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Study on Assessment and Feasibility of Hythane From POME to Improve Power Plant Performance

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ABSTRACTS

Biogas power plant from POME is getting trendier because Indonesia is the largest palm oil producer in the world as the amount of palm oil production produces more POME and has a high COD. COD is commonly used as a base stoichiometry calculation for CH_4 conversion. Correction on COD conversion for biogas production was done by considering CO_2 rather than CH_4 only. Combining H_2 with CH_4 is a worthy breakthrough because it can increase by 15% of electricity output. Such H_2 and CH_4 mixing has some advantages on the unique combustion property of H_2 in CH_4 (hythane). Economic analysis comparison on this mixing of biogas and conventional biogas was assessed to see the improvement because of an increase in LHV value in biogas. Based on previous experiments conducted by cascading H_2 and followed by CH_4 production, with an H_2 in CH_4 ratio of 1:3, an economic analysis was calculated according to an industry capacity of 60 tonnes FFB/hour. A previous biogas power plant needed an investment of $1,502,000 for 1.35 MWe, but $400,000 was later invested for 1.59 MWe by hythane, increasing 15%. The investment performance of this power plant gave IRR 43.96%, 9.95% higher, and low BEP, 34%. The biogas power plant is economically safe, does not suffer from losses even produces only 34% capacity. The payback period was 2.6 years, seven months shorter. In conclusion, an additional one bioreactor on the existing power plant is economically feasible.

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INTRODUCTION

Based on the United Nations, the world population is 7.7 billion today, and within little more than a decade, the world population will reach around 8.5 billion and almost 10 billion by 2050 [1]. The population projections indicate that nine countries will make up more than half of the projected growth of the global population between now and 2050, including Indonesia. This growth affects food needs both from plantation and livestock sources. For this livestock, it will increase to around 14.5% of the total anthropogenic greenhouse gas emissions of 7.1 Gigaton CO_2. This amount is equivalent to 2005 [2]. GHG emissions are related to palm oil plantations. Based on a yield range of 3.2-4 tons CPO/ha*yr, GHG emissions per ton of CPO are in the order of 45-125 kg CO_2, which in total can reach 5 million tons CO_2 [3].

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The impact of POME treatment on methane was mainly produced by an anaerobic bio-digester. CH_4 is a gas that affects global warming 28 times higher than CO_2, whereas CO_2 equivalent is a standard unit used to account for the global warming potential [4]. In the case of palm oil plants, Indonesia is the highest country in the production of Crude Palm Oil (CPO) worldwide. Biogas with CH_4 as the main component can be collected and utilized as fuel for a power plant or bio-CNG. Cikasungka Palm Oil Industry, located in Bogor-West Java, and Kertajaya Palm Oil Industry, located in Malimping-Banten are currently managed by PTPN VIII, a state-own company in Indonesia. The palm area is 20,153.9 ha and is spread across 9 garden units, including Kertajaya, Bojong Datar, Cikasungka, Cisalak Baru, Sukamaju, Gedeh, Tambaksari, Parakan Salak, Panglejar, Cikasungka, and Kertajaya. Both palm oil plants have a capacity of 30 and 60 tons of EFB/hour in Cikasungka and Kertajaya, respectively. They have to manage POME at about 46 m3/hour with a COD content of 30,000 – 35,000 ppm.

POME could be treated to generate H_2 only (bio H_2) and CH_4 (biogas or bio CH_4) through two subsequent fermentation. The previous experiment showed that POME could be treated to produce bio H_2 by suppressing methanogenesis microbes. Bio H_2 and bio CH_4 from POME would have good prospects as renewable energy in the future energy market. Bio H_2 has been described as the key energy carrier and a sustainable energy carrier. Moreover, H_2 could be captured and has the potential to be applied for transport fuel and electricity because it has 2.75 times higher than light hydrocarbon, 122 kJ/g [5] [6].. Bio H2 and Bio CH_4 used for renewable fuel are currently counted towards the target of 20% renewable share of the final energy consumption of renewable sources by 2020. In addition, the use of bio-methane in transport can also contribute to satisfying the goal of reducing the average GHG emissions [7].

Based on the existing biogas power plant and the development of bio H_2 from POME at BPPT, this work assessed the possibility of further improvement in the biogas power plant. The quality of fuel by mixing H_2 and CH_4 of biogas products from POME theoretically increases LHV. The mixing of H_2 in CH_4 gives some advantages because there are unique combustion properties of H_2 in CH_4. Therefore, analyses and estimations of economic feasibility were done in the scenario of whether an additional bio H_2 reactor was added to the existing biogas power plant.

METHODS

The data in this research was obtained from the biogas power plant in Terantam, supported by additional technical data from previous research.

Materials

Kertajaya Ltd, a state-owned palm oil firm (PTPN VIII) based in Malimping, Banten province, provided POME for this study. Adolina Ltd., Medan, North Sumatera, provided active sludge comprising a microbial community generated from POME. To enrich hydrogen content in biogas, active sludge was combined with cow manure. The initial gas production test was conducted for POME by PTPN III and applicable for the POME from PTPN VIII, which yielded almost similar results. The phosphate buffer was only utilized at the start of the anaerobic fermentation process. Merck EMD Millipore Corporation, a German company, provided the buffer.

Methods

Biogas production for hydrogen was done in 100 mL capped bottles in a batch experiment. The hydrogen biogas created was trapped in bottles that were firmly closed, and the biogas produced was measured every two days. A 2.5 L bioreactor was utilized to capture the active sludge. Bio H_2 production for both bottle and bioreactor scales used buffer only at the starting fermentation for about 10%.

Fed-Batch experiment: Biogas production was scaled up in a semi-continuous system with a five-day total incubation time. The fermentor has a capacity of 2.5 liters and a working volume of roughly 2 liters. A separator was installed in this system to separate POME liquid waste from the resultant gas. The Up Stream Anaerobic Sludge (UASR) approach was used to feed POME using a peristaltic pump at a low speed. The fermentor system also had a feature as a pH monitoring tool.

Analysis

COD

With 0-15,000 ppm COD/CSB vials containing potassium dichromate, $HgSO_4$, and 61 percent sulfuric acid, COD was measured using the Lovibond MD 100 COD kit. Fresh POME typically has a ppm range of 15,000 to 100,000. [8]. Therefore, according to COD prediction, the sample should be diluted using aqua dest in 2-8 times.

Gas Chromatograph

The hydrogen, carbon dioxide (CO_2), and methane were analyzed using a gas chromatograph thermal conductivity detector (GC Shimadzu-TCD 8A) and Shimadzu 2014. (CH_4). The injection, cooling, and final temperatures were all set to 100, 50, and 50 degrees Celsius, respectively. The gas was put into the sampling bag by gently pushing it for 30 seconds.

Water Displacement

The total biogas produced was calculated using water displacement. The biogas that had passed through this water displacement was collected in a sample bag and analyzed using a GC Shimadzu-TCD 8A to determine its composition.

RESULTS AND DISCUSSION

The assessment of the feasibility of improving biogas quality was performed by mixing bio H_2 and CH_4. Some reports showed that hydrogen/methane (hythane) blends in a single-cylinder research engine would improve combustion behavior, emissions, and performance of the engine fueled [8].

The first information was reviewed based on the data from the biogas power plant in Terantam – Riau. This biogas power plant was built to utilize POMEas liquid waste of the palm oil industry. Based on biogas from POME data of the biogas power plant, the power plant has set the biogas engine to work at 50% CH_4 as the minimum concentration biogas engine inlet at the commissioning stage. In addition, CH_4 level in biogas from covered lagoon) at this biogas power plant was, on average, about 54%. Estimation for electricity produced by the biogas engine was calculated based on a low heating value, where there was no phase change of the water component in the combustion process [9].

$$CH_4+O_2 \rightarrow CO_2+H_2O \ \Delta H=-0.2475 \text{ kWh} \quad (1)$$

At commissioning, testing of electricity production by Jenbacher biogas engine was conducted at the flow rate of biogas by 442.6 Nm3/h, which could be converted to electricity at level 864 kW. Therefore, the efficiency of the biogas engine was 34%.

Bio H_2 Production

Table 1. Data compilation at bio H_2 and bio CH_4 production from POME at PTSEIK – BPPT.

Parameter	Quality
POME properties	
COD	35,000 ppm
pH	4 – 5
After bio H_2 production	
COD	25,860 ppm
pH	5 – 6
After bio CH_4 production	
COD	5,520
pH	6.5 – 7.5

The second information was extracted from the results of the bio H_2 experiments from POME at a 1 m3 bio-reactor prototype. In previous research, suppressing methanogenesis microbes was successfully conducted in order to produce bio H_2 from POME at PTSEIK laboratory, BPPT. The processing of POME produced only H_2 and CO_2, but no CH_4 was detected. In addition, a bio-H_2 level reached 57% at the beginning of batch fermentation and only 32% at the end of fermentation [10], confirming the potential of any agricultural waste to produce bio H_2 [11]. Therefore, we propose to combine bio H_2 production and CH_4 production as the inlet biogas for the biogas engine.

Proposing of Process Design for Hythane Production

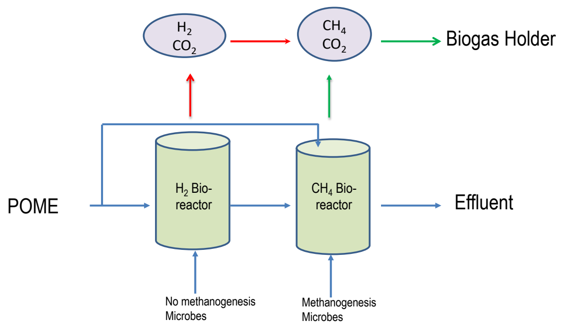

Figure 1. Diagram of Design for Hythane Production Process Flow from POME.

Based on experimental data for bio H_2, the design process to produce bio H_2 was drawn as presented in Figure 1. Bio H_2 production from POME should be conducted first. Bio H_2 production can only degrade 26.1% COD [10]. Afterward, Bio CH_4 production took place as the second process to convert 58.11%. A total of 84.21% of COD could be converted and produced biogas from the cover lagoon system that had already been established. The same conversion was predicted by two-step bioconversion at a laboratory scale that degraded COD and produced hythane as given at a laboratory scale. Unfortunately, the final COD for hythane production was still more than 5,000 ppm at the laboratory. Moreover, COD outlet POME of the existing cover lagoon for biogas (CH_4) production was also still up to 4,000 ppm, which still could not be disposed directly to the environment based on Environmental Ministry regulation [12] [13].

Assessment for Economic Feasibility of Bio-Hythane for Power Plant

In general, biogas design estimation to calculate the potential POME was based on COD equivalence to CH_4. COD conversion was written based directly on the need for O_2 to convert COD as follows [14]:

$$CH_4 + 2O_2 \text{ ------------------> } CO_2 + 2H_2O \quad (2)$$

The need for O2 was supposedly for COD. Therefore, 4 g COD would produce 1 g of CH4 or 1.4 L CH4. This work proposed the compilation of subsequent processes: COD to Bio H_2 converted about 26.1%, while COD to biogas converted about 58.11%. Therefore, the estimation of this bio-conversion took place in 2 steps.

Before going through estimation for two steps of bioconversion, the previous analysis of biogas production is described below.

$$COD \rightarrow CH_4 + CO_2 \quad (3)$$

For the first scenario, which was a conventional estimation, a calculation was made on the potential POME to biogas and electricity then. Existing POME was converted biologically to biogas by considering that COD should be converted to CH_4 as the base calculation. The next process from biogas to electricity at an existing power plant uses a Jenbacher biogas engine for a 1 MWe capacity. The palm oil industry at Terantam – Riau has a capacity of 60-tonnes of Fresh Fruit Bunch/hour and produces 39-ton POME. On average, the COD of POME was 60,000 ppm. At full capacity, the biogas power plant had the potential to produce electricity of up to 2.49 MWe. Unfortunately, the operational production was, on average, at a level of 60 -70% yearly. Therefore, on average, the power should produce 1.62 MWe.

In the second scenario, the power plant estimation considered CO_2 produced besides CH_4, which converted COD presumed as C source. Based on biogas data provided in the field, the main components, CH_4 and CO_2, were 54% and 40%, respectively. The 54% CH_4 measured at the biogas engine with its flow rate was used to calculate the electricity produced by the biogas engine. The biogas power plant should produce 1.07 MW. This amount is more reasonable based on the current conditions in which maximal electricity generated reaches 0.850 MWe. Nevertheless, the biogas power plant is designed to manage POME half of the capacity of a palm oil mill.

In the third scenario, the digester should be split into two steps. In the first step, the digester would produce bio H_2 with an H_2 level, on average, of 46%. CO_2 produced at this step was used to determine the conversion of COD.

$$COD \rightarrow H_2 + CO_2 \quad (4)$$

Based on the laboratory experiment, COD that converted reached 26.1%. The effluent of the first bioreactor was supposed to be the feeding at digester to be bio-converted to CH_4. The product of the first bioreactor was mixed with biogas from the digester. By this design, the biogas produced was CH_4 and H_2 with a concentration level of 29.48% and 20.89%, respectively. Furthermore, the total volume of biogas was also increased by these two steps biogas production, bio H_2, and bio CH_4. The LHV of this mixing biogas can be estimated based on Figure 2, which describes that the 29.48% CH_4 in H_2 was 58 MJ/kg. It was estimated with this composition that the biogas potential would produce 1,588 MWe and improve about 15%.

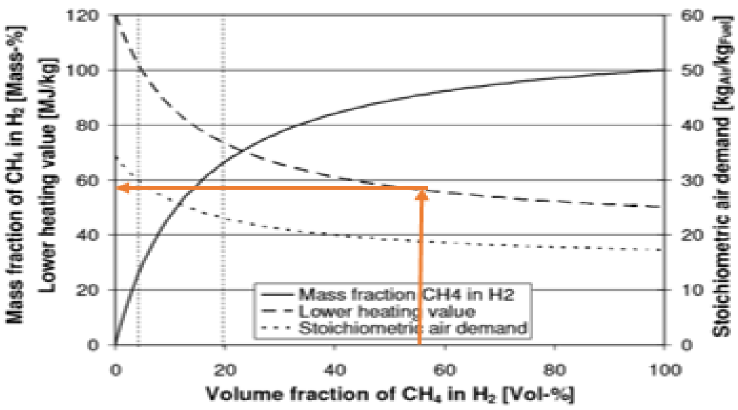

Figure 2. Influence of composition on fuel properties [15].

Feasibility Analysis

An economic analysis was estimated based on the discussion between bio H_2 Research Group and Feng Chia University researchers. Capital Expenditures (CAPEX) and Operational Expenditures (OPEX) were estimated for the standard price in Sumatera in 2016 to establish a biogas power plant and its additional equipment for hythane, as shown in Table 2. The project was located in Pekanbaru in the area of PTPN V, a state-owned company. Therefore, this analysis ignored the costs incurred for the area procurement. Secondly, the selling price of electricity produced was analogous to the sale of electricity as the price at the state electricity corporation (PLN), $0.1/kWh. At full capacity of 11 months and 15% of electricity for internal usage, the company's revenue in one year will reach $ 792,744 [16].

In terms of OPEX, some expenses are detailed in Table 3. All employees were counted as full-time workers. This biogas power plant was operated 24 hours per day with three rotatable shifts. The biogas power plant was designed with an automatic system; thus, the number of labor and administration staff could be minimized.

Investment Performance

The performance of economic analysis, firstly shown in Figure 3, discusses Break-Even Point (BEP) was reached by 34% production capacity. Low BEP means that the biogas power plant will not experience any losses even though the biogas power plant is only operated at 34% of the planned capacity.

Table 2. Capital Investment.

Capital Investment	Price Biogas CH_4	Additional investment for Hythane
Civil work	$400,000	
Bio-reactor		$400,000
Cover Lagoon	$250,000	
Mechanical	$33,333	
Piping	$65,000	
Down Stream Process	$157,500	
Biogas engine	$600,000	
Total	$1,106,233	$1,506,233

Table 3. List of Operational Expenditures.

Fixed Cost	Expenses Biogas CH_4	Expenses Hythane
Depreciation [17]	$110,623.30	$150,623.30
Salary	$75,311.65	
Utility and administration	$10,000.00	
Total	$195,934.95	$235,934.95

Variable Cost	Price	
POME	$9,406.80	
Maintenance and utilities	$110,623.30	$150,623.30
Total	$120,030.10	$140,030.10

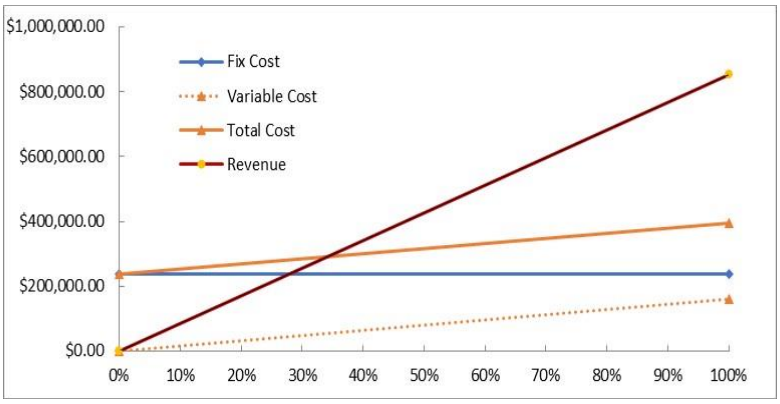

Figure 3. BEP Analysis.

Investment performance was analyzed by calculating the Internal Rate of Return (IRR) and Pay Back Period (PBP). The biogas power plant was built under a program budget of a government research institution, so it did not take into account bank interest for this investment performance analysis. Moreover, an economic analysis was calculated in the U.S. dollar currency to ignore the inflation rate. The investment needed $1,506,233, and the project was estimated to generate $852,191 in cash flows each year for ten years. The IRR of 43.96% is the rate at which those future cash flows can be discounted to equal $1,506,233. PBP could be achieved within two years and eight months.

CONCLUSION

Economic feasibility assessment has demonstrated that the electricity output of the biogas engine can be improved at 15% by mixing bio H_2 and CH_4. Bio H_2 production is proposed as the first stage before biogas existing cover lagoon. Proposing a bio H_2 reactor at the biogas power plant will increase the electricity productivity from 0.846 MWe to 960 MWe, which is still within the capacity of the biogas engine. Besides, the presence of bio H2 in biogas will increase the LHV to 58 MJ/kg. Moreover, based on mass balance estimation of POME treatment at two steps, bio-reactors would also increase the amount of total biogas. Economic feasibility analysis at full capacity of palm oil production would give an IRR of 43.96%, 9.95% higher than biogas CH_4. Therefore, an additional bioreactor, with an additional investment of $400,000 on an existing biogas power plant, is considered feasible to be applied.

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