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Techno-economic Analysis of co-firing waste Refused Derived Fuel (RDF) in coal-fired power plant

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Abstract

Massive efforts have been made to reduce CO2 emissions around the world from the used of fossil fuels by seeking alternative fossil fuels in power plants. The utilization of waste in the energy sector with co-firing technology is one way to reduce the impact on the environment. The Indonesian government is currently issuing SNI 8966:2021 to take advantage by using of biomass waste as raw material for making Refused Derived Fuel or RDF in power plants (BSN, 2021. RDF which has a calorific value of 1800 kcal/kg will be tested in PLTU Indramayu which the coal has caloric value 4100 kcal/kg. The mass ratio for blending is 1% RDF and 99% Coal. This study aims to analyze the feasibility of economical, operational, and environmental if co-firing test carried out with waste RDF at PLTU. RDF is processed from waste using the concept of collaboration with DLH Indramayu. RDF processing site is carried out at PDU Indramayu using the peuyeumization method. Within 11 days, the plant produced RDF 14 tons which will be supplied as mixed fuel for co-firing PLTU Indramayu. Operational observations at the Indramayu PLTU during the 1% BBJP co-firing process showed parameters that were still within operational safe limits, but there was an increase in SO2 and NOx emissions which were still below the KLHK emission standards. The results of the techno-economic analysis show that if there is an increase in LCOE of 0.16-rupiah in the co-firing test with 1% BBJP, while for the Net Present Value (NPV) parameter a value of Rp.40,437,359 is obtained, the Internal rate return (IRR) parameter is 8.25%, the Profitability index (PI) parameter is 1.011 and the last payback period (PBP) is 6.63 years indicating the feasibility of investing in the BBJP processing project. From an economic point of view, the surrounding community provides opportunities for employment and business provision of consumable materials for BBJP processing projects.

1. Introduction

Fossil-based energy sources used for electricity generation, especially coal, are increasingly needed every year. (Ministry of Energy and Mineral Resources Public Relations, 2020). Coal itself is still the foundation for the Asia Pacific region in providing affordable and cheap energy. Indonesia's coal reserves currently reach 38.84 billion tons with an average coal production of 600 million tons per year, so the age of coal reserves is still 65 years if it is assumed that there are no new reserves found (KesDM Public Relations, 2021). Apart from coal reserves, there are also coal resources which were recorded at 149 billion tons (MEMR, 2021). Optimizing the use of coal in the energy sector causes Indonesia to tend to be left behind in terms of the transition away from using coal for electricity. Until the end of 2021, of the total power generation capacity of 73,736 MW, the capacity of steam power plants (PLTU) is still dominant, which is around 50 percent (Indonesia's energy outlook, 2019). In the energy mix, the supply of electricity with coal is also dominant, namely more than 65 percent which is marked by an increase in the construction of Steam Power Plants (PLTU) in Indonesia until 2025 (KESDM, 2021). During 2021-2030 it is estimated that an additional 13,585 MW of PLTU will start operating and at least until 2027 it reaches 13,565 MW of PLTU will operate, then in 2029 there will be an additional 20 MW (Ministry of Energy and Mineral Resources, 2021). This adds to the fact that the energy transition towards carbon neutral or net zero emission in 2060 will be difficult (IESR, 2022).

Meanwhile, the level of compliance of hundreds of coal mining companies to meet the DMO is very low. Of the 2021 target of 137.5 million tonnes, only 63.47 million tonnes or around 46% was achieved, the lowest since 2017 (Ministry of Energy and Mineral Resources, 2021). Until the end of 2021, there are only 85 companies that have met the coal DMO of 25 percent of the 2021 production plan (MEMR, 2021). Of the 5.1 million metric tons assigned by the government, until January 1 2022, only 35 thousand metric tons were fulfilled, or less than 1 percent (Ministry of Energy and Mineral Resources, 2021) (Arinaldo et al., 2019). As a result of the domestic coal supply crisis, there are 20 Steam Power Plants (PLTU) with a power of around 10,850 megawatts which will go out and have the potential to disrupt the stability of the national economy. The use of fossil fuels has a negative impact on the environment and human health (Iacovidou et al., 2018).

On the other hand, according to the Ministry of Energy and Mineral Resources, biomass reserves in Indonesia have a total potential of 32.6 Gigawatts (GW). Biomass contains much less sulfur than most coal (National Renewable Energy Laboratory, 1997). The use of biomass on a large scale with a large investment for generators does not yet exist in Indonesia (Basu, 2018) . There are several small-scale biomass generators that are managed by the private sector. The main obstacle for biomass power plants for large-scale power plants is the problem of the availability of a supply of raw material for biomass (PLN Puslitbang, 2021). Utilization of biomass on a large scale can also be carried out by the co-firing method with existing coal plants (Gil & Rubiera, 2019). The advantages obtained by co-firing are: no need for large investments, the use of biomass can be intermittent (adjusting to the supply of biomass), reducing emissions and reducing dependence on fossil fuels (National Renewable Energy Laboratory, 1997).

Based on its category, domestic waste can consist of organic waste and non-organic waste (Pavoni, J.L., Heer, J, E., and Hagerty,D.J. 1975. Handbook of Solid Waste Disposal. Van Nostrand Reinhold). In Indonesia, domestic waste is dominated by organic waste, namely as much as 28.3% of total waste is food waste by 2021. Food waste is the largest composition of waste in Indonesia not only in 2021, but also several years before (Matli et al., 2019). Plastic waste is in second place with a proportion of 15.73%. As much as 12.75% of the waste is in the form of wood/rating. Then as much as 12.36% of waste is paper/cardboard. Then, waste in the form of metal reached 6.86%. Then there was 6.57% in the form of cloth waste. There are also types of waste in the form of glass and rubber/leather with a proportion of 6.46% and 3.49% respectively. Meanwhile, 7.48% of waste was of other types. Meanwhile, the amount of waste generated in Indonesia last year was 21.53 million tonnes. As much as 66.51% of the waste has been successfully managed, while 33.49% of the other waste has not been managed (KLHK, 2021). Food waste in Indonesia is a serious problem. However, this type of waste has the potential for high calorific value if it is treated before the combustion process.

One way to extend the life of a landfill is by utilizing old waste (mining landfill waste) as an energy source in the form of Refused Derived Fuel (RDF). This step can be a solution for waste management whose volume continues to increase along with rapid industrialization, population growth and economic improvement (Sihombing & SAC, 2021). Unmanaged waste in Indonesia is still very large every year, amounting to 9,613,599.40 tons/year or 36.04% of the total waste collected, so a waste management plan is needed that can be useful to reduce the amount of unmanaged waste and assist in handling energy crisis. However, an analysis of waste processing techniques and economic calculations in Indonesia for a commercial scale that is capable of producing renewable energy sources for electricity generation and is economical has not been carried out (Chen et al., 2020). Therefore it is necessary to carry out a technical and economic analysis by focusing on the formulation of the following problems: 1) What is the waste management system that produces solid waste fuel (BBJP); 2) What are the preparation stages for the BBJP co-firing process at the PLTU; 3) What is the feasibility of using BBJP in Co-firing of the Coal Power Plant from an operational and financial standpoint. 4) Is there a significant reduction in GHG emissions when using BBJP for co-firing at PLTU (Nasional, 2014).

The purpose of this study is 1. Obtain the LCOE / BPP value of electricity when using solid waste cofiring fuel (BBJP). 2. Obtain a comparison of the economic value between the use of BBJP co-firing and 100% use of coal as fuel for PLTU Indramayu from the generator and community side in Indramayu, West Java. 3. Obtain a comparison of the amount of total emission reduction at PLTU Indramayu between cofiring using solid waste jumputan fuel (BBJP) and using 100% coal. 4. Mapping the business model canvas (BMC) for the BBJP Solid Jumputan Fuel production project.

Until now research on co-firing BBJP from waste at the Indonesian Coal PLTU has been carried out by several researchers. The summary of the research is presented in the following table.

Table 1. List of BBJP research for co-firing in Indonesia

No	Researcher	Year	Research result
1	Muhammad Fadli, Dianta Mustofa Kamal, Pribadi Mumpuni	2019	The aim of this study was to analyze the feasibility of direct co-firing waste pellets and coal in a CFBC type boiler at the PT Makmur Sejahtera Mine Mouth Power Plant with a capacity of 2x30MW in Tabalong Kalimantan using a SWOT analysis approach. The waste obtained from Klungkung Regency is processed into pellets and briquettes using the peyeumization method. The result is feasible to implement in PLTU MSW, with an internal factor value of 3.03 or rounded to 3 (strong) and an external factor value of 2.6 or rounded to 3 (strong). Several strategies are structured in order to use strengths to take advantage of opportunities and improve weaknesses and reduce threats. (Fadli et al., 2019)
2	Adolf Leopald SM Shombing, Ragil Darmawan SAC.	2021	This study aims to look at the characteristics of old waste (*mining landfill*) in several cities (Semarang, Manado, Yogyakarta, Pontianak, and South Tangerang) which have the potential to become fuel for co-firing through testing *proximate* and *ultimate* as well as conducting a comparative analysis of SNI 8966:2021. The test results show that the moisture content of the old waste is around 41.80% - 57.70%. This value is still above SNI 8966:2021 which requires a moisture content of 15-20%. The calorific value of old waste is in the range of 470-1232 kcal/kg or 1.97-5.16 MJ/kg. Testing the old waste parameters at the Jatibarang TPA at a depth of 2 meters and 5 meters is 0.9-2.6 MJ/kg and 1.2-4.4 MJ/kg, respectively. In theoretical calculations, the calorific value of old waste will increase to 750-2500 kcal/kg or 3-10 MJ/kg at 17% moisture content. The calorific value of old waste is still below the standard value set in SNI 8966:2021, which is at least 10 MJ/kg. Utilization of old waste as raw material for RDF needs to be combined with other biomass so that it fulfills the composition. (Sihombing & SAC, 2021)
3	Anton Irawan	2021	Stating that in order to obtain a stable combustion performance in the co-firing process at a power plant, it is necessary to improve the quality of the biomass. Torrefaction technology can be applied to improve the quality of biomass in Indonesia so that it can be used as fuel for co-firing power plants. One of the most potential biomass is empty fruit bunches (EFB) from oil palm processing with a potential of around 48 million tons per year or equivalent to 30 GW. Each palm oil factory that processes 25 tons/hour of fresh fruit bunches of oil palm can produce about 5.25 tons/hour of OPEFB. With so many palm oil mills, torrefaction technology can be used to store torrefied EFB which can change the properties of biomass from hydrophilic to hydrophobic. The government's role in supporting the utilization of biomass, including EFB, is urgently needed in increasing cooperation between palm oil mills and power plants. (Irawan, 2021)

No	Researcher	Year	Research result
4	Faridha, Budi Pirngadie, Nina Konitat Supriatna	2015	This study aims to identify the potential for the utilization of waste into electricity from waste that enters the Cilowong TPA, Serang City. The methodology used is to carry out a survey and take samples of waste at the Cilowong TPA, examine samples in the laboratory and carry out calculations to determine the electricity potential generated. From the research results it is known that most of the waste in Cilowong TPA is organic waste, namely 70.99%, with the amount of waste that goes to Cilowong TPA, Serang City, as much as 120 tonnes/day, generating 2.19 MW of electricity (thermochemical conversion) and 1.09 MW (biochemical conversion). (Farida et al, 2015)
5	Irma Natasya et al	2018	This study aims to analyze the calorific value of the passive zone combustible waste of TPA Jati Barang as raw material for BBJP by testing a sample of 100 grams with a calorimeter. And the results state that a high calorific value is produced if the waste is at a low depth so that it has more potential as a raw material for BBJP or RDF. (Hutabarat et al, 2018)
6	UU surma dkk	2020	Conveying the solution offered in reducing waste at TPSA Ciniru, Kuningan Regency is to process waste into a waste power plant with two methods, namely: energy utilization with thermochemical conversion methods and biological conversion methods. In the thermochemical conversion method, waste from TPSA has wet and dry waste, where wet food waste it will be reprocessed using biological methods. As for dry waste, it can be used for RDF (Refuse Derived Fuel) as fuel for a waste-powered power plant with a steam power cycle (PLTU). With the calculation results of thermochemical and biochemical processes, the power that can be generated is 154 MW (thermochemical) and 1.4 MW (methane gas). The total potential energy of electric power that can be generated is 155.4 MW. For the biological potential to use the biodigester as a process of utilizing the power energy obtained is 2.1.
7	Darmawan et al., 2021		This study aims to examine the characteristics of biomass, especially waste and Eichornia crassipes and the utilization of RDF biomass as an alternative fuel for co-firing in coal-fired power plants in Amurang. The results show that the 5% co-firing target requires 52.8 tons of biomass per day. The Eichhornia Crassipes biomass in Lake Tondano only supplies CPP for 62 days. MSW usually has the same heating and moisture values as Eichhornia Crassipes biomass, around 3766-4194 kcal/kg and 31.7-87.1%. The use of MSW to cover the shortage of Eichhornia Crassipes will ensure the continuity of the supply of biomass raw materials in the co-firing program at PLTU Amurang. (Bangun et al., 2015)

2. Materials and Methods

The first stage in this research was to conduct a literature study regarding the study of co-firing waste with solid jumputan fuel originating from waste. The second stage is to collect the data needed for the research process, namely initial data related to the characteristics of the coal used in the Indramayu steam power plant (PLTU). To find out the characteristics of the fuel used in co-firing, it can be analyzed by looking at the physical properties and chemical content of the fuel mixture (a mixture of coal and BBJP waste) which can be determined through laboratory tests obtained from data from coal suppliers, independent laboratories and chemical laboratories of PT. PLN NP UBJOM Indramayu. The third stage is a biomass survey around the Indramayu PLTU for the purposes of the BBJP co-firing trial carried out in areas around West Java Province because there is BBJP potential in the Indramayu area.

The fourth stage is preparing for the need for solid jumputan fuel, which includes the processing of waste into solid jumputan fuel at PDU SumberMulya. The method of storing and processing waste at PDU Sumbermulya uses the peuyeumization method. That is the method of storing organic waste mixed with waste decomposing bacteria and leaving it for several days so that chemical and biological reactions occur when waste is decomposed using bacteria which aims to increase the calories from the waste content so that it helps in the combustion process in the PLTU Indramayu boiler area.The fifth stage is the mixing process between BBJP waste and coal in the coal yard. The coal yard at PLTU Indramayu is quite protected from rain and weather because there is a coal shelter / coal dome.

The sixth stage is the implementation of testing. For actual data comparison, operational parameters were observed under conditions prior to the co-firing test or under unit operating conditions with 100% coal, with the same type of coal as that to be used in the waste BBJP co-firing test. The next day a 1% Co-firing trial with Solid Jumputan Fuel will be carried out. The seventh stage is the operational observation carried out at a load setting of 300 MW. The main parameters or critical points observed are: coal flow, total airflow, furnace exit gas temperature (FEGT), mill outlet temperature, main steam temperature, main steam pressure. The eighth stage is testing exhaust emissions (Białowiec et al., 2017). Testing of exhaust emissions is carried out by comparing data on exhaust emissions when testing 100% coal with BBJP co-firing testing of 1%. Data collection was carried out at the air heater outlet using independent laboratory services that were accredited and appointed by PT PLN NP. The ninth stage is the calculation of CAPEX and OPEX. Investment costs/capital costs (CAPEX), which include costs for purchasing equipment/technology, installation costs, and project planning and preparation costs.

3. Results and Discussions

3.1 Operation Observation

Co-firing test of 1% Solid Jumputan Fuel Biomass at the Indramayu Coal Power Plant was carried out on April 12 2023. Visual observation of coal biomass mixing shows that the results of mixing coal with 1% Solid Jumputan Fuel (BBJP) are mixed well and with coal. Testing 1% of the biomass of Solid Jumputan Fuel at PLTU Indramayu is fed to one of the coal feeders so that it becomes 5% in 1 coal feeder, but observed for all operating coal mills:

Gambar 4.1. Pengamatan sampling *fuel mixing* batubara - BBJP dari *coal feeder*

3.1.1 Observation of Baseline Operating Parameters

This operating data will be used as a baseline or comparison for operating data*co-firing*. The operating conditions of the units tested will be treated the same and use the same type of coal both for the 100% coal operation test and the 1% co-firing operation test. Operational data collection for 100% coal conditions was carried out at PLTU Indramayu on April 11, 2023 using coal with a heating value of 4,452 kCal/kg. Monitoring of operating parameters is carried out at a load setting of 300 MW. The main parameters or critical points observed are: total air flow, total coal flow, main steam temperature, main steam pressure, gas economizer outlet temperature, gas outlet temperature air heater, spray reheater total flow, and spray superheater total flow.

Table 2. Operational Data on Tests Using 100% Coal Fuel

No	Parameter	Operation Limitation	Unit	310 MW Before, Date: 11 April 2023								
				13:00	13:30	14:00	14:30	15:00	15:30	16:00	16:30	17:00
1	Load	<330	MW	304,83	303,13	305,94	308,08	307,13	308,71	310,12	305,75	304,08
2	Total Air Flow	±1400	t/h	1024,90	1039,28	1018,99	1037,14	1047,87	1058,02	1038,19	1003,05	1070,65
3	Total Coal Flow	180-210	t/h	191,01	191,93	189,95	188,84	188,13	184,32	182,94	182,68	184,43
4	Main Steam Pressure	19,6	MPa	17,04	16,97	17,15	17,61	17,54	17,64	17,71	17,47	17,01
5	Main Steam Temperature	538-548	°C	543,34	542,59	543,14	542,78	543,62	543,28	543,20	543,66	543,28
6	Gas Inlet Temp AH A	408	°C	389,92	390,85	391,08	390,66	390,15	390,62	391,01	390,20	391,39
7	Gas Inlet Temp AH B	408	°C	396,32	396,86	397,01	396,87	396,48	397,15	397,41	396,70	396,45
8	Gas Outlet T AH A		°C	201,01	201,17	201,03	200,97	201,03	201,07	201,01	200,73	200,31
9	Gas Outlet T AH B		°C	189,65	188,90	188,47	188,49	188,41	188,86	192,26	192,43	192,63

3.1.2 Observation of 1% Co-Firing Operating Parameters

Observation of the Co-Firing operating parameters was carried out by taking operating data on the condition of 99% Coal – 1% Biomass at PLTU Indramayu on April 12, 2023 using coal with a heating value of 4,452 kCal/kg. Monitoring of operating parameters is carried out at a load setting of 310 MW. The main parameters or critical points observed are: coal flow, total air flow, furnace exit gas temperature (FEGT), main steam temperature, main steam pressure, main steam flow, mill current, mill outlet temperature

Table 3. Operational Data on 1% Co-Firing Test

No	Parameter	Operation Limitation	Unit	310 MW 1% BBJP, Date: 12 April 2023								
				12:00	12:30	13:00	13:30	14:00	14:30	15:00	15:30	16:00
1	Load	<330	MW	307,15	307,07	306,03	310,65	310,21	308,58	310,04	311,79	310,51
2	Total Air Flow	±1400	t/h	1049,35	1085,22	1038,91	1042,94	966,63	1031,51	1009,52	1014,98	994,02
3	Total Coal Flow	180-210	t/h	181,58	186,29	185,94	186,36	186,90	189,49	186,31	188,30	186,90
4	Main Steam Pressure	19,6	MPa	17,25	17,27	17,24	17,29	17,10	17,06	17,24	17,56	17,56
5	Main Steam Temperature	538-548	°C	543,16	542,59	543,31	543,09	542,45	543,35	543,76	542,74	542,51
6	Gas Inlet Temp AH A	408	°C	392,88	393,34	393,18	392,28	392,34	392,42	392,34	392,00	391,98
7	Gas Inlet Temp AH B	408	°C	398,39	398,82	399,28	398,66	398,63	398,37	399,25	398,89	398,18
8	Gas Outlet T AH A		°C	201,58	201,60	201,31	201,32	201,23	201,08	200,77	200,75	200,39
9	Gas Outlet T AH B		°C	192,14	192,97	192,26	192,43	192,63	192,63	192,63	192,63	192,63

The table above is operational data for the co-firing test of PLTU Indramayu using 1% BBBJP biomass at the same load (310 MW). Some of the observations of the main operating parameters in the boiler, such as load, total coal biomass flow, MST (*main steam temperature*), MSP (*Main Steam Pressure*) during normal monitoring testing is not much different from the results of 100% coal testing and still meets the design parameters. The gas inlet temperature of the air heater has increased to ±7°C.

3.1.3 Observation of Load, Total Coal Biomass Flow, and FEGT

Retrieval of test data for both 100% coal operation and 1% co-firing operation of PLTU Indramayu is set at a load of 310 MW. Other operating parameters follow the settings in the 310 MW load range. Several parameters that will be evaluated include: load, total coal biomass flow, and FEGT.

3.1.4 FEGT (Furnace Exit Gas Temperature) Observation

Observations on the FEGT boiler when it is 100% coal and 99% coal – 1% BBJP are as shown in the graph below:

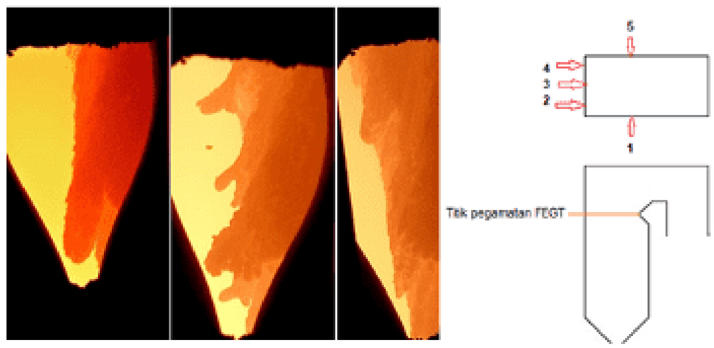

Figure 2. Visualization of conditions in FEGT

Knowing the combustion temperature in the boiler is a very important indicator to determine the combustion and boiler performance both from an economic and environmental perspective. FEGT can have a major impact on boiler performance and reliability. Boiler design involves an energy balance between the fire side and the steam side. In boilers there is generally sufficient monitoring of the steam side, but not sufficient fire monitoring and control. Beginning with the mixing of fuel and air, then combustion occurs in the furnace, and the next monitoring focus is on the exhaust gas path to the temperature outside the boiler furnace. So the control points between exiting the burner and exiting the boiler furnace, one of which is FEGT. This extra control point (FEGT) has a major impact on boiler performance and reliability. Basically, the furnace exit point separates the radiation zone from the convection zone. FEGT is an important design parameter for boilers (Geertsma et al., 2017). FEGT defines the ratio of heat absorption by radiant heating and convective heating. The FEGT control point also observes the potential for fouling of the boiler tube in the convective area.

3.1.5 Observation of Corrosion Potential (2S/Cl ratio) and Slagging

To determine the potential for corrosion and slagging of the fuel used in co-firing, it can be analyzed by looking at the physical properties and content the chemistry of the fuel mixture (a mixture of coal and biomass) which can be determined through laboratory tests. Because the release of S and Cl into the gas phase during the combustion of biomass is rather constant (80-90% for S and >90% for Cl [P. Sommersacher, T. Brunner and I. Obernberger, "Fuel Indexes: A Novel Method for the Evaluation of Relevant Combustion Properties of New Biomass Fuels," Energy & Fuels, p. 11, 2011], it is possible to evaluate the risk of deposition of alkaline chlorides in the superheater and the risk of Cl-induced active oxidation based on the fuel composition.

3.2 Observation of Exhaust Emission Test Results

The emission quality standard for PLTU refers to the Minister of Environment Regulation Number 15 of 2019 as shown in Table 4.5 below. Mixing fuel, coal with Dense Jumputan Fuel in co-firing will affect the exhaust emissions produced, for this reason exhaust emission tests are carried out to observe changes that occur during the test *co-firing*.

Table 4. Emission Quality Standards for Coal Power Plants

No	Parameter	Up to Maximum		
		Coal (mg/Nm3)	Diesel oil (mg/Nm3)	Gas (mg/Nm3)
1	Sulfur Dioxide (SO2)	550	650	50
2	Nitrogen Oxide (NOx)	550	450	320
3	Particulate (PM)	100	75	30
4	Mercury (Hg)	0,03	-	-

3.2.1 Exhaust Emission Testing

Testing of exhaust emissions is carried out by comparing data on exhaust emissions when testing 100% coal with testing*co-firing* by using 1% BBJP. Data collection was carried out on*outlet air heater* like in the picture below.

Figure 3. Data Collection for Emission Tests at PLTU Indramayu

The results of testing exhaust emissions through tests conducted by third parties, show the average emissions at several measurement points are as follows:

Table 5. Resumes of 0% and 1% Co-firing emission testing

Emission	Unit	0%	1%

SO_2	mg/Nm3	215,40	413,85
NO_x	mg/Nm3	346,70	514,50
Mercury	mg/Nm³	0,001	0,004

Note: 0% operating data represents 100% BB operating data and 1% operating data represents 1% co-firing operating data. As if depicted in graphical form the emissions of sulfur dioxide and nitrogen monoxide are as follows:

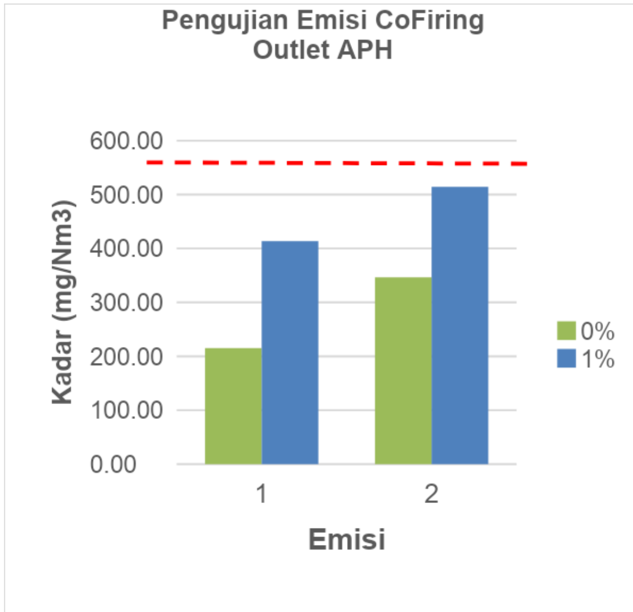

Figure 4. Graph of 0% and 1% BBJP Co-Firing Emissions

Note: 0% operating data represents 100% coal operating data and 1% operating data represents 1% co-firing operating data.

Based on the measurement results of exhaust emissions, the following results are obtained:

1. SO emission$_2$ the average shows an upward trend from 215.40 mg/Nm3 in the 100% coal operation test to 413.85 mg/Nm3 in the 1% Co-firing test, while the KLHK emission quality standard is 550 mg/Nm3.
2. emission NO_x the average shows an upward trend from 346.70 mg/Nm3 in the 100% coal operation test to 514.50 mg/Nm3 in the 1% Co-firing test, while the KLHK emission quality standard is 550 mg/Nm3.
3. The measuring instrument used meets the standards and calibration for measurements in the PC Boiler. The amount of exhaust emissions is good SO_2 and NO_x in the Co-firing test of 1% Solid Jumputan Fuel at PLTU Indramayu it still meets the Environmental Quality Standards according to Minister of Environment Regulation Number 15 of 2019.

3.3 Calculation of LCOE

The top cost of electricity generation (LCOE) is the cost required to generate each kWh of electrical energy, which is the quotient between all the cost components required to generate electricity, namely CAPEX and OPEX, by the energy produced. LCOE is expressed in rupiah/kWh.

Calculations for the CAPEX & OPEX of the Indramayu PLTU are obtained from the existing 2022 financial report data *audited.* The estimation of the remaining life of the PLTU is obtained from the results of the unit RLA and asset valuation by KJPP which is 30 years. Meanwhile, data on sales of electrical energy per year and the amount of coal needed per year are obtained from the 2022 operational performance report of PLTU Indramayu. The average CF of PLTU Indramayu from 2018-2022 is 81.6%. From the data obtained using the LCOE formula in equation 3.1, the LCOE value for the 100% scheme using coal is Rp. 780.53/kWh. This is in accordance with the reference LCOE value for sub-critical PLTU from IRENA, IESR in 2019, which is IDR 611/kWh up to IDR 841/kWh. While the LCOE calculation for the 1% BBJP scheme (solid jumputan fuel) with 99% coal obtained a value of Rp.780.69/kWh. The following is a table of data and calculation of LCOE values for the 100% coal and co-firing scheme of 1% BBJP and 99% coal.

Table 5. Calculation of LCOE with two schemes namely 100% Coal and co-firing 1% BBJP with 99% Coal.

INDICATOR	SCHEDULE 100% COAL	SCHEME 1% GDP & 99% COAL
PLTU CAPEX (Rp) PLTU Indramayu in 2022 (2022 audited LK data)	11.719.860.891.144	11.723.395.891.144
OPEX 2022 (Rp) (2022 audited LK data)	4.012.425.584.336	4.013.195.812.958
Remaining Age of PLTU Indramayu (years)	30	30
Electricity sales per year (MWh) already taking into account OH (lapkinop PLTU Indramayu data for 2022)	5.641.136,81	5.641.136,81
Annual coal demand (mtons)	3.655.000	3.654.535,45
LCOE (Rp/kWh)	780,53	780,69

From the table above it is known that if there is an increase in the LCOE value of Rp.0.16 for the co-firing scheme using 1% BBJP with 99% Coal. This was due to an increase in investment costs for purchasing equipment of IDR 3,535,000,000.00 as well as the additional purchase of BBJP which added to the 2022 OPEX burden of IDR 1,164,774,000.00.

The OPEX costs for BBJP processing were obtained from the budget plan submitted by DLH Indramayu Regency to the PLTU according to table 3.5.3. namely 61 million rupiah for one time production of 14 tons of BBJP. As for the next BBJP shipment, the OPEX cost for the 14 ton production will be IDR 34,300,000.00. The following is a description of the costs to supply BBJP needs at PLTU Indramayu in 1 year as well as the total OPEX costs for 1 year using the 1% BBJP co-firing scheme.

Table 6. BBJP Needs Cost in 1 year

INFORMATION	MARK
Cost of the first 14 tons of BBJP (Rp)	61.000.000
Cost of the second 14 ton BBJP etc. (Rp)	34.300.000
Cost of coal per year (Rp)	3.104.245.970.505
BBJP production of 14 tons in 11 days	33,18
BBJP delivery needs in 1 year (times)	
BBJP fee in 1 year (Rp)	1.164.774.000,00
BBJP realization per year (tons)	464,55
BBJP requirement of 1% per year (tons)	36.550
14ton BBJP for unit operation (hours)	24
In a year operating days using BBJP (days)	33

Table 7. OPEX calculation with two schemes namely 100% Coal and co-firing 1% BBJP with 99% Coal

Information	OPEX fee 100% coal	OPEX costs 99% coal with 1% BBJP
OPERATING EXPENSES	4.012.425.584.336	4.013.195.812.958
- Purchase of Electricity		
- Sewa Diesel/Genset		
- Transmission Usage Expenses		
- Carbon Emission Load		
- Fuel and Lubricating Oil	3.148.083.293.270	3.148.853.521.892
- H S D	35.481.803.924	35.481.803.924
- Coal	3.104.245.970.505	3.103.851.425.127
- Mixture of Fuel Oil, Chemicals, etc	4.656.301.783	4.656.301.783
- Biomassa(BBJP)		1.164.774.000
- Lubricant	3.699.217.058	3.699.217.058
- Maintenance	350.639.548.641	350.639.548.641
- Material Usage	2.763.837.447	2.763.837.447
- Wholesale Services	347.875.711.194	347.875.711.194
- Decreasing asset	512.603.110.133	512.603.110.133
- Administration	1.099.632.292	1.099.632.292

3.4 Calculation of Economic Analysis

Economic feasibility analysis is used to evaluate the return on investment from the project being built. The economic feasibility analysis in this study itself is used to evaluate and analyze predetermined electricity sales rates that are economically feasible or not feasible using the selling price of electricity. As for the LCOE for co-firing 1% BBJP, it is IDR 780.69/kWh, while the electricity selling rate for PLTU Indramayu to PT PLN (Persero) is in accordance with the agreement. *power purchase* agreement (PPA) is IDR 839/kWh. So that the implementation of 1% BBJP co-firing is still considered very feasible. In addition, according to the discussion of economic analysis in Chapter 3, there are several parameters for analyzing techno-economy in evaluating electricity sales rates for the 1% BBJP co-firing, namely *net present value* (NPV), *Internal rate of return* (IRR), *Profitability Index* (PI) as well as *pay back period* (PBP). In the following discussion, we will review in detail the techno-economic analysis from the company side and from the community side (Khorshidi et al., 2013).

3.4.1 Discussion Economic analysis from the company side.

a. Calculation and Analysis Results *Net Present Value* (NPV)

Net Present Value (NPV) is a parameter that describes an income that is obtained in the future for which interest has been paid upfront or discounted. The purpose of calculating the NPV is used to calculate the allocation of capital to analyze the benefits of a project implemented in order to build the same project in the future. With the initial investment cost for purchasing a BBJP counter tool of IDR 3,535,000,000.00 and the annual electricity sales revenue with a 1% BBJP co-firing scheme is IDR 532,845,602 with a discount rate taken from the inflation rate the highest during the last 10 that is equal to 8%. So by using equation 2.1, the NPV value is Rp.40,437,359. The following is the NPV calculation table.

Table 8. BBJP Project Net Present Value (NPV) Calculation

Year	Investment Cost	Cash In	Discount Factor	Nilai Kas
0	IDR 3,535,000,000	(Rp. 3,535,000,000)	1	(Rp. 3,535,000,000)
1		IDR 532,845,601.00	0,936	IDR 493,375,557
2		IDR 532,845,601.00	0,857	IDR 456,829,219
3		IDR 532,845,601.00	0,794	IDR 422,990,018
4		IDR 532,845,601.00	0,735	IDR 391,657,424
5		IDR 532,845,601.00	0,681	IDR 362,645,763
6		IDR 532,845,601.00	0,630	IDR 335,783,114
7		IDR 532,845,601.00	0,584	IDR 310,910,291
8		IDR 532,845,601.00	0,540	IDR 287,879,899
9		IDR 532,845,601.00	0,500	IDR 266,555,462
10		IDR 532,845,601.00	0,463	IDR 246,810,613
		Total		IDR 3,575,437,359
		NPV		IDR 40,437,359

From the results of the NPV calculation above, it is found that the NPV value is > 0 or in other words the project being worked on is positive which indicates that the income earned is greater than the investment value. So it can be concluded that the investment project to purchase BBJP equipment provides benefits for the company and is feasible to run.

b. Calculation and Analysis Results *Internal Rate of Return* (IRR)

The IRR parameter is a parameter used to obtain an interest rate that equates the total present value of expected cash flow receipts with the total present value required to invest. By using equation 2.2, an IRR of 8.25% is obtained. From the results of the IRR calculation, it shows that the IRR value is greater than the prevailing rate of return on investment, which is 8%. So that for the implementation of the BBJP tool investment project it can be said that it is feasible because the IRR is> 8% in accordance with the criteria of the IRR parameter.

c. Calculation and Analysis Results *Profitability Index* (PI)

Parameter *profitability index* (PI) is the ratio between the present value of cash flow receipts and the present value of cash flow payments. The PI parameter is also known as the benefit cost ratio parameter. From calculations using equation 2.4, it is found that the present value of receipts is Rp. 3,575,437,359 with the present value of spending for investment is Rp. 3,535,000,000, so that the value*profitability index* (PI) of 1.011. In accordance with the PI parameter criteria, namely the project is said to be feasible if the PI value is equal to or greater than 1, whereas on the other hand the project is rejected if the PI value is less than 1. From the results above it is known that if the PI value is> 1, which is worth 1.011, which means the project investment is purchasing BBJP tools are declared eligible to be accepted and run.

d. Calculation and Analysis Results *Pay Back Period* (PBP)

Parameter *Pay Back Period* (PBP) is used to calculate and find out how long it takes to pay back investment capital in a project that has been built from incoming cash flow. The PBP calculation is obtained by dividing the investment cost of the entire system which is worth IDR 3,535,000,00.00 with the inflow or average profit obtained for 10 years through the sale of electrical energy produced using the 1% BBJP co-firing scheme which is IDR .771.910.109,00. So that the PBP value obtained by using equation 2.6 is 6.63 years. From PBP's calculations to return the investment capital as a whole it takes 6.63 years from the asset's age value of 10 years. This shows that the total investment costs incurred by the company will be covered before it expires *lifetime* BBJP enumerator that is for 10 years. In the 7th year, PLTU Indramayu can buy a BBJP Return counter to increase BBJP's production capacity, which was initially only 14 tons per 11 days.

3.4.2 Discussion Economic analysis from the Community side.

The development of the administrative area in Indramayu Regency until 2011 consisted of 31 sub-districts, 308 villages and 8 sub-districts. As for several areas directly adjacent to the sea along the north coast of Indramayu, there are 11 sub-districts with a total of 38 villages. (Indramayu Regency Government, 2015). Characteristics of the area of Indramayu Regency is an urban, coastal residential area with fishing activities as the dominant activity. Residential areas for fishermen while for other areas the characteristics that appear are still influenced by agricultural activities. The coastal area has a lot of milkfish pond cultivation because the majority of the population's livelihoods are fishermen and pond farmers. While the other area is an agricultural area with community activities as a farmer and entrepreneur. In addition, many people migrate out of town in search of work. With the project for making BBJP in Indramayu district, it will increase the absorption of the workforce of the surrounding population as workers in the project or as workers supplier consumables for the project. Absorption of labor for the manufacture of BBJP in one cycle is as many as 18 people with a daily salary of IDR 120,000.00. In addition, residents around the project can take advantage of opportunities as suppliers or providers of materials such as gloves, masks, sacks, plastic, shovels, and bio activator chemicals. So that the project for making BBJP in Indramayu district will automatically improve the economy of local residents around the project.

From an environmental standpoint, Indramayu district generates 1,091 tonnes/day of waste, with 663.54 tonnes/day of waste managed by the local government or 60.76%. Waste management consists of waste handling of 526.25 tons/day or 48.19% and community-based waste reduction through the TPST (integrated waste processing site) program and 3R (*Reduce, Reuse, Recycle*) of 137.29 tonnes/day or 12.57%. With the BBJP project, a waste management unit will be provided in each village that will sort and process waste with an integrated waste treatment site for the manufacture of BBJP. From the waste management balance data for 2021-2022, it was found that the reduction of waste utilized as an energy source was only 0.11% with a capacity increase of 1%. This shows that the success of the BBJP project in Indramayu district will have an impact on fulfilling service standards in the cleaning sector, especially waste management and the use of renewable energy in a comprehensive, equitable, and integrity manner, the results of which can truly be felt and utilized by the people around Indramayu.

Table 9. Indramayu Regency Waste Management Balance Sheet for 2021-2022

No	Information	Year 2021	Year 2022	Change
1	Potential waste generation	394.685	398.524	3.839 (1%)
2	Waste reduction amount	46.422 (11,76%)	50.110 (12,57%)	2.687 (6%)
3	Total Waste Handling	163.192 (41,35%)	192.037 (48,19%)	28.845 (18%)
4	Garbage processing			
	- Raw Materials (animal feed, compost etc.)	105	148	43
	- Utilized as a source of energy	442 (0,11%)	446 (0,12%)	4,01 (1%)
5	Final processing	162.644	191.442	28.798 (18%)
6	Managed Waste	209.614 (53,11%)	242.148 (60,8%)	32.533 (16%)
7	Unmanaged Garbage	185.070 (46%)	156.376 (39%)	26.693 (16%)

3.5 *Business model canvas* (BMC)

Based on the description above, the BBJP manufacturing project can maximize revenue and control costs efficiently if the project is able to offer superior value to the customer segments it serves by taking into account various elements in its business system, so it is important for companies to be able to model a business system for BBJP manufacturing projects. Therefore, it is necessary to develop a "Business Model Canvas regarding its application to the BBJP manufacturing project at PLTU Indramayu with *key activities* namely mapping the business model canvas for the BBJP manufacturing project which consists of several elements, namely from *customer segments, value proposition, channels, customer relationship, key resources, key partnerships*, and *key activities*, to the *revenue stream* and *cost structure* on the BBJP manufacturing project.

It is easier for planners and decision makers in the project to see the logical relationship between the components of their business, so that value for consumers and value for the company can be generated. If it turns out that consumers prefer competitors over the products offered, companies need to look again at the target market, current needs, and value proposition compared to competitors. This is also related to the resources owned and the activities carried out. So that a project that was initially a small scale with a concept scheme of cooperation between consumers, investors, and regulators, in the future will become a medium to large-scale company that is still based on the people's economy.

4. Conclusion

BBJP processing of waste for the Indramayu PLTU uses the concept of collaboration with DLH Indramayu Regency. The BBJP processing site is carried out at the Indramayu Recycling Center using the peuyeumization method. Within 11 days, 14 tons of BBJP production were obtained which will be supplied as a mixed fuel for co-firing at PLTU Indramayu. Results of Technical and Operational Evaluation In visual mixing, the technique of mixing coal and biomass fuel before entering the silo using the manual process of heavy equipment at the coal yard shows that the two types of fuel (coal and Dense Jumputan Fuel) can still be mixed properly. Monitoring operational parameters at a gross load of 310 MW at PLTU Indramayu between 100% coal operation and 1% co-firing operation for critical points such as total air flow, total coal flow, main steam temperature, main steam pressure, gas air heater outlet temperature, and mill outlet temperature shows that it is still within safe limits on testing up to 1% BBJP. The volatile matter content in the biomass which tends to be the same as that of coal is also observed to be safe at the mill outlet temperature, which does not show a significant increase, making it safe for coal mill operations. FEGT temperature monitoring shows that the Co-Firing of 1% biomass of Dense Jumputan Fuel is still within safe limits where the average FEGT co-firing of biomass tends to increase compared to the existing condition of 100% coal from previously 881.60 °C to 882.87 °C with Co- Firing 1% BBJP. In general, the results of operational feasibility from monitoring visual mixing, pyrite material samples, monitoring coal mill operational parameters, monitoring FEGT boilers are still safe and within normal limits.

Evaluation results from the environmental side. The average SO2 emission shows an increasing trend from 215.40 mg/Nm3 in the 100% coal operation test to 413.85 mg/Nm3 in the 1% Co-firing test, while the KLHK emission quality standard is 550 mg/Nm3. The average NOx emission shows an increasing trend from 346.70 mg/Nm3 in the 100% coal operation test to 514.50 mg/Nm3 in the 1% Co-firing test, while the KLHK emission quality standard is 550 mg/Nm3. The amount of exhaust emissions is good SO_2 and NO_x in the Co-firing test of 1% Solid Jumputan Fuel at PLTU Indramayu it still meets the Environmental Quality Standards according to Minister of Environment Regulation Number 15 of 2019.

Evaluation results of LCOE values. Based on the calculation results, the LCOE value for the 100% scheme using coal is Rp. 780.53/kWh. While the LCOE calculation for the 1% BBJP scheme (solid jumputan fuel) with 99% coal obtained a value of IDR 780.69/kWh for an average CF value (*capacity factor*) by 81%. The increase in LCOE will increase linearly with the increase in the percentage of co-firing. Results of the evaluation of the economic value of the BBJP Project. From the calculation of the economic value, the NPV value is Rp.40,437,359, the IRR value is 8.25%, the profitability *index* (PI) of 1.011, and the payback period (PBP) of 6.63 years. Using 4 parameters of economic value shows the results of the BBJP processing project are feasible to implement.

The results of the evaluation of economic value from the community side. The BBJP manufacturing project in Indramayu district will improve the economy of local residents around the project by absorbing 18 workers with a daily salary of IDR 120,000.00. In addition, residents around the project can take advantage of opportunities as suppliers or providers of materials such as gloves, masks, sacks, plastic, shovels, and bio activator chemicals. From an environmental standpoint, there is a reduction in waste utilized as an energy source of 0.11% in 2022, with a capacity increase of 1% from 2021. By using the business canvas model, the BBJP manufacturing project can maximize revenue and control costs efficiently.

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