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Biohythane system using two steps of POME fermentation process for supplying electrical energy: economic evaluation

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Abstract. Indonesia as the largest producer of palm oil in the world has the prospective to generate additional benefits such as electricity by utilizing Palm Oil Mill Effluent (POME). The high Chemical Oxygen Demand (COD) content of 35,000 ppm POME is a great potential for conversion to hydrogen and methane through a fermentation process. In this study, two stages of fermentation using a microbial consortium have been performed in the 1 m³ BioHythane reactor system to produce biohydrogen and biomethane. After two-stage fermentation process for 24 hours in this system, the microbial consortium succeeds in producing biohydrogen and biomethane of 32 and 60 vol. %, respectively. This gas product after the purification process could be converted to electricity to be 0.02 and 0.75 kWe, respectively. Furthermore, as result of economic calculation analysis, this biohythane system showed up the value of Capital Expenditures (CAPEX) of US $ 26,39540 and Operating Expenses (OPEX) of US $ 14,712 per year, and resulted total generated electricity cost of US $ 2.478 / kWh.

1. Introduction

Palm plant has been an interesting commodity to be developed continuously due to its high potency even in Indonesia which has the biggest production in the world. During its development, the use of palm plant is mostly prioritized as an raw material for household necessity, although in fact it has high potency to produce renewable energy product based on waste which are not still optimal yet to be developed that consists of kernel, Fresh Fruit Bunch FFB, branch, and POME. POME provides potency as high supplier emission in plantation sector. It is caused by still high CO₂, CH₄ and other gases (in CO₂ equivalent unit) which still be large to be released to surrounding without additional treatment process.

In West Java at Bogor regency has been established Cikasungka palm oil plant underauspice of PTPN VIII company which produce Crude Palm Oil (CPO) having capacity 30 ton FFB/hour which has potency to produce POME amount 300 liter/ton FFB with COD content around 35,000 ppm. The steps for processing POME were analyzed at BPPT by conducting two steps fermentation of POME using consortium bacteria to produce biohydrogen continued by biomethane production. Naturally, the process of POME degradation were started from hydrolysis, acidification, acetat acid formation until methanation process (figure 1). Biohydrogen formation occurs in acetate acid formation step from

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which the content of biohydrogen could achieve 32 vol. % of first-fermentation product. In this step there would be conversion of COD process by 25% of total COD remaining recidual-fermentation process which still has high COD composition by 75% of total COD in POME. The specification of recidual waste still could not to be disposed directly to surrounding because the required standardization was not complete yet. Therefore, the second fermentation step for producing methane were carried out to degrade remained COD which could produce CH\(_4\) by 60 vol. % of second-fermentation product.

Biohydrogen become prospective commodity which could be used as source of new energy source (fuel), raw material, reductor and chemical. Meanwhile, hydrogen is still produced dominantly from natural-gas-reforming process in chemical and petrochemical industries. Furthermore, there is another technology growing up hydrolysis technology, due to the high operational cost makes this technology could not to be developed well.

Related to availability of natural gas as principal hydrogen supplier, Indonesian dependence against natural gas would be unstable due to the decrease of natural gas sources. Even Indonesia was forecasted to be net natural gas importer in 2024 based on Indonesia Energy Outlook 2016 analysis [1]. Another effect that would be problem was the purchasing price of natural gas by industry sector which tends to increase, thus only big industries having big funding for providing natural gas which would keep existing.

The fact became a reason why the use of renewable energy for natural gas substitution like biohydrogen and biomethane should be realized soon. It could be proper solution in current energy crisis. In the other hand, dissemination of palm plant areas and palm industries from Sabang until Merauke shows up that a big potential-POME reserve have been available. Recorded in 2015 that total palm plant area was 11,300,370 hectare with total CPO production achieved 31,284,306 tonne [2].

Currently, utilization of hydrogen is dominantly used as feedstock and fuel cell power plant system which mostly used as portable electricity supply in Base Transceiver Station (BTS) and installations which are placed or not connected with electricity grid yet. Meanwhile, the utilization of hydrogen has been started and continuously developed as future transportation fuel having low emission content too.

Regarding to utilize Hydrogen from POME, BPPT has been developing biohythane prototype system with capacity 1 m\(^3\)/day. The operation of this system has been started by conducting initial laboratory scale research began from 5 ml, 50 ml, 2.5 liter, 40 liter and 1 m\(^3\) capacities. Each different
capacity consist of POME was added by microbes contained inside sludge which was obtained from an anaerobic pond at PKS Cikasungka as well. These obtained microbes were bred, screened and inoculated in to get consortium microbes which support hydrogen formation process. Within 24 hours, consortium microbes would convert COD become H₂ and CO₂ as dominant compounds which were detected during anaerobic fermentation condition.

Output POME from first fermentor was chaneled into second RTD more than 24 hours, the composition of gas from fermentation had changed where methane had been formed become dominant product in line with the increase of RTD. The peak composition of methane could achieve 60 vol. % and CO₂ 40 vol. %.

Based on the results of research above. The highest composition of Biohythane and Biomethane amount 32 vol. % and 60 vol. % respectively would be purified to achieve 99% wt and used to estimate potencial energy especially electricity which could be generated from prototype 1 m³ Biohythane system. Furthermore, economic calculation and analysis were conducted for estimating the value of Capital Expenditures (CAPEX), Operational Expenditures (OPEX) and electricity generation cost resulted from Biohythane system.

2. Experimental procedure and methodology
Methodology of analysis and calculation was conducted by using the data of research result. It was supported by additional data and assumptions referred to engineering references related with electricity and economic calculation methods. Detail methodologies were explained together with explanation of result calculations in sub points at below.

2.1. Analysis Electricity Potency
Calculation for electricity analysis did not only use some internal data but also use external-source data derived from some relevant research and engineering references that have been published for substitute data against unknown information data in this economic calculations. Calculation of electricity capacity involved electrical calculations of biohydrogen and biomethane which were channeled toward fuel cell engine and biogas/biomethane engine to generate electricity.

A. There were some data resulted from research and calculation on prototype 1 m³ Biohythane, namely :=
   1. HHV of Biohythane (Bio-H₂ 99% wt) = 10.1 MJ/m³
   2. HHV of Biomethane (Bio-CH₄ 99% wt) = 33.6 MJ/kg
B. There were some data from PKS Cikasungka, namely:
   1. Production capacity of PKS Cikasungka = 30 ton FFB/hour.
   2. POME waste production = 300 liter POME/ton FFB.
   3. Total COD = 35,000 ppm

C. There were some assumptions used for electricity potency analysis, namely:
   1. POME was supplied 0.6 m$^3$/day or 60% of total prototype capacity.
   2. H$_2$ density = 0.08698 kg/m$^3$
   3. CH$_4$ density = 0.656 kg/m$^3$
   4. COD consumption for biohydrogen synthesis amount 25% of total COD [3].
   5. COD consumption for biomethane synthesis amount 75% of total COD [3].
   6. Ratio of H$_2$/COD = 0.0892 nm$^3$/day
   7. Ratio of CH$_4$/COD = 0.35 nm$^3$/day [3]
   8. H$_2$ target for fuel cell engine = 99%
   9. CH$_4$ target for biogas/biomethane engine = 99%
   10. Gas engines efficiency = 34.6% [3]

2.2. Analysis of Economic Calculation
Economic calculation and analysis were classified into three calculation parts on 1 m$^3$ biohythane prototype system which will be planned to be placed at PKS Cikasungka. These parts were Capital Expenditures (CAPEX), Operational Expenditures (OPEX) and electricity generation cost calculation. There were real data used in calculation which supported by some external data and relevant assumptions. Base year calculation used the year of 2015 because the availability of external data and assumptions were the most complete. The following real and supporting data were described in detail as follows:

D. There were some real data were obtained from direct survey which closely related to Biohythane prototype information, namely:
   1. The land cost was assumed free of charge.
   2. Electricity consumption was supplied from external plant distributed by Indonesian Electricity State Enterprise (PLN) where the cost of purchasing electricity from PLN was
   3. Water consumption was assumed free of charge.
   4. Employee salary info was the real data obtained from a small scale power plant info.

E. There were some assumptions which used in economic calculation including as follows:
   1. One m$^3$ plant was operated for 365 days having life time 16 years.
   2. The capital was owned 100%, not a loan.
   3. Exchange rate was IDR 13,000/US$.
   4. POME was obtained free in charge and transported from POME pond to Biogythane prototype by using truck with length-distance around 200 meters.
   5. All equipments were not imported.
   6. Calculation of working capital cost before prototype could contiously operate was assumed 1 month.
   7. Annual tax income was 10% of total obtained profit which referred to government regulation.
   8. Electricity generation in prototype used capacity factor by 90% of total generated electrical capacity
   9. Depreciation cost was calculated by straight line method [4].
  10. Electricity cost and Indonesian electricity consumer indices were used to project future costs especially on data which were available before year 2015 [5].
  11. Return on Investment Rate (ROR) was stated 13%.
3. Results and Discussion
The result of calculation in this part was obtained using information from calculation methodology above with some equations which will be further explained in this part. The result of CAPEX and OPEX calculations, and economical analysis would be analyzed in detail as source information to explain potency utilization of Biohydrogen and Biomethane according to economic aspect.

3.1. Electricity Potency Estimation
The calculation of electricity capacity potential was referred to detail POME info. It consists of some equations which closely related to some info in part 2.1 namely as follows:

1. Daily wastewater flow
   
   \[ \text{Daily wastewater flow} = \text{Daily waste water volume (No.C1)} \] [3]

2. COD Loading (kg.COD/day)
   
   \[ \text{COD Loading} = \text{COD POME (No.B3) x Daily wastewater flow (eq.1) x } \frac{\text{kg}}{1.000.000 \text{mg}} \times \frac{1000}{\text{m}^3} \] [3]

3. Bio-H₂ or Bio-CH₄ Production (Nm³ H₂ or CH₄/day)
   
   \[ \text{Bio-H₂ or Bio-CH₄ Production} = \text{COD loading (eq.2) x COD eff (No.C8 or C9) x H₂ or CH₄/COD (No.C6 or C7)} \] [3]

4. Generated Electricity Capacity (kWe)
   
   \[ \text{Generated Electricity Capacity} = \frac{\text{H₂ or CH₄ production (eq.3) x HHV}}{24 \times 60 \text{ minutes} \times 60 \text{ seconds}} \times \frac{\text{H₂ or CH₄}}{\text{COD}} \times \text{Eff. Gas Engine (No.C10)} \] [3]

According to equation 1 to 4 above, the calculation of electricity power potency on 1 m³ biohythane system was conducted by different calculation from POME fermentation for biohydrogen and POME fermentation for biomethane. The result of calculations were given in table 1.

| No | Remark                              | Biohydrogen | Biomethane |
|----|-------------------------------------|-------------|------------|
| 1  | Daily wastewater flow (m³ POME/day) | 0.6         |            |
| 2  | COD loading (kg.COD/day)            | 5.25        | 15.75      |
| 3  | H₂ production or CH₄ (Nm³/day)      | 0.464       | 5.457      |
| 4  | Electricity Generation Capacity (kWe) | 0.019 kWe   | 0.734 kWe  |

Total electricity capacity (kWe) 0.753 kWe

According to calculation, one m³ biohythane system had potency to generate 0.735 kWe electricity capacity. This capacity showed up potential-capacity value was big enough to generate electricity although it was only generated from 1 m³ plant capacity.

3.2. The Estimation of CAPEX
The estimation of CAPEX was closely determined by two-important components namely Fixed Capital Investment cost which having cost by 98% of CAPEX and Working Capital cost by 2% of CAPEX. By inputting data both real and assumption data based on engineering references, then the result of CAPEX calculation could be summarized into table 2.
Purchased equipment cost (No.A.I.1) in fixed-capital investment was real data which considered safety cost by assuming it by 5% of total purchase equipment too. Electrical component system (No.A.I.2) was obtained from real data for electricity distribution having length-distance 200 meters connected with PLN network electrical distribution. Contingency component was calculated by assuming it at amount of 15% of total fixed-capital investment (No.A).

In Working Capital calculation, transportation POME cost (No.B.4) was obtained from fuel vehicle consumption for length-distance 200 meters/day by truck. The intensity of solar consumption for truck was assumed 0.33 liter/km and diesel/solar price was stated amount IDR 6,950/liter based on diesel/solar price in 2015.

Monthly regular-employee salaries (No.B.5) consist of financing expense for three employees. These employees were assumed as permanent employee who have been involved before starting prototype operation. General administration cost was important-enough component which should be available in each project. It was calculated by assuming it by 15% of total monthly regular-employee salaries (No.B.5). Start-up cost component (No.B.7), it has close relationship with monthly regular-employee salaries (No.B.5) where involved employees as well. The difference was mechanism of salary payment where start-up cost was paid daily (for 14 days), not monthly.

According to the estimation results, total CAPEX was US$ 26,395. It consists of US$ 25,833 and US$ 563 for Fixed Capital Investment and Working Capital Costs, respectively.

### Table 2. CAPEX estimation of Biohythane system.

| No | Component                                                                 | Cost ($) |
|----|---------------------------------------------------------------------------|----------|
| I  | Direct Cost                                                               |          |
|    | 1 Purchase Equipment (PE), including instalation, instrumentation & control, piping and safety percentage costs (5% of PE)* | 19,304   |
|    | 1.1 Biohythane production system*                                         | 11,923   |
|    | 1.2 Biohythane purification system*                                       | 3,462    |
|    | 1.3 Biohythane electricity generation system*                             | 3,000    |
|    | 2 Electrical system cost [6],**                                           | 2,654    |
|    | ** Total Direct Cost (Total No.1 and 2)                                    | 21,958   |
| II | Indirect Cost                                                             |          |
|    | 1 Contingency [6]                                                         | 3,875    |
|    | ** Total Indirect Cost (Total No.3)                                       | 3,875    |
| A  | Fixed Capital Investment Cost (Total No. I.1, I.2 and II.3)                | 25,833   |
|    | 1 Transportation POME cost (around 200 metes)*                            | 1        |
|    | 2 Monthly regular-employee salaries **                                    | 462      |
|    | 3 General administration cost                                             | 69       |
|    | 4 Start-up cost (including interim laborer salaries)**                     | 31       |
| B  | Working Capital Cost (WC) (Total No. 4,5,6)                                | 563      |
|    | ** Total CAPEX (Total A + B)                                               | 26,395   |

* = Data was closely related with process of prototype 1 m³ biohythane.
** = Data for these components were external data obtained from direct survey.

### 3.3. The Estimation of OPEX

On the calculation of OPEX, it was calculated by summing Variable Production Cost, Fixed Cost and Plant Overhead Cost. The result of calculations as shown in table 3.

In principal, POME transportation cost calculation (table 3) used the same method as transportation cost in the working capital cost of CAPEX calculation (table 2) for annual calculation. Annual regular-
employee salary (table 2) in this calculation used the same method as monthly regular-employee salary (table 2) in CAPEX calculation.

The calculation of utilities cost (table 3) were highlighted on the consumption of electricity consist of heater, generation system and purification system pumps as shown in table 4 which were calculated by summing total electricity consumption including additional safety cost by 5% of total utilities cost. The electricity was supplied from PLN by using electricity tariff in 2015 amount US$ 1,116/kWh for consumer with grade I-3.

**Table 3. The estimation of OPEX on Biohythane system.**

| No | Component                                                                 | Cost (US$/year) |
|----|---------------------------------------------------------------------------|-----------------|
| 1  | POME transportation cost*                                                | 13              |
| 2  | Annual regular-employee salaries**                                       | 7,385           |
| 3  | Utilities (e.g. electricity)**                                           | 4,951           |
| 4  | Maintenance and Repair cost [6]                                          | 1,056           |
| 5  | Operational supply (e.g. lubricant, chemicals) [6]                       | 158             |
|    | **Total Variable Production Cost (Total No. 1,2,3,4,5)**                | **13,560**      |
|    |                                                                          |                 |
| 6  | Depreciation [6],[10]                                                   | 1,149           |
|    | **Total Fixed Charge (Total No.6)**                                     | **1,149**       |
|    | TOTAL OPEX (Total A + B)                                                | **14,712**      |

* = Data was closely related with process of prototype 1 m³ biohythane.
** = Data for these components were external data obtained from direct survey.

Meanwhile, maintenance and repair cost (No.A.4) were calculated with assumption by 4% of Fixed Capital Investment (table 2). Operational supply cost was calculated by using assumption as well. Operational supply consists of some purchased chemicals and lubricants which were needed during operational process. Especially in Biohythane system, some chemicals consist of alkaline solutions, alcohol and aquadest. In this calculation, operational supply was calculated by 15% of maintenance and repair cost.

**Table 4. Electricity consumption on 1 m³ Biohythane prototype’s equipments.**

| No | Equipment                     | Unit | Power consumption (KW) |
|----|-------------------------------|------|------------------------|
| 1  | Heater                        | 1    | 5                      |
| 2  | Generation system pumps       | 2    | 0.42                   |
| 3  | Purification system pumps     | 2    | 0.42                   |
|    | **TOTAL**                     |      | **5.84**               |

The depreciation cost as the one component which was considered in fixed charge calculation (table 3) of biohythane system equipment. It was calculated by referring to depreciation tariff based on Finance ministry regulation of Indonesia KMK.138/KMK.03/2002 as shown in table 5 at below.

**Table 5. Depreciation tariff based on Finance ministry regulation of Indonesia.**

| Components | (year) | Tariff | Detail components for each list                  |
|------------|--------|--------|-------------------------------------------------|
| **Non Building** |        |        |                                                 |
| 1st Category | 4      | 25%    | Office machines, spareparts, tools              |
| 2nd Category | 8      | 12.5%  | Car, vehichles                                 |
| 3rd Category | 16     | 6.25%  | Industry machines                              |
On the other hand, depreciation cost on 20 kV electricity distribution equipments (table 2) was calculated too according to real data from PLN. Depreciation cost was calculated using equation 5 and 6.

\[
\text{Salvage value} = \left( \frac{\text{Real component life}}{\text{Component Life in regulation}} \right) \times \text{Tariff} \times \text{Initial component cost}
\]

(5)

\[
\text{Depreciation} = \frac{\text{Initial component cost} - \text{Salvage value}}{\text{Real component Life}}
\]

(6)

According to overall calculation, total resulted OPEX was US$ 14,712/year consist of total Variable Production Cost and total Fixed Charge Cost amount US$ 13,563/year and US$ 1,149/year respectively.

3.4. The estimation of Economic Analysis

Economic analysis was conducted to determine Electricity Generation Cost (EGC) calculation. In other hand, it involved profit, payback of period time and return of investment cost (POT & IRR) even Break Even Point (BEP) calculations as well. EGC value was calculated using equation 7.

\[
\text{EGC} = \frac{\text{Total OPEX}}{\text{Capacity factor} \times 0.753 \text{ kWe} \times 8,760 \text{ hr/year}}
\]

(7)

Rate on Return (ROR) became an absolute parameter whose its value referred to an engineering reference which presented good calculation about economic prospect of biogas power plant. Although it has different type with Biohythane, ROR value from biogas power plant could be a parameter which has close relativeness with other economic parameters.

By using biogas references, ROR value used was 13% [8]. The ROR was used as principal parameter which determined the value of other parameters using iteration method. As long as iteration, the value of ROR keep the value of ROR always keep 13%. The value of all economic parameters after iteration were shown in table 6.

Based on calculation, the value of EGC achieved US$ 2.478/kWh. Meanwhile, others parameters could be determined as well including annual cash flow, Pay Out Time value (called POT) was 7.55 years, IRR was 11% and BEP was 23% or around 3.71 years. POT, IRR and BEP were calculated by equation 8,9 and 10.

Annual Cash Flow (ACF) was calculated from difference of total Annual Electricity Sale Price (ESP) which had been multiplied with annual total generated electricity to total OPEX (see Table 3) and income tax (10% of ACF-(total annual ESP x annual total generated electricity (kWh/year))). Annual generated electricity amount 5,938 kWh/year was calculated by multiplying between assumed capacity factor (90%) and total electricity capacity 0.753 kWe (see Table 1). The value of ESP obtained was US$ 3.118/kWh which was calculated from iteration of ROR = 13% as well. In order to achieve profitability, the value of ESP always have to set be higher than EGC.

\[
\text{POT} = \frac{\text{FCI (see No. A in Table 2) + Interest of CAPEX}}{\text{ACF (No.3 in Table 6)}}
\]

(8)

Remark : Interest of CAPEX was zero due to do not have a loan

\[
\text{CAPEX (see Table 2) = ACF (No.3 in Table 6) } \left[ \frac{1}{(1+i)^1} + \frac{1}{(1+i)^2} + \ldots + \frac{1}{(1+i)^n} \right]
\]
Where \( i = IRR \), \( n = \text{life time of prototype (16 years)} \)

\[
BEP = \left( \frac{\text{Total Fixed Charge (see No.8 in Table 3)}}{\text{Total Electricity Sale Cost - Total Variable Production Cost (see No.4 in Table 3)}} \right) \times 100\% \quad (10)
\]

The whole calculations showed that this power plant already has good prospect to be built although the value of EGC was high enough. Moreover, if it was compared with some fossil and renewable energy power plants in commercial scale which has lower EGC value. However it still could be understood because prototype capacity was small. Thus, it might be possible to result lower cost when the prototype capacity was increased.

**Table 6.** The economic calculation of biohythane system.

| No | Parameter                                | Unit   | Result  |
|----|------------------------------------------|--------|---------|
| 1  | Electricity Generation Cost (EGC)        | US$/kWh| 2.478   |
| 2  | Electricity Sale Price (ESP)             | US$/kWh| 3.118   |
| 3  | Annual Cash Flow (ACF)                   | US$/year| 3,422   |
| 4  | Payout Time (POT) [7]                    | years  | 7.55    |
| 5  | Internal Rate of Return (IRR) [8]        | %      | 13%     |
| 6  | Break Even Point (BEP)                   | % or years | 23% or 3.71 years |

**4. Conclusion and Recommendation**

The prototype of 1 m³ biohythane system could generate electricity 0.735 kWe resulted from two steps anaerobic fermentation process of POME with COD content 35,000 ppm. It was transported from PKS Cikasungka which have been fermented achieving \( H_2 \) and \( CH_4 \) amount 32 vol. % and 60 vol. % from first and second fermentations, respectively which have been purified by biohythane purification system. According to economic calculation, the prototype has CAPEX and OPEX values amount US$ 26,395 and US$ 14,712/year, respectively. On the other hand, it resulted EGC at amount of US$ 2.478/kWh.

The increase of generated electricity capacity by increasing prototype capacity could be an effort to decrease EGC value. Calculation and analysis using higher capacity become recommendation to achieve EGC even ESP value which could compete with other EGC an ESP values from other power plant types. Regarding to effort to increase \( H_2 \) and \( CH_4 \) compounds from two steps fermentation process, then the use of different source POME pond which would probably produce higher COD. The COD used in calculation was 35,000 ppm. This value was categorized small because in theory that general COD from POME could achieve composition more than 50,000 ppm. Therefore, by increasing COD then it would affect the increase of Biohydrogen and Biomethane compounds which could increase generated electricity from these gases as well.

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