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Methane Capture and Clean Development Mechanism Project for the Sustainability of Palm Oil Industry in Malaysia

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Abstract: Anaerobic treatment with methane capture for the Clean Development Mechanism (CDM) project is currently the most promising treatment method for palm oil mill effluent (POME). With CDM, Annex 1 countries could achieve their greenhouse gases (GHG) emission reduction target, promoting environmental-friendly and sustainable development projects and providing substantial local economic and social sustainability and demonstrate and disseminate new and modern bio-energy technology with lower investment costs and risks by establishing partnership with host countries like Malaysia. As at end of March 2009, there were 12 methane recovery CDM projects in Malaysia registered with the Executive Board (EB) of United Nation Framework on Climate Change (UNFCCC), which expecting to contribute an annual average of 612,097 tonnes of CO_2 equivalent of certified emission reductions (CER). Although this is small despite the huge potential available, the trend is growing. Therefore Annex I countries should urgently take this opportunity to be actively involved in this new business opportunity for the sustainability of the palm oil industry.

Key words: Palm oil mill effluent, Methane, Clean Development Mechanism, Certified Emission Reduction, Sustainability development

INTRODUCTION

Globally there is a great concern for reducing the emission of the greenhouse gases (GHG) such as nitrous oxides, methane and carbon dioxide to the atmosphere particularly by the developed countries through Clean Development Mechanism (CDM) project. The mechanism which was established under the Kyoto Protocol in 1997 has a dual purpose of assisting the non-Annex I Parties in achieving sustainable development and also assisting the Annex I Parties (developed countries) in achieving compliance with their quantified GHG emission commitments[20]. For instance Japan has committed to reduce the emission of GHG by 6% (about 60 million tonnes of CO_2 equivalent) from year 2008 until 2012 based on 1990 emission level and one possible way to achieve this target is through CDM project. Moreover Annex 1 country could also promote the environmental-friendly and sustainable development projects in the host countries like Malaysia and the project may provide substantial local economic growth (by allowing the host countries to receive transfer of financial, technological and human resources) and social sustainability (by human capital formation, job creation and building of local capacity) to the host countries[51,18]. From the bio-energy perspective, CDM could also be used as a platform to demonstrate and disseminate new and modern bio-energy technology with lower investment risks and enhanced project's cost-efficiency[52].

Being a tropical country with suitable climate and geographical factors for the cultivation of oil palm, Malaysia is currently the world largest exporter of palm oil products[51,72]. During the processing of oil palm fruits for its oil, large amount of biomass is produced because the oil fraction from the mesocarp and kernel

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is only 24%[23]. The biomass resources from the palm oil industry could be classified as mesocarp fibre, palm kernel shell, empty fruit bunch and palm oil mill effluent (POME). Oil palm is perennial crop and oil palm biomass of the whole tree is also available during the re-planting period (usually after 25-30 years). In Malaysia more than 50 million tonnes of POME is generated annually and the trend is growing[75]. POME which originates from the sterilization and clarification stages of the palm oil milling process contained high amount of organics (15,000 – 100,000 mg/L)[23]. This is the reason of high methane concentration measured and quantified during methane emission study from POME treatment either from open digesting tanks or anaerobic ponds[51,74,75].

Based on a year of study on several 3600 m^3 open digesting tanks in FELDA Serting Hilir Palm Oil Mill, the methane contents in the biogas were recorded between 13.5 and 49.0% with biogas volumetric flow ranging from 0.8 to 9.8 $L/min \cdot m^2$ which resulted in average methane mass flow per tank of nearly 520 kg/day[74]. However during the same period of study, the anaerobic ponds system recorded better performance with methane contents between 35 and 70% and the biogas volumetric flow ranging from 0.5 to 2.4 $L/min \cdot m^2$ which resulted the average methane mass flow per anaerobic pond was 1043 kg/day[75]. The calculated methane yield was higher in the pond system at 0.24 $kgCH_4/kgCOD$ removed in comparison to only 0.11 $kgCH_4/kgCOD$ removed in the open digesting tanks which suggests higher retention time was needed for higher substrate conversion to methane. Based on these results, a 500 m^3 semi-commercial scale closed anaerobic digester was constructed and operated in FELDA Serting Hilir Palm Oil Mill to evaluate the POME treatment efficiency and quantify the methane gas generation during anaerobic treatment of POME as to closely mimic the actual 3600 m^3 commercial scale closed digester tank system[73]. Throughout the start-up operation, the system demonstrated a remarkable performance on high chemical oxygen demand (COD) removal efficiency (up to 97%) and satisfactory volatile fatty acids to alkalinity ratio (VFA:Alk) between 0.1 and 0.3. The start-up operation was successfully achieved in less than three months which partly due to suitable seed sludge obtained from the existing open digesting tank system. In a further study on the same unit by Sulaiman *et al.*[53], high COD removal efficiency of greater than 90% removal was achieved with highest organic loading rate of 10.0 $kgCOD/m^3 \cdot d$ with the average of methane production of 12 m^3 CH_4/m^3 POME applied. This project has been selected by FELDA to proceed to the commercial scale and recently this project has been registered by the EB UNFCCC as a CDM project. In Malaysia, in addition to this project, there are a great deal of research and commercial set-up of the anaerobic treatment of POME for the methane capture and currently there are 12 CDM projects registered with the EB UNFCCC. The objective of this review paper is to update the progress on both research and commercialization of POME treatment for methane capture project in Malaysia, particularly on FELDA Palm Industries Sdn. Bhd. initiative in Serting Hilir Palm Oil Mill, as a module for CDM project towards the sustainability of the palm oil industry in Malaysia.

Technologies for POME Treatment: The current POME treatment system in palm oil mills involves series of pond system with different biological processes namely anaerobic, facultative and aerobic treatments and it is at the anaerobic stage large amount of methane is released to the atmosphere and the major reduction of POME polluting strength occur[23]. The idea of anaerobic digestion offers several advantages and an ideal solution for organic waste treatment for the production of useful methane gas as a valuable product, low volume of sludge generation which can be used as fertilizer low energy requirement process[49]. The anaerobic degradation process of organic matters occurs in four metabolic stages namely hydrolysis, acidogenesis, acetogenesis and methanogenesis and simplified in a diagram by Bouallagui *et al.*[13] and shown in Figure 1. According to Hassan *et al.*[23], POME is colloidal slurry consisting of water, oil and fine cellulosic materials. In the first stage the non-soluble organics will undergo liquefaction by extracellular enzymes before being taken up by the acidogenic bacteria. The soluble organic components are then converted to organic acids alcohols, hydrogen and carbon dioxide by acidogens. In the third stage acetic acid, hydrogen and carbon dioxide are produced and finally methane is produced by methanogenic bacteria from acetic acid, hydrogen and carbon dioxide. The anaerobic treatment of organic waste for biogas generation has been a subject of interest since many decades ago. The technology of anaerobic digestion for the bioconversion of organic materials for biogas has been reported for different types of organic waste sources such as dairy cattle waste[70], semisynthetic waste waters[17], particulate industrial waste[1], banana peel and pineapple waste[6], animal waste[30], cattle-manure slurry[46], domestic wastes[22,32], swine and piggery waste[50,25] and fruit and vegetable wastes[29,13,47].

In the case of anaerobic treatment of POME for methane, over the years it has attracted many researchers using different treatment technologies since 1980 and is summarized in Table 1. By using a single stage reactor Keong[31] observed that as the HRT was

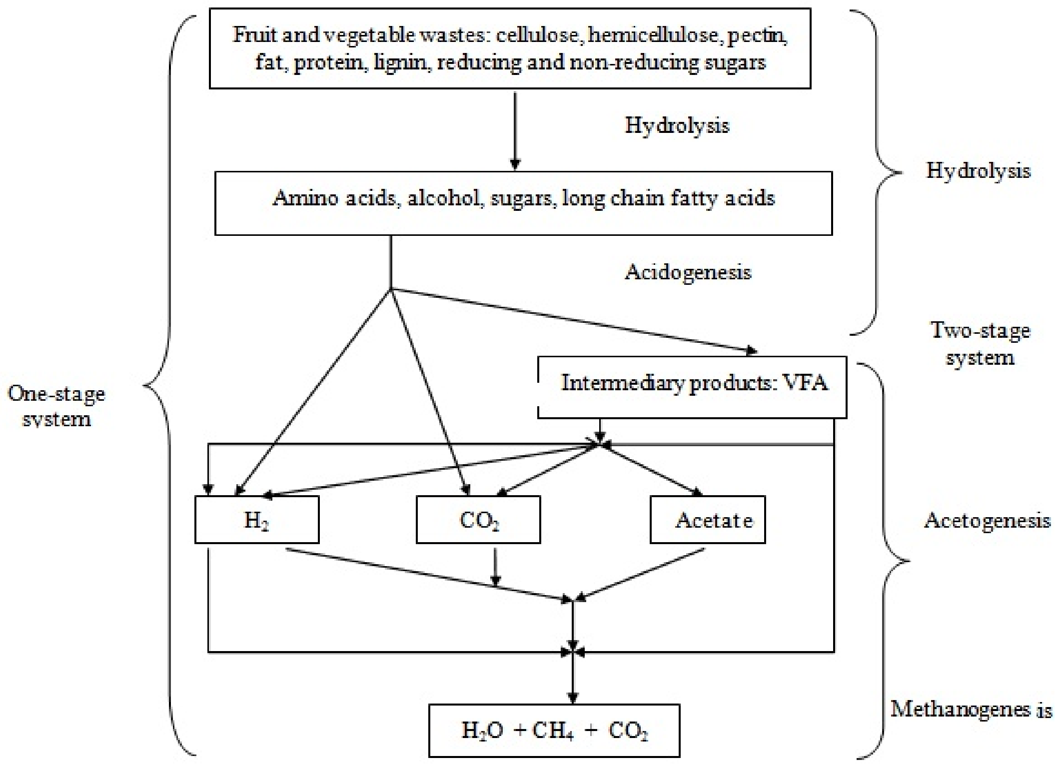

Fig. 1: Reaction scheme for anaerobic digestion of particulate organic material[13]

Table 1: Development of anaerobic treatment of POME research and their performances

No	Reactor type	Scale	Condition	HRT (days)	Biogas/Methane Yield or Production Rate	Organic reduction	Reference
1	Single Stage	Lab.	Thermophilic 55°C	5-35	0.7-1.7 L Biogas/g BOD utilized	70-89 % of VS reduction	Keong *et al.*, (1981)
2	Two-phases	Lab. 16 L each	Mesophilic 32°C in both phases	Acid phase: 1-6 Methane phase: 10-30	0.98-2.12 L Biogas /gCOD utilized	Acid phase:54-70 % COD removal Methane phase: 78-85% COD removal	Ng *et al.*,(1985)
3	Single stage	Lab.2 L	Mesophilic	5.6	234 mL Methane /gCOD applied	>97% COD removal	Cail and Barford (1985a)
4	Single stage	Lab.2 L	Thermophilic 57°C	1.3	214 mL Methane /g COD applied	>97% COD removal	Cail and Barford (1985b)
5	Single stage	Lab.15 L	Mesophilic 32°C	14-100	0.19-0.56 L Biogas /gCOD utilized	50.5-90.0% COD removal	Ng *et al.*, (1987a)
6	Two-phases	Lab. First phase :0.87 L Second phase :12-15 L	Mesophilic 32°C	First phase:31 Second phase:10-30	0.44-0.98 L Biogas /gCOD utilized	63.9-74.1% COD removal	Ng *et al.*, (1987a)
7	Single stage	Lab. 2L	Thermophilic 55 °C	5-35	0.21-0.37 L Biogas /gCOD utilized	70.6-95.6% COD removal	Ng *et al.*, (1987a)
8	Single-stage	Lab.10L	Mesophilic 27-30 °C	15-40	0.78-0.94 m^3Biogas/ kg BOD removed		Ma *et al.,* (1988)
9	Upflow Hybrid	50 L	Mesophilic 30 °C		7 L Biogas/day	62% COD removal	Mohd Noor *et al.*, (1989)
10	Single stage immobilized cell	Lab.1L	-	6.2	0.325 L Methane /gCOD	96.2% COD removal	Borja and Banks (1994)
11	Anaerobic Filter	Lab.1L	Mesophilic 35 °C	3 .5	8.0-20.0 L Biogas/day	88.0-91.0%	Borja and Banks (1995)

Table 1: Continue

12	Anaerobic Fluidized Bed	Lab.1L	Mesophilic 35 °C	0.5	4.0-6.2 L Biogas/day	92-93%	Borja and Banks (1995)
13	Modified Anaerobic Baffled	Lab.20L	-	6	0.42 L Methane/g COD removed	95%	Faisal and Unno (2001)
14	Upflow Anaerobic Sludge-Fixed Film	Lab.~5L	Mesophilic 38 °C	3	0.346 L Methane /gCOD removed	97% COD removal	Najafpour *et al.*, (2006)
15	Single stage	Pilot 500m^3	Mesophilic 37-42 °C	17	0.11 kgMethane /gCOD removed	97% COD removal	Yacob *et al.*, (2006b)
16	Single stage CSTR	Lab.1.6L	Mesophilic 37 °C	7	3.73 L Biogas/day	71% COD removal	Choorit and Wisarnwan (2007)
17	Single stage CSTR	Lab.1.6L	Thermophilic55 °C	5	4.66 L Biogas/day	70% COD removal	Choorit and Wisarnwan (2007)
18	Expanded Granular Sludge Bed	Lab. 21.56L	Mesophilic 37 °C	2	46% of the theoretical methane yield	91%	Yejian *et al.*, (2008)

increased from 5 to 35 days, the gas yields have also increased from 0.7 to 1.7 L Biogas/gBOD utilized with satisfactory reduction of volatile solid (70-89%). This indicates longer HRT was required for good substrate utilization and conversion to biogas. Ng *et al.*[44] conducted a study on a two-phase anaerobic treatment system and made a similar conclusion where the gas yield increased from 0.98 to 2.12 L/gCOD utilized once the HRT was increased from 10 to 30 days, respectively. The influence of temperature (mesophilic and thermophilic) on biogas production during anaerobic treatment of POME was studied by Cail and Barford[14,15]. For both conditions, good COD removal efficiency (>97%) was achieved but thermophilic achieved higher space loading of (52 kg COD/m^3·d which corresponded to HRT of 1.3 days). For the methane yield, mesophilic achieved slightly higher yield of 234 mL/gCOD applied due to longer HRT applied (5.6 days) to the system. Here, the methane yield was low due to slow degradation of plant cells by microorganisms at shorter HRT. By combining both single and two-phases system in mesophilic and thermophilic conditions, Ng *et al.*[43] demonstrated the gas yield increased as the HRT was increased. The highest gas yield recorded by mesophilic one-stage, mesophilic two-phase and thermophilic one-stage were 0.56 L/gCOD utilized, 0.98 L/gCOD utilized and 0.37 L/gCOD utilized at HRT of 100 days, 61 days and 35 days, respectively. By focusing on the sterilizer condensate, Ma *et al.*[33] performed a mesophilic (27-30°C) anaerobic digestion and found that the gas production rate increased with the increased in organic loading rate (OLR) applied and the maximum gas production achieved was 0.94 m^3 biogas/kg BOD removed at HRT of 16.7 days but reduced to 0.76 m^3 biogas/kg BOD removed at HRT of 15 days. Up-flow hybrid reactor was first reported by Mohd Noor *et al.*[37] operated with seed sludge obtained by mixing the digested POME and cow dung mixed liquor. Approximately 7 liters of biogas was produced daily with 62% COD removal and these performance parameters were lower compared to previous study may be due to impropriate seeding strategy and operating the digester at high organic loading rate. The immobilization of microorganisms was studied by Borja and Banks[12]. In this study, high COD removal (96.2%), high OLR (10.6 kgCOD/m^3·d which corresponds to HRT of 6.2 days) and high methane yield (0.325 L CH_4/gCOD which correspond to 93% of the theoretical yield) were achieved. This suggests significant contributions of large microorganism's population for POME treatment and biogas production.

In another study, Borja and Banks[11] investigated the treatment performance of two different reactor designs (anaerobic filter and anaerobic fluidized bed reactor). The anaerobic filter reactor and fluidized bed reactor performed similarly in terms of organic loading at low substrate concentration (1.0 gCOD/L) but at higher concentration (2.2 gCOD/L), the fluidized bed reactor performed better with 31.2 gCOD/L·d compared to 17 gCOD/L·d for anaerobic filter reactor which was due to diffusion limitations and less active biomass in the anaerobic filter reactor. The maximum gas rate obtained were 8.0 L/d and 6.2 L/d for anaerobic filter reactor (at HRT of 24 hours) and fluidized bed reactor (at HRT of 12 hours) respectively. Faisal and Unno[21] demonstrated the capability of an anaerobic baffled reactor in holding high retention time of cells in bioreactor to improve the methane yield. The highest methane yield obtained was 0.42 L CH_4/gCOD removal at 6 days of HRT which was attributed to high volatile suspended solid measured (6.5 – 36 gVSS/L) inside the digester. The study on retaining high biomass concentration was also studied by Najafpour *et al.*[39] by combining up-flow sludge blanket and up-flow fixed film technology. By operating at mesophilic temperature (38°C) with HRT between 1.5 and 3 days (OLR between 2.63 and 23.15 g COD/L·d), high COD removals of 89 and 97% were obtained at HRT of 1.5 and 3 days respectively with a maximum methane yield recorded at 0.346 LCH_4/gCODremoved. This is due to formation of flocculated biomass over the sludge blanket which served as a natural hydrophobic core for granule formation inside the digester.

A large 500 m^3 semi-commercial scale closed digester tank (Fig. 2) for treating POME and methane recovery was reported by Yacob *et al.*[73]. During the start-up period the shortest HRT (17 days) was achieved in less than three months with high COD removal (up to 97%) and satisfactory VFA-to-alkalinity ratio of 0.1-0.3. However the methane yield recorded 0.1 kg CH_4/kg COD removed which was lower than previously reported[14,15,11,12,21,40]. That was basically due to lower biomass retention inside the digester and currently the research strategies have been focused on getting longer solid retention time in the system by sludge recycling and other operational manipulation. The effect of temperature on POME treatment was studied by Choorit and Wisarnwan[16] by using continuous stirred tank reactor operated at 37 ºC and 55 ºC, respectively. Higher OLR and biogas production rate was observed in the thermophilic temperature as compared to the mesophilic temperature. The methane yields obtained for both mesophilic and thermophilic reactors were quite similar at 0.44 LCH_4/gCOD and 0.45 LCH_4/gCOD respectively which was due to the high degradable fraction of the organic in POME used (COD/BOD ratio is 1.56). In normal POME source the COD/BOD ratio is approximately 2.0. Recently, the expanded granular sludge bed reactor has been studied by Yejian *et al.*[76]. The results on COD removal was good with 91% at HRT of 2 days, but the maximum transformation of organic matter in POME into biogas(with 70% v/v methane) was only 46%. As far as the methane yield is concerned this is lower compared to the previous studies[11,12,14,15,21,40], which may be due to lower biomass accumulation.

In addition to biogas generation, research on POME utilization has also been focused on disposal on land[71], organic removal by centrifugal fractionation[27], electroflotation treatment[26], treatment by polymer coagulant[42], production of polyhydroxylalkanoates from POME[24], residual oil and suspended solid removal in POME by natural absorbents[4], residual oil adsorption from POME using rubber powder[3], COD removal in POME by rotating biological contactors[40], drinking water reclamation from POME using membrane technology[2], pre-treatment of POME using Moringa oleifera[10], residual oil and suspended solid coagulation by chitosan, alum and PAC[5] and aerobic treatment of POME[68].

Palm Oil Industry, its Sustainability and Clean Development Mechanism (CDM) Project: Sustainability in not a new concept where it could be traced back at least 4000 years ago in the Sumerian Empire of Mesopotamia and in the Indus Valley city civilisation of Harrapa and Mohenjo-daro[28]. In the Malaysian palm oil industry, sustainability in terms of economic, environmental and social aspects is going to be the key factors for its growth[7]. This is important because every year huge amount of biomass is generated from this industry and it has to be handled properly. It was estimated each year more than 30 millions tonnes of biomass is produced where only small percentage are recycled to useful products (i.e. pulp and paper, medium density fibreboard, automotive compartments from empty fruit bunches and trunk, methane from palm oil mill effluent) while the rest are being dumped into the environment through incineration, mulching, boiler fuel and open lagoon anaerobic treatment. It was estimated by the year 2020, palm oil from Malaysia will contribute to 42% (18 million tonnes) of the world's palm oil or 9.74% of the world's oil and fats production.[8]. In the future, sustainable development in terms of the economic, environmental and social aspects in the oil palm industry will be focused but not limited to maximizing values, risk management, environmental management system, improved methods for greenhouse gas measuring and monitoring and pollution prevention[7]. Sustainability strives for the maintenance of economic well being, protection of the environment and prudent use of natural resources and equitable social progress which recognizes the just needs of all individuals, communities and the environment[38].

As for the environmental protection aspect, much has been said about its sustainability and the need to reduce the greenhouse gas emission[7,69]. After the ratification of the Kyoto Protocol in 2002, Malaysia has established a proper framework to handle Clean Development Mechanism (CDM) projects and the Ministry of Natural Resource and Environment (NRE) has been appointed as the designated national authority (DNA) with Malaysia Energy Centre (PTM) and Forest Research Institute Malaysia (FRIM) as the energy and forestry technical committee leaders, respectively[48]. In 1994 Malaysia has already submitted GHG emission inventory on carbon dioxide, methane and nitrous oxide which focused on energy, industry, agriculture, waste and land use sectors in which 2.23 million tones of methane was yearly emitted from Malaysia and approximately 0.214 million tones came from the palm oil industry[51]. Besides many critics, the implementation of CDM project will contribute to ultimate goal of UNFCCC to stabilize the GHG concentration in the atmosphere, to assist Annex 1 countries to achieve their emission target and also to assist non-Annex 1 countries in achieving sustainable development[48]. On the other hand, the palm oil mills could earn carbon credits as revenue by the utilization of methane gas a renewable energy from anaerobic digestion of POME[49].

Fig. 2: The 500 m^3 semi-commercial scale closed anaerobic digester dedicated for methane recovery for renewable energy research belongs to UPM-KIT-FELDA joint R&D collaboration in Serting Hilir Palm Oil Mill, Negeri Sembilan, Malaysia.

Table 2: List of CDM registered projects in Malaysia (as at end of March 2009)

No	Reg. Date	Project Name and No.	Scale	Annex 1 Country	Annual Average CER
1	8 Apr. 2007	Kim Loong Methane Recovery for Onsite Utilization Project (Project No. 0867)	Large	Switzerland	57,656
2	8 Nov. 2007	Methane recovery and Utilization project at United Plantations Berhad, Jendarata Palm Oil Mill (Project No. 1153)	Large	Denmark	20,271
3	19 Mar. 2008	Methane recovery and Utilization project at TSH Kunak Oil Palm Mill (Project No. 1916)	Large	Switzerland	76,610
4	17 June 2008	Methane Recovery in Wastewater Treatment Project (Project No. 1616)	Small	Netherlands	57,094
5	27 Sept. 2008	KKSL Lekir Biogas Project (Project No. 1888)	Small	Netherlands	33,955
6	22 Oct. 2008	Methane Recovery and Utilization Project at Desa Kim Loong Palm Oil Mill (Project No. 1737)	Large	Germany	38,340
7	24 Oct. 2008	Methane Capture from POME for Electricity Generation in Batu Pahat (Project No. 1783)	Small	Japan	48,234
8	26 Jan. 2009	Methane Capture and On-Site Power Generation Project at Syarikat Cahaya Muda Perak (Oil Mill) Sdn. Bhd. (Project No. 2181)	Large	United Kingdom of Great Britain and Northern Ireland	67,133
9	26 Jan. 2009	Methane Capture and On-Site Power Generation Project at Sungai Kerang Palm Oil Mill (Project No. 2185)	Large	United Kingdom of Great Britain and Northern Ireland	78,962
10	14 Feb. 2009	Methane Recovery and Utilization Through Organic Wastewater Treatment in Malaysia (Project No. 2313)	Small	Japan	43,152
11	15 Mar. 2009	FELDA Serting Hilir Biogas Power Plant Project (Project No. 2336)	Small	United Kingdom of Great Britain and Northern Ireland	37,251
12	19 Mar. 2009	Methane Recovery and Utilization Project at TSH Sabahan Palm Oil Mill (Project No. 2332)	Small	United Kingdom of Great Britain and Northern Ireland	53,439
		Total Annual Average CER	612,097		

Currently there are more than 1500 CDM projects registered worldwide which will contribute more than 1.5 billions tonnes of CO_2 equivalent of expected CER until 2012 with majority are from China, India and Korea[54]. In China the implementation of CDM projects was effectively carried out through capacity building assistance, establishment of streamlined and transparent CDM procedures and sound governance, lesson learned and experience gained from the earlier CDM projects and amendment of its current interim CDM regulations[77]. Unlike China, the CDM market for Malaysia only became established in the second-half of 2006 with more buyers and project developer entered the market, competing for the CDM projects and by December 2007, 20 Malaysian projects had registered with the CDM Executive Board[48]. As at end of March 2009, there were 44 CDM projects registered with the EB UNFCCC and 12 projects specifically focus on methane gas capture[55]. These methane capture projects are listed in Table 1. The total expected annual CER contribution from all of the CDM projects in Malaysia is nearly 3.1 million tonnes of CO_2 equivalent. With estimation of USD 10/tonne of CO_2 equivalent by Basiron and Simeh[8], this contributes around USD31 millions to the industry in the form of carbon credit. In Malaysia the CDM business is mainly focusing on the biomass originating from the palm oil industry. The reason is because of the largest greenhouse gas (methane gas) contributors in Malaysia is from the palm oil industry and the reduction of methane gas from this industry was one of the potential candidate for the CDM project[51]. Amongst the project are biomass for energy, co-composting, energy efficiency and methane recovery through anaerobic digestion technology which involves many Annex 1 countries such as Denmark, Japan, UK of Great Britain and Northern Ireland, Canada, Switzerland, France and Netherlands. Most of the types of biomass used are from the palm oil industry which includes palm oil mill effluent, empty fruit bunches, decanter sludge, bunch ash, mesocarp fibres and palm kernel shells. With respect to methane recovery from palm oil mill effluent projects using the anaerobic digestion technology, there are currently 12 methane recovery and utilization projects and listed in Table 1. The total average annual estimated CER is 612,097 tonnes of CO_2 equivalent. This is in fact still small despite huge potential available in the palm oil industry. The following section will elaborate these projects in more details.

The Overview of the Registered CDM Methane Capture Project in Malaysia: As at end of March 2009, there were 12 CDM projects on methane recovery and utilization registered with the EB UNFCCC. With the operation of the projects, they will contribute to the sustainability development from many aspects of environment, economic and social. For the environmental sustainability, the uncontrolled emissions of methane will be reduced, the use of methane will reduce the consumption of fossil fuels thus reduce the emissions of GHG from the use of fossil fuel and pollution (air and water) will be reduced as well. For the economic sustainability, the displacement of fossil fuels by methane will reduce the operating and maintenance costs and reduction of the national fossil fuel import bill. For the social sustainability, the air and water pollution will be reduced and the project activity will also provide opportunities for the management and the operators to acquire new technological knowledge and skills thus provide employment opportunity during construction and operation

Kim Loong Methane Recovery (Project 0867) is the first project registered with the EB UNFCCC with the intention to reduce the methane emissions from the existing POME treatment by closing the anaerobic digesters and utilize the methane for on-site heat and power generation[56]. The methane gas is captured in a closed biogas system and used in a boiler to produce steam for direct steam application (heat as energy source) where part of the steam is used to generate electricity for the mill and other planned integrated facilities on site. From this project the total annual average of emission reduction is estimated to be 403,595 tonnes of CO_2 equivalent over the entire crediting period.

The second project is the Methane Recovery at Jendarata Palm Oil Mill (Project 1153)[57]. The project involves the installation of a closed continuous-flow stirred tank reactor (CSTR) for the treatment of POME. The system is equipped with a dual-function complete mixing mechanism (pump-aided circulation and gas-lifting mixing) to facilitate long-term continuous operations without any interruptions for sludge removal. The biogas generated is captured and utilized to displace the fossil fuels used in the steam boilers and/or thermal heaters of palm oil refinery plant located next to the palm oil mill. The total annual average of the estimated emission reduction is approximately 141,897 tonnes of CO_2 equivalent over the entire crediting period. The third project is the Methane Recovery at TSH Kunak Oil Palm Mill (Project 1916)[58]. This project uses a CSTR digester for the treatment of POME and methane capture and will replace the existing open lagoon treatment method. The methane is captured and utilized for power generation and the electricity will be supplied to a nearby industrial plant. The total annual average of the estimated emission reduction is approximately 536,272 tonnes of CO_2 equivalent over the entire crediting period.

The fourth project is the Methane Recovery in Wastewater Treatment (Project 1616)[59]. In this project the methane is captured and combusted by utilizing a simple, effective and reliable technology to capture lagoon-produced biogas by installing sealed covers (synthetic high-density polyethylene/HDPE geo-membrane) over existing lagoons and this enables capture of the biogas produced. The system will incorporate the use of multiple agitators and a sludge handling and removal system. The captured biogas will be routed to the high temperature, enclosed flares to destroy methane gas to CO_2. The flaring system is automated to ensure biogas will be completely combusted. In the next phase, the methane will be utilized for renewable energy generation. The total annual average of the estimated emission reduction is approximately 399,655 tonnes of CO_2 equivalent over the entire crediting period. The fifth project is KKSL Lekir Biogas Project (Project 1888)[60]. This purpose of project is to cover two of the existing open anaerobic ponds and the captured methane-rich biogas will be combusted in a dual fuel generators (fired with a mixture of diesel and biogas) to generate electricity. The total annual average of emission reduction estimated for this project is approximately 339,550 tonnes of CO_2 equivalent over the entire crediting period.

The sixth project is Methane Recovery at Desa Kim Loong Palm Oil Mill (Project No. 1737)[61]. The CDM project activity aims to reduce the methane emissions from the treatment of POME by closing the existing open anaerobic tanks. A biogas capture and collection system will be installed for on-site heat and power generation for use at the palm oil mill. The treated POME will be channelled into the subsequent aerobic and polishing lagoons for further treatment before the final discharge for land application. The total annual average of the estimated emission reduction is approximately 383,401 tones of CO_2 equivalent over the entire crediting period.

The seventh project is Methane Capture in Batu Pahat (Project No. 1783)[62]. The project will install four closed digester tanks to replace the existing anaerobic ponds for POME treatment. The biogas will be captured and use to generate electricity that will be supplied to the grid. Over the entire crediting period, this project is expected to contribute 476,511 tonnes of CO_2 equivalent of CER. The eighth project is Methane Capture at Syarikat Cahaya Muda Perak Oil Mill Sdn. Bhd. (Project No. 2181)[63]. The activity will involve the treatment of POME by installation a closed continuous-flow stirred tank reactor (CSTR) anaerobic digester plant and a biogas capture system. The methane will be utilized for on-site electricity and steam generation and eliminate methane emissions to the atmosphere. The estimated annual average of CER over the entire crediting period is approximately 671,327 tones of CO_2 equivalent

The ninth project is Methane at Sungai Kerang Palm Oil Mill (Project No. 2185)[64]. The project will install a closed continuous-flow stirred tank reactor (CSTR) anaerobic digester plant complete with biogas capture system and the captured methane will be utilized for onsite electricity and steam generation. The project is estimated to produce on average 789,665 tones of CO_2 equivalent annually over the entire crediting period. The tenth project is Methane Recovery through Organic Wastewater Treatment (Project No. 2313)[65]. The project involves the installation of an anaerobic bioreactor for the high strength organic wastewater. Prior to feeding, the pH of the POME will be adjusted. In the digester, the POME will undergo anaerobic process to produce methane. The biogas with high methane content will be captured and flared. The heat recovered from the flaring system will be utilized as clean energy source to heat up the digesters at appropriate temperature. The project will also install a polishing system comprises of primary clarifier, secondary clarifier and chemical precipitation pond. The annual average of the estimated CER for this project is approximately 43, 152 tonnes of CO_2 equivalent over the entire crediting period.

The eleventh project is FELDA Serting Hilir Biogas Power Plant (Project No. 2336)[66]. The project will retrofit the existing open digester tanks for the production of biogas. The methane gas will be captured and utilized to produce electricity which will be connected to the TNB grid or used within the mill. Over the entire crediting period, it is expected the project will generate an annual average of 37,251 tonnes of CO_2 equivalent. The following section shall elaborate this project in more details as the commercialization of this project was initiated from the earlier semi-commercial scale and related studies[51,74,75,73]. The twelfth project is the Methane Recovery at TSH Sabahan Palm Oil Mill (Project No. 2332)[67]. The project will involve the installation of a CSTR –contact process anaerobic to replace the open lagoon treatment system. The generated biogas will be captured and utilised for electricity generation. A portion of the biogas will be sent to the boiler for steam generation for the mill's usage. The annual average CER for the project is estimated to be 53,439 tonnes of CO_2 equivalent over the entire crediting period

The Experience with CDM Project in Serting Hilir Palm Oil Mill, Malaysia: The interest on CDM project from anaerobic treatment of POME in FELDA Serting Hilir Palm Oil Mill has begun since early 2000 with series of related researches[51,74,75,73,53]. Since early 2000, this research has attracted FELDA Palm

Industries Sdn. Bhd. (the largest palm oil company in the world) to joint the research and development (R&D) collaboration on biogas from POME which involves three parties namely Kyushu Institute of Technology (Japan), Universiti Putra Malaysia (Malaysia) and FELDA Palm Industries Sdn. Bhd. (Malaysia). Based on earlier study for FELDA Serting Hilir Palm Oil Mill Biogas Project, the total GHG emission reduction for a year was estimated to be 1064 tonnes of methane gas and RM2.6 millions could be obtained from selling of electricity and CER trading[51]. This is very attractive and additional income could also be obtained from the saving of diesel displacement with methane for the steam boiler and sales of extra palm kernel shell and fibres. Even though high methane yield experiments have been widely reported on anaerobic treatment of POME, those were mainly for laboratory scale digesters. To proceed with the commercialization stage, FELDA Palm Industries Sdn. Bhd. requested more results on the industrial scale and proven technology for POME treatment. Thus in 2005, a large 500 m^3 semi-commercial closed digester tank was successfully commissioned and operated for this purpose[73]. This digester is shown in Figure 2. This closed digesting tank is to replace the existing open digesting tank and open pond system that is used in the mill. Based on the previous estimation, the total capital cost for CDM project at Setting Hilir Palm Oil Mill was USD3.68 millions which mainly contributed by the six units of closed digesting tanks (USD290,000 each), costs for power station (USD500,000), grid connection (USD590,000), and 30% contingency cost[51]. This high investment was not attractive and additional incomes through sales of CER and electricity to TNB were required to improve the project's financial feasibility. With CDM, the total revenue for the mill (54 tonnes/hr) was approximately USD680,000 a year. Recently, idea has been developed to lower the capital cost and boost methane production by retrofitting the existing 3600 m^3 open digesting tank and operate the digester in thermophilic condition for the commercial set-up as shown in Figure 3. The overall conditions of the open tank are still good (except replacing the top plates on certain tanks) even though they have been used for more than 20 years. For the commercial unit, the roof was installed and the digester walls are insulated. The total capital cost estimation for this retrofitting project is shown in Table 3. The total capital cost estimation is USD1.34 millions. The expected yearly revenue from sales of electricity and CER are USD0.49 million and USD0.97 million respectively by using the method previously developed by Shirai *et al.*[51] except for currency exchange rate (USD1=RM3.5) and new TNB electricity tariff (RM0.21/kWh). The expected gross yearly revenue for the mill is approximately USD1.46 millions and this is very attractive considering other benefits could also be obtained from the projects such as a more sustainable waste management, reduction of air and water pollution and GHG emission, technology transfer for bio-energy technology and improvement the local's economic and social standard. Recently the project has be approved and registered in the UNFCCC website.

Future Outlook: The future for the renewable energy is bright especially in the developing countries where the trend of renewable energy market is shifting from the fringe to the mainstream for sustainable development. The support for renewable energy has been building in government, multilateral organizations, industry and non-governmental organization (NGOs) at local, national and global levels[34]. This is due to recognition of renewable energy contribution to the rural development, energy independence and effort for climate change mitigation. With the increase of world's population, higher energy demand and intensity and higher fossil fuel and carbon process, the market share of the renewable energy is expected to increase from 16.5% in 2004 to 25% (high scenario in 2020) and further increase to 40-50% (high scenario in 2050)[35].

For Malaysia, the future scenario is quite similar in terms of renewable energy market share. In the Ninth Malaysian Plan report (2006-2010), Malaysia committed to continuously focus on the sustainable development to support the economic growth, enhanced competitiveness and contribute towards achieving a balanced development for Malaysia. The strategies outlined includes reducing high dependence on petroleum products, increasing use of alternative fuels, promoting greater use of renewable energy for power generation, fostering a more conducive environment to support the implementation of Small Renewable Energy Program (SREP) by reviewing the terms and conditions of the Renewable Energy Power Purchase Agreement (REPPA) and issues related to project viability[19]. In this view, concentrated efforts are being undertaken by the government of Malaysia to ensure the sustainability and long-term reliability and security of both the depleted and renewable energy resources by adopting various energy policies[36].

One of the tangible approaches is by actively and carefully exploring other CDM potential projects. Currently most of the registered CDM projects in Malaysia are utilizing oil palm empty fruit bunches (EFB) for renewable energy generation. This is because EFB is readily available with consistent characteristic and concentrated in mills. Moreover, presently its' require cost for mulching and cause air pollution once incinerated for fertilizer (ash). With CDM, EFB is combusted for energy and CER is claimed through the displacement of more fossil fuel and methane

Table 3: Costs and revenues estimation for Serting Hilir Palm Oil Mill CDM project

Item	Dollars (US)
Preliminaries	13429
Refurbishment works to the existing tanks (5 units)	340000
Plant equipment and other structure (5 units) *(such as mixer, pump, heat exchanger, pressure relief system, instrumentation, gas scrubbing system, gas storage, gas engine, electrical works, freight forwarding and training)*	751429
Project Management, testing and commissioning fees	180857
Contingencies	57143
Total capital cost	1342858
Yearly revenue from sales of electricity (at RM0.21/kWh)	491400
Yearly revenue from sales of CER	971429
Gross yearly revenue (without operation and maintenance costs)	1462829

* Based on June 2007 estimation, Foreign exchange is calculated at 1USD=RM3.5

Fig. 3: The commercialization stage of the methane recovery project from anaerobic treatment of palm oil mill effluent in Serting Hilir Palm Oil Mill, Negeri Sembilan, Malaysia.

avoidance from biomass decay. In addition the investors could further benefits from the sales of electricity to TNB at a very attractive tariff of RM0.21/kWh. For EFB and other oil palm biomass, quite substantial amount of research work has been developed to produce higher value-added products such as fuel briquette, pulp and paper, medium density fibreboard, automotive components, fibre strands, plywood, block boards, particleboards, glucose for further conversion to ethanol, citric acid, butanal and other single cell protein from hemicelluloses and lignin[8]. The uses of EFB and other biomass would also open-up new opportunities for Annex 1-Malaysia joint venture cooperative research and commercialization projects. In a recent study, Nasrin *et al.*,[41] demonstrated EFB, palm kernel expeller and sawdust could be compacted to produce briquettes fuel at high temperature and pressure using a screw extrusion technology with good combustion properties. This briquette fuel is suitable for boiler and incinerator to produce steam and electricity. The future second-generation biofuel will be based on the conversion of cellulosic fibre or biomass into liquid fuel[9]. This is more promising future direction for the biomass utilization and future research should be directed into this area.

In the case of POME, currently there are two methods to utilize it. The first is the anaerobic treatment to produce biogas or organic acids (mixture of acetic, butyric and propionic acids) and eventually bioplastic. The second would be utilizing the treated POME sludge for co-composting with EFB. Both approaches still produce effluent and further polishing is required before discharge as to comply to the Department of Environment (Malaysia) regulations at BOD of 100 mg/L, suspended solid of 400 mg/L, oil and grease of 50 mg/L, ammoniacal nitrogen of 150 mg/L and total nitrogen of 200 mg/L[23]. In the future the regulation for the effluent discharge level from the palm oil mills in the peninsular Malaysia will be more stringent (BOD level of less than 20 mg/L). At this level many of the mills may face problems and advanced technologies may be required to handle this. Technology for water recycling (zero-discharged) may be possible and research should be focused for cost-effective treatment technologies and this will open up new opportunities for technology transfer between Annex 1-Malaysia cooperative researches. In this respect Nishio and Nakashimada[45] recommend three different processes to handle different types of waste namely complete anaerobic treatment of high-strength wastewater (CARP process), dry methane fermentation of organic solid wastes (AM-MET process) and hydrogen-methane production from organic wastewater (HY-MET process). On other perspective, Wu *et al.*[72] proposed to recover bioresources from POME or its conversion into useful substitutes for fermentation media for the production of antibiotics, bioinsecticides, acetone-butanol-ethanol solvents, polyhydroxyalkanoates, organic acids, enzymes, hydrogen, fertilizer, live food for animals and aquaculture organisms.

Among other future challenges in the sustainability of palm oil production is the need to implement a scheme to enable palm oil to be certified with full traceability through Round Table on Sustainable Palm Oil (RSPO), land conservation for forest and wildlife conservation issues[9]. The window of opportunity for CDM business is opened until 2012 and may be continued by the UNFCCC. Various CDM businesses could be explored from different biomass resources especially in the palm oil industry where huge amount of biomass is available and ready to be exploited for commercialization. Thus the developed countries should urgently take this opportunity to actively involve in the CDM business. In returns, Malaysia will benefits from the sustainable development of the palm oil industry.

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