Economic Feasibility Study on Establishing an Oil Palm Biogas Plant in Malaysia

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ABSTRACT

The processing of oil palm fresh fruit bunch (FFB) primarily for palm oil results in the production of large amount of wastes, particularly in the form of palm oil mill effluent (POME). Production of POME can be estimated at almost three times the quantity of crude palm oil (CPO) produced. It can pollute the environment through the production of biogas which can be captured through a biogas-capturing system in a biogas plant. After capturing, the biogas can be utilised either for fueling the mill boiler, electricity generation, flaring or as cooking gas. This current study was carried out with the objective of assessing the economics of establishing an oil palm biogas plant based on the four different utilisation methods of the biogas. The results indicate that utilising biogas for the boiler gives higher economic returns compared with the other three options, given certain conditions. This study finally concludes with some issues that have an impact on any interested investor in a biogas project.

INTRODUCTION

During the Climate Change Summit (COP15) from 17-18 December 2009 in Copenhagen, Denmark, the Malaysian Prime Minister had announced that the country would voluntarily reduce emission intensity of greenhouse gas (CHG) emission by up to 40% based on 2005 levels by 2020 (NRE, 2000). This reduction is an indication of Malaysia's serious commitment to combating climate change issues as stipulated in the National Green Technology Policy, launched by the Prime Minister on 24 July 2009. Under this policy, a fund amounting to about RM 1.5 billion was allocated to the Natural Resources and Environment Ministry to finance projects aimed at reducing GHG emissions. Some of the projects that are being financed are those related to achieving energy efficiency and exploiting renewable energy (RE) sources, and they are mostly in the the oil palm sector.

The palm oil industry is the fourth largest component of the national economy, covering a value chain spanning from upstream activities to downstream processing. With limited land available to continue the expansion of oil palm plantations, the government desires to increase production efficiency and focus on providing greater value-added

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through downstream activities. One of the eight palm oil projects under the National Key Economic Area (NKEA) is to develop gradually biogas facilities at all palm oil mills by 2020 to capture methane under Entry Point Project (EPP) 5.

The palm oil industry has already embarked on green initiatives to reduce carbon emissions, and now it has been enhanced through the implementation of the NKEA projects. One of the initiatives includes trapping of biogas such as methane to generate electricity for fuelling steam turbines. The inclusion of the palm oil sector under NKEA is to achieve a high income status nation by 2020. Under EPP 5, all palm oil mills are mandated to build biogas facilities. This EPP is expected to generate 2000 job opportunities, and will contribute about RM 2.9 billion to gross national income while incurring an investment amounting to RM 2.8 billion (www.pemandu.gov.my). As at December 2012, 57 biogas facilities had been completed while 16 biogas facilities were under construction. At the same time, 150 biogas facilities were under planning (MPOB, 2012).

The palm oil industry produced 18.7 million tonnes of crude palm oil (CPO) in 2012 (MPOB, 2013). However, the production of such an amount of CPO resulted in a larger amount of palm oil mill effluent (POME), which is estimated at almost three times the quantity of CPO produced (Vijaya *et al.*, 2008). POME can pollute the environment if discharged directly into the waterways due to its high chemical oxygen demand (COD) and biochemical oxygen demand (BOD). Nevertheless, palm oil mills are currently practicing widely both aerobic and anaerobic pond systems to reduce COD and BOD. Between these two systems, the latter system has been recognised as a clean development mechanism (CDM) under the Kyoto Protocol. With that recognition, CDM-certified RE-producers such as biogas producers can issue Certified Emission Reduction (CER) units which can be sold later to buyers as stated under the Kyoto Protocol.

As POME has the potential to be the main source for future RE, the inclusion of methane trapping in the NKEA initiatives is in the right direction. Among the alternative sources of RE, such as wind, solar and mini hydro, POME can be considered as having an advantage over the others in terms of its quantity, consistency and availability as it is sourced from the existing palm oil industry. As RE has been included in the Malaysian Five-Fuel Policy since 2001, and is targeted to support 5.5% of the total energy demand in 2015 (EPU, 2010), it is important to undertake a feasibility study on the establishment of a POME biogas plant. A feasibility study would assist investors in their decision-making in whether to embark on such biogas plant projects. However, there is no available information in the public domain regarding investment analysis on developing such a plant which can serve as guidance to prospective investors.

Therefore, the objective of this study is to assess the economics of establishing a biogas plant. For this purpose, the assessment will be carried out on a palm oil biogas plant with four possible forms of usage of the biogas, namely, for the mill boiler, electricity generation, flaring and as cooking gas.

LITERATURE REVIEW

In Malaysia, there are two basic methods of capturing methane gas from POME, namely, by the covered lagoon and closed tank. Both methods have their advantages and disadvantages in terms of capital expenditure (CAPEX) and operational expenditure (OPEX), methane recovery rate and retention time (MPOB, 2009). For example, CAPEX cost for the covered lagoon method was estimated to be lower at about RM 4 million than that for the closed tank system which was estimated to cost between RM 7 and RM 8 million (Project Design Document Form, 2007). In contrast, CAPEX for the closed tank was recently estimated to be higher at between RM 10 and RM 12 million.

In 2012, there were 429 mills in the country that processed about 92.3 million tonnes of fresh fruit bunch (FFB) (MPOB, 2013). Most of the mills were located in Peninsular Malaysia (248 mills or 58%), processing 51.6 million tonnes of FFB. Processing operations produce a considerable amount of organic waste in the form of POME. This gives rise to a challenging task to the palm oil industry of handling such a large amount of organic waste. The conventional method for handling this organic waste is by using a pond system in which anaerobic digestion process takes place. Anaerobic digestion is a natural process that occurs in the absence of air and that releases biogas as the output. Production of biogas and its quality are dependent on maintaining a delicate balance between the acid-forming and methanogenic bacteria in a digester (Maizirwan *et al.*, 2008). The balancing process is done through the control of several factors, including the type of substrate, carbon nitrogen (C/N) ratio of the substrate, temperature, pH, organic loading rate and the concentration of solids in the digester charge.

To calculate the monetary returns to the producers of biogas, the establishment cost together with fixed and variable costs need to be estimated. The information needed to calculate the total costs are capital, fuel, financing and running costs (Stevens, 2007). The capital cost is normally correlated positively with power output as measured by kiloWatt hours (kWhr), but the authors noted that smaller combustion plants [of 10-15 megaWatt (MW) capacity range] could cost £2520 (RM 17 388[1]) kWhr while a larger plant (of 30-40 MW capacity range) could bring the figure down to £1860 (RM 12 834) kWhr. This scenario can best describe the concept of economies of scale where more output produce will result in a reduction in input cost.

The *Sanwa Engineering Report* (2006) estimated that the investment cost for a biogas facility from a 40 t/hr mill was RM 3.2 million with RM 0.3 million per annum for operating expenditure. For methane trapping using the continuously stirred tank reactor (CSTR) method, the investment cost was estimated at about RM 7.2 million with an annual operating cost of RM 0.2 million (Project Design Document Form, 2007). In west Kalimantan, Indonesia, the investment cost for a biogas project from a 60 t/hr mill was around USD 3.1 million (RM 10 million, RM 3.2=USD1) (National Technical Experts, 2004). From that total, USD 2.9 million was for CAPEX and USD 0.12 million for OPEX.

Capital, operating and maintenance costs of biogas production and upgrading system vary significantly due to the different technologies adopted as well as the scale of production (Maizirwan *et al.*, 2008). To investigate the economic feasibility of the plant, the authors suggested gathering relevant influencing parameters, such as payback period, plant lifetime, discount rate, construction cost, operation and maintenance (O&M) costs, fuel and efficiency, and load factor, to be used in the simulation analyses. In carrying out the analysis, Steven (2007) also showed that the payback period for most biomass plants with a full 20-year lifetime was 15 years, but for others it may be much shorter. Therefore, increasing the plant lifetime will result in cost reduction, estimated at between 7% and 12%. Although O&M is a smaller component of the total costs, it still has an impact because it is applicable over the full lifetime of the plant. It was noted that fuel costs represented a major portion of the total costs, and even more significantly during the later years of the plant, especially after the 15-year payback period. The last two variables are efficiency and load factor that are very much dependent on the technology adopted for the plant. An increase in load factor and efficiency will lead to a reduction in cost.

METHODOLOGY

It was observed that the cost of establishing a biogas plant depends on whether a palm oil mill discharges its POME directly into the tank, or into the pond first and then into the tank. For the latter, the tank may be smaller than for the former because the mill may not necessarily discharge all the POME into the tank at any one time, but can keep some of it in the pond. If the mill discharges its POME directly into the tank, it may require larger tank to accommodate all the POME produced by the mill. Hence, the tank capacity can give an impact on the cost because clearly a larger tank can result in a higher cost.

In addition, a palm oil mill may either use an existing tank, already built earlier on, due to space limitation, or it may build a new one. The existing tank, however, needs to be refurbished before use, which indeed can reduce the investment cost compared with building a new tank.

Based on the above scenario, the investment cost can vary. Due to this, the study made several assumptions in estimating the cost. First, a palm oil mill will discharge its POME directly into the tank, eliminating the need to discharge POME into the pond first. It is also further assumed that the plant will be using a new steel tank rather than refurbish an existing one.

To estimate the economic feasibility of a biogas plant, the study adopted a financial analysis approach. This approach had been adopted by Stevens (2007), Project Design Document Form (2007) and National Technical Expert (2004). The variables to be collected were mill capacity, FFB production, POME production, percentage of methane gas captured, tax rate, CAPEX, OPEX and investment period. Other assumptions for this analysis included the following:

- mill capacity was 60 t FFB per hour;
- estimated volume of FFB processed was 360 000 t FFB per year;
- POME produced was 600 m^3 per day;
- percentage of methane gas capture was estimated at 65%;
- operational cost was 5% of the capital expenditure;
- tax holding on income for first five years of operation and 25% subsequently; and
- investment period was 16 years.

The biogas plant was given four different options to utilise the captured biogas, either for running the boiler (Option A), for electricity generation (Option B), for flaring (Option C) and for cooking gas (Option D). To utilise the biogas, the plant had further requirements, depending on the option or the purpose. These are shown in *Table 1*.

For each of the options in *Table 1*, the analysis further assumed

TABLE 1. ADDITIONAL ASSUMPTIONS USED IN THE SENSITIVITY ANALYSIS

Option	Additional assumption	Remarks
Option A – for boiler	a) Investment cost of the biogas plant is between RM 19 and RM 20 million. b) Maximum sales of palm kernel shell (PKS) and mesocarp fibre are 90% and 75% respectively of the total productions. c) Continued use of the current boiler with no or minimal modification cost.	The biogas that is captured under this option is channeled to the biomass boiler for heat and energy purposes. The boiler operates using a small amount of PKS and mesocarp fibre estimated at around 10% and 25% respectively. The remaining PKS and mesocarp fibre can then be sold to other industries, such as cement industry. The investment amount for this option is expected to be between RM 19 and RM 20 million. Income from sales of PKS and mesocarp fibre is expected to repay part of the investment cost. To simplify the analysis, only PKS price is changing while price for mesocarp fibre remain at RM 50/t.
Option B – for electricity generation	a) Investment cost of the biogas plant is between RM 23 and RM 24 million. b) Installed capacity for producing electricity is less or equal to 4 MW. c) Cost of purification (fixed and variable costs) is estimated at RM 1 million. d) Transmission cable cost is estimated at RM 1 million/km.	For this option, there is a need to have an additional investment due to the purchase of a gas engine and the cost of connecting an electrical transmission cable between the mill generator and a TNB power sub-station. These investments result in an increase in cost amounting to RM 20 million to RM 24 million. Hence, two additional variables were used in the sensitivity analysis, *i.e.* the length of the transmission cable and the tariff rate. The distance of the electrical transmission cable connection ranged between 10 and 30 km, while the tariff ranged between RM 0.3184 and RM 0.4184 kWhr.
Option C – for flaring	a) Investment cost of the biogas plant is assumed to be at RM 19 million.	This option is the simplest form of utilising the biogas. In fact, it is almost similar to option A where the investment cost of biogas plant is also about RM 19 million. The only form of revenue generated from this option is from issuing Certified Emission Reduction (CER). For sensitivity analysis, different rates of CER received were tested, ranging from RM 15 to RM 25/t carbon credits.
Option D – for cooking gas	a) Investment cost of the biogas plant is RM 19 million while for investment cost of the bottling gas plant is RM 7 million. b) Retail price of a 14-kg gas cylinder is RM 48 (RM 26.60 sales price and RM 21.40 government subsidy). Sales price is 70% of the retail price. c) Operational cost is 5% of the capital expenditure for both plants. d) Cost for purification (fixed and variable costs) is estimated at RM 1 million.	A bottling plant needs to be set up for this option The investment cost of a bottling plant is estimated at RM 7 million with a refill capacity of 60 000 gas cylinders per year.

that the plant was given another two sub-options, *i.e.* revenue without CER and revenue with CER. Hence, there were eight scenarios representing all possible options as shown in *Figure 1*.

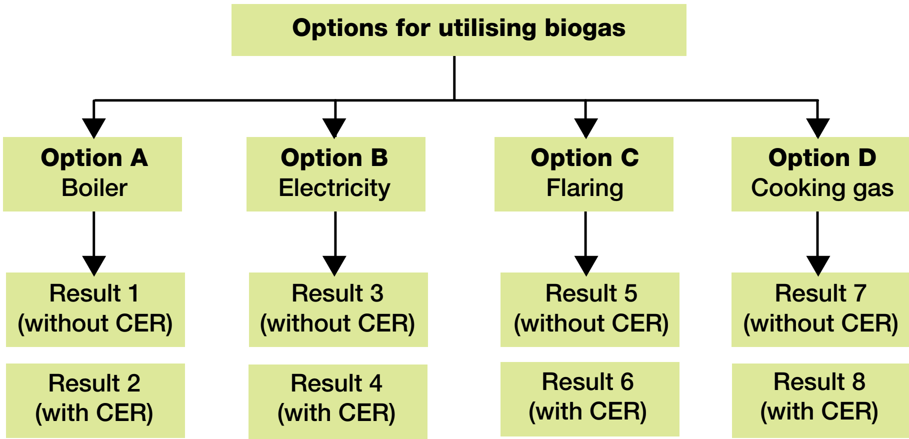
The analysis produced economic parameters, such as internal rate of return (IRR), payback period and net present value (NPV), which are common indicators for assessing the economic feasibility of each option.

RESULTS AND DISCUSSION

To fully understand the economic feasibility of the biogas project, a sensitivity analysis was carried out on each of the four options.

Option A – Producing Biogas for the Boiler

The main influencing factor when utilising methane gas for running the boiler without CER is the price of palm kernel shell (PKS) in addition to income from selling mesocarp fibre in which its price was fixed at RM50/t.



Note: CER - Certified Emission Reduction.

Figure 1. Four options for utilising biogas.

The estimated production of PKS and mesocarp fibre was 5% and 7% respectively from total FFB processed annually (Astimar *et al.*, 2011). When the price of PKS is RM 150/t, IRR is only about 0.78% with a negative NPV. If price of PKS increased to RM 200/t, it will definitely improve IRR to 8.36% and NPV to RM 7355 (*Table 2*). IRR, NPV and the payback period will improve further if the price of PKS rose to RM 250/t.

The contribution of CER is also significant in improving the feasibility. A combination of a PKS price at RM 150/t and a price of CER at RM 20 will give IRR of 8.24% and NPV of RM 7433. When the price of PKS increases to RM 250/t and CER to RM 25, the value of IRR will correspondingly increase to more than 20% and NPV to RM 28 769.

In summary, without applying CER and letting the price of PKS range between RM 150 and RM 250/t, the simulation analysis shows that the IRR values will fall between 0.78% and 14.29%, NPV from – RM 2639 to RM 16 769, and the payback period from seven to 15 years, for capturing biogas for the boiler. If the analysis included CER with values ranging from RM 15 to RM 25/t carbon, and coupled with a price of PKS between RM 150 and RM 250, IRR will be between 6.57% and 20.66%, NPV between RM 4921 and RM 28 769, and the payback period between five and nine years.

Option B – Producing Biogas for Electricity Generation

For Option B, the sensitivity analysis was carried out on three variables, *i.e.* electricity tariff, CER value and distance of electrical transmission cable between the mill and a Tenaga Nasional Berhad (TNB) power sub-station. *Table 3* is the result of the sensitivity analysis using varying rates of electricity tariff and varying values of CER.

The current tariff rate for electricity (in 2013) for a project approved by the government is RM 0.3184 kWhr. At this rate, without CER, an investment on biogas for electricity generation gives an IRR value of 2.59%, NPV of RM 743 and a payback period

TABLE 2. SENSITIVITY ANALYSIS FOR PRODUCING BIOGAS FOR THE BOILER

PKS price (RM/t)	Parameter	Without CER	With CER (RM Carbon/credit)		
			RM 15	RM 20	RM 25
150	IRR (%) NPV (RM) Payback	0.78 (2 639) 15	6.57 4 921 9	8.24 7 433 8	9.85 9 941 8
200	IRR (%) NPV (RM) Payback	8.36 7 355 8	12.54 14 339 7	14.01 16 487 6	15.45 19 355 6
250	IRR (%) NPV (RM) Payback	14.29 16 769 6	17.92 23 735 6	17.92 23 753 5	20.66 28 769 5

Note: IRR - internal rate of return; NPV - net present value; payback is calculated in years. PKS - palm kernel shell. CER - Certified Emulsion Reduction.

TABLE 3. SENSITIVITY ANALYSIS FOR PRODUCING BIOGAS FOR ELECTRICITY GENERATION

Electricity tariff (RM kWhr)	Parameter	Without CER	With CER (RM carbon/credit)		
			RM 15	RM 20	RM 25
0.3184	IRR (%)	2.59	6.00	7.28	8.51
	NPV (RM)	(743)	5 803	8 456	11 087
	Payback	13	10	8	8
0.3684	IRR (%)	5.90	8.90	10.03	11.13
	NPV (RM)	5 540	11 927	14 438	16 946
	Payback	10	8	8	7
0.4184	IRR (%)	8.72	11.49	12.57	13.62
	NPV (RM)	11 397	7.787	20 295	22 803
	Payback	8	7	7	6

Note: IRR = internal rate of return; NPV = net present value; payback is calculated in years; distance of transmission cable is fixed at 10 km. CER – Certified Emulsion Reduction.

of 13 years. If the tariff rate were to increase by 5 sen to RM 0.3684 kWhr, IRR will improve to 5.90%, NPV to RM 3540 and the payback period reduced to 10 years. A further increase in tariff rate, *e.g.* by 10 sen from the current tariff, and the investor will enjoy better IRR of 8.72%, NPV of RM 11 397 and a payback period of eight years.

The contribution to revenue from CER is noticeable. At the current tariff rate of RM 0.3184 and a CER value of RM 15, the IRR value will be 6.00% and NPV RM 5803. If the CER value reached RM 25, it will lead to IRR valued at 8.51% and NPV at RM 11 087. If both tariff and CER were to increase to RM 0.4148 kWhr and RM 25, respectively, the investment can yield IRR of 13.62% and NPV of RM 22 803, with a payback period of only six years.

Similar to tariff rate, the distance of electrical transmission cable from the mill to a TNB power sub-station can also influence revenue and return to investment of the biogas plant. For the analysis, the costs for 5, 10 and 15 km of the transmission cable were set at RM 5, RM 10 and RM 15 million, respectively (*Table 4*).

It was noticed that without CER, the IRR value will decrease from 2.59% for 5 km to 1.69% for 15 km of transmission cable. Increasing the distance between the mill and the TNB sub-station further will lead to a negative value for NPV and smaller value of IRR. With CER, the return was much better with a IRR value of 6% and NPV of RM 5803 if the CER value was RM 15.

In summary, with CER, the minimum IRR value of 1.53% and NPV of RM 3644 will result if the transmission line was 15 km, and CER was RM 15, while the highest value of IRR (8.51%) and NPV of RM 11 087 will be achieved for a 5 km distance between mill and sub-station with CER at RM 25.

Option C – Producing Biogas for Flaring

Table 5 shows the results of the feasibility study when biogas is used for flaring. Without any activity that can generate income, the project clearly indicates a negative return of NPV at –RM 27 783. Even with the revenue

TABLE 4. SENSITIVITY ANALYSIS FOR PRODUCING BIOGAS FOR ELECTRICITY GENERATION

Distance (km)	Parameter	Without CER	With CER (RM carbon/credit)		
			RM 15	RM 20	RM 25
5	IRR (%)	2.59	6.00	7.28	8.51
	NPV (RM)	(743)	5 803	8 455	11 087
	Payback	12	10	9	8
10	IRR (%)	0.20	3.61	4.78	5.92
	NPV (RM)	(5 743)	1 355	4 054	6 752
	Payback	16	12	11	10
15	IRR (%)	(1.69)	1.53	2.63	3.68
	NPV (RM)	(10 743)	(3 644)	(945)	1 752
	Payback	>16	14	10	12

Note: IRR = internal rate of return; NPV = net present value; payback is calculated in years; electricity tariff set at RM 0.3184 kWhr. CER – Certified Emulsion Reduction.

generated from CER, this is still not sufficient to cover the investment cost.

Option D – Producing Biogas for Cooking Gas

Under this option, an additional investment is needed to establish the gas refilling plant and to purchase new gas cylinders (*Table 6*). This additional investment is estimated at RM 7 million. Without CER, the investment indicates a negative return as the NPV value is -RM 24 294, and the payback period is more than 16 years. Even with a contribution from CER, the returns are still not sufficient because all the economic parameters indicate negative returns.

ISSUES

Of the various issues discussed with the biogas players, some merit further deliberation for a clearer picture of the future prospects of the biogas industry.

Consistency

The amount of methane generated is based on the assumption of 65% from the biogas. The real amount could be less, especially during rain or in the low cropping seasons. The activity of microorganisms (which is crucial in ensuring productivity) can also lead to inconsistencies in the amount of gas produced. Microorganisms are very sensitive to drastic changes in temperature of POME. Less methane produced will have an impact on the amount of electricity generated or the heat produced.

Maintenance and Replacement Costs

The presence of hydrogen sulphide (H_2S) can cause corrosion to steel pipings and valves. This can lead to higher replacement as well as maintenance costs. Regular monitoring is needed to maintain the safety of the biogas plant.

Financial Aspect

The connection cost of the electrical cable between the transformer at the mill and the nearest TNB sub-station is still an issue. A connection cost of about RM 1 million/km is currently being borne by the biogas producer. It has a significant impact on the total investment cost. Another issue is being able to secure a loan from commercial banks for a biogas project. Not many commercial banks are willing to fund such investments. The process for claiming CER is another issue because the requirement to issue CER as well as to obtain payment is quite rigid, coupled with the fluctuating CER price in the world market.

Human Resource Management

Establishment of a biogas plant requires manpower either from existing or new staff. If manpower is obtained from the existing staff, it means that there will be

TABLE 5. SENSITIVITY ANALYSIS FOR PRODUCING BIOGAS FOR FLARING

Parameter	Without CER	With CER (RM carbon/credit)		
		RM 15	RM 20	RM 25
IRR (%)	-	-	-	-
NPV (RM)	(27 783)	(21 546)	(19 310)	(17 073)
Payback	>16	>16	>16	>16

Note: IRR = internal rate of return; NPV = net present value; payback is calculated in years. CER – Certified Emulsion Reduction.

TABLE 6. SENSITIVITY ANALYSIS FOR PRODUCING BIOGAS FOR COOKING GAS

Parameter	Without CER	With CER (RM carbon/credit)		
		RM 15	RM 20	RM 25
IRR (%)	-	(8.81)	(6.02)	(4.01)
NPV (RM)	(24 294)	(16 691)	(13 993)	(11 294)
Payback	>16	>16	>16	>16

Note: IRR = internal rate of return; NPV = net present value; payback is calculated in years; refill capacities of 200 cylinder per day x 25 days x 12 months = 60 000 gas cylinders per year.

Total price = consumer price of RM 26.60 + government subsidy of RM 21.42 = RM 48.02 per cylinder of cooking gas.

Assuming producer sales price = 70% of total price = RM 33.61 per cylinder of cooking gas.

Plant refilling investment = RM 7 million.

a diversification of jobs and extra responsibility for the staff. There is also an increase in the training cost because a biogas plant needs to be handled and supervised by skilled personnel. In addition, there is also a need to engage a consultant who is responsible for project preparation, a baseline study, and emission trading which is one of the important components for the success of the biogas project. Selecting an 'inexperienced' consultant could result in an unfavourable outcome to the investment.

CONCLUSION

The feasibility studies indicate that utilising methane for the boiler can result in higher returns compared with the other options. The main reason is due to the total investment in utilising methane for the boiler (RM 20.4 million – without CER) which being at par with flaring, but less than those for electricity generation (RM 23.2 million – without CER) and cooking gas (RM 27.4 million – without CER). The advantage is from the sales revenues from PKS (RM 4.4 million – without CER), which is higher than the revenue from electricity generation (RM 3.2 million – without CER) and cooking gas (RM 2 million – without CER).

Even though the revenue from selling PKS in Option A (biogas for boiler) is higher than for the other options, it is less consistent as compared with the revenue from electricity generation and cooking gas. This is because of the fluctuating PKS price in the world market. In contrast, the selling price for electricity has been fixed at RM 0.3184 kWhr (for projects approved in 2013), while cooking gas has been categorised as a 'price control product' by the government. This is where the businesses need to make their own sound judgment.

CER is crucial in increasing investment return; thus, it is worth the effort of ensuring that it is successfully issued and paid for. To this end, engaging an experienced consultant is important so that an investor gets the right CER price. The question of who should bear the cost of installing the electrical transmission cable needs to be resolved. This is important because it has an impact on the investment costs as well as on returns, and helps in the decision-making process of would-be investors.

REFERENCES

ASTIMAR, A A; LOH, S K; LIM, W S and CHOO, Y M (2011). *Business Opportunities in Palm Biomass for SME.*

EPU (2010). *Tenth Malaysian Plan 2011-2015*. Economic Planning Unit.

MAIZIRWAN, M; SANY, I I and ERRY, Y T A (2008). *Biogas Energy Potential in Riau, Indonesia.*

MPOB (2009). *Biogas Utilization in Palm Oil Mills*. MPOB, Bangi.

MPOB (2012). *PEMANDU Progress Updates Report December 2012*. Unpublished.

MPOB (2013). *Malaysian Oil Palm Statistics 2012. 32nd Edition*. MPOB, Bangi.

NATIONAL TECHNICAL EXPERT (2004). *Utilization of Biogas Generated from the Anaerobic Treatment of Palm Oil Mills Effluent (POME) as Indigenous Energy Source for Rural Energy Supply and Electrification*. Pre-feasibility study report.

NRE (2000). *Malaysia-Second National Commnication to the UNFCCC*. A publication by the Ministry of National Resources and Environment, Malaysia.

PEMANDU (2012). www.pemandu.gov.my, accessed on 14 March 2012.

PROJECT DESIGN DOCUMENT FORM (2007). *Methane Capture and On-site Power Generation Project at Syarikat Cahaya Muda Perak (Oil Mill) Sdn Bhd in Tapah, Perak*. Version 1.4 04/11/2007.

SANWA ENGINEERING CO. LTD (2006). *Feasibility Study on Efficient Methane Recovery and Heat Generation in Palm Oil Mill in Malaysia*. Summary report.

STEVENS, A S N (2007). *Economic Viability of Promising Biomass Utilisation Technologies in the East of England*. M. Sc., School of Engineering, Cranfield University.

VIJAYA, S; MA, A N; CHOO, Y M and NIK MERIAM, N S (2008). *J. Oil Palm Res. Vol. 20*: 484-494