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A Study on the Potential of Electrical Energy based on Gasification Technology from Oil Palm Empty Fruit Bunch in Landak West Kalimantan

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--*ABSTRACT*--
The growth of oil palm plantations in Landak, West Kalimantan, Indonesia, has greatly increased. Fresh fruit bunches (FFB) of oil palm have been produced at 2,148,210.62 tons in Landak region in 2011-2016. This directly increases the production of crude palm oil (CPO) in palm oil mills (POM). However, the increase in oil palm processing has resulted in increased solid and liquid wastes. One of the solid wastes produced in 2011-2016 was the empty fruit bunches (EFB), which amounted to 322,232 tons. Nowadays, a small amount of EFB is used for compost, but most of it is still disposed of in landfills so it is less useful and even causes environmental pollution. For this reason, this paper examines the potential utilization of EFB from the processing of POM to produce electrical energy based on gasification technology. The result indicates that the total EFB of POM in Landak can produce clean gas (Syngas) with an electricity potential of 1,057,479.16 MWh per year. This result shows that the implementation of EFB-based gasification technology can increase the electricity production in Landak region and simultaneously reduce environmental problems.
KEYWORDS;*-Biomass energy, crude palm oil (CPO), empty fruit bunches (EFB), gasification, Syngas*

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I. INTRODUCTION

Indonesia is one of the countries that has the largest oil palm plantation in the world. The potential of energy produced is an interesting subject to be studied. The growth of oil palm plantations in Landak, West Kalimantan, Indonesia, is increasing every year. At the end of December 2016, the area of oil palm plantations inLandak had reached 113,800.56 ha consisting of 60,403.69 ha with production and 53,396.9 ha with no production [1]. The land area has the potential to increase, this shows that the palm agroindustry is still very promising to be developed [2].

The increase in oil palm plantations and the amount of crude palm oil (CPO) production raise many environmental problems that require the right solution. This problem arises from inappropriate land use and the handling of wastes from plantation products and CPO factories that have not been maximized. The amount of biomass from disposed CPO industrial waste is generally much greater than the amount that can be utilized, resulting in the accumulation of oil palm solid waste [3]. Most of the waste is left alone in the environment or in a pile and partly is burned so as to produce pollutant gas.

Besides producing CPO, POM also produces waste in the form of empty fruit bunches (EFB), fibre, kernel shells and liquid waste (Palm Oil Mill Effluent or POME). Fibre and kernel shells are currently used as boiler heating fuel for oil palm processing and steam power plants. On the other hand, a small proportion of EFB in Landak is used as compost, but most of it is disposed of in landfills so that it is of no economic value and also causes environmental issues. If it is processed with the right technology, the high amount of EFB can be very potential to be developed into a source of electrical energy. Processing one ton of oil palm is estimated to produce 473 kg (22.5%) of wet EFB or 150 kg (15%) of EFB in dry condition. The production of fresh fruit bunches (FFB) in Landak in 2011-2016 was 2,148,210.63 tons. Thus, the total amount of FFB can produce 322,232 tons of dry EFB. FFB is processed in five POMs located in Landak with a total production capacity of 225 tons per hour. More detailed studies related to this matter will be interesting and will be discussed in the next section in this paper. The study focuses on analysing the potential utilization of EFB, especially in the area of Landak as an energy raw material in power plants that use gasification based technology. Based on the knowledge of the author, there is currently no publication that discusses this matter, specifically related to the potential of electrical energy from EFB in Landak.

II. MATERIAL AND METHOD

A. Oil Palm Processing

The extraction of palm oil in CPO mills is still carried out mechanically. The process is chosen because it is easier and the production costs are relatively smaller because it does not use any additives. CPO mills use FFB as raw material and water as a component that assists the extraction process. The main product is CPO and the by-products are fibres, kernel shells, EFB and liquid waste. One ton of FFB can produce 21.8% CPO, 22.5% EFB, 6.7% kernel shells, 14.3% fibre, 5.4% kernel and 54.8% POME [4]. The composition of the CPO plant output depends on the processing and raw materials used.

The processing of oil palm into CPO starts from receiving FFB to be processed. FFB is selected first before entering the factory to maintain the quality of the CPO produced. Harvested FFB must be processed within 24 hours to avoid an increase in free fatty acid (FFA). High FFA level will affect the quality of CPO [5]. FFB that has passed the sorting process then enters the factory through several process units to produce CPO, the process units are as follows:

- Sterilisation, FFB is cooked using steam in a 2.5-3 atm tank at a temperature of 135-150°C for 90 minutes. The sterilisation process is conducted to stop the formation of FFA, remove the sap, stop the activity of oil-breaking enzymes, and prepare the fruit for the next process.
- Threshing, is the separation of fruit from bunches using a tool called thresher. The fruit bunches that have been emptied are collected at the EFB collection point and then burned in the incinerator or distributed to the plantation as compost or disposed of in the landfill.
- Digestion and Pressing, palm fruit is heated at a temperature of 85-95°C and continuously crushed in a digester to separate fibre from the palm kernel and to break down oil fibre cells. The fruit that comes out of the digester is then extracted mechanically using a screw press at 50 kg / cm² and a temperature of 85-90°C for 6-10 minutes. The remaining solids from the screw press are then sent to the kernel processing unit.
- Clarification, Purification and Drying, the oil resulting from the pressing process which is still mixed with water, shell fragments, fibre and other solid materials is then pumped to the clarifier tank to separate the oil from the impurity. The oil from the clarifier is then purified and dried to reduce the moisture content in the vacuum dryer. The CPO that has been clean and met the standards is then pumped into the CPO storage tank, while the dirt and mud resulting from oil refining is then processed to separate the oil that is carried along before then flown to the waste treatment unit.
- The kernel processing begins with the separation of fibre and seeds in the depericarper. The separated seeds are then dried and broken down to separate the kernel from the shell. Clean kernels are then stored or directly processed to produce palm kernel oil (PKO). Most of the fibre and palm shells produced are sent to the boiler as fuel.

B. Energy Use in CPO Plant

The production of FFB into CPO requires a lot of energy in the form of heat and electricity. The energy is generated from the combustion of palm shells and fibre in the boiler. Boiler produces heat in the form of steam for processing needs or for electricity generation. Steam is used in the sterilisation, threshing, pressing and turbine processes. Electricity generated from turbines is used to drive process equipment at factories and for other purposes such as offices and supporting facilities. In general, the combustion process in boilers in CPO plants is direct combustion, the method is widely implemented in CPO plants because the process is easy and the boiler design is not too complicated. However, there are still some disadvantages of this technology, such as energy conversion that is not relatively high and the amount of exhaust emissions [6].

Conventional boiler uses 8-10 tons of biomass / hour consisting of 2% shells and 14% palm fibre from the total FFB processed to produce the energy needed by the CPO mill. The amount of energy needed for the plant is around 15-17 kWh per ton of FFB treated [7]. The larger the plant, the greater the energy needed. The type of boiler is one of the important factors that influence the energy gain from the combustion process. Fire tube type boilers are generally used in small factories with a capacity of 20-30 tons FFB per hour, while for large factories with a capacity of 50-60 tons of FFB per hour water tube boiler is often used [8].

Electricity is generated from the turbine using 21 bar pressure steam which then drops to 3 bar. Steam with 3 bar pressure is then used for processing purposes such as in the sterilizer and digester. The energy produced from generators in CPO mills is generally about 1.2 MW. When the factory does not operate, the electricity needs for lighting and other supporting needs are supplied from diesel generator. This generator is not needed if the factory location is connected to the national electricity network because the electricity needs can be supplied by the State Electricity Company (Perusahaan Listrik Negara/PLN) [7].

C. Application of Gasification Technology

Gasification is a thermochemical conversion of solid fuel into a combustible gas. Combustion in the gasification process takes place completely in a reactor called the gasifier. The results of complete combustion of biomass generally consist of nitrogen (N2), water vapour, carbon dioxide (CO2) and excess oxygen. While the results of incomplete combustion consist of carbon monoxide (CO), hydrogen (H2), methane (CH4) and other products such as tar and ash [9]. The gasification process is a combination of several stages of the process namely drying, pyrolysis, oxidation and reduction. Each stage of the process is related to the other stages of the process. The advantages of gasification compared to direct combustion are that the conversion rate of energy produced is higher and the exhaust gas produced is also much cleaner.

The basic components found in the biomass gasification system are gasifiers, gas purification units, internal combustion engine and generator. The selection of gasifier design depends on the fuel to be used and the desired capacity. To produce synthesis gas from biomass combustion, a high operating temperature is needed [8]. The gas purification process serves to filter, clean and cool the synthesis gas produced. Just like boiler that produces steam for turbines, gasification of clean gas can be used directly on the internal combustion engine or turbine to produce electricity.

There are several types of gasifiers including fixed bed gasifiers with updraft and downdraft systems, fluidized bed gasifiers with bubbling, circulating and entrained flow systems. EFB is effective enough to be gasified using an updraft type gasifier [10].

Power plants with gasification technology are very prospective to be developed. Apart from the large level of domestic electricity demand and the availability of biomass as fuel, the energy conversion of the gasification process is much higher than other energy conversion technologies. Development with a gasification system can increase the value of energy conversion efficiency. The direct combustion system has an energy conversion efficiency of 10-30%, whereas with gasification system the energy conversion efficiency can be increased to 50-70% [6].

The application of biomass gasification technology in CPO mills can not only meet the energy needs of the factory, but also generate profits by utilizing the excess electricity produced to be sold to PLN. Another advantage of using palm oil waste as gasification fuel is that it can utilize the waste that is not handled well. Thus gasification technology can be a solution to energy and environmental problems.

D. Data Collection and Processing

The number of POM in Landak which are currently ready to process oil palm with a minimum production capacity of 30 tons per hour are five companies, namely PT. Agro Nusa Investama (PT. ANI), PT. Perkebunan Nusantara (PTPN) XIII Ngabang, PT. Satria Multi Sukses (PT. SMS), PT. Multi Perkasa Sejahtera (PT. MPS), PT. Kapuas Rimba Sejahtera (PT. KRS). Data collection was carried out with direct observation of the five POM. Supporting data from Ditjenbun 2016, Statistik Perkebunan Indonesia KomoditasKelapaSawit 2013-2015 [1].

The study was conducted in a non-experimental qualitative method. From the data collection, some information is generated:

1) The total area of oil palm plantations is as follows:

- Area with plants that have produced is 60,403.69 ha, with production of 2,148,210.630 tons.
- Area with plants that have not produced is 53,396.9 ha.
- The total plantation area is 113,800.59 ha.

2) The number of production capacity per hour of the 5 POM is presented at TABLE 1.

TABLE 1. Data on Oil Palm Processing Plants in Landak

No	Oil Palm Company	Production Capacity
1	PT. ANI	30 tons FFB/hour
2	PTPN XIII Ngabang	60 tons FFB/hour
3	PT. SMS	60 tons FFB/hour
4	PT. MPS	30 tons FFB/hour
6	PT. KRS	45 tons FFB/hour
Total		225 tons FFB/hour

3) Based on the percentage of total FFB production by referring to the mass balance percentage that 1 ton of FFB produces 15% dry EFB [5], so the total dry EFB obtained is 322,232 tons. Table 2 shows the average calorific value of palm oil solid waste which will be used as a basis for calculating EFB energy potential [11].

TABLE 2. Calorific Value of Palm Oil Solid Wastes

Solid Waste	Average Calorific Value (kJ/kg)	Range of Calorific Value (kJ/kg)
Shells	20.093	19.500-20.750
Fibre	19.055	18.800-19.580
EFB	18.795	18.000-19.920
Fronds	17.471	17.000-17.800
Trunks	15.719	15.400-15.680

E. Analysis of Energy Potential

1). Estimated Energy Potential of EFB: The estimated energy potential of EFB as solid raw material is carried out based on the calculation of conversion to calorific value as follows:

Formulation of the potential of total production capacity (C):

$$C = \frac{W_{tbs}}{T} \quad (1)$$

where :
C : production capacity (kg/hour)
W tbs : processed FFB (kg)
T : processing duration (hours)

Formulation of fuel input power of EFB solid waste (Ptks) :

$$P_{tks} = Q_{tks} \times NK_{tks} \quad (2)$$

where :
Ptks : EFB input power (kcal)
Qtks : EFB weight (kg)
NKtks : EFB calorific value (kcal/kg)

Formulation of electrical energy potential of EFB solid waste (Wtks):

$$W_{tks} = Q_{tks} \times NK_{tks} \times NS_{tks} \quad (3)$$

where :
Wtks : EFB electrical energy (kWh)
NStks : conversion value (kcal/kg)

2). Estimated Potential of Syngas Energy : Calculation estimation of the gasification process using performance test reference of small scale EFB gasification reactor with updraft type [12] are as follows:

Formula for conversion efficiency (ηgas) of solid fuel to Syngas:

$$\eta_{gas} = \frac{m_{gas} \times HHV_{gas}}{m_{fuel} \times HHV_{fuel}} \quad (4)$$

where :
mgas : mass flow rate of produced gas (kg/s)
HHVgas : Higher Heating Value of gas (MJ/kg)
mfuel : mass flow rate of EFB (kg/s)
HHVfuel : Higher Heating Value of EFB (MJ/kg)

Formula of calorific value of HHVgas is calculated by equation (5)[13]:

$$HHV_{gas} = 13.1\,YCO + 41.2\,YCH_4 + 13.2\,YH_2 \quad (5)$$

where :
YCO : mole fraction of carbon monoxide (%)
YCH4 : mole fraction of methane (%)
YH2 : mole fraction of hydrogen (%)

Formula for calculating the potential estimation of Syngas energy:

$$W_{gsf} = \eta_{gas} \times W_{tks} \quad \textbf{(6)}$$

Where :
Wgsf : Syngas electrical energy (kWh)

D. Research procedure
The research procedure that has been carried out regarding the study on the potential of electrical energy from EFB based on gasification technology is as follows:
- Preparing study by searching and collecting some literature and supporting theories related to research and observing the objects to be studied.
- Studying literature and supporting theories as well as object observation result to determine the research direction.
- Studying the influential factors that cause the EFB to be untapped as fuel for electricity generation.
- Gathering primary and secondary data including, data on plantations and POM, as well as data on the gasifier that can be used to generate Syngas.
- Identifying the amount of FFB and EFB produced
- Analysing the utilization of EFB generally as an existing fuel for generator and calculating the energy potential of EFB as raw material for gasification and the potential of Syngas.
- Drawing conclusion of the potential of electrical energy that can be produced.

III. RESULTS AND DISCUSSIONS

A. Oil Palm Production

The amount of FFB processed at the five POM from 2011 to 2016 is shown in TABLE 3.

Tabel 3. The Amount of FFB Processed in 2011-2016

Year	**Production of FFB (tons)**				
	PT ANI	**PTPN XIII**	**PT SMS**	**PT MPS**	**PT KRS**
2011	117,768.16	233,541.65			
2012	114,549.09	259,448.14			
2013	114,494.43	216,980.93			
2014	108,472.37	203,803.89	105,554.53		
2015	126,200.60	181,056.35	167,903.30	8,833.79	
2016	0	0	0	171,804.41	17,799.00
Subtotal	581,484.65	1,094,830.96	273,457.83	180,638.20	17,799.00
Total	2,148,210.64				

Table 3 shows the amount of FFB processed in 2011-2016. PT. SMS started processing in 2014, PT. MPS began processing in 2015, while PT. KRS started processing in 2016. For the upcoming years all POM can carry out production simultaneously, so the total amount of FFB to be processed will increase, and the production of EFB will also increase.
Calculation of the estimated amount of dry EFB is carried out with a percentage of 15% of processed FFB, shown in the TABLE 4.

Table 4. Production Results of Dry EFB waste (QTKS) in 2011-2016

Year	**Amount of Q_{tks} (ton)**				
	PT ANI	**PTPN XIII**	**PT SMS**	**PT MPS**	**PT KRS**
2011	17,665.22	35,031.25			
2012	17,182.36	38,917.22			
2013	17,174.17	32,547.14			

2014	16,270.86	30,570.58	15,833.18		
2015	18,930.09	27,158.45	25,185.50	1,325.07	
2016	0	0	0	25,770.66	2,669.85
Subtotal	87,222.70	164,224.64	41,018.68	27,095.73	2,669.85
Total	322,231.6				

B. Energy Potential of EFB waste

EFB waste has a fairly high energy value, so it can be processed into energy raw materials which can be used as fuel for cheap and renewable power plants.

Based on TABLE 2, the average calorific value of EFB is 18.795 kJ / kg, if the conversion of 1 kJ / kg = 0.23884 kcal / kg and 1 kcal = 1.163 x 10-3 kWh [14], then the calorific value (NKtks) is 4.489 kcal / kg. If calculated using equation (3), for example, the energy potential of dry EFB at PT. ANI in 2011 is as follows:

W tks_ANI = 17,665,220,000 kg x 4,489 kcal/kg x 1.163 x 10-3 kWh
= 92,224,937.7 kWh
(or 92,224.94 MWh)

With the same method, the calorific value of dry EFB can be calculated for the other four companies. The data in Table 5 shows the estimated energy potential of EFB solid waste as raw materials from 2011-2016 for the five POM in Landak.

Table 5. Estimated Energy Production (WTKS) of Dry EFB Waste in 2011-2016.

Year	**Estimated W_{tks} (MWh)**				
	PT ANI	**PTPN XIII**	**PT SMS**	**PT MPS**	**PT KRS**
2011	92,224.94	182,887.89			
2012	89,704.07	203,175.40			
2013	89,661.31	169,919.08			
2014	86,945.40	159,600.04	82,660.40		
2015	98,828.45	141,786.31	131,486.12	6,917.8	
2016	-	-	-	134,541.07	13,938.5
Subtotal	455,364.16	857,368.73	214,146.51	141,458.87	13,938.5
Total	1,682,276.77				

Table 4 shows the estimated amount of energy production of solid EFB as raw materials which if processed using gasification technology can produce Syngas fuel for electricity generation. Based on the study on [15], Syngas has a gasification efficiency of 62.86% and is highly potential to be used as fuel for a gas turbine power plant or internal combustion engine. The energy potential of EFB based on gasification technology can be calculated using Equation (6). For example, the energy potential of gasification technology-based from PT ANI in 2011 is:

W_{gsf_ANI} = 62.86% x 92,224.94 MWh
= 57,972.60 MWh.

With the same calculation, the potential of gasification-based electrical energy in the other five companies is shown in Table 6.

Table 6. Estimation of Gasification Energy Production (WGSF) of Dry EFB Waste in 2011-2016.

Year	**Amount of W_{gsf} (MWh)**				
	PT ANI	**PTPN XIII**	**PT SMS**	**PT MPS**	**PT KRS**
2011	57,972.61	114,963.32			
2012	56,387.99	127,716.06			
2013	56,361.08	106,811.13			
2014	53,396.66	100,324.60	51,960.32		
2015	62,123.57	89,126.88	82,652.16	4,348.53	
2016	-	-	-	84,572.52	8,761.74

Subtotal	286,241.90	538,942.00	134,612.48	88,921.04	8,761.74
Total	1,057,479.16				

The energy potential of gasification in Table 6 can be used to serve the electricity needs in POM, offices and employee housing. Electrical energy required to process 1 ton of FFB is between 20-25 kWh with 0.73 tons of steam [16]. In this study, the calculation of 25 kWh / ton is used, so the processing of the FFB produced by each POM needs an amount of electricity as shown in TABLE 7. The percentage of energy requirements for palm oil processing in 2011-2016 on the estimated production of gasified energy is 5.1%.

Table 7. Electrical Energy Requirement for FFB Processing

Year	**Electrical Energy for FFB Processing (MWh)**				
	PT ANI	**PTPN XIII**	**PT SMS**	**PT MPS**	**PT KRS**
2011	2,944.20	5,838.54			
2012	2,863.73	6,486.20			
2013	2,862.36	5,424.52			
2014	2,711.81	5,095.10	2,638.86		
2015	3,155.02	4,526.41	4,197.58	220.84	
2016	0	0	0	4,295.11	444.98
Subtotal	14,537.12	27,370.77	6,836.45	4,515.96	444.98
Total	53,705.27				

The remainder of the estimated production results after reducing the estimated energy requirements for plant needs is shown in Figure 1.

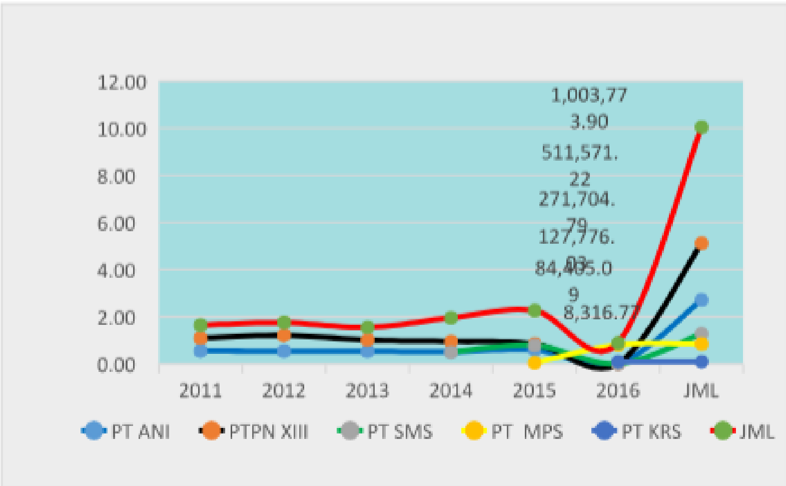

Figure 1. Graph of Estimated Potential of Electrical Energy in POM in Landak (Table 8).

The estimation of the remaining production results of EFB gasification in Landak in 2011-2016 is shown in Table 8. In Figure 1, PTPN XIII produces the highest energy potential of EFB while PT KRS produces the lowest potential, because the company just started production in 2016.

Table 8. Estimation of The Remaining Production of Gasification Energy (WGSF) from Dry EFB Waste in 2011-2016

Year	**Remaining electrical energy after gasification (W_{gsf}) MWh**				
	PT ANI	**PTPN XIII**	**PT SMS**	**PT MPS**	**PT KRS**
2011	55,028.40	109,124.78			
2012	53,524.26	121,229.86			
2013	53,498.72	101,386.61			
2014	50,684.85	95,229.50	49,321.46		
2015	58,968.55	84,600.47	78,454.57	4,127.68	

2016	0	0	0	80,277.41	8,316.77
Subtotal	271,704.79	511,571.22	127,776.03	84,405.09	8,316.77
Total	1,003,773.90				

To calculate the energy potential of EFB in the future, this study uses the potential data of the highest processing result from each POM based on the production year, so that the following data are obtained :

- PT. ANI possessed the highest energy processing potential (Wgsf) of EFB in 2015, at 58,968.55 MWh.
- PT PN XIII owned the highest energy processing potential (Wgsf) of EFB in 2012, at 121,229.86 MWh.
- PT. SMS holds the highest energy processing potential (Wgsf) of EFB in 2015, at 78,454.57 MWh.
- PT. MPS obtained the highest energy processing potential (Wgsf) of EFB in 2016, at 80,277.41 MWh.
- PT. KRS achieved the highest energy processing potential (Wgsf) of EFB in 2016, at 8,136.77 MWh.

The estimation of the energy production of EFB does not reflect the additional production from the plants that will produce in the 2011-2016 with an area of 53,396.9 ha.

The estimation of energy production above after deducting the energy for own use in factories and the work environment, can be utilised as energy excess power that can be sold and become a source of additional income.

III. CONCLUSION

This paper has presented an estimated potential of electrical energy (Wgsf) of EFB in Landak in the future which can be harnessed as excess power Syngas with an energy value of 347,247 MWh per year. This amount can increase according to the development of crop production that will produce after 2011-2016 with an area of 53,396.9 ha. If calculated based on the sales price per kWh of Rp. 1,438.20 (maximum purchase rate by PLN), the potential of electrical energy can generate potential revenue of Rp 499.41 billion per year.

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