OPTIMISATION OF BIOMETHANE FROM PALM OIL MILL EFFLUENT FOR OFFSITE UTILISATION

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DEDICATION

I dedicate my dissertation work to my family and many friends. A special feeling of gratitude to my loving parents, Mohtar Bin Awang Man and Ruhanah Binti Abd Halim whose words of encouragement and prayers. My wife Nurul Aufa, Binti Ab Majid and my son Abu Naufal Bin Aminullah who have never left my side and are very special.

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ABSTRACT

Palm oil mill effluent (POME) is a source that can be used for biogas generation that can be a substitute for fossil fuel. High content of biological oxygen demand and chemical oxygen demand of POME has the advantage to produce large amount of biogas through anaerobic digestion. The purpose of this research was to develop a mathematical model to determine the optimal process pathway of biogas, covering from the purification technology to the mode of transportation and utilisation by using a mixed integer programming model and general algebraic modeling system as the solver software. A case study based on PPNJ Kahang palm oil mill was conducted to run and test the model, in which different target locations with different utilisation modes were chosen. The model chose membrane scrubber as the purification technology and truck transportation to the targeted site, and electricity generation as the optimal pathway for biogas processing and utilisation. Total capital investment of 2,934,564 USD and yearly operational cost of USD 350,843 would give a payback period of 6 years for this optimal pathway. Sensitivity analysis on feed-in-tariff (FIT) determined that FIT should be increased to 0.116 USD/kWh to ensure that investment in biogas is worthwhile. Sensitivity analysis on compressed biomethane (CBM) was performed to determine the impact of product price on the biomethane process pathway selection. The sensitivity analysis revealed that the price of CBM has an impact on the model. Sensitivity analysis suggested that the CBM sales price should be at least 8.2 USD/MMBtu to be economically feasible and 12.9MMBtu to be profitable. In addition, a subsidy of 2.67 USD/MMBtu should be imposed for CBM project to ensure its economic viability and 7.37 USD/MMBtu to be a more economically attractive option than utilised as electricity.

ABSTRAK

Air kumbahan kilang kelapa sawit (POME) adalah sumber penjanaan biogas yang boleh menjadi pengganti bahan bakar fosil. Kandungan tinggi permintaan oksigen biologi dan permintaan oksigen kimia POME mempunyai kelebihan untuk menghasilkan sejumlah besar biogas melalui pencernaan anaerobik. Tujuan penyelidikan ini adalah untuk mengembangkan model matematik untuk menentukan pilihan laluan proses biogas yang optimum, meliputi teknologi penulenan hingga mod pengangkutan dan penggunaan dengan menggunakan model pengaturcaraan integer bercampur dan sistem pemodelan algebra umum sebagai perisian penyelesai. Kajian kes di kilang sawit PPNJ Kahang digunakan untuk menjalankan dan menguji model, di mana lokasi sasaran yang berbeza dengan mod penggunaan yang berbeza dipilih. Model ini memilih pembersih membran sebagai teknologi penulenan dan pengangkutan trak ke lokasi yang disasarkan, dan penjanaan elektrik adalah sebagai pilihan yang optimum untuk pemprosesan dan penggunaan biogas. Jumlah pelaburan modal sebanyak USD 2,934,564 dan kos operasi tahunan sebanyak USD 350,843 memberikan tempoh pembayaran balik selama 6 tahun untuk laluan optimum ini. Analisis kepekaan pada *feed-in-tariff* (FIT) menentukan bahawa FIT harus ditingkatkan menjadi 0.116 USD/kWh untuk memastikan pelaburan dalam biogas berbaloi. Analisis kepekaan pada biometana termampat (CBM) pula dilakukan untuk menentukan kesan harga produk terhadap pemilihan laluan proses biometana. Analisis kepekaan menunjukkan bahawa harga CBM memberi kesan kepada model. Analisis kepekaan mencadangkan harga jualan CBM sekurang-kurangnya 8.2 USD / MMBtu dapat dilaksanakan untuk tujuan ekonomi dan 12.9MMBtu untuk keuntungan. Sebagai tambahan, subsidi sebanyak 2.67 USD / MMBtu harus dikenakan untuk projek CBM untuk memastikan daya maju ekonominya dan 7.37 USD/MMBtu menjadi pilihan yang lebih menarik dari segi ekonomi daripada penggunaanya sebagai tenaga elektrik

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LIST OF ABBREVIATIONS

AD	-	Anaerobic digestion
BOD	-	Biochemical oxygen demand
CA	-	Chemical Absorption purification technology
CBM	-	Compressed biomethane
COD	-	Chemical oxygen demand
$\mathrm{Comp}_{\mathrm{c}}^{\mathrm{UnitCapex}}$	-	Unit capital cost of compressor with capacity
$\mathrm{Comp}_{\mathrm{c}}^{\mathrm{UnitOpex}}$	-	Unit operating cost of compressor with capacity
$\mathrm{Comp}_{\mathrm{c}}^{\mathrm{Cap}}$	-	Maximum capacity of compressor
$\mathrm{Comp.Stage}_{\mathrm{pr,t}}^{\mathrm{Truck}}$	-	Compressor stage requirement to compress biomethane from purification unit pressure to required truck pressure
$\mathrm{Comp.Stage}_{\mathrm{pr}}^{\mathrm{Pipe}}$	-	Compressor stage requirement to compress biomethane from purification unit pressure to required pipeline pressure
$\mathrm{Comp.Stage}_{\mathrm{pr,t}}^{\mathrm{Truck2}}$	-	Compressor stage requirement to compress biomethane from truck to required utilisation pressure
$\mathrm{Comp.Stage}_{\mathrm{pr}}^{\mathrm{Pipe2}}$	-	Compressor stage requirement to compress biomethane from pipeline to required utilisation pressure
$Comp_{pr,t}^{Econs,Truck}$	-	Unit power requirement to compress biomethane produced to required pressure of truck
$Comp_{pr}^{Econs,Truck2}$	-	Unit power requirement to compress biomethane from truck to required utilisation pressure
$Comp_{pr}^{Econs,Pipe}$	-	Unit power requirement to compress biomethane produced to required pipeline transportation pressure
$Comp_{pr}^{Econs,Pipe2}$	-	Unit power requirement to compress biomethane from pipeline to required utilisation pressure
$Comp_{pr,t}^{Power,Truck}$	-	Compressor power requirement to compress biomethane produced to required pressure of truck
$Comp_{pr}^{Power,Truck2}$	-	Compressor power requirement to compress biomethane from truck to required utilisation pressure
$Comp_{pr}^{Power,Pipe}$	-	Compressor power requirement to compress biomethane produced to required pipeline transportation pressure

$Comp_{pr}^{Power,Pipe2}$	-	Compressor power requirement to compress biomethane from pipeline to required utilisation pressure
C50	-	Compressor capacity at 50 kW
C100	-	Compressor capacity at 100 kW
C150	-	Compressor capacity at 150 kW
C200	-	Compressor capacity at 200 kW
C250	-	Compressor capacity at 250 kW
C300	-	Compressor capacity at 300 kW
CRF	-	Capital recovery factor
CPO	-	Crude palm oil
$\mathrm{CNG}^{\mathrm{price}}$	-	Selling price of CBM
CV	-	Calorific value
D	-	Transportation distance
DOE	-	Department of Environment
EFB	-	Empty fruit bunch
EQA	-	Environment Quality Act
FFB	-	Fresh fruit bunches
$\mathrm{F}^{\mathrm{Biogas}}$	-	Annual production of raw biogas
$\mathrm{F}_{\mathrm{pr}}^{\mathrm{CNG}}$	-	Amount of biomethane utilised as CBM
$\mathrm{F}_{\mathrm{pr}}^{\mathrm{HV}}$	-	Heating value of biomethane purified by technology
FC	-	Fuel cost
FiAH	-	Feed-in Approval Holder
FiT	-	Feed in Tariff
F_{pr}^{In}	-	Amount of biomethane processed by purification technology
F_{pr}^{Out}	-	Amount of biomethane produced in purification technology
$F_{pr}^{Comp,pipe}$	-	Amount of biomethane transported through pipeline
$F_{pr,t}^{Comp,truck}$	-	Amount of biomethane transported through truck
$F_{pr}^{Pipe,cng}$	-	Amount of pipeline transported biomethane used as CBM
$F_{pr}^{Pipe,elec}$	-	Amount of pipeline transported biomethane used for electricity generation
$F_{pr,t}^{Compout,truck}$	-	Amount of biomethane after compression to transportation pressure of truck

F_{pr}^{Elec}	-	Amount of biomethane utilised as electricity
F_{pr}^{CNG}	-	Amount of biomethane utilised as CBM
GAMS	-	General Algebraic Modelling System
GP	-	Annual gross profit of the system
GHG	-	Greenhouse gas
i	-	Interest rate
LBM	-	liquefied biomethane
LT	-	The number of plant operating hours in a year
LPG	-	Liquefied petroleum gas
LP	-	Linear program
MILP	-	Mixed Integer linear Programming
MINLP	-	Mixed Integer Non-linear Programming
MSWL	-	Municipal solid waste landfills
MS	-	Membrane scrubber purification technology
MPOB	-	Malaysian Palm Oil Board
$N_{pr,t}^{trip}$	-	Number of trips required
$N_{pr,t}^{truck}$	-	Number of trucks required
$N_{pr,c}^{Comp,Truck}$	-	Number of compressor with capacity required to compress biomethane to truck transportation pressure
$N_{pr,c}^{Comp,Truck2}$	-	Number of compressor with capacity required to compress biomethane from truck to utilisation pressure
$N_{pr,c}^{Comp,Pipe}$	-	Number of compressor with capacity required to compress biomethane to pipeline transportation pressure
$N_{pr,c}^{Comp,Pipe2}$	-	Number of compressor with capacity required to compress biomethane from pipeline to utilisation pressure
NGV	-	Natural gas vehicles
NLP	-	Nonlinear program
NKEA	-	National Key Economic Area
PSA	-	Pressure swing absorption purification technology
PP_{pr}^{cap}	-	Capacity of power plant
PP^{capex}	-	Capital cost of power plant
$PP^{fixedopex}$	-	Fixed operating cost of power plant
$PP^{varopex}$	-	Variable operating cost of power plant

$Pipe^{Capex}$	-	Capital cost of pipeline
$Pipe^{Opex}$	-	Operation cost of pipeline
$\mathrm{P^{pr}}$	-	Initial pressure of biomathene at purification technology outlet
$\mathrm{P^{Truck}}$	-	Pressure required for truck transportation
$\mathrm{PR_{pr}^{Eff}}$	-	Purification efficiency
$\mathrm{PR_{pr}^{UnitCapex}}$	-	Unit capital cost of purification technology
$\mathrm{PR_{pr}^{UnitOpex}}$	-	Unit operating cost of purification technology
PKS	-	Palm kernel shell
POME	-	Palm oil mill effluent
RE	-	Renewable energy
ROI	-	Return on investment
$Sales^{CNG}$	-	Sales revenue of CBM
$Sales^{Elec}$	-	Sales revenue of electricity
TLT	-	Time Load Tariff
$\mathrm{TR_{t}^{unitprice}}$	-	Price of a single truck
$\mathrm{TR_{pr,t}^{cap}}$	-	Capacity of truck
$\mathrm{TR_{t}^{FE}}$	-	Fuel efficiency of truck
$\mathrm{TR^{Opex}}$	-	Truck operating cost
$\mathrm{TR^{speed}}$	-	Truck travelling speed
$\mathrm{TR^{LoadTime}}$	-	Time for product loading
$\mathrm{TR^{AvailTime}}$	-	Time availability of truck in a day
TR^{Capex}	-	Truck capital cost
TR^{Opex}	-	Truck operating cost
$TotalCost$	-	Total system cost per year
T100	-	Truck pressure at 100 bar
T150	-	Truck pressure at 150 bar
T200	-	Truck pressure at 200 bar
T250	-	Truck pressure at 250 bar
VFA	-	Volatile fatty acids
WS	-	Water scrubber purification technology
Y^{SL}	-	System lifespan

LIST OF SYMBOLS

CH_4	-	Methane
CO_2	-	Carbon dioxide
H_2S	-	Hydrogen sulphide
H_2	-	Hydrogen gas

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CHAPTER 1

INTRODUCTION

1.1 Background of Research

One of the largest Malaysia's key economy development is from the palm oil industry. During the production of crude palm oil (CPO) from fresh fruit bunch (FFB), it has created huge wastes, such as palm based biomass (empty fruit bunch, mesocarp fiber and palm kernel shell) and palm oil mill effluent (POME) (Chin *et al.,* 2013). In recent year, palm based biomass has become a new source of income for palm oil mill and serving the demand of biomass as source of fuel for industrial heating application.

POME is one of the major environmental pollutants in Malaysia. It contains high biochemical oxygen demand (BOD) and chemical oxygen demand (COD) which makes it more polluted than the municipal sewage. The effluent also is regarded as a complex compound which consists of carbohydrates, nitrogenous compounds, free organic acids, water soluble components of palm fruits and suspended materials (Lok *et al*., 2020). Therefore, discharging POME directly into the river body without treatment can be a huge threat to the environment and it is an offend against Malaysia's Law of Environmental Quality Act (EQA) as the final effluent of the treated POME must comply with the discharge standards set by the Department of Environment (DOE), Malaysia (Kamyab *et al*., 2018). The fact that the potential energy from POME cannot be utilised or transported to elsewhere before treatment makes POME left untapped abundantly compared to palm based biomass.

The procedure to extract the oil requires essentially extensive amounts of sterilisation of fresh fruit bunches and refining the extracted oil. According to *Chin et al*., (2013), in each tonne of fresh fruit bunches (FFB) processing, it is estimated around 3 m^3 of water are typically end up as discharge water known as POME. Based on the statistical value from the study by Madaki *et al*. (2013) on total CPO production in May 2011, the production of 985 065 tonnes of CPO consumed a total of 1.5 million m^3 of water, with 738 797 m^3 of POME generation and 20 686 176 m^3 of biogas production in one month alone.

POME is a concentrated yellow fluid with a particular intimidating smell. It has a high chemical oxygen demand value ranging from 44 300 to 102 69l mg/L. The biochemical oxygen demand also in a high value ranging from 25 000 to 65 714 mg/L. The other attributes of POME include its acidic nature (pH 3.4–5.2), high salt and suspended solids (18 000– 46 011 mg/L), and high oil and grease (4 000–9 341 mg/L) substance (Chin *et al*., 2013). POME can cause extensive threat to the environment if released with no compelling treatment (Wang *et al*., 2015). POME has a chemical oxygen demand (COD)/ biological oxygen demand (BOD) ratio of 0.5, indicating its biodegradable constituent. Good value of COD/BOD ratio reflect the effective POME treatment is by the means of biological process (Metcalf, 2003). Crude palm oil (CPO) production in Malaysia from 2013 until 2020 (MPOB, 2021) and estimated POME available is shown in Figure 1.1. The estimation of POME generation is based on based on 3m^3 POME generated from 1 tonnes of CPO processing (Abdullah & Lazim, 2007). The trend in Figure 1.1 shows an increments with an average of 460 654 tonnes increments of CPO production annually. This reflect that the potential of POME generation is also increase.

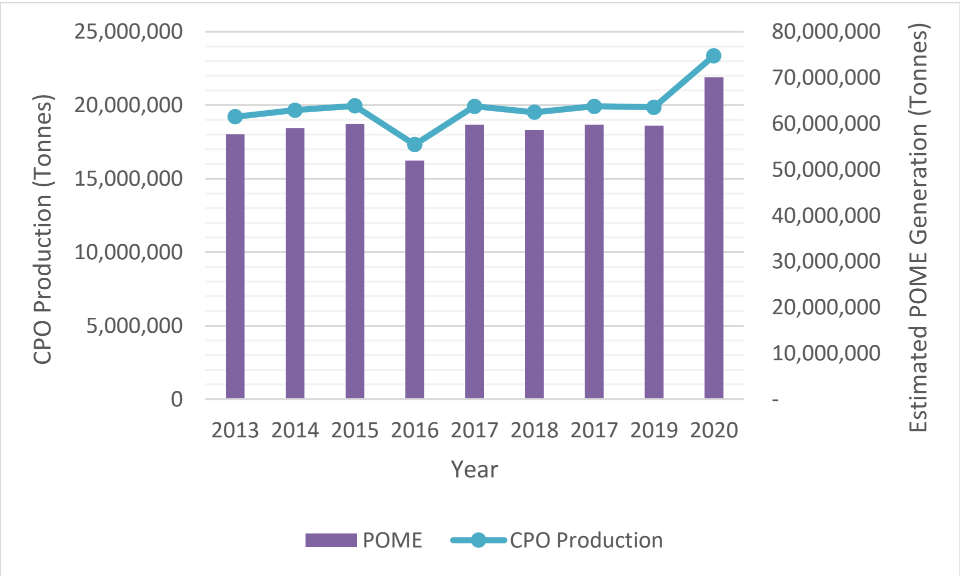

Figure 1.1 Estimated POME Generation Based on The Crude Palm Oil Production in Malaysia (MPOB, 2021)

The common treatment system for POME in the palm oil mills are anaerobic and aerobic ponds. Anaerobic digestion (AD) is the biodegradation of organic matter under the absence of oxygen, and energy-containing biogas such as methane (CH_4) is produced. Methane generation from POME is also known as biomethane. The potential of biomethane generation through biological means remains untapped. Since POME is non-toxic by nature and contain high numbers of organic matter, it can be a good source of nutrients for the microorganisms to produce CH_4. A palm oil mill plant of 400,000 m^3 POME annual capacity can produce up to 3.8 MW power generation plant capacity with 40% efficiency of gas engine (Albatayneh *et al*., 2020).

The potential of biomethane yield form POME in Malaysia is shown in Table 1.1. The capacity of biomethane generated is based on the production of POME. Considering the year of 2020 alone, more than 70 million m^3 of POME is produced with a potential power estimated of 545.2 MW (assuming the gas engine operating 8000 hr/yr with 40% efficiency). This figure shows that POME as a palm oil waste can be a promising source of renewable energy in Malaysia after it is converted into biomethane. However, according to Gonzalez (2019), Malaysia currently has 68 MW installed biomethane capacity under the feed in tariff (FiT) scheme which is less than 20% utilisation of total biomethane from POME potential.

Table 1.1 Estimated Biomethane Potential from POME in Malaysia from 2013 to 2020

Year	CPO Production (Tonnes) (MPOB, 2020)	Potential Biomethane Available (NKEA EPP5, 2011)	Estimated Power Plant Capacity (MW)
2020	23,362,350	1,962,437,400	545.2
2019	19,858,367	1,668,102,828	463.4
2018	19,516,141	1,639,355,844	455.4
2017	19,919,331	1,673,223,804	464.8
2016	17,319,177	1,454,810,868	404.1
2015	19,961,581	1,676,772,804	465.8
2014	19,667,016	1,652,029,344	458.9
2013	19,216,459	1,614,182,556	448.4

As reported by Malaysian Palm Oil Mill (2020), the palm oil mill plantation from year 2016 to 2019 has increase from 5,642,943 hectares to 5,900,157 hectares. The difference of 257,214 hectares or 5% increment shows that the palm oil plantation in Malaysia has expended significantly. According to SEDA (2016), only 20% of biomethane potential has been tapped and commissioned from POME biomethane plant. The remaining biomethane potential is left unutilised.

In 2019, 19 638 638 tonnes of crude palm oil (CPO) is produced whereby 53% of total CPO is contributed from West Malaysia and the 47% from East Malaysia. Figure 1.2 shows the total 2019 CPO production from each state in Malaysia. Johor Darul Takzim hold the third highest plantation area in Malaysia and CPO producer whereby it is recorded 3,157,647 tonnes or 16% of total CPO production is came from Johor.

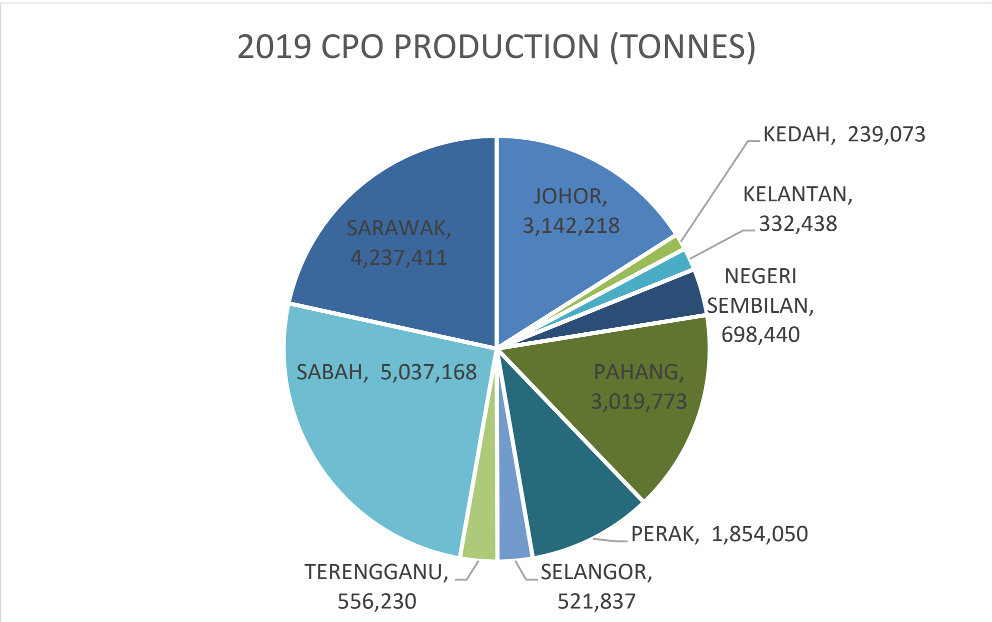

Figure 1.2 2019 Crude Palm Oil (CPO) Production in Malaysia (MPOB, 2020)

This figure indicates that the total POME produced in Johor is estimated around 9, 141,147 m^3 which equivalent to 255, 952, 116 m^3 of biomethane production. There are 65 palm oil mills in Johor which potentially can generate biomethane. This research will be carried out in Kahang palm oil mill cluster. There are 5 mills in that area which has 1,058,400 m^3 of POME capacity in total annually (SIRIM, 2014). The estimated POME and biomethane generation for each mill in Kahang is shown in Table 1.2. The overall plant capacity that can be harnessed from POME biomethane in Kahang is around 8.2 MW where the largest contributor is from Kilang Kelapa Sawit Sungei Kahang (3.2 MW).

Table 1.2 Estimated POME Biomethane Potential in Kahang Palm Oil Mill Cluster

Name Of Mill	Average POME Generated (m3/year) (ETRC, 2014)	Average Biomethane Generated (m3/year) (NKEA EPP5, 2011)	Energy (MJ)	Power Plant Estimated Capacity (MW)
K.K.S Ladang Padang	72,000	2,016,000	40,320,000	0.6
K.K.S. Kahang	194,400	5,443,200	108,864,000	1.5
Kahang Palm Oil Mill Sdn. Bhd.	144,000	4,032,000	80,640,000	1.1
Kilang Kelapa Sawit PPNJ Kahang	216,000	6,048,000	120,960,000	1.7
Kilang Kelapa Sawit Sungei Kahang S/B	432,000	12,096,000	241,920,000	3.4
Total	1,058,400	29,635,200	592,704,000	8.2

Generation of biomethane from POME treatment in AD can give a great revenue to the palm oil mill in term of using the energy for onsite application (heat source or electricity) and selling excess biomethane for offsite application. Production of electricity by biomethane as source of fuel for gas engine can also be injected into national grid and sell. However, since the receiver power station has a fix capacity, excessive electricity supply from substation will cause power trip. Hence, the excess of biomethane is flared to prevent over generated electricity. If the excess biomethane is utilised, it can be stored in a tank (bottling) and sell for other offsite application (i.e cooking, boiler).

Based on energy potential estimated in Table 1.2, a comparison of gross profit from selling biomethane as compressed biomathene (CBM) and electricity from each palm oil mill in Kahang is shown in Table 1.3. The gross profit in presented in Table 1.3 is estimated based on selling price of 5.535 USD/MMBtu (ST, 2021) for CBM and 0.077 USD/kWh (SEDA, 2021) for electricity under Feed in Taarif (FIT) scheme. The annual total potential gross profit from Kahang palm oil mill cluster is estimated at USD 3,110,025/y for CBM selling and USD 5,071,318/y for electricity selling. This is an enormous economic potential that worth exploring.

Table 1.3 Estimated Gross Profit from Utilisation of Biomethane in Kahang Palm Oil Mill Cluster

Name Of Mill	Potential Annual Energy		Estimated Gross Profit (USD/y)	
	MJ	MMBtu	Compressed Biomethane	Electricity
K.K.S Ladang Padang	40,320,000	38,223	211,566	344,988
K.K.S. Kahang	108,864,000	103,203	571,229	931,467
Kahang Palm Oil Mill Sdn. Bhd.	80,640,000	76,447	423,133	689,975
Kilang Kelapa Sawit Ppnj Kahang	120,960,000	114,670	634,699	1,034,963
Kilang Kelapa Sawit Sungei Kahang S/B	241,920,000	229,340	1,269,398	2,069,926
Total	592,704,000	561,883	3,110,025	5,071,318

1.2 Problem Background

As the global demand of oil and fat increased, the numbers of CPO generation will also continue to increase. As a result of increment of CPO production, POME will also increase in its generation. High organic content showed by high value of chemical oxygen demand (COD) and biological oxygen demand (COD) prove that POME can be a threat to the environment if it is not properly treated before discharge to the river.

In Malaysia, open pond system is the utmost conventional treatment method that has been practice by 85% of palm oil mill player. This system if found to be both effective and incurred low operation and maintenance cost (Wu *et al*., 2011). Apart from water pollution, open ponding system also contribute to air pollution such as global warming due to emission of greenhouse gases. A better option to treat POME is by anaerobic decomposition of POME with a biomethane capturing system. This solution reduces the impact of global warming as well as generating useful energy for various utilisation options. According to Lam and Lee (2011), with almost 50% of overall Malaysian palm oil mills still lacks of comprehensive biomethane capturing system, the potential to harness green energy from POME is vast.

Biomethane generation after treatment by means of anaerobic digestion process is required to be captured. Therefore, it is compulsory for palm oil mill to invest for a biomethane capture system in order to tap biomethane from POME. Biomethane recovered from anaerobic digestion process is usually used to generate electricity onsite through gas engine. The electricity generated can be used onsite or injected to the power station. However, as palm oil mills are located in remote area, the energy demand is often low and excess biomethane that is generated has to be flared to prevent over accumulation of biomethane. The practice to flare biomethane is a waste of energy. To prevent such wastage, biomethane can be upgrade into biomethane after purification and transported by truck or pipeline to an off-site facility.

To purify the biomethane, several technologies such as chemical absorption, pressure swing absorption and scrubber can be implemented to remove CO_2 and H_2S. CO_2 is a gas that will reduce the calorific value while H_2S is corrosive and will damage the system. As for transportation, biomethane can be bottled and delivered by truck or injected into a natural gas pipeline. There are also several options for utilisation other than generating electricity, such as CBM, and used as cooking gas. However additional transportation and treatment exponentially increases the cost of investment and without substantial government support, off-site biomethane utilisation will not be possible. It is important to study the process of treating, transporting and utilizing biomethane in order to identify the optimal technology that results in highest rate of return of investment while exploring possible subsidy schemes that could make off-site biomethane implementation more attractive.

1.3 Research Objectives

The overall objective of this research is to optimize off-site utilisation of biomethane generated from palm oil mill effluent (POME). The overall objective can be further divided into:

i. To identify the optimal pathway to purify and transport biomethane generated from palm oil mill effluent (POME) in remote area for off-site utilisation via mathematical modelling approach

ii. To evaluate the techno-economic analysis of the optimal pathways to identify suitable subsidies to support off-site biomethane utilisation

1.4 Scope of Study

In order to achieve research objective, the scope of work is listed below:

i. Studying the state-of-art for POME biomethane purification technology

ii. Primary data collection from palm oil mill effluent (POME) biomethane plant at PPNJ Kahang palm oil mill:

a. Composition of biomethane.

b. Caloric value of biomethane.

iii. Secondary data:

a. Costing of biomethane scrubbing,

b. Costing of biomethane compression

c. Costing of biomethane transportation

iv. Development of superstructure for offsite utilisation pathway from POME biomethane plant to the point of distribution.

v. Mathematical model formulation from the POME biomethane utilisation problem.

vi. Application of case study in PPNJ Kahang palm oil mill by coding of mathematical model in GAMS.

vii. Sensitivity analysis to study the changes of input data in term of capacity, local demand and distance point of distribution.

1.5 Significance of Study

The generation of biomethane through AD offers huge substantial advantage over different types of renewable energy (RE) resources. It can significantly reduce the greenhouse gas (GHG) emissions contrasted with fossil fuel by usage of locally available resources (Weiland, 2010). Currently, fossil fuel is the primary energy resource in Malaysia. The increase in energy demand and environmental concern has stimulated the advancement of renewable energy. Renewable energy has been included in the Fifth Fuel Policy by the Malaysian Government in the effort to promote renewable energy (Chin Haw *et al.*, 2006). The effort to harness power from biomethane while preventing CH_4 emission as a greenhouse gas is in line with Malaysia's government voluntary commitment to reduce the country's carbon intensity by 40% by year 2020 as well as to comprehend the government's energy policy stated in Rancangan Malaysia Kesepuluh (RMK10) which encourages the use of renewable energy (RE) in anticipation of fossil fuel depletion.

This study is expected to assist and guide the decision maker to select the suitable location (point of biomethane distribution), technology (biomethane scrubber and compressor) and mode of biomethane transport (pipeline or truck), by considering the trade-off between economic and process performance. This study will contribute to make the biomethane sustainable and meet the supply and demand chain. A proper government incentive and policy need to be introduce in order to make sure an appropriate framework for renewable energy (gases) is established. The establishment of framework from policy maker will open ample windows of opportunities to palm oil industries and its supply chain network in sustaining a green and renewable business model through POME biomethane.

Biomethane standard will be varies depending on the application of end user. These different standard will reflect the requirement of biomethane purification and upgrade in order to make sure it is safe to be transport and use. This study focusing on utilising biomethane for offsite usage will help to broaden the range of its application. An upgraded biomethane that is ready to be transported offsite will not just be benefit for its many applications but, it will give a proper quality standard which equivalent to petroleum gas in term of transporting the material at the point of the delivery as well. Hence, biomethane recovery and utilisation system from POME will help to determine the suitable technology in converting the composition of biomethane (percentage of CH_4, CO_2, H_2O and H_2S) into tolerable value and value added product; electricity and heat.

The purified and compressed biomethane makes it easy to be transportable as it equivalent to petroleum gas where the characteristic is almost similar and its infrastructure for transportation (gas pipeline and tanker truck) is already exist. Malaysian standard and legislation for gas transportation is established to give guideline for handling and transporting as well as ensure the quality of the biomethane is up to certain standard that it will not cause any safety issue. Transporting biomethane with truck relatively lower cost compared to pipeline, however, there is a strict safety requirement on the road. On the other hand, pipeline transportation using existing infractruction required stringent biomethane quality set by the local gas pipeline. This study will help to a deeper understanding the more sensitive cost and analyse the best option of biomethane transport in term of cost, safety and efficiency.

Last but not least greenhouse gas (GHG) is one of the side products when producing energy in power plant. The well-known GHG are carbon dioxide and methane. The utilisation of methane will decrease the usage of energy thus lessen the production of GHG. This unwanted gas is further reduced by the application of renewable energy in energy sector. Utilising biomethane both onsite and offsite of the plant will not only help stakeholder to gain a better revenue in a green business sector but in a bigger picture, it is also promote toward saving the earth and a better environment.

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