

Figure 5 (a) Comparison of Simulated Fuel Consumption, (b) Comparison of Simulated Thermal Efficiency with SNI BBJP Class Specifications

To further assess the suitability of the BBJP used, a comparative analysis was conducted between the BBJP properties and the specifications for each SNI class. Figure 4.6(a) presents a graphical comparison of the simulated fuel consumption relative to the specifications across different SNI BBJP classes, while Figure 4.6(b) shows the comparison of thermal efficiency performance under similar conditions.

The BBJP sample closely matches the criteria for SNI Class 2, given its calorific value slightly exceeding 15 MJ/kg and low ash and sulfur contents. Although it meets the minimum requirements, it is situated near the lower boundary for calorific value within Class 2 specifications. This classification implies that while the BBJP is technically suitable for combustion in coal-fired power plants, optimization efforts to increase energy content would further enhance its operational performance.

3.6 Overall Discussion

This study confirms the technical and economic feasibility of co-firing Refuse-Derived Fuel (RDF), locally known as Bahan Bakar Jumputan Padat (BBJP), in a 400 MW pulverized coal power plant. Aspen Plus simulations demonstrated that increasing BBJP blending ratios up to 20% resulted in significant coal savings of up to 35 tons/hour and a 25% reduction in SO_2 emissions, while only slightly decreasing boiler thermal efficiency by less than 1%. The levelized cost of electricity (LCOE) also declined modestly from Rp450.90/kWh to Rp447.74/kWh, indicating potential economic benefits.

The BBJP used in this study complied with the Indonesian national standard (SNI 8966:2021), with favorable moisture, ash, and sulfur content values, making it technically suitable for co-firing applications. This study has limitations of the simulation model particularly in accurately predicting NO_x emissions due to the absence of combustion kinetics. Additionally, hidden operational challenges such as increased slagging potential, fouling, and the low grindability index of BBJP may affect long-term boiler performance and maintenance costs.

Despite these challenges, the findings support BBJP as a viable local RDF alternative that aligns with Indonesia's decarbonization goals while addressing municipal waste issues. To ensure large-scale implementation, further research is recommended, particularly through Computational Fluid Dynamics (CFD) modeling and pilot-scale trials. Long-term performance assessments and life cycle analyses are also essential to fully capture the environmental and economic trade-offs of BBJP co-firing in Indonesia’s power sector. Future research should also focus on long-term operational assessments, especially considering the variability in BBJP quality and its impact on boiler reliability and maintenance costs [15]. A comprehensive lifecycle analysis would be essential to fully quantify the environmental and economic trade-offs of large-scale BBJP co-firing implementation.

References

[1] Yurisman, N. and Arizona, R., *Dampak penambahan limbah biomassa cangkang kelapa sawit sebagai bahan bakar boiler terhadap heat rate dengan metode co-firing*, 2022

[2] Triani, M., Anggoro, D. D. and Yunianto, V. D., *Potensi Dekarbonisasi Pembangkit Listrik Batubara Melalui Cofiring Biomassa Dan Carbon Capture Utilization*, METANA, vol. 20, no. 1, pp. 57–68, Jun. 2024, doi: 10.14710/metana.v20i1.63102.

[3] PA3KN, *Buletin APBN*, vol. IX, 2024. [Online]. Available: www.pa3kn.dpr.go.id

[4] [4] Sidiq, A. N., *Pengaruh Co-Firing Biomassa terhadap Efisiensi Boiler PLTU Batubara*, KILAT, vol. 11, no. 1, pp. 21–31, Apr. 2022, doi: 10.33322/kilat.v11i1.1553.

[5] N. Cahyo, *Studi Dampak Techno-Ekonomi Pengoperasian Kontinyu Co-firing Sawdust – Batubara di PLTU Pulverized Coal Sistem Jawa Bali*, Studi Internal PLN Puslitbang, Jakarta, Indonesia, Mar. 2022.

[6] H. A. M. Salman, *Optimizing Biomass Pre-Treatment Technologies for BBJP Plants in Indonesia: A Multi-Criteria Decision Making Approach*, Advance Sustainable Science, Engineering and Technology, vol. 6, no. 1, p. 02401021, Jan. 2024, doi: 10.26877/asset.v6i1.17877.

[7] A. D. Ariyanto and L. Mustakim, *Analisis Pengujian Co-Firing Biomassa pada PLTU Batubara dengan Beberapa Bahan Bakar Alternatif sebagai Upaya Bauran Energi Baru Terbarukan*, MARTABE: Jurnal Pengabdian Masyarakat, vol. 6, pp. 98–104, 2023, doi: 10.31604/jpm.v6i1.98-104.

[8] A. Sugiyono, I. Febijanto, E. Hilmawan, and Adiarso, *Potential of biomass and coal co-firing power plants in Indonesia: a PESTEL analysis*, in *IOP Conf. Ser.: Earth and Environmental Science*, vol. 963, 2022, doi: 10.1088/1755-1315/963/1/012007.

[9] Y. Liu, X. Yang, J. Zhang, and Z. Zhu, *Process Simulation of Preparing Biochar by Biomass Pyrolysis Via Aspen Plus and Its Economic Evaluation*, Waste Biomass Valorization, vol. 13, no. 5, pp. 2609–2622, May 2022, doi: 10.1007/s12649-021-01671-z.

[10] G. Thirugnanam, T. Ganesh, and P. Vignesh, *Refuse Derived Fuel To Electricity*,2013.[Online] Available:https://www.researchgate.net/publication/265684610

[11] D. Satrio, N. Nyoman, A. I. Trisnayanthi, and J. Pratilastiarso, *Analysis of the Effects of Fuel Type Selection on the Performance and Fuel Consumption of a Steam Power Plant*, vol. 11, no. 5, 2021.

[12] I. A. Shah, X. Gou, Q. Zhang, J. Wu, E. Wang, and Y. Liu, *Experimental study on NOx emission characteristics of oxy-biomass combustion*, J Clean Prod, vol. 199, pp. 400–410, Oct. 2018, doi: 10.1016/j.jclepro.2018.07.022.

[13] AspenTech, *Aspen Plus User Guide*, Bedford, MA, USA: Aspen Technology, Inc., 2024. [Online]. Available: https://www.aspentech.com

[14] J. Dian, H. D. Saksono, and A. Nugroho, *CFD Modeling to Analyze Palm Shell Co-firing Percentage on Ketapang CFB Power Plant*, *IOP Conf. Ser.: Mater. Sci. Eng.*, vol. 1096, p. 012131, Mar. 2021, doi: 10.1088/1757-899X/1096/1/012131.

[15] A. Darmawan, et al., *Cofiring Potential of Biomass Waste: Ash Behaviour and the Effects of Additives on Deposit Formation*, pp. 137–168, 2025, doi: 10.1007/978-981-97-9360-0_5.

[16] F. Alfaruq, Tumiran, and Sarjiya, *Evaluation of Co-firing in a Pulverized Coal Boiler Using Multi-Biomass: Sawdust and Rice Husks*, in *Proc. ICEECIT 2024*, IEEE, pp. 431–435, doi: 10.1109/ICEECIT63698.2024.10859495.

[17] M. Z. A. Arta, Widayat, and Muchammad, *Studi Pengaruh Biomassa Bahan Bakar Jumputan Padat (BBJP) pada Proses Co-firing di PLTU*, ELKOMIKA, vol. 12, no. 4, p. 995, Dec. 2024, doi: 10.26760/elkomika.v12i4.995