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Palm Oil Mill Effluent (POME) Biogas Techno-Economic Analysis for Utilisation as Bio Compressed Natural Gas

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The production of palm oil will continue to rise with increasing demand of fats and oils. The increase of palm oil production will result in high production of palm oil mill effluent (POME). POME is polluting due to its high chemical oxygen demand (COD) and biological oxygen demand (BOD). High COD and BOD of POME has the advantage to produce large amount of biogas through anaerobic digestion (AD). As upgraded biogas has equal composition to natural gas, it can be potentially used as compressed natural gas (CNG) or also known as bio-CNG. Bio-CNG at its current state is too expensive for implementation where subsidies are required to enable the technology, especially for countries where energy price is low such as in Malaysia. This paper studies on the economic potential of the bio-processing technology which consists of an anaerobic digester, purification unit, and compression up to 20 MPa as the biogas will be utilised as CNG. The parameter that is considered in the economic analysis includes the cost of the AD, purification unit, compression of biogas (based on the outlet pressure of the purification unit up to 20 MPa), transportation cost of bio-CNG, and lastly the profit obtained from the sales of bio-CNG. It is revealed that the system that utilises membrane separation technology has the lowest payback period and hence is most economical.

1. Introduction

Malaysia has a substantial amount of palm oil mill effluent (POME) which can be used to generate biogas. It is evaluated that for 1 t of crude palm oil produced, 5 to 7.5 t of water is required and more than 50 % of water will wind up as POME (Chin et al., 2013). The crude palm oil (CPO) production of 19,510,000 t is estimated to have the potential to produce 58.53 million m^3 of POME annually (MPOB, 2016) and through anaerobic digestion (AD), POME has the potential to generate up to 1,044,760,500 m^3 of biogas which is equivalent to 4.38 TWh/y of electricity (assuming 40 % gas engine efficiency). POME being a waste with high organic carbon content has become a promising source for biogas production and can potentially boost up the renewable energy sector. Based on data of annual power generation of commissioned RE Installations for POME biogas from SEDA (2016), only 41,122.4 MWh of energy is harvested. The potential biogas energy that can be harvested is up to 257,213 MWh.

Other than electricity generation, biogas that is made of mostly of methane gas can be upgraded and applied similarly to natural gas (Urja, 2016). One of the potential application for biogas is using it as compressed natural gas (CNG) or also known as bio-CNG. Biogas has to be purified by removing hydrogen sulphide (H_2S), moisture, and carbon dioxide (CO_2) and further compressed to be used as fuel (bio-CNG) in natural gas vehicles (NGV) (Subramanian et al., 2013).

The application of biogas as bio-CNG is proven, but in Malaysia, due to the low energy cost, bio-CNG processing which requires upgrading and compression is considered too expensive and is not economically competitive compared to conventional CNG (Urja, 2016). Another major issue that is POME is found mostly in rural areas where energy demand is low, any form of energy based on POME whether it is electricity or bio-

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CNG have to be transported to a local town which is often over 10 km away from the palm oil mill further increasing the processing cost (Mohtar et al., 2017).

There are many technologies for biogas purification, all with different capital and operating cost. The operating condition for each technology is also different (Sun et al., 2015). Technology that purifies biogas at higher pressure may require less compression as the pressure of the gas is already high, while technology that purifies biogas at lower pressure may require more compression.

This paper intends to analyse the economics of bio-CNG processing plant by considering capital and operating cost of AD, purification units, compressor and compression, and mode of transportation and its corresponding transportation cost. Section 2 describes the bio-CNG purification and compression system while section 3 describes the methodology for the economic analysis, section 4 describe the case study and data used in the analysis, and section 5 discusses the results.

2. Bio-CNG Purification and Compression

Upgrading biogas to a quality comparable to conventional natural gas is a multiple step procedure. Figure 1 shows the route for biogas conversion to bio-CNG including the mode of transportation which can be through the natural gas pipeline or bottled and transported via truck. For purification, several technologies are available such as water scrubber, cryogenic, physical absorber, chemical absorber, pressure swing absorption, and membrane technology. Typically, purification process of biogas starts with the scrubbing unit consisting of CO_2 separation unit, H_2S separation unit and moisture separation unit. After purification, CH_4 composition should be more than 97 %, with CO_2 less than 3 % by volume, H_2S less than 10 ppm and water content should be less than 32 mg/m^3 (Subramanian et al., 2013). Based on the operating pressure of the purification unit and the required pressure for transportation, the purified biogas will have to be compressed. For transportation via natural gas pipeline, the Malaysian natural gas pipeline operates at 2 to 7 MPa. If the operating pressure of the purification technology is higher than the pipeline operating pressure, the biogas has to be depressurised. If the operating pressure of the purification technology is lower, further compression is required. For transportation via truck, the biogas has to be bottled. Similarly, the pressure of the biogas has to be adjusted. The common pressure for biogas bottling is up to 20 MPa. Once the biogas is transported, the biogas has to be further pressurised if the pressure is lower than the required pressure of NGV's.

For the compressor, reciprocating compressors (RC) is considered in this study as RC is capable to compress gas at near-atmospheric inlet pressure to a pressure of up to 30 MPa (Frenz and Hüllenkremer, 2012). It is noted that CNG usually operates around 20 MPa. RC is also widely used in the compression of natural gas in a natural gas grid and in NGV fuelling station (IGU-UNECE, 2012). Since biogas has identical chemical composition with natural gas, RC is suggested to be the best option for biogas compression.

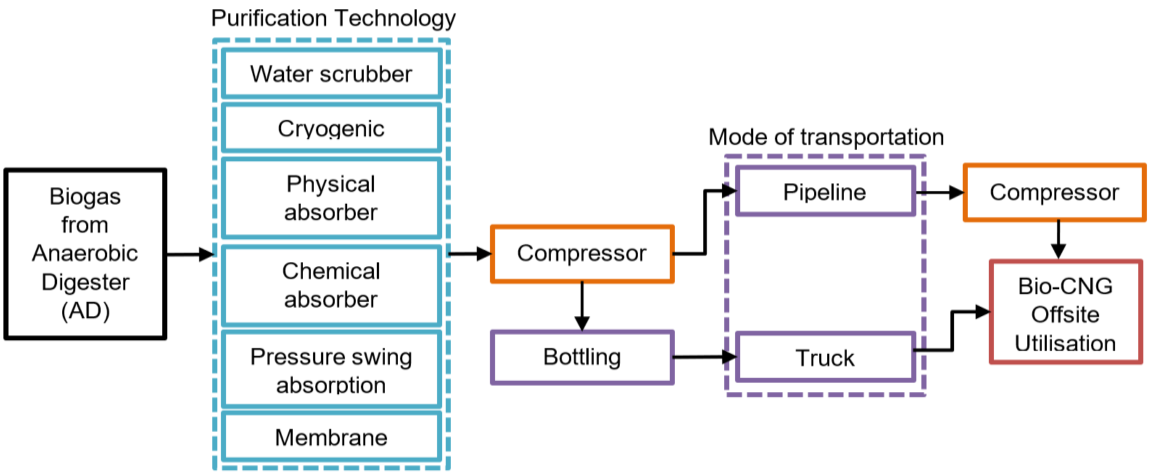

Figure 1: Bio-CNG processing pathway

3. Methodology

In order to evaluate the economics of biogas conversion to bio-CNG, Eq(1) is used to calculate the cost of AD, while Eq(2) is used to calculate the cost of purification technology (PT). All of the operational cost is calculated based on 25 y of lifetime (LT).

$$\text{Cost of AD} = \text{Capital Cost of AD} \ \times \text{Capacity of AD} + (\text{Operational Cost} \ \times \text{LT}) \quad (1)$$

$$\text{Cost of PT} = \text{Capital Cost of PT} \times \text{PT Capacity} \ + (\text{Operational Cost of PT} \ \times \text{Flowrate of Biogas} \ \times \text{LT}) \quad (2)$$

The cost of compressor is calculated using Eq(3). The capital cost of compressor is obtained from a graphical correlation retrieved from Loh et al., (2002), The graph relates the capital cost with the operating pressure of the compressor and the processing volume in (m^3/min). The operating cost of compressor is calculated using Eq(4). In this equation it is assumed that the compressor runs at 100 %. The energy consumption of the pump depends on the pressure differences between the inlet and outlet and is obtained from a graph correlation retrieved from McAllister (2013).

$$\text{Cost of compressor} = \text{Capital Cost of Compressor} + (\text{Operating Cost of Compressor} \ \times \text{LT}) \quad (3)$$

$$\text{Operating Cost of Compressor} = \frac{\text{Energy consumption (kWh)} \times \text{electical tariff (USD/kWh)}}{\text{Motor efficiency}} \quad (4)$$

In this study, two modes of transporting biogas were identified, transportation using the natural gas pipeline, or bottled and transported via truck. Eq(5) and Eq(6) are used to calculate the cost of transportation. Eq(7) is used to calculate the number of trip to deliver the biogas via truck. P_P is the cost of transportation via pipeline and P_T is the cost of transportation via truck.

$$\text{Transportation Cost (Pipeline)} = P_P\left(\frac{\text{USD}}{\text{km}}\right) \times \text{Biogas volume at 2 MPa } (m^3) \times \text{Distance (km)} \times \text{LT} \quad (5)$$

$$\text{Transportation Cost (Truck)} = P_T\left(\frac{\text{USD}}{\text{km}}\right) \times \text{Number of trip} \times \text{Distance (km)} \times \text{LT} \quad (6)$$

$$\text{Number of Trip} = \frac{\text{Biogas Volume at 20 MPa } (m^3)}{\text{Truck capacity } (m^3)} \quad (7)$$

The profit of selling bio-CNG is calculated using Eq(8). The energy content of bio-CNG is calculated using Eq(9). The payback period for each utilisation option is calculated by using Eq(10).

$$\text{Profit} = \text{bioCNG energy content} \times \text{Price of bioCNG} \quad (8)$$

$$\text{bioCNG energy content} = \text{Biogas Volume at 20 MPa} \ \times \ \text{Biogas density} \times \text{Biogas heating value} \quad (9)$$

$$\text{Pay Back Period} = \frac{\text{Profit}}{\text{Cost of AD + Cost of PT + Cost of Compressor + Transportation Cost}} \quad (10)$$

4. Case Study

Johor region is the largest palm oil planted area as well as the largest CPO producer in peninsular Malaysia. In 2015, the total CPO produced in Johor is 3,047,049 t which accounted for 29.95 % of overall CPO production in peninsular Malaysia. In this study, Felda Sungei Kahang palm oil mill, Johor is taken as a case study. The data used in this study is shown in Table 1. The capital cost of PT and operating cost of PT is shown in Table 2.

Table 1: Data used in case study

Data	Value
Capacity of AD	41,320 m^3/d
Capital Cost of AD (Gorgec et al., 2016)	1.09 USD/m^3
Operation Cost of AD (Affiliated Engineers, 2014)	8 % of AD Capital Cost
Electricity Tariff (TNB, 2014)	0.06 USD/kWh
Motor Efficiency	95 %
Cost of Transportation via Pipeline, P_P (Brightman et al., 2011)	0.004 USD/km
Cost of Transportation via Truck, P_T (Brightman et al., 2011)	1.176 USD/km
Biogas volume at 2 MPa	351,601.8 m^3
Biogas volume at 20 MPa	35,160.2 m^3
Distance (Palm oil mill to local town)	50 km
Truck Capacity	30 m^3
Price of bio-CNG (Seng, 2015)	1.136 x 10^{-5} USD/kJ
Biogas density at 20 MPa	136.019 kg/m^3
Biogas heating value (Chin et al., 2013)	55.5 MJ/kg

Table 2: Capital cost, operating cost, and operating pressure of purification technology

Purification Technology	Capital Cost (USD/m^3)	Operating Cost (USD/m^3)	Operating Pressure (MPa)	Reference
Water scrubbing	5,669	0.58	1	IEA Bioenergy (2011)
Cryogenic separation	6,338	5.57	20	Starr et al. (2012)
Physical absorption	5,669	1.23	0.5	IEA Bioenergy (2011)
Chemical absorption	5,669	1.33	0.1	IEA Bioenergy (2011)
Pressure swing absorption	6,123	1.07	1	Bauer et al. (2013)
Membrane technology	4,654	1.00	2	Sun et al. (2015)

For the compressor, if the biogas is to be transported via pipeline, two compressors are required. Table 3 shows the pressure differences between the purification technology and the mode of transportation and from the transportation to utilisation. It is noted that the operating pressure for the pipeline is at 2 MPa, bottling (transportation via truck) is at 20 MPa, and bio-CNG at 20 MPa. If the biogas is transported via truck, there is no need further compression. Options for selecting PT and transportation mode is labelled as "path" as listed in Table 3.

Table 3: Pressure differences between operation units

Purification Technology	Transportation Mode	Compressor Pressure Differences for PT to Transportation (PTT)	Compressor Pressure Differences for Transportation to Utilisation (TTU)
Water scrubbing (Path 1)	Pipeline	10	180
Cryogenic separation (Path 2)	Pipeline	N/A (PT OP is higher than pipeline OP)	
Physical absorption (Path 3)	Pipeline	15	180
Chemical absorption (Path 4)	Pipeline	19	180
Pressure swing absorption (Path 5)	Pipeline	10	180
Membrane technology (Path 6)	Pipeline	0	180
Water scrubbing (Path 7)	Truck	190	N/A
Cryogenic separation (Path 8)	Truck	0	N/A
Physical absorption (Path 9)	Truck	195	N/A
Chemical absorption (Path 10)	Truck	199	N/A
Pressure swing absorption (Path 11)	Truck	190	N/A
Membrane technology (Path 12)	Truck	180	N/A

5. Result and discussion

Based on the data on technology cost, the cost for AD, PT, compressor (PT to transportation), transportation, and compressor (transportation to utilisation) is calculated and tabulated in Table 4.

Based on the results in Table 4, the AD cost is calculated as 135,116 USD, the cost is the same for all pathways as described in the case study as the designed capacity of the AD is 41,320 m^3/day and the operational cost is 8 % from AD total capital cost. The PT cost result indicates that membrane technology has the lowest cost while the highest cost is cryogenic separation.

Path 5 has the most expensive overall cost with 25,913,399 USD expenditure where the PT option is pressure swing absorption technology and it is transported by pipeline. The cheapest overall cost is path 6 with 17,257,161 USD expenditure where the PT option is by membrane and the bio-CNG is transported by pipeline. Although pipeline transportation required 2 compressors, Path 6 does not require PT to transportation compression as the pressure is already at 2 MPa after undergoing purification process via membrane technology.

In other options, pathways with truck transportation have a lower total cost than pipeline transportation. Initially, transportation cost via truck is more expensive compared to pipeline, but when transporting bio-CNG via pipeline, it requires an additional compressor and that makes the total cost higher. So, it is better to compress it once and deliver it to the utilisation site. Using pipeline may also require additional cost to construct the pipeline as most palm oil mill does not have a natural gas pipeline connected. For bio-CNG application, the best option is to go for transportation via truck where the biogas is pre-compressed. As for PT, membrane which has a high efficiency and becoming more economical over the years is the suitable technology to be applied for biogas purification.

Table 4: Cost of various operating unit for bio-CNG processing for 25 y of lifetime

	AD Cost (USD)	PT Cost (USD)	Compressor Cost for PTT (USD)	Transportation Cost (USD)	Compressor Cost for TTU (USD)	Total Cost (USD)
Path 1	135,116	12,812,940	1,722,022	1,722,850	3,306,756	19,699,684
Path 2	135,116	20,967,727	-	1,722,850	3,306,756	22,825,694
Path 3	135,116	18,425,484	1,994,426	1,722,850	3,306,756	25,584,632
Path 4	135,116	14,566,860	2,111,171	1,722,850	3,306,756	21,842,753
Path 5	135,116	19,026,655	1,722,022	1,722,850	3,306,756	25,913,399
Path 6	135,116	12,092,438	-	1,722,850	3,306,756	17,257,161
Path 7	135,116	12,812,940	3,331,078	1,758,009	-	18,037,143
Path 8	135,116	20,967,727	-	1,758,009	-	22,860,853
Path 9	135,116	18,425,484	3,340,807	1,758,009	-	23,659,416
Path 10	135,116	14,566,860	3,350,535	1,758,009	-	19,810,521
Path 11	135,116	19,026,655	3,331,078	1,758,009	-	24,250,858
Path 12	135,116	12,092,438	3,306,756	1,758,009	-	17,292,320

As for the profit from sales of bio-CNG, the total revenue is calculated to be 3,015,242.38 USD. The payback period for each pathway is then computed as shown in Table 5. In agreement with the cost analysis, the pathway with the lowest payback is pathway 6 by 5.72 y.

Table 5: Bio-CNG payback period

	Payback period (y)
Path 1	6.53
Path 2	7.57
Path 3	8.49
Path 4	7.24
Path 5	8.59
Path 6	5.72
Path 7	5.98
Path 8	7.58
Path 9	7.85
Path 10	6.57
Path 11	8.04
Path 12	5.73

6. Conclusion

In this study, the cost of biogas offsite utilisation is analysed with the primary focus of estimating the investment cost to overcome techno-economic barriers of increased Bio-CNG utilisation and its implications of different technology selection. Utilisation of POME Bio-CNG as renewable energy is considered as new technology and financing these projects is perceived as high-risk investment. Out of other PT option, membrane separation technology has the lowest payback period and hence most economical. In term of transportation, it is revealed that although pipeline has a cheaper transportation cost, but additional compressor cost makes it less practical compared to truck transportation which make overall cost lower.

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