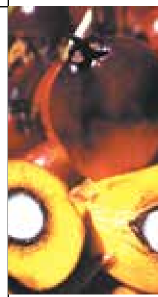
Feature Article



Development of Biogas Upgrading Plant for the Production of Bio-Compressed Natural Gas (Bio-CNG) in Palm Oil Mills

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INTRODUCTION

Palm oil mill effluent (POME) is a high-strength organic wastewater generated from the extraction of crude palm oil (CPO) from fresh fruit bunches (FFB) in palm oil mills. The wastewater is treated conventionally via a series of ponding systems involving anaerobic and aerobic microbial processes. Anaerobic digestion (AD) is the most commonly used method by the palm oil industry to treat POME to an acceptable level as set by the local authority before finally discharge to a watercourse, or for land application. This treatment process generates and emits huge quantities of biogas uncontrollably to the atmosphere. At a production rate of 28 m^3 biogas for every m^3 of POME, it was estimated that 1562 million m^3 of biogas was generated from 85.84 million t of FFB processed in 456 palm oil mills nationwide in 2016 (MPOB, 2017).

The biogas contains approximately 65%methane (CH_4) and 35% carbon dioxide (CO_2), of which both are greenhouse gases (GHG) that cause global warming. The biogas emission poses a major challenge for the industry to meet the stringent requirement for sustainable palm oil production, particularly with CH_4 having 25 times the global warming potential of CO_2 (Chin *et al*., 2013; Loh *et al*., 2017). Capturing and utilising biogas as a source of renewable energy fuel have been commercially exploited by the industry for both environmental and economic benefits.

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This is especially important to enhance market acceptance of palm oil and palm products. The potential installed electricity capacity and GHG savings were 482 MW and 15.60 million t CO^2eq considering all the Malaysian palm oil mills capture and utilise the biogas for electricity generation in 2016 (*Table 1*). In doing so, additional GHG savings can also be made from displacement of fossil fuels by biogas.

BIOGAS CAPTURE AND UTILISATION IN PALM OIL MILLS

The socio-economic potential of biogas for energy generation has been identified under the Economic Transformation Programme (ETP) through the implementation of Entry Point Project No. 5 (EPP5) - National Key Economic Areas (NKEA) for palm oil sector. Malaysian Palm Oil Board (MPOB) is an implementing agency in monitoring and facilitating the commercial development of biogas plants in palm oil mills (Loh *et al.*, 2017). Under this initiative, the Government is targeting all palm oil mills to install biogas capturing facilities by 2020. As of September 2017, 94 mills have installed biogas plants with varying energy applications. The captured biogas is typically used for heat and electricity generation either for mill use or grid connection (*Table 2*). Besides, there are 56 biogas plants merely flare the biogas, most of which were built under the Clean Development Mechanism (CDM) scheme for carbon credit trading.

Among the reasons for a slow uptake and lack of biogas efficient use where majority just flared the biogas is self-sufficient energy in palm oil mills which has hindered immediate uses for the

TABLE 1. POTENTIAL OF ELECTRICITY GENERATION AND GREENHOUSE GASES (GHG) SAVINGS FROM BIOGAS IN PALM OIL MILLS (2016)

Parameter	Value
Annual fresh fruit bunch processed (FFB), million tonne	85.84
Annual crude palm oil production (CPO), million tonne	17.32
Palm oil mill effluent (POME)[a], million t (million m^3)	55.80
Biogas generation[b], million m^3	1562
Potential installed electricity capacity[c], MW	482
Greenhouse gases (GHG) saving[d], million t CO_2 eq t^{-1} CPO	15.60

* [a]*0.65 t POME t-1 FFB processed (Vijaya* et al., *2008)*
[b]*28 m3 m-3 POME (Loh* et al., *2017)*
[c]*gas engine operates 7200 hrs yr-1 with 40% efficiency (Loh* et al., *2017)*
[d]*0.9 t CO2 eq t-1 CPO (Vijaya* et al., *2010)*

TABLE 2. STATUS OF BIOGAS CAPTURE AND UTILISATION UNDER THE ENTRY POINT PROJECT NO. 5 (EPP5) OF NATIONAL KEY ECONOMIC AREAS (NKEA) FOR PALM OIL SECTOR*

No. of palm oil mills	453
No. of palm oil mills with biogas plant	94
Technology used (No. of mills)	i) Digester tank : 56 ii) Covered lagoon : 38
Type of biogas utilisation (No. of mills)	i) Electricity generation : 24 ii) Combined heat and power : 12 iii) Steam generation / others : 2 iv) Flaring : 56

*As of September 2017

captured biogas. One of the approaches to optimise and diversify biogas utilisation for external uses is to further treat the raw biogas for the production of high quality gaseous fuel such as biomethane or bio-compressed natural gas (Bio-CNG). The Bio-CNG is a natural gas like fuel which can be used for transportation purpose and industrial processes. Biogas upgrading is an emerging technology providing a new option to the country's biogas industry though it has already been implemented in some developed countries, especially in Europe since early 90's where Sweden and Switzerland were among the pioneers (Wellinger, 2013).

The major process involved in Bio-CNG production is methane enrichment via removal of hydrogen sulphide (H_2S), moisture and CO_2 (Ryckebosch *et al*., 2011). Commercially, CH_4 and CO_2 are separated *via* (1) pressurised water scrubber, (2) pressure and vacuum swing adsorption, (3) amine scrubbing, (4) scrubbing with organic solvents, (5) membrane permeation and (6) physical and chemical CO_2 absorption (Makaruk *et. al*., 2010; Ryckebosch *et al*., 2011). Realising the needs to explore commercial potential of Bio-CNG that may spur the growth of the biogas industry in palm oil mills, MPOB, Felda Palm Industries Sdn Bhd (FPISB) and Sime Darby Offshore Engineering Sdn Bhd (SDOE) have established a strategic partnership to deploy the world's first Bio-CNG commercial plant for upgrading biogas generated from POME.

MPOB-FPISB-SDOE BIOGAS UPGRADING PLANT

A 400 m^3 hr^{-1} biogas upgrading plant developed by MPOB, FPISB and SDOE is located at Felda Sg Tengi Palm Oil Mill, Kuala Kubu Bahru, Selangor (*Figure 1*). The site was chosen due to several factors, among others, (1) readily available biogas plant and (2) strategic location which is close to industrial area (for Bio-CNG distribution). The plant processes 600 m^3 hr^{-1} raw biogas captured from a covered lagoon digester to produce 400 m^3 hr^{-1} Bio-CNG which is equivalent to 80 000 MMBTu per annum. The plant worth RM 7.0 million was constructed starting in February 2014, fully commissioned in January 2015 and launched in October 2015.

The Bio-CNG produced from POME is basically subjected to three main processes; (1) pretreatment (H_2S and water removal); (2) purification and upgrading (CO_2 removal and CH_4 enrichment) and; (3) gas compression and storage (*Figures 2* and *3*). The raw biogas generated and captured

Figure 1. The bio-compressed natural gas (Bio-CNG) commercial plant at Felda Sg Tengi Palm Oil Mill.

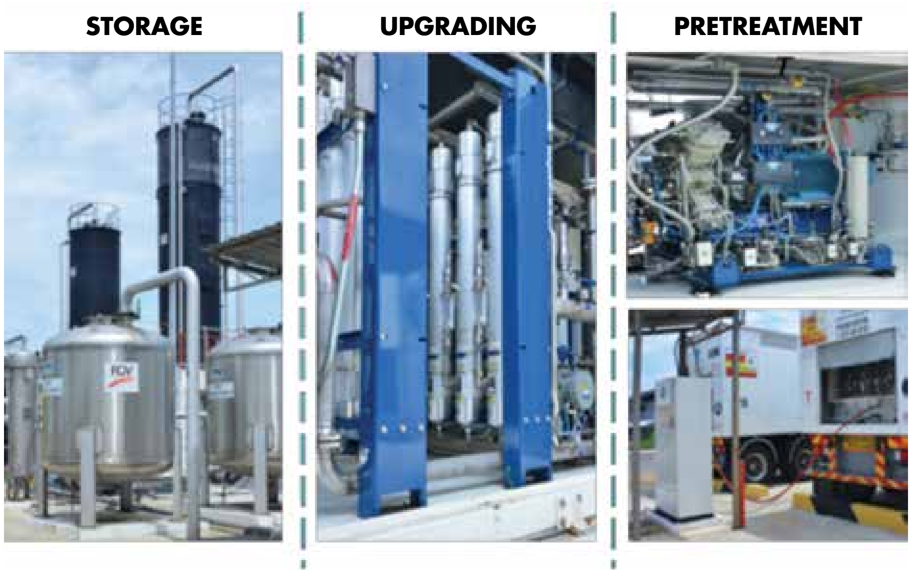

Figure 2. Main operation units of the bio-compressed natural gas (Bio-CNG) plant.

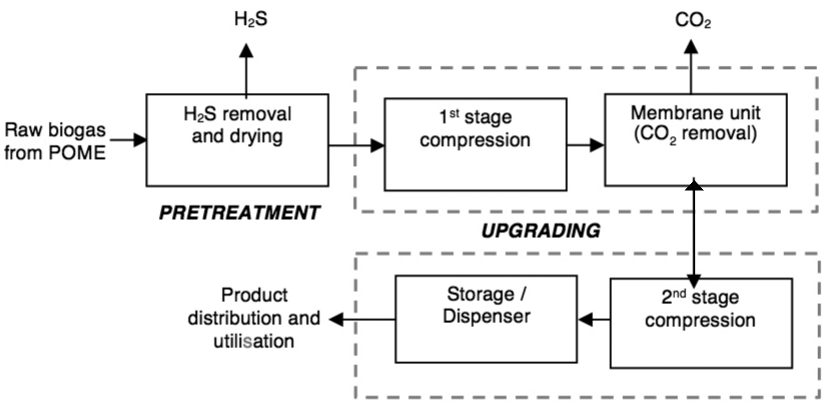

Figure 3. Process flow diagram for the production of bio-compressed natural gas (Bio-CNG) from palm oil mill effluent (POME).

from the closed anaerobic digester is firstly pre-treated using a combined biological and chemical process to reduce the H_2S level from approximately 2000 ppm to <10 ppm. The pre-treated biogas is then compressed prior to removal of CO_2 using membrane technology. This approach enriches CH_4 content in biogas to >90% or the required value (subjected to technical specification), which is similar to natural gas quality. The purified and enriched biogas high in CH_4 is compressed to 250 barg and temporarily stored in cylinders or directly dispensed into a compressed natural gas (CNG) trailer for delivery to a nearby factory. The Bio-CNG can be used to replace liquefied petroleum gas (LPG) with potential fuel cost reduction up to 30%.

CHARACTERISTICS OF BIO-CNG

Bio-CNG is a colourless, odourless and non-toxic clean fuel produced from renewable sources such as POME which is a promising alternative to fossil fuel. It has a more consistent gas composition and quality compared to the raw biogas, and can be used efficiently as a fuel similar to natural gas. As a comparison, natural gas contains >92% CH_4 and 6% gaseous hydrocarbon such as ethane, butane, as well as propene, thus making it slightly higher in energy

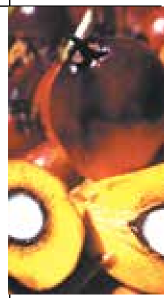

TABLE 3. SPECIFICATION OF BIO-COMPRESSED NATURAL GAS (Bio-CNG) AND OTHER SIMILAR GASEOUS FUELS

Parameter	Biogas (POME)	Bio-CNG	Natural gas
CH_4, %	55 - 65	> 92	> 92
Other hydrocarbons, %	-	-	6
CO_2, %	35 - 40	< 7	< 2
H_2S, ppm	2 500 - 4 000	< 5	< 3
Pressure	2 - 5 mbar	250 bar	250 bar
Calorific value, MJ Nm^{-3}	20	35.95	36.61

Source: Nasrin *et. al*. (2017a), Nasrin *et. al*. (2017b).
Note: POME = palm oil mill effluent.

content than Bio-CNG (*Table 3*). The use of Bio-CNG produces less pollutants and emissions compared to fossil fuels, thus less GHG emissions and a better carbon footprint for palm oil production. Besides being used on-site for energy generation and as a vehicle fuel in palm oil mills and plantation complexes, Bio-CNG can be transported using CNG trailer to potential users' site (mobile pipeline) or injected to the existing national gas pipeline (virtual pipeline) for industrial processes, subject to meeting certain technical specifications.

THE COMMERCIAL BENEFITS

Bio-CNG is a feasible commercial alternative for biogas offsite utilisation, in particular for those mills in close proximity to industrial areas and is deemed not feasible to develop grid-connected biogas plants (*Table 4*). It provides both economic and environmental benefits to the Bio-CNG producers and the industrial users. Due to its cost-effectiveness, compact and flexible design, the Bio-CNG plant can be easily integrated with the existing biogas plant, thus making the project more economical and competitive. Bio-CNG can be potentially used by the industrial sector and as a vehicle fuel. However, direct replacement of Bio-CNG with natural gas in these two sectors is unlikely and not feasible at the moment. This is due to the lower subsidised market price of natural gas than Bio-CNG either at the natural gas vehicle (NGV) station or supplied by Gas Malaysia Berhad (GMB) through the national gas pipeline. As a start, the sectors targeted are the industries and factories that currently use fuels other than natural gas such as diesel, medium fuel oil (MFO), and LPG. Substantial savings can be made by switching to Bio-CNG from fossil fuels.

The successful deployment of this project indirectly develops the whole supply chain of the Bio-CNG industry, in particular for product marketing and distribution. For example, initial efforts are seen through the establishment of Sime Darby – Gas Malaysia Bio-CNG Sdn Bhd, a joint-venture company between SDOE and GMB which is responsible for the purchasing and delivering of Bio-CNG to potential industrial customers. Besides, GMB has recognised Bio-CNG as a new business which can opportunistically supplement the natural gas in Malaysia (Gas Malaysia Berhad, 2017). Active involvement of the existing natural gas players and the CNG industry in providing market access and product distribution between the Bio-CNG producers and the users is vital in order to continue driving the market growth of Bio-CNG in the country. Such endeavor reflects the huge potential of this industry and will be able to realise it in the near future.

CONCLUSION

Bio-CNG from POME offers good prospect for biogas offsite utilisation as a sustainable alternative to fossil fuels. The first biogas

TABLE 4. ECONOMIC ANALYSIS OF THE 400 M^3 HR^{-1} BIO-COMPRESSED NATURAL GAS (Bio-CNG) PLANT

Description	Value	
	Bio-CNG plant only	With biogas plant
Investment cost, RM (million)	7.0	12.0
Annual production, million m^3 @ 7200 hr yr^{-1}	2.46 (~80,000 MMBTu)	
Assumption: • Bio-CNG selling price @ RM 40.00 – 46.00 $MMBTu^{-1}$ • Operational expenditure @ RM 25.50 $MMBTu^{-1}$		
Net present value (NPV) @10%, RM (million)	1.82	0.17
Internal rate of return (IRR), %	14.36	10.25
Payback period, year	6.03	7.50

upgrading plant commercially established in Malaysia has successfully demonstrated the techno-economic viability in producing Bio-CNG from POME. This initiative creates new businesses which eventually complements the country's primary energy supply chain and diversifies fuel mix to reduce high dependency on fossil fuels. In addition, it supports the government's policies on renewable energy and climate change as well as voluntary commitment in reducing up to 45% in terms of carbon emissions intensity based on gross domestic product (GDP) by 2030 (relative to emission intensity of GDP in 2005). Nevertheless, more efforts gearing towards strengthening a supporting framework to provide incentive, infrastructure, technical support and standards development are needed to further boost the commercialisation potential of Bio-CNG in Malaysia.

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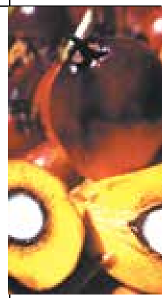

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