Analysis of the feasibility of small-biomass power generation from the palm oil mill – study case: palm oil mill in Riau-Indonesia

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Abstract. Solid waste from a palm oil mill in Indonesia is a tremendous potential for power generation, especially on Riau-Sumatra. The potential of electrical energy that can generate is determined by measuring or calculating the calorific value and amount of solid waste palm oil available. To be burned in the boiler continuously and more efficiently, the solid waste water content of palm oil must reduce to no more than 30%. The conservative substantial waste palm oil calorific value (HHV) is 3,500 kcal/kg. As a result, the mass and power plant balance are capable of producing a gross power of 4.6 MW using 80% efficient fluidised bed boilers and a steam turbine capacity of 5 MW with an isentropic efficiency of 85% with assumption percentages combination fibre: 30 % shell: 70 % fibre. The environmental impacts of power generation from empty fruit bunch (EFB) based on steam turbine generator technology evaluated. The results revealed that EFB utilisation for power generation is environmental friendly than fossil fuel power plants regarding global warming potential and acidification potential with GWP are 89.5 kg CO₂ eq per MWh, and 0.515 kg SO₂ eq per MWh. Also, the financial analysis of the Biomass Power Plant with a lifetime duration of 25 years, which the project is feasible to implement because IRR is 22.70%, higher than Weighted Average Cost of Capital (WACC) which amounted to 15.61%.

1. Introduction
The source energy of empty bunches is enormous potential to rise capacity electricity, especially on Sumatra Indonesia. At least about 70 palm oil mills in Sumatra managed by PT Perkebunan Nusantara (PTPN), which is a State-Owned Enterprise of Indonesia (BUMN). Based on data, the potency of energy from empty fruit bunch (EFB) is equivalent approximately 510 MW [1]. Also, the environmental impacts of power generation from EFB based on steam turbine generator technology have been evaluated. Base on study literature, the waste palm oil solid fuel is less emission than coal power plants [2].

The palm oil mill waste consists of EFB, shell and fibre bunches for utilisation as solid fuel boilers in palm oil mills to supply electricity process plant or in condition when surplus electricity they can sell electricity to other as additional profit. Empty bunches are containing high water moisture about 50% - 60% and potassium (K) 2.4% also corrosion effect will increase with Cl content, and potassium may reduce heat transfer process in the furnace [3].
For generating power generation in Indonesia there are many regulations, one is Build Operate Transfer (BOT) Scheme. BOT Scheme regulation consists in the utilisation of local property by other parties by constructing buildings or facilities and facilities. For utilised by other parties within the agreed period, then returning land and buildings and facilities and facilities after the term expiration the time of the Minister of Home Affairs Regulation Number 19 of 2016 concerning Guidelines for the Management of Regional Property Indonesia.

Thus, the study case, the location of PTPN V palm oil mill with a capacity of approximately 60 tons of fresh fruit bunches (FFB/hour will produce 12.6 tons/hour of empty palm bunches (EFB). The objective of this paper is to present an analysis of the feasibility of using the biomass resulting from residues palm oil. In addition that is combination between shell and fibre as solid fuel in a boiler in the palm oil plant where they are produced, for the generation of electric power considering economic analysis based on BOT, also, study review comparison emission value between coal and biomass base one Global warming potential and Acidification value. The main study case is calculation heat and mass balance to make sure the feasibility efficiency of biomass (shell and fibre) power generation. It is also intended for recommendation to PTPN V, to render such biomass utilisation better feasible.

2. Methodology
The methodology of determining the feasibility of small-biomass power generation from the palm oil mill is similar to coal-fired power plants method. First is location aspects, the location indicated by general conditions, geological conditions, environmental conditions and supporting facilities located at the location that influence with the transportation system. As a result, they will a significant influence for economic feasibility calculation [4] — the financial analysis of the Biomass Power Plant base one BOT scheme as Indonesia policy that will predict revenue time with feasible analysis.

The second is an analysis of fuel for boiler, from that analysis can show characteristic of biomass from palm oil, calorific value and determine percentage ratio content between shell and fibre base on heat and mass balance calculation, moreover, from this analysis it would know an efficiency and can decide best type of boiler for biomass. The environment analysis of this paper is a comparison emission value between coal and biomass from palm oil based on Global warming potential and Acidification value based on study literature.

3. Results and discussion
The capacity of palm oil mills is already operating approximate range from 30 to 90 tons of EFB/hour [5]. For this study, sources of raw materials from oil palm mills with a capacity of 60 tons of FFB/hour operate at 100% capacity. The palm oil mills with a design capacity of fewer than 60 tons of FFB/hour were modified to be increased to 60 tons of FFB/hour by PTPN V in North Sumatra. Wastes or by-products of palm oil factories that can utilise as fuel for boiler plants are shells, fibre and EFB. Table 1 shows the design of the palm oil mill PTPN V [5].

Referring to the balance sheet table 1, the number of empty bunches that used as fuel is about 12.6 tons/hour with a moisture content of about 60% and palm oil mill operations average about 20 hours per day and 285 days per year. Thus, the annual solid waste palm oil production is about 72,000 tons (60% moisture content). The potential of electrical energy that can generate is determined by measuring or calculating the calorific value and amount of solid waste palm oil. To be burned in the boiler continuously and more efficiently, the solid waste water content of palm oil must reduce to no more than 30% through the drying process.

| Input                      | Output |        |
|----------------------------|--------|--------|
| Processed FFB              | CPO    | 14.6   |
| Boiling Steam              | PKO    | 3.3    |
| Steam Digester             | EFB    | 12.6   |
| Hot Water Pressing         | Fibre  | 8.4    |
The heating value of solid waste palm oil in table 2 is calculated using a formula developed [7] as a result of the average value from 4 samples of the solid waste palm oil (HHV) value of 3,927 kcal/kg. Nevertheless, for this study, the conservative solid waste palm oil (HHV) calorific value (HHV) is 3,500 kcal/kg.

**Table 2.** Mass balance of palm mill plant capacity 60 tons EFB / hour

| Test Parameter | Source of EFB |
|----------------|---------------|
| Source Plant A | Source Plant B | Source Plant C | Source Plant D |
| Ultimate Analysis (wt.%): |
| Water content | 30.00 | 30.00 | 30.00 | 30.00 |
| Ash (A) | 4.11 | 3.79 | 3.36 | 4.12 |
| Carbon (C) | 37.58 | 40.32 | 36.92 | 34.04 |
| Hydrogen (H) | 4.61 | 6.32 | 5.04 | 4.07 |
| Sulphur (S) | 0.11 | 0.11 | 0.14 | 0.06 |
| Nitrogen (N) | 3.26 | 0.00 | 0.00 | 0.44 |
| Oxygen (O) | 20.32 | 19.46 | 24.55 | 27.27 |

| Heating Value (HHV) (kcal/kg) |
|-----------------------------|
| Channiwala formula | 3,901 | 4,643 | 3,876 | 3,289 |

The capacity of 60 tons of fruit palm oil/hour from palm oil of 12.6 tons of solid waste palm oil/hour or equivalent to 21% of the weight of fruit palm oil that is the factory weighing with condition waste palm oil obtains from oil palm mills with an average operating time of 20 hours/day. Alternatively, it can be compared with 285 days/year same as 5,700 hours/year, while on the other side coal-fired power plant is planned to operate for 24 hours/days and 300 days/years or a total of 7,200 hours/year. Therefore, there must be a correction factor of 5,700 / 7,200 or equal to 0.79167 so that the actual production of solid waste palm oil from the palm oil plant capacity of 60-ton fruit palm oil /hour to about 12.6 tons/hour x 0.79167 or 9.975 tons/hour.

Furthermore, boiler selection for solid waste palm oil is a comparison between stoker boiler type and the fluidised bed type with operated at 50% excess air with a final temperature of 177°C (350°F) exhaust gas. As shown in Table 3, the most significant energy loss in the boiler is heat loss through the chimney. This loss can contribute up to 30-35% of the fuel input for an old type boiler with minimal maintenance also it decreased moisture content from 35% to 0% increased efficiency by 6%.

Table 3. The efficiency of fluidised boiler bed is higher when compared to the stoker boiler because it has lower burning losses. Stocker boilers can produce 30-40% carbon in ash and additional volatiles and CO in the flue gas, while fluidised bed boilers can usually achieve 100% combustion. The turbulence conditions in the combustion chamber combined with the inertia of the heat of the bed material resulted in complete, controllable and uniform combustion. These factors are vital in maximising thermal efficiency, minimising char and controlling emissions.

**Table 3.** The efficiency of Biomass Boiler Based on Combustion Parameters and Fuel Characteristics

| Characteristics | Biomass Stoker Dry | As received | Fluidized Bed Biomass Dry | As received |
|------------------|---------------------|-------------|---------------------------|-------------|
| Excess air (%)   | 50.00               | 50.00       | 50.00                     | 50.00       |
| Dry flue gas (kg/kg bb) | 15.25               | 10.68       | 15.25                     | 10.68       |
### Characteristics

| Characteristics                  | Biomass Stoker | Fluidized Bed Biomass |
|----------------------------------|---------------|----------------------|
|                                  | Dry | As received | Dry | As received |
| Final temp. Exhaust (°C)         | 177.00 | 177.00 | 177.00 | 177.00 |
| HHV (kJ/kg)                      | 19.77 | 13.84 | 19.77 | 13.84 |
| Water content bb(%)              | 0.00 | 30.00 | 0.00 | 30.00 |
| Hydrogen content bb(%)           | 4.59 | 3.21 | 4.59 | 3.21 |

**Loss of fuel efficiency**

| Dry flue gas losses (%)          | 11.63 | 11.63 | 11.63 | 11.63 |
| Water content bb(%)              | 0.00 | 5.90 | 0.00 | 5.90 |
| Latent heat (%)                  | 5.69 | 5.69 | 5.69 | 5.69 |
| Unburned fuel (%)¹               | 3.50 | 3.50 | 0.25 | 0.25 |
| Radiation, etc (%)²              | 2.03 | 2.03 | 2.03 | 2.03 |

**Total burning loss (%)**

| Dry flue gas losses (%)          | 22.85 | 28.74 | 19.60 | 25.49 |
| Water content bb(%)              | 77.15 | 71.26 | 80.40 | 74.51 |

Notes:

1. Estimation
2. Include radiation, steam in the air. [6]

In figure 1, the design of the mass and power plant balance is capable of producing a gross power of 4.6 MW using 80% efficient fluidised bed boilers and a steam turbine capacity of 5 MW with an isentropic efficiency of 85%. The total generator efficiency alone is 19.71%, by the estimates in which assumes 20% total plant efficiency. The net heating rate that achieves is 4,363 kcal / kWh; this value is relatively proportional to small-scale coal-fired power plants using low-quality stoker and coal boilers.

**Figure 1.** Mass and heat balance design solid waste palm oil-power generation 4.5 MW

Furthermore, based on study literature the environmental impact categories selected in this study consists of global warming potential (GWP100), and acidification potential (AP). The criteria for evaluating the environmental impacts selected from environmental problems that significantly in this case study. The emission factor is used from this case study from IPCC-2006 [8] and EMEP/EEA-2013 [9]. GWP is related to emissions of greenhouse gases to the air. Global warming potential with 100 years (GWP100) [10].
Table 4. Global warming potential and Acidification impact assessment of all stages from 1MWh of EFB utilisation for power generation

| Impact Assessment       | Global Warming (GWP100) | Acidification |
|-------------------------|-------------------------|---------------|
|                         | kg CO₂ eq               | kg SO₂ eq     |
| Oil Palm Plantation     | 35.38                   | 0.312         |
| CPO Extraction          | 14.89                   | 0.093         |
| Power Generation        | 89.51                   | 0.515         |
| Transportation          | 9.92                    | 0.066         |

By considering the whole environment analysis of the EFB utilisation for power plants, there is a significant potential resulting from power generation, oil palm plantation, CPO extraction, and transportation table 5. This category concerns the effects of toxic substances on the human environment. Health risks of exposure in the working environment are not included. For each toxic substance, HTP’s are expressed as 1, 4-dichlorobenzene equivalents. Table 5 shows AP is expressed as kg SO₂ equivalents [11]. AP is contributed by NOx and SO₂ emissions. For the EFB utilisation for power generation process.

For a coal-fired power plant, when coal is burned, carbon dioxide, sulphur dioxide, nitrogen oxides, and mercury compounds are released. Especially sulphur dioxide is a high volume from this stage, and it can cause acid rain [12]. For that reason, the emission rate is high more than biomass, With AP 5.15E-01 kg SO₂ eq with EFB and 1.50E+01 kg SO₂ eq with coal, also GWP 100 3.54E+01 kg CO₂ eq for EFB and 1.32E+03 kg CO₂ eq for coal.

Finally, The financial analysis of the Biomass Power Plant with a lifetime duration of 25 years is shown in Graph 6. The power plant base on solid waste palm oil is feasible to be implemented because IRR is 22.70%, higher than the Weighted Average Cost of Capital (WACC) which amounted to 15.61% and this is understandable because the owner of coal-fired power plant biomass has a relatively long revenue-taking time (25 years) in operating the plant. Also, loan payments are distributed within 15 years so that the annual instalment to be paid becomes small. The magnitude of this instalment effect on Generating Cost which for this simulation is in the range of IDR 805.37/kWh. If a comparison is made to the electricity selling rate of IDR 1.150/kWh, then there is sufficient margin for the loan repayment. Under these conditions, the total balance sheet is positive in the fifth year in which the payback period has been fulfilled in 5 years and 2 months [13].

Figure 2. Financial analysis

The increase of investment cost to 20% turns out the project is still feasible to be implemented if based on IRR value (20,32%) which is still higher than WACC (15.61%). This increase in investment costs may occur if there is a strengthening of the exchange rate of foreign currency (US $) against rupiah because most of the mechanical, electrical and instrumentation equipment at the plant is imported. The
underlying assumption of an escalation of electricity tariff increase of 3% per year, if this assumption is reduced to 2% is still feasible because the project IRR value (19.29%) is still higher than WACC (15.61%).

4. Conclusion
Solid waste palm oil considered renewable and less emission which is a substantial potential possibility in Indonesia especially at Riau, with source range about 30 – 90-ton EFB. This study approved the feasibility of power generation as solid fuel fibre and shell with BOT 25 years and IRR 22.70%. Based on study literature has shown that biomass power generation is less emission than coal-fired power generation with acidification potential is 5.15E-01 kg SO$_2$ eq for empty fruit bunch (EFB) and 1.50E+01 kg SO$_2$ eq for coal, and Global warming potential (GWP-100) is 3.54E+01 kg CO$_2$ eq for empty fruit bunch (EFB) and 1.32E+03 kg CO$_2$ eq for coal.

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