

Heat Quality Enhancement and Carbon Dioxide Emissions Reduction from Coal Burning by Combining Low-Ranked Coal with Biomass Waste as A Clean Energy Solution to Achieve Energy Security in Indonesia

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Abstract. Indonesia is the fifth largest coal producer in the world with coal reserves reaching 39.56 billion tonnes. Coal reserves of medium and high quality are expected to be exhausted in 2048, therefore it is necessary to utilize low-ranked coals. Low-ranked coals have a low heating value (<5,100 kcal/kg) and produce greater CO₂ emissions compared to medium and high rank coals. One method to increase heating value and reduce CO₂ emissions from low-ranked coals is through the Utilization of hybrid coal. Hybrid coal is low quality coal combined with biomass waste and has undergone a pyrolysis process together. The mixing and co-pyrolysis of low-ranked coal with biomass waste such as rice husk, empty palm fruit bunches, and rubber wood with a ratio of 7:3 is known to be able to increase the final product calorific value by 31.10–44.12% and reduce non-neutral CO₂ emissions by 15.56–21.31%. The hybrid coal production process is highly prospective to be implemented in Indonesia, especially in Central Java, South Sumatra and South Kalimantan. The payback period from the hybrid coal industry with a production capacity range of 540 thousand to 4.5 million TPY can be achieved in 10–13 years with a net profit range of IDR 137 billion to IDR 493 billion per year and a net present value range of IDR 285 billion to IDR 1.1 trillion.

Keywords: biomass, coal, CO₂ emission, co-pyrolysis, hybrid coal

1. Introduction

As one of the fastest developing country in the world, Indonesia has abundant population of approximately 267 million people. The population and subsequent GDP are also projected to be increasing throughout years. Consequently, this will lead to an increase in energy consumption and demand. Fact shows that through the years of 2012 up to 2017, there was a significant annual increase of 7% in Indonesia's electrical consumption. This projection urges the country to find the proper technology or innovation which utilizes country's abundant resources in order to fulfill the rapidly increasing energy demand, and furthermore achieving energy security.

1.1 Current Indonesian Energy Condition and Its Security

International Energy Agency (IEA) defined energy security as the prodigious, continuous and uninterrupted energy at affordable price and accessible state. Indonesia has an extensive number of diverse energy sources, hence being able to use and optimize all energy sources, including oil, natural gas, coal and renewables, is highly essential to achieve energy security. Analyzing the energy sector for the last few years, Indonesia has been fueled with various energy supplies which include the previously mentioned energy sources. Indonesia Energy Outlook 2019 has noted the total primary energy production of all these sources reaching up to 411.6 MTOE in 2018. It should be highlighted that

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Indonesia is currently known as the fourth largest producer of coal in the world with total coal export activity reaching around 261.4 MTOE. The Ministry of Energy and Mineral Resources has predicted that the energy demand will rise annually as the population for the upcoming years is projected to be increased. The energy demand will rise with an annual growth of 5.0%, 4.7% and 4.3% for three different scenarios, which are Business as Usual (BaU), Sustainable Development (SD) and Low Carbon (LC), respectively (Suharyati, Pambudi, Wibowo, & Pratiwi, 2019). The growth of energy demand for 2020 up to 2050 period is shown in Figure 1.

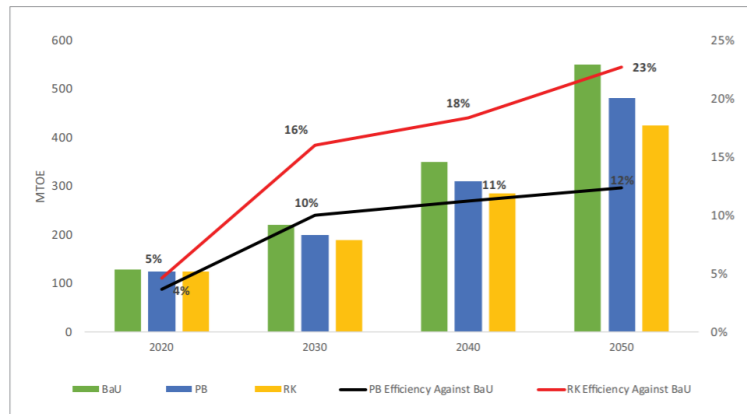


Figure 1. Comparison of Indonesia energy demand growth in three scenarios (Suharyati et al., 2019).

Based on Figure 1, the final energy demand of Indonesia in 2050 will reach 548.8 MTOE, 481.1 MTOE, and 424.4 MTOE, respectively (Suharyati et al., 2019). Nevertheless, the rising concern regarding global warming issues has led officials to shift the country energy demand into renewable resources. This affects the non-renewable sources of energy, such as coal especially, to be less favorable despite of its vast quantity.

1.2 Coal Consumption and Coal Quality in Indonesia

Coal is one of the largest energy sources in Indonesia. Indonesia's coal production were recorded at 560.7 million tonnes with coal reserves of 39.56 billion tonnes (Kementerian Energi dan Sumber Daya Mineral, 2020). More than 80% of domestic coal consumption is used for electricity generation (Direktorat Jenderal Mineral dan Batubara, 2020). Furthermore, coal consumption for electricity generation is expected to increase from 90 million tonnes in 2018 to 153 million tonnes in 2028 (PT. PLN (Persero), 2019).

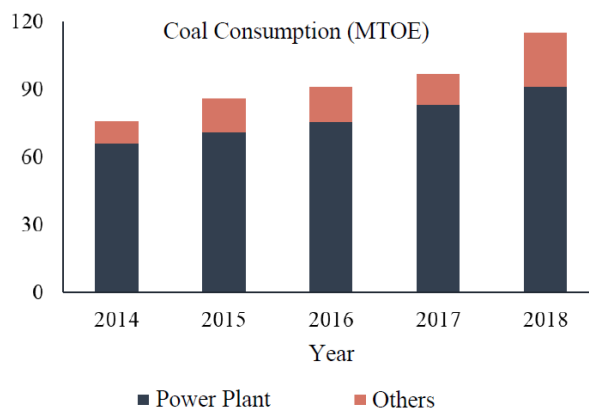


Figure 2. Coal domestic consumption (PT. PLN (Persero), 2019).

However, proven reserves of medium to high ranked coal are projected to be exhausted in 2038, and the total reserves of medium to high ranked coal will be exhausted in 2048 (BPPT, 2018). Since the better coal quality mostly used by metallurgy and cement production industry, powerplant with less

grade specification requirement will use low quality coal (<5,100 kcal/kg) which still has several problems such as relatively high water content, low calorific value, low efficiency and high transportation costs (Song, Tahmasebi, & Yu, 2014).

The amount of CO₂ emissions produced by burning coal is very dependent on the grades of coal used. The higher the rank of coal, the lower the carbon emission for each unit of energy produced. Burning low quality coal will produce relatively higher CO₂ emissions for each unit of energy it produces. CO₂ is a greenhouse gas (GHG) that causes global warming. The average emission factor from burning coal is 99,718 kg CO₂/TJ (Kementerian Energi dan Sumber Daya Mineral, 2017). With a total coal-fired power plant capacity of 25.7 GW, CO₂ emissions due to burning coal to produce electricity reached around 68 GTonne/year. On the other hand, Indonesia has committed to reducing CO₂ emissions as much as 26% by 2020 and 29% by 2030 as stated in Indonesia's first Nationally Determined Contribution (NDC) in 2016. Therefore, it is extremely crucial to discover a cleaner and more efficient technology to utilize the abundance of coal as a way to achieve Indonesia's energy security. Figure 3 shows the magnitude of the emission factor by each type of coal.

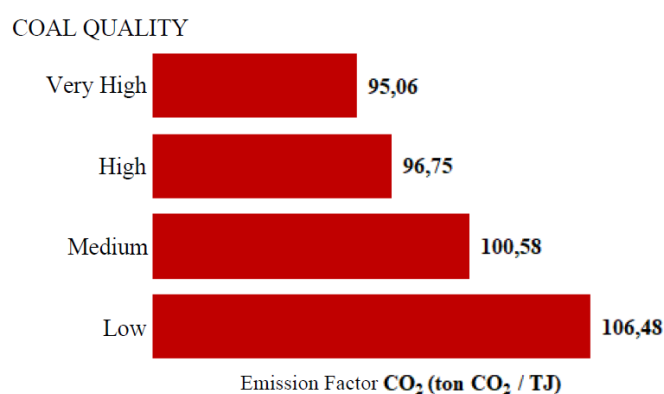


Figure 3. Comparison of coal emission factor (Kementerian Energi dan Sumber Daya Mineral, 2016).

The average coal combustion will produce 0.36 kg of CO₂ for every kWh of electricity generated. To date, 59.91% of Indonesia's electricity generation is still dependent on coal (PT. PLN (Persero), 2018). The International Renewable Energy Agency (IRENA) noted that the total capacity of coal-fired steam power plants reached 25.7 GW. With this total capacity, the CO₂ emissions produced by Indonesia are estimated to reach 68.54 GTonnes every year just to generate national electricity.

1.3 Potential Indonesian Biomass Sources

Besides coal, another solid fuel that can also be used to produce energy is biomass. Biomass is a new and renewable energy source, whose sources can be categorized into agricultural waste, forestry waste, urban waste, oil-producing plants and biological waste (Basu, 2013). Burning biomass from these sources produces neutral CO₂ which does not have any impact on the accumulation of CO₂ in the atmosphere. In addition, SO_x and NO_x emissions produced from biomass are also small so they do not pollute the atmosphere.

Indonesia has abundant biomass resources with a total potential of 32.6 GW. The potential of various kinds of biomass is shown in Figure 4. According to the Director General of New, Renewable Energy and Energy Conservation, Ministry of Energy and Mineral Resources, the total general potential of biomass waste into electricity in Indonesia is 32,654 MWe with rice having the second largest potential of 9,808 MWe after oil palm with a potential of 12,654 MWe (Ditjen EBTKE, 2016). Although the potential of biomass in Indonesia is extensive, biomass has a much lower heat density compared to coal. Table 1 shows the calorific value of lignite coal and several types of biomass. The low heat density of biomass causes the need for more biomass to produce the same energy as coal. This will cause problems, especially for its transportation.

Table 1. Calorific value of lignite coal and biomass waste (Sasongko, Wulandari, Rubani, & Rusydiansyah, 2017).

Material	Calorific Value (kcal/kg)
Rice Husk	2.73
Empty Fruit Bunch	3.93
Rubber Wood	4.06
Lignite Coal	5.03

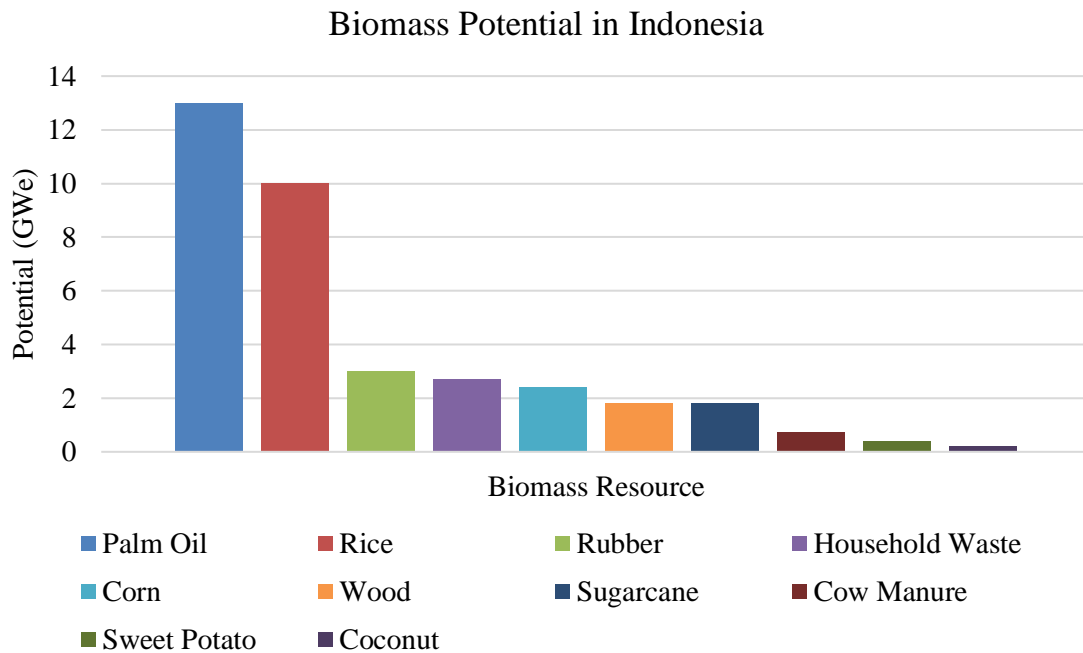


Figure 4. Comparison of biomass potential in Indonesia (Gielen, Saygin, & Rigter, 2017; Tun, Juchelkova, Win, Thu, & Puchor, 2019).

1.4 Objective of The Study

The concern of Indonesian energy security can be answered through the utilization of Indonesia’s current big coal reserves. Unfortunately, various new policies and regulations that are implemented and signed revolving ways to reduce global warming and CO₂ emission, and thus making coal uncosiderably to be a non-clean technology. In addition, the quality of the produced coal is considered to be low-ranked coal. Therefore, in order to maximize the utilization of coal potential in Indonesia, a new innovation and technology is required to enhance the heat quality of the low-ranked coal and produce lower CO₂ emission. This can only be achieved by involving biomass waste potential, which also abundant in Indonesia, into the coal enhancement effort. The quality of Indonesia's low-ranked coal is upgraded to the equivalent of higher rank coal by mixing waste biomass to form hybrid coal, followed by co-pyrolysis. In hybrid coal co-pyrolysis, the type of coal and biomass affect the energy gain of the co-pyrolysis product and it is necessary to know the relationship (Quan & Gao, 2016). Several study and work related to coal and various biomass waste type co-pyrolysis have shown the same tendencies on increasing hybrid coal calorific value and decreasing CO₂ emission. The study shows that hybrid coal have lower H/C ratio from coal, thus inferred that the ignition temperature of hybrid coal is lower compared to its raw coal and biomass which implicates on reducing the initial energy required to burn hybrid coal (Quan & Gao, 2016; Sasongko et al., 2017).

The objective of this study is to present a product innovation of hybrid coal by co-pyrolysis process of low-ranked coal and biomass waste mixture. This will include the product quality and feasibility analysis and examination of hybrid coal to produce a higher heat quality of coal with lower CO₂ emission. Moreover, considering the potential of biomass in Indonesia, this study also analyzes the

feasibility of different biomass waste implementation into the hybrid coal production. With the appropriate technology, coal and biomass waste can be combined as hybrid coal and thus becoming reliable and cleaner resource for Indonesia to achieve energy security. This analysis is achieved through a series of literature review and lab scale experiment.

2. Coal and Biomass Utilization Technology

2.1 Co-firing Process Technology

One of the biomass utilization processes that have been developed is the burning of biomass altogether with coal which is known as the co-firing process. In this process, biomass is directly burned together with coal without going through any series of prior treatments. A literature stated that the use of biomass for pulverized firing is still very limited, especially in terms of biomass particle size and water content. As a result, the biomass that can be used for this method is only the one that has been reduced in size into powder form, for example sawdust. The same literature also indicates that direct co-firing of biomass with coal cannot be carried out in fixed bed furnace (Roni et al., 2017). Most of the current existing coal powerplant technology are facing technical issues regarding coal burning. The presence of biomass without additional pre-treatment will have high alkali and moisture content. This will worsen the current technical issue and makes the combustion less effective. Therefore, the co-firing process of coal with biomass is still considered to be less efficient, especially in Indonesia.

2.2 Co-pyrolysis Process Technology

Another method for harnessing the energy and carbon neutral nature of biomass is through the co-pyrolysis process. Co-pyrolysis is the process of heating coal with biomass altogether without the presence of oxygen. Heating causes reduction in water content and volatile hydrocarbon compounds contained in coal. Subsequently, this leads to an increase in the calorific value of the mixture. Heating also causes thermal decomposition of the chemical structure of biomass so that biomass becomes less susceptible to decay. The mechanism that occurs in the co-pyrolysis process can be divided into 5 regimes based on the temperature (Basu, 2013):

- Regime A is a non-reactive drying regime in which a reduction in water content occurs without being followed by a change in chemical composition that takes place in the temperature range of 50–120 °C.
- Regime B is a regime in which lignin softens into an adhesive material which takes place in the temperature range of 120–150 °C.
- Regime C is a reactive drying regime in which the breaking of the C-H bonds and the depolymerization of hemicellulose produce a condensed short polymer which takes place in the temperature range of 150–200 °C.
- Regime D is a hemicellulosic torefaction regime, characterized by devolatilization and carbonization of solids due to the breaking of intermolecular and intramolecular hydrogen bonds, C-C, and C-O to form tar and gases, which take places in the temperature range of 200–250 °C.
- Regime E is a regime in which the decomposition of hemicellulose continues, accompanied by devolatilization and carbonization of cellulose and lignin which takes place in the temperature range of 250–300 °C. The cell structure of the biomass has been completely destroyed to produce a brittle, hydrophobic solid product.

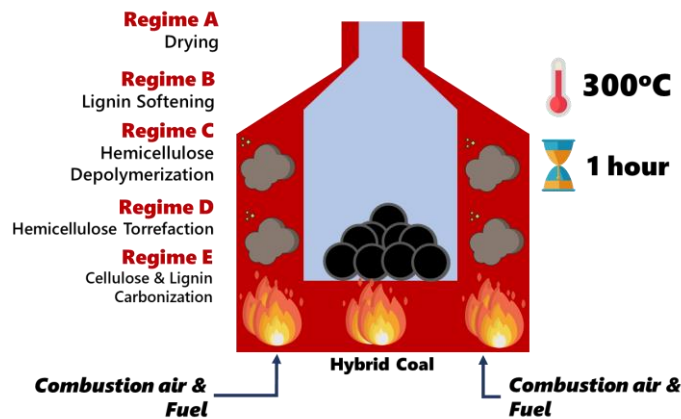


Figure 5. Illustration of regimes during co-pyrolysis process.

The co-pyrolysis product of coal and biomass will produce a new solid fuel called hybrid coal. Combining biomass with coal can reduce the non-neutral CO₂ emissions originally produced by pure coal burning. Then it is followed by a co-pyrolysis process to increase the calorific value of the biomass. A research shows that co-pyrolysis of coal and biomass mixture at a ratio of 7:3 is able to increase its heating value up to 31% and reduce CO₂ emissions up to 14.3% making it advantageous to be implemented (Sasongko et al., 2017). In addition, the relatively mild process condition of co-pyrolysis process makes it generally feasible to be up-scaled to the industrial production. Nevertheless, this process requires additional pre-treatment stage which makes it relatively costly in CAPEX.

3. Methodology

3.1 Materials

The co-pyrolysis process in the production of hybrid coal requires two main raw materials, which are low-ranked coal and biomass. There is also supporting material, which is molasses, as binding agent to tighten the coal and the biomass during the co-pyrolysis process. In addition, water is also used to liquefy the molasses. The complete equipment and materials used during the experiment are presented in Table 2.

Table 2. Equipment and materials used during the laboratory scale experiment.

Equipment	Materials
Furnace (co-pyrolysis reactor)	Lignite type coal
Oven/ Dryer	Biomass Waste:
	Rice Husk
	Rubber Wood
	Empty Fruit Bunch
	Molasses
	Water
	Nitrogen (N ₂)

This research was aimed to compare the quality of mixture of lignite type coal with 3 different types of biomass waste, namely rice husk, rubber wood and palm oil empty fruit bunch. The mixture has the 7:3 ratio of coal to biomass. On the laboratory scale experiment, the co-pyrolysis process takes place in a furnace which further called as the co-pyrolysis reactor. The reactor scheme is depicted in Figure 6.

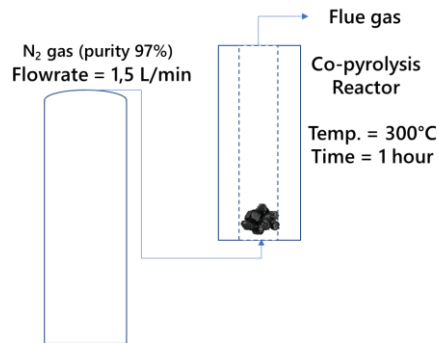


Figure 6. Co-pyrolysis reactor configuration on a laboratory scale experiment.

3.2 Methods

The hybrid coal production process consists of 3 main stages, namely size reduction, mixing and molding, and co-pyrolysis. The stages in the production of hybrid coal are shown in Figure 7.

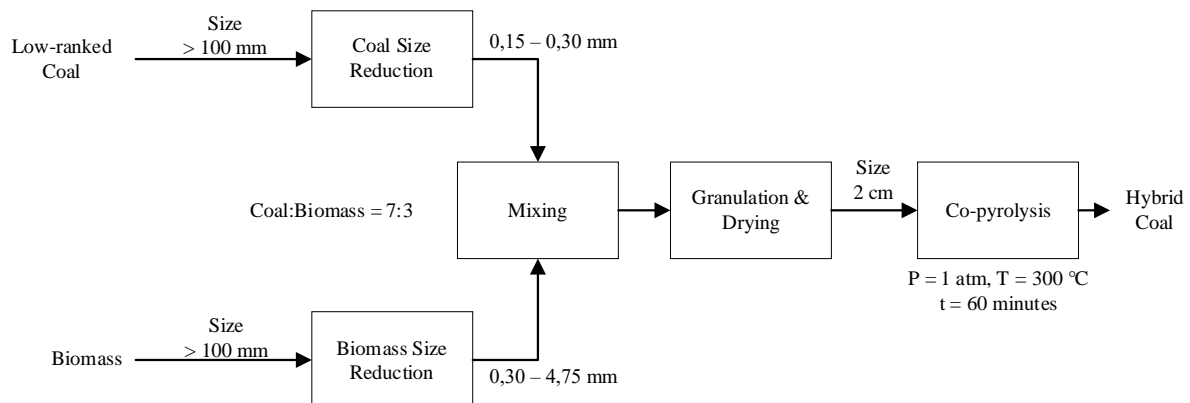


Figure 7. Hybrid coal production stages on a laboratory scale experiment.

Firstly, coal is reduced in size to 0.15–0.30 mm diameter and biomass is reduced to 0.30–4.75 mm diameter. The size reduction stage aims to facilitate the homogeneous mixing process of coal and biomass. Size reduction was carried out using a blender and a ball mill. After reaching the desired size, coal and biomass are mixed with a mass ratio of 7:3 (referring to the optimum ratio used by Sasongko et al. in their research) until they are homogeneous. An adhesive agent in the form of molasses is added to the coal-biomass mixture to support the granulation (molding) process. At this stage, the mixture of coal, biomass and molasses is granulated to gain sphere pellets having approximately 2 cm in diameter. Then, the pellets are dried in an oven at 100 °C for 24 hours to reduce the moisture content and compact the pellet structure, hence reducing the heating load of the following co-pyrolysis process. The drying process produces solid coal-biomass mixture pellets which sticks firmly inside. After drying, the pellets are put into the co-pyrolysis reactor. The co-pyrolysis process was run at 300 °C for 1 hour. During co-pyrolysis process, N₂ gas is passed through the reactor as an inert gas to reduce the O₂ concentration in the reactor, thus preventing combustion. Combustion is undesirable since it will consume the fixed carbon content in the pellets. The co-pyrolysis process produces hybrid coal as the desired product. The hybrid coal is then cooled and stored for proximate, ultimate and calorific value analysis.

The economic evaluation was conducted using three economic parameters namely Payback Period, NPV and IRR which calculated based on following terminology (Turton, Bailie, Whiting, Shaeiwitz, & Bhattacharyya, 2012). It requires graphical analysis of the cashflow diagram in order to earn the values.

- Payback Period: Time required, after start-up, to recover the fixed capital investment for the project.
- NPV: Cumulative discounted cash position at the end of the project.
- IRR: Interest or discount rate for which the net present value (NPV) of the project is equal to zero.

4. Hybrid Coal Quality Analysis

Analysis were carried out on hybrid coal products with rubber wood and oil palm empty fruit bunch. Meanwhile, the analysis on hybrid coal product with rice husk refer to data obtained from the literature (Sasongko et al., 2017). The overall analysis result for all hybrid coal products are shown in Table 3.

Table 3. Hybrid coal quality analysis result.

Materials	Proximate Analysis (%-wt dry basis)				Ultimate Analysis (%-wt dry basis)						GCV (kcal/ kg)
	Ash	Fixed Carbon	Volatile Matter	Moisture	C	H	O	N	S	Other	
Rice Husk (Sasongko et al., 2017)											
Coal	2.07	37.71	42.20	18.02	54.81	5.46	36.87	0.71	0.08	2.07	5,027
Biomass	32.21	11.50	47.41	8.88	28.65	4.60	33.67	0.77	0.10	32.21	2,726
Hybrid	11.89	51.04	34.00	3.07	65.06	3.73	18.26	0.86	0.20	11.89	5,689
Empty Fruit Bunch											
Coal	18.07	29.84	34.35	17.74	46.08	5.01	29.83	0.58	0.43	18.07	4,183
Biomass	8.10	17.02	65.16	9.72	41.70	6.06	43.31	0.70	0.13	8.10	3,925
Hybrid	12.53	45.80	40.75	0.92	63.30	4.04	18.14	1.15	0.84	12.53	5,918
Rubber Wood											
Coal	18.07	29.84	34.35	17.74	46.08	5.01	29.83	0.58	0.43	18.07	4,183
Biomass	1.70	16.31	70.57	11.42	44.27	6.37	47.47	0.07	0.12	1.70	4,058
Hybrid	11.22	47.67	39.71	1.40	62.22	4.13	20.65	1.07	0.71	11.22	5,716

According to the analysis result, it is known that there is an increase in calorific value which is initially in the range of low-ranked coal/ lignite (<5,100 kcal/kg) to medium-ranked coal/ subbituminous (5,100–6,100 kcal/kg). This shows that the co-pyrolysis process is the effective method to increase the heating value of coal and biomass so that it can be used as a more efficient fuel. The increase in heating value occurs due to the evaporation of water content and volatile compounds in coal and biomass that happened during the co-pyrolysis process. The presence of water in coal causes the combustion heat absorption to raise the temperature and evaporate the water which affects the remaining combustion heat to be utilized. In addition, the reduction in volatile compounds which have a lower heating value than fixed carbon also causes the increase in the heating value of hybrid coal. The combustion of volatile compounds will cause fire, while combustion of fixed carbon will produce flaming embers.

Biomass has higher content of volatile compounds than coal. As a result, burning biomass will firstly produces fire prior to flaming embers formation. If this is applied to a furnace, the burning of biomass will leave unburn carbon in the form of a black stain on the furnace wall. This is definitely undesirable for industrial coal burning furnaces in power plants, especially those that utilize Pulverized Coal Combustion furnaces. The application of co-pyrolysis process is able to reduce the volatile matters in biomass, making the biomass suitable and better to be applied to the furnace.

Based on the results of this research, the hybrid coal produced using the process of co-pyrolysis is able to increase the heating value and reduce the total CO₂ emissions from original coal burning. Table 4 shows both the increase and decrease percentage of the material calorific value and CO₂ emission, respectively.

Table 4. The increase in calorific value and decrease in CO₂ emission of hybrid coal.

Biomass Waste Constituent of the Hybrid Coal	Calorific Value Increase (%)	CO ₂ Emission Decrease (%)
Rice Husk	31.10	15.56
Empty Fruit Bunch	44.12	18.40
Rubber Wood	37.87	21.31

The calorific value is the energy released in the form of heat per unit mass of solid product when the solid undergoes complete combustion. The calorific value of coal raw materials, biomass raw materials, hybrid coal products, and standard types of coal in the form of GCV are shown in Table 3. According to Table 4, there is an increase in hybrid coal calorific value with the percentage range of 31.10–44.12% compared to its coal raw material constituent. This increase occurs due to reduction of water content and volatile compounds in coal and biomass mixtures, followed by an increase in fixed carbon content during co-pyrolysis. The carbon content is the main source of heat energy released when burning a fuel.

In addition, non-neutral CO₂ reduction occurred as shown in Table 4. Calculations were carried out on the basis of the amount of energy generated from the complete combustion of a hybrid coal sample to reach 100 MW. The carbon neutral composition of the biomass in the hybrid coal product is assumed to follow the theoretical calculation results according to the biomass raw material yield, while the non-neutral carbon composition of the coal in the hybrid coal product is the residual value. This assumption is used because of the synergistic effect on hybrid coal recovery that occurs due to changes in the thermal decomposition of coal components. Hence, the theoretical calculations according to coal raw material yield cannot be used. The reduction in CO₂ emissions of hybrid coal varies and is in a narrow range of 15.56–21.31%. These results indicate that hybrid coal is more environmentally friendly than the original coal when used as fuel in a power plant. The high non-neutral CO₂ emission reduction value from hybrid coal occurs due to the high calorific value of hybrid coal and the low composition of non-neutral C elements in the product. The high calorific value causes the required mass amount of hybrid coal to be reduced, while the low elemental composition of non-neutral C causes the emission of non-neutral CO₂ to also be low.

5. Feasibility Study

Hybrid coal is a very prospective source of energy since it has the ability to increase the calorific value of biomass and low-ranked coal as well as reducing non-neutral CO₂ emissions. As a country rich in biomass sources and abundant coal reserves, Indonesia has great potential to produce hybrid coal for commercial purpose. Hybrid coal production in Indonesia on an industrial scale can follow the process configuration as shown in Figure 6.

5.1 Material & Plant Location Study

There are several prospective locations to build hybrid coal plants in Indonesia. The locations are determined based on the distance closeness criterion which cover all the required material sources for hybrid coal production such as biomass, coal mines, water sources, and most importantly the market target which is steam power plant with large electricity capacity. It is also based on the most optimum biomass potential in the area and the diversification of the existing biomass for each area. The geopotential study gives three most suitable areas for the hybrid coal plant location, namely South Sumatra, South Kalimantan, and Central Java. The corresponding biomass potential is presented in Table 5.

Table 5. Biomass potential in Indonesia (Kementerian Pertanian, 2018).

Biomass	Production (as per 2018)		
	Total	Region with optimum production	
Rice	81.15 M tonnes	Central Java	11.40 M tonnes
Palm Oil	37.80 M tonnes	South Kalimantan	1.36 M tonnes
Rubber Wood	3.63 M tonnes	South Sumatra	997,682 tonnes

Based on 2018 agricultural statistics, 21% of palm oil biomass is the empty fruit bunch waste, 20% of rice is the rice husk waste and 18% of rubber production is the rubber wood waste. These biomass wastes are the ones that is underutilized in Indonesia (Kementerian Pertanian, 2018). The detailed results of the location and raw material study of the hybrid coal plant are presented in Table 6.

Table 6. Raw material and market target location of hybrid coal plant.

Plant Area	Raw Material Source			Market Target	
	Coal	Biomass Waste	Water	Power Plant	Capacity
Central Java	PT AGM	Spread*	Java Sea	Tanjung Jati B	4 x 660 MW
South Kalimantan	PT AGM	CPO Plant	Barito River	Asam-asam	2 x 65 MW
South Sumatera	PT BA	PTPN 7	Enim River	Sumsel 8	2 x 620 MW

*The rice husk sources are spread all around Central Java, it is recommended to built approximately 3 warehouses collection point throughout Central Java.

Based on Table 5 and 6, the three area has met several predetermined criteria, hence they are eligible to be places for the hybrid coal production plant. Coal and biomass transportation can be carried out using trucks and barges. Meanwhile, biomass waste transportation system may differ for each type. The source of biomass waste in Central Java is collected by setting up three warehouses in several areas across Central Java to collect rice husk from multiple location nearby, then it is transported to the location of a hybrid coal plant in Jepara. In South Sumatra, rubber wood is directly transported from PTPN 7 rubber wood plantations. For South Kalimantan area, empty fruit bunches are taken from CPO mills located nearby the area.

5.2 Economic Study

An economic study was conducted to see the financial feasibility of the hybrid coal plant. The assumptions used in this economic study are as follows.

1. Hybrid coal production capacity is in accordance with the biomass waste availability, the coal to biomass ratio applied is 7:3.
2. The plant life from the beginning of the project until the end of operation is 22 years.
3. The average interest rate for bank loans for industry is 9.91%.
4. The area of land required is 40 hectares with the approximation based on the required space for process equipments, material storages, utilities, waste treatment, green area and future expansion.
5. The dollar exchange rate is IDR 14,050,00.
6. Calculation of coal price refers to the reference coal price in September 2019. The selling price has an additional valuation due to the environmentally friendly offered benefit.
7. Employee salary is 3 times the Provincial Minimum Wage, with a total employee consisting of 4 shifts and 3 teams.
8. The electricity is generated from PLN, while the water used comes from its own water source.
9. The biomass waste prices are based on actual survey to several representative farmers, and it has been set above the average price in order to improve farmers economical well-being.

The price of low-ranked coal (lignite) is obtained from the Reference Coal Price with a value of USD 40–50 per tonne, while the biomass price is presented in Table 7. Meanwhile, the plant capacity and demand for low ranked coal and biomass waste for the hybrid coal plant is presented in Table 8.

Table 7. The used biomass waste price.

Biomass Waste Type	Price per Tonne
Rice Husk	IDR 100,000,00
Empty Fruit Bunch	IDR 110,000,00
Rubber Wood	IDR 20,000,00

Table 8. Capacity and demand for coal & biomass in hybrid coal plants.

Plant Area	Plant Capacity (TPY)	Raw Material Demand (TPY)	
		Low Ranked Coal	Biomass Waste
Central Java	4,498,894	4,485,667	1,922,000
South Kalimantan	1,078,936	1,078,000	462,000
South Sumatera	540,022	598,200	179,460

Based on Table 8, hybrid coal plant which requires the largest coal demand are located in the Central Java area. This is due to the fact that rice husk biomass has the largest production in Indonesia, especially in Central Java, so the need for coal is also the largest in the area. In addition, the price of equipment (bare module cost) for the hybrid coal plant is mostly reviewed from several sources, such as simulations using ASPEN Process Economic Analyzer V10 and CapCost calculations. Furthermore, the cost calculation and economical calculations are based on Turton’s textbook (Turton et al., 2012). The supply chain general schemes for all three designated locations are shown in Figure 8 to Figure 10.

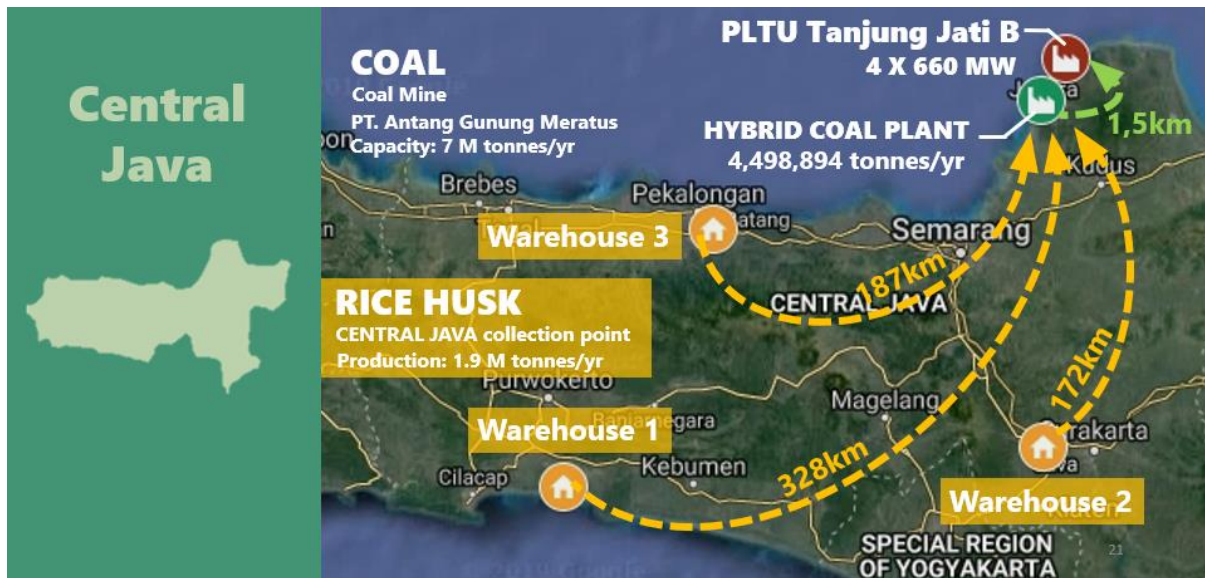


Figure 8. Hybrid coal plant supply chain and market target scheme in Central Java.

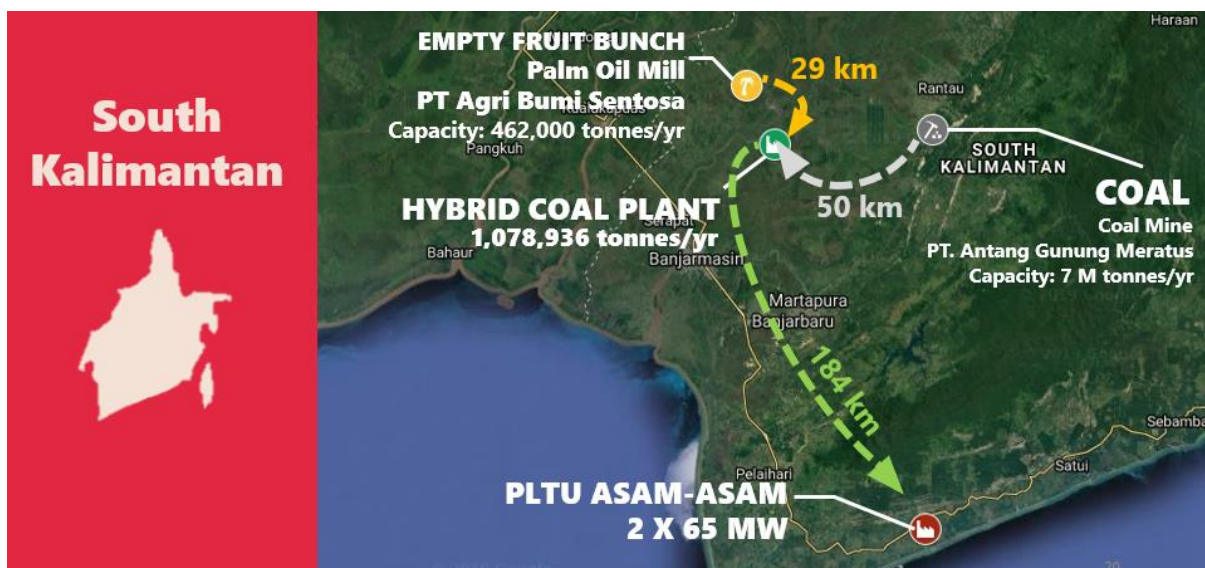


Figure 9. Hybrid coal plant supply chain and market target scheme in South Kalimantan.

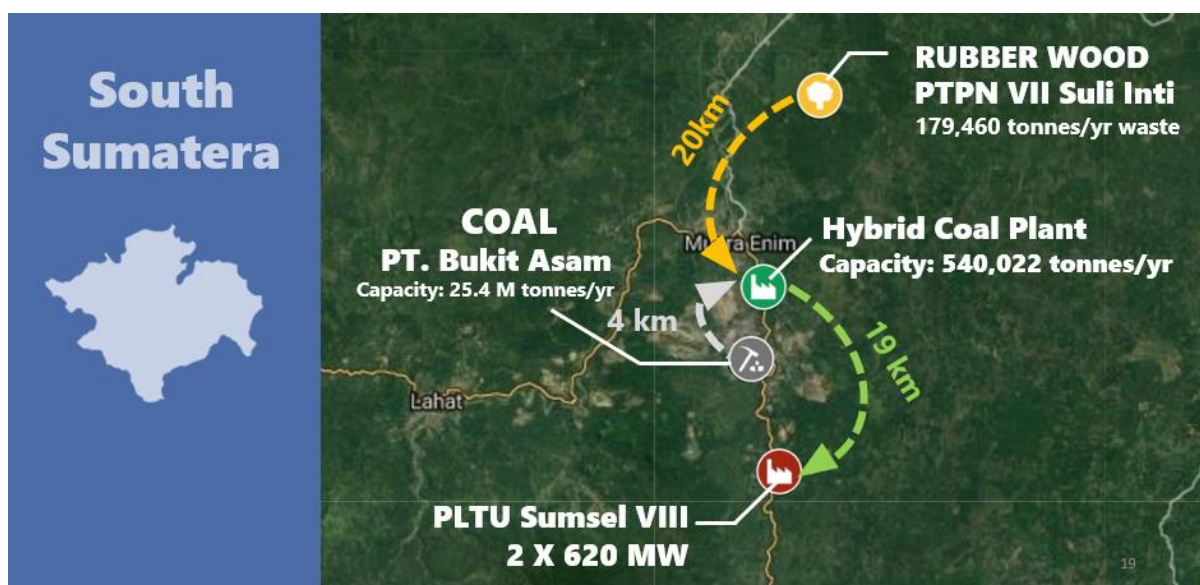


Figure 10. Hybrid coal plant supply chain and market target scheme in South Sumatera.

The basis for consideration of the selling price of hybrid coal product is based on the carbon tax and carbon regulations that will be applied in near future starting at USD 10/tonne CO₂. The total CO₂ produced by low-ranked coal burning is 103.8 tonnes/hour, while hybrid coal burning produces 96.54 tonnes/hour with 18.4% of CO₂ emitted being neutral. Therefore, the selling price of hybrid coal product is set at USD 80/tonne or IDR 1,124,000/tonne and the coal utilization comparison results are presented in Table 9.

Table 9. Comparison of the use of lignite coal and hybrid coal in power plant.

Parameter	Low Ranked Coal	Hybrid Coal
Coal Demand	350,285 TPY	249,308 TPY
Coal Price (annually)	IDR 255.9 Billion	IDR 280.2 Billion
Carbon Tax (annually)	IDR 115.5 Billion	IDR 87.7 Billion

Based on Table 9, although the cost of purchasing the hybrid coal is almost IDR 25 billion/year higher than the low-ranked coal, the carbon tax paid is lower by almost IDR 28 billion/year, making it an annual savings of 13%. Economic analysis and calculation of economic parameters are carried out using discounted cumulative cashflow analysis for hybrid coal plants in each area referring to Turton's textbook (Turton et al., 2012). Economic parameters that are important to find out when analyzing project feasibility are payback period, net present value (NPV) and internal rate of return (IRR). Based on this analysis, the net profit from hybrid coal plants is in the range of IDR 137 billion to IDR 495 billion annually. Further details regarding forementioned economic parameters are presented in Table 10.

Table 10. Hybrid coal plant economic parameters.

Plant Area	Economic Parameter		
	Payback Period	NPV	IRR
Central Java	10.5 years	IDR 1,107,221,794,028	15.9%
South Kalimantan	13.2 years	IDR 285,767,582,175	13.2%
South Sumatera	10.2 years	IDR 312,404,755,148	16.0%

Based on the economic parameters in Table 10, it is known that the time required to recover the capital costs for the construction of hybrid coal plant is in the range of 10–13 years after the plant start-up period. This figure is still within the typical range for the construction of a chemical process industry, which is in the 7–13 year range (Turton et al., 2012). In terms of cash position, this project is already profitable since the NPV is not negative and has a large value ranging from IDR 285 billion to IDR 1.1

trillion. Lastly, in terms of interest rate criteria, the IRR of the project has promising value and is categorized as economically feasible project which sufficiently reasonable to be funded. The average WACC of the national banking system is 7%, while the average deposit interest rate is 9%. Therefore, the internal rate of return by investing funds in this project can be considered very profitable since it is able to provide higher interest than the bank WACC and deposits. The approximate discounted cumulative cashflow diagram for the hybrid coal plant project is depicted in Figure 11.

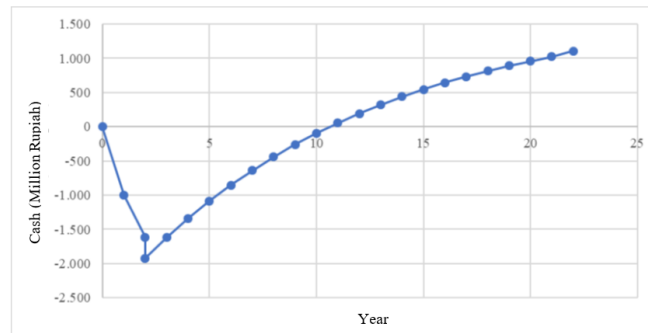


Figure 11. Hybrid coal plant project discounted cumulative cashflow.

6. Conclusion

The utilization of Indonesian potential energy sources that are extremely abundant such coal reserves (especially low-ranked coal with a potential of 39.56 billion tonnes) and biomass waste (32.6 GW potential) is necessary in order to achieve energy security and fulfill the increasing energy demand in Indonesia. Hybrid coal product innovation might be a solution to optimize existing energy source while solving biomass waste problem in Indonesia. Hybrid coal can be produced by combining lignite coal with biomass waste such rice husks, empty fruit bunches and rubber wood with a ratio of coal to biomass of 7:3. The process used is the co-pyrolysis process which increases the calorific value of coal and biomass mixture by 31.10–44.12% and reduces non-neutral CO₂ emissions by 15.56–21.31% compared to its constituent coal, making it more environmentally friendly source of energy. In the industrial scale production of hybrid coal, there are 3 prospective locations to build hybrid coal plants: Central Java, South Sumatra and South Kalimantan. Economic analysis of hybrid coal industry project with production capacities of 540 thousand to 4.5 million TPY produces payback period of 10–13 years with a profit range of IDR 137 billion to IDR 493 billion per year and a net present value range of IDR 285 billion to IDR 1.1 trillion. This industry is also profitable for investors by providing IRR estimation range of 13.2% to 16.0%. In addition, hybrid coal products also provide benefits for users like power plants in the form of annual savings of 13% when the carbon tax policy is implemented. Through various experimental research and analysis of the hybrid coal production and its industrial feasibility, hybrid coal is the current most promising and prospective innovation in all economical, qualitative and environmental manner. It is believed to be a reliable source to achieve energy security in Indonesia.

Abbreviations

AGM	= Antang Gunung Meratus	MW	= Mega Watt
BA	= Bukit Asam	MWe	= Mega Watt equivalent
C	= Carbon element content	N	= Nitrogen element content
CPO	= Crude Palm Oil	NDC	= Nationally Determined Contribution
GCV	= Gross Calorific Value	NPV	= Net Present Value
GDP	= Gross Domestic Product	O	= Oxygen element content
GHG	= Greenhouse Gases	PLN	= Perusahaan Listrik Negara
GW	= Giga Watt	PTPN	= PT Perkebunan Nusantara
H	= Hydrogen element content	S	= Sulphur element content
IRR	= Internal Rate of Return	TPY	= Tonnes Per Year
kWh	= kilo Watt hour	WACC	= Weighted Average Cost of Capital
MTOE	= Million Tonnes of Oil Equivalent		

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